

Application of a front observer on real atrial data

PhySio

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Annabelle Collin(UB), Yves Coudière(UB),
Philippe Moireau(Inria)

1 Introduction

2 Data

3 Modelling

4 Results

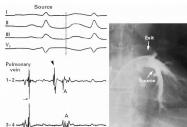
5 Perspectives

LIRYC : L'Institut de Rythmologie et *modélisation* Cardiaque

A multidisciplinary research, clinical and teaching Institute

Cardiology, Electrophysiology (cell, tissue)
Imaging, *Modeling*, Signal processing

- + Teaching center
- + Industrial partners

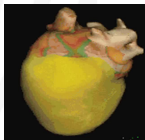


Headed by Pr. M. Haissaguerre

“The project Carmen deals with developing of computational approaches for clinical research in LIRYC.” (CR3)

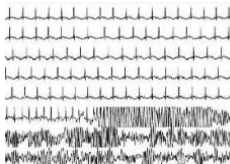
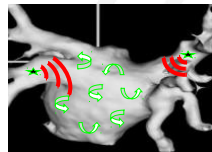


Research Themes



ATRIAL FIBRILLATION

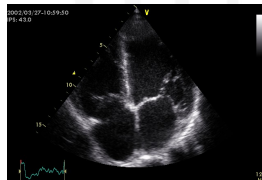
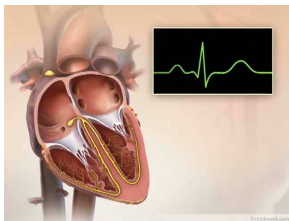
Europe: 5 millions
Major Cause of Stroke



VENTRICULAR

ARRHYTHMIAS AND SUDDEN CARDIAC DEATH

Europe: 350 000
deaths/year



HEART FAILURE AND ELECTRICAL DYSSYNCHRONY

Europe: 9 millions
350 000 deaths/year

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2 Data

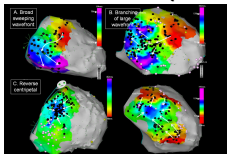
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Data acquisition

Data acquisition system : CARTO (Biosense Webster)



Several kind of catheters



Exported data from CARTO

- huge amount of files (*.xml, *.txt, *.mesh, ...)
- lot of different data per recording point

Name	Type	Modified	Size	Ratio	Checked	Address	Path
1-14-104_P100_CONNECTOR_Ext	Text Document	12/21/2011 12:23 AM	5,207	24%	1,264	A	
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1-14-104_P100_CONNECTOR_Ext @electrodes_Posizione.txt	Text Document	12/21/2011 12:23 AM	2,559	54%	1,201	A	
1-14-104_P100_CONNECTOR_Ext @electrodes_Posizione.txt	Text Document	12/21/2011 12:23 AM	1,600	90%	161,146	A	
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1-14-104_P100_CONNECTOR_Ext @electrodes_Posizione @dysrhythmia.txt	Text Document	12/21/2011 12:23 AM	4,180	20%	1,876	A	
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Figure : example of exported files with CARTO system

Postprocess CARTO data

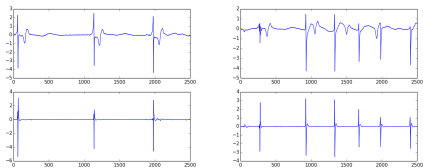


Figure : example of signals post-process from CARTO files

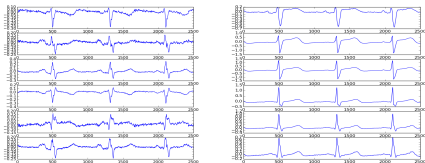
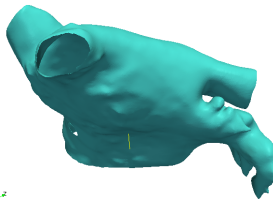
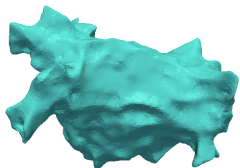


Figure : example of ECG post-process from CARTO files



What we use in practice ?

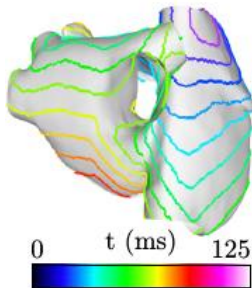


Figure : In silico activation map.
A.Collin

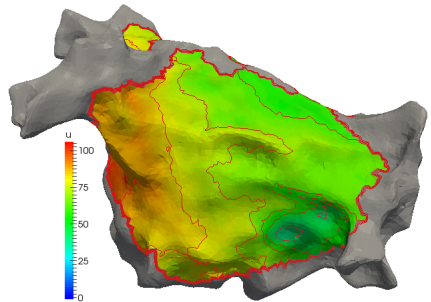


Figure : activation time from
CARTO system

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Bilayer Model

Explanation

- reaction-diffusion on 2 surfaces : $\Omega^{(1)}$: Endo and $\Omega^{(2)}$: Epi

Bilayer model introduced by Labarthe, Bayer, Coudière, Henry, Cochet, Jaïs, and Vigmond [2014] :

$$\left\{ \begin{array}{l} A(C\partial_t u^{(k)} + f(u^{(k)}, w^{(k)})) = \text{div}(\sigma^{(k)} \nabla_x u^{(k)}) \quad \text{on } \Omega^{(k)} \\ \partial_t w^{(k)} = g(u^{(k)}, w^{(k)}) \quad \text{on } \Omega^{(k)} \\ \sigma^{(k)} \nabla_x u^{(k)} \cdot n = 0 \quad \text{on } \partial\Omega^{(k)} \\ u^{(k)}(0, x) = u_0^{(k)}(x), \quad w^{(k)}(x) = w_0^{(k)}(x) \quad x \in \Omega^{(k)} \end{array} \right.$$

Bilayer Model

Explanation

- reaction-diffusion on 2 surfaces : $\Omega^{(1)}$: Endo and $\Omega^{(2)}$: Epi
- Average in depth

Bilayer model introduced by Labarthe et al. [2014] :

$$\left\{ \begin{array}{l} A(C\partial_t u^{(k)} + f(u^{(k)}, w^{(k)})) = \text{div}(\sigma^{(k)} \nabla_x u^{(k)}) + (-1)^k \gamma(u^{(1)} - u^{(2)}) \text{ on } \Omega^{(k)} \\ \partial_t w^{(k)} = g(u^{(k)}, w^{(k)}) \text{ on } \Omega^{(k)} \\ \sigma^{(k)} \nabla_x u^{(k)} \cdot n = 0 \text{ on } \partial\Omega^{(k)} \\ u^{(k)}(0, x) = u_0^{(k)}(x), \quad w^{(k)}(x) = w_0^{(k)}(x) \quad x \in \Omega^{(k)} \end{array} \right.$$

Bilayer Model

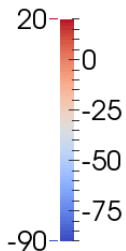
Explanation

- reaction-diffusion on 2 surfaces : $\Omega^{(1)}$: Endo and $\Omega^{(2)}$: Epi
- Average in depth
- Possible dissociation between layer

Bilayer model introduced by Labarthe et al. [2014] :

$$\begin{cases} A(C\partial_t u^{(k)} + f(u^{(k)}, w^{(k)})) = \text{div}(\sigma^{(k)} \nabla_x u^{(k)}) + (-1)^k \gamma(u^{(1)} - u^{(2)}) & \text{on } \Omega^{(k)} \\ \partial_t w^{(k)} = g(u^{(k)}, w^{(k)}) & \text{on } \Omega^{(k)} \\ \sigma^{(k)} \nabla_x u^{(k)} \cdot n = 0 & \text{on } \partial\Omega^{(k)} \\ u^{(k)}(0, x) = u_0^{(k)}(x), \quad w^{(k)}(x) = w_0^{(k)}(x) & x \in \Omega^{(k)} \end{cases}$$

bilayer simulation



Luenberger observer for reaction-diffusion equations

Collin, Chapelle, and Moireau [2015]

Consider a simple reaction-diffusion equation :

$$\begin{cases} \partial_t u - \nabla \cdot (\sigma \cdot \nabla u) = kf(u) & \text{on } \Omega \\ (\sigma \cdot \nabla u) \cdot n = 0 & \text{on } \partial\Omega \\ u(x, 0) = u_0(x) & x \in \Omega \end{cases}$$

Luenberger observer for reaction-diffusion equations

Collin, Chapelle, and Moireau [2015]

Consider a simple reaction-diffusion equation :

$$\begin{cases} \partial_t u - \nabla \cdot (\sigma \cdot \nabla u) = kf(u) + \lambda \delta(\Gamma_u, x) (-(z - C_1(\Omega_u^{in}))^2 + (z - C_2(\Omega_u^{in}))^2) & \text{on } \Omega \\ (\sigma \cdot \nabla u) \cdot n = 0 & \text{on } \partial\Omega \\ u(x, 0) = u_0(x) & x \in \Omega \end{cases}$$

- Ω_u^{in} : time dependant space corresponding to already depolarized area of observer.
- C_1 and C_2 are the mean of observations z inside and outside of Ω_u^{in}

$$C_1(\Omega_u^{in}) = \frac{\int_{\Omega_u^{in}} z dx}{\int_{\Omega_u^{in}} dx} \quad C_2(\Omega_u^{in}) = \frac{\int_{\Omega \setminus \Omega_u^{in}} z dx}{\int_{\Omega \setminus \Omega_u^{in}} dx}$$

Application on bilayer model

Observer for bilayer model

We apply the observer only on one layer because usually patient data are available only for endocardium in atria.

$$\left\{ \begin{array}{l} A\left(C\partial_t u^{(k)} + f(u^{(k)}, w^{(k)})\right) = \operatorname{div}(\sigma^{(k)} \nabla_x u^{(k)}) + (-1)^k \gamma(u^{(1)} - u^{(2)}) \\ \quad + \lambda \delta(\Gamma_{u,x}) \left(-(z - C_1(\Omega_u^{in}))^2 + (z - C_2(\Omega_u^{in}))^2 \right) \mathbb{1}_{\Omega^{(1)}}(x) \text{ on } \Omega^{(k)} \\ \partial_t w^{(k)} = g(u^{(k)}, w^{(k)}) \text{ on } \Omega^{(k)} \\ \sigma^{(k)} \nabla_x u^{(k)} \cdot n = 0 \text{ on } \partial\Omega^{(k)} \\ u^{(k)}(0, x) = u_0^{(k)}(x), \quad w^{(k)}(x) = w_0^{(k)}(x) \quad x \in \Omega^{(k)} \end{array} \right.$$

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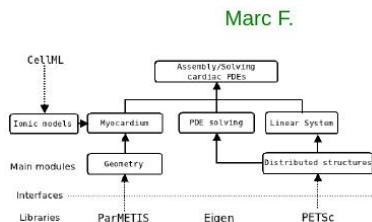
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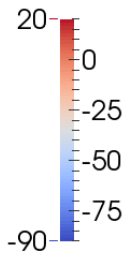
Software

CEPS : Cardiac Electrophysiology Simulator

- Open source C++ software from CARMEN team (Inria Bordeaux)
- Parallel implementation (PETSc, MPI, Parmetis or Scotch,...)
- Current models (monodomain, several ionic models, ...)
- Code easily new model or method (surface model)



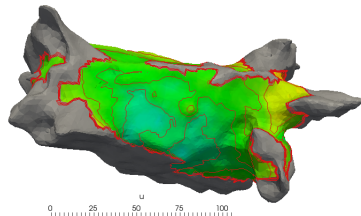
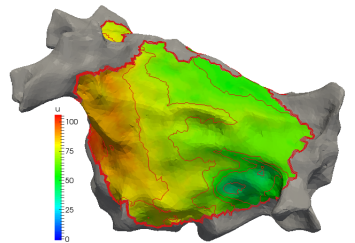
Square simulation



Pre-process patient data



postprocess



spatial gain

- Define a spatial gain function which we denote $\beta(x)$ to deal with hole in data :

$$\beta(x) = \begin{cases} 1 & \text{if } x \in \text{data points} \\ 0 & \text{elsewhere} \end{cases}$$

- Add this spatial gain in Luenberger Observer :

$$\lambda\beta(x)\delta(\Gamma_u, x)(-(z - C_1(\Omega_u^{in}))^2 + (z - C_2(\Omega_u^{in}))^2)\mathbb{1}_{\Omega(1)}(x)$$

fibers

- Give a priori fibers directions on some patches (literature)
- Complete on all atria using geodesic interpolation (P.Moireau, A.Collin)

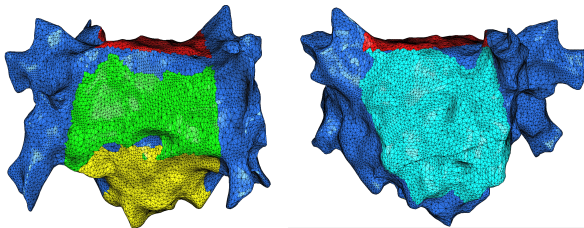
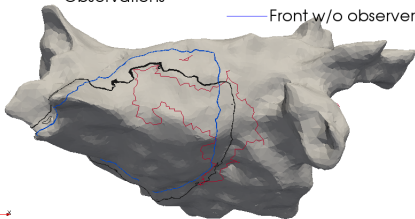


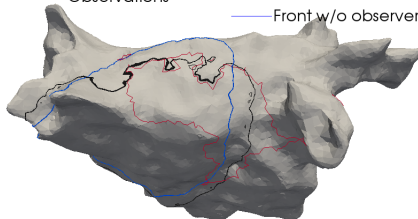
Figure : patch where we know fibers direction. (A.Collin)

Patient-data simulation

— Observations — Front with observer
— Front w/o observer



— Observations — Front with observer
— Front w/o observer



Application of observer on real data

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- topological gradient term to detect new front
- parameter estimation and coupling CEPS with Verdandi
- remeshing mesh from CARTO (mmgs)
- reconstruct activation map from patient data
- Use more information than with activation times

- topological gradient term to detect new front
- parameter estimation and coupling CEPS with Verdandi
- remeshing mesh from CARTO (mmgs)
- reconstruct activation map from patient data
- Use more information than with activation times
- Patient-specific modeling, Radio-frequency ablation planning

A Collin, D Chapelle, and P Moireau. Sequential state estimation for electrophysiology models with front level-set data using topological gradient derivations. In *Functional Imaging and Modeling of the Heart*, pages 402–411. Springer, 2015.

Simon Labarthe, Jason Bayer, Yves Coudière, Jacques Henry, Hubert Cochet, Pierre Jaïs, and Edward Vigmond. A bilayer model of human atria : mathematical background, construction and assessment. *Europace*, 16(suppl 4) :iv21–iv29, 2014.

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Thanks for your attention...