Application of a front observer on real atrial data

PhySio

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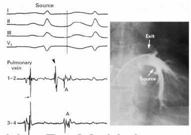
LIRYC :

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

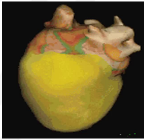


Headed by Pr. M. Haissaguerre

ELECTROPHYSIOLOGY AND HEART MODELING INSTITUTE
BORDEAUX

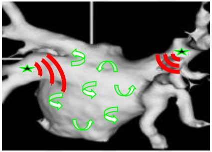
"The project Carmen deals with developing of computational approaches for clinical research in LIRYC." (CR3)

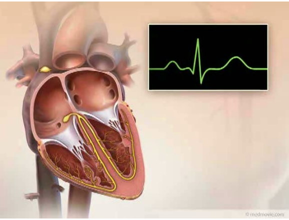
Research Themes

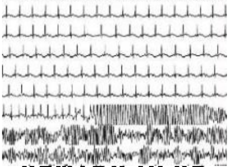


ATRIAL FIBRILLATION

Europe: 5 millions
Major Cause of Stroke

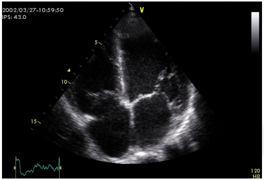






VENTRICULAR ARRHYTHMIAS AND SUDDEN CARDIAC DEATH

Europe: 350 000 deaths/year

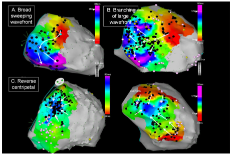


HEART FAILURE AND ELECTRICAL DYSSYNCHRONY

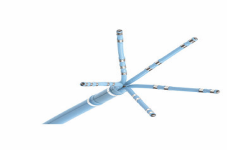
Europe: 9 millions
350 000 deaths/year

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

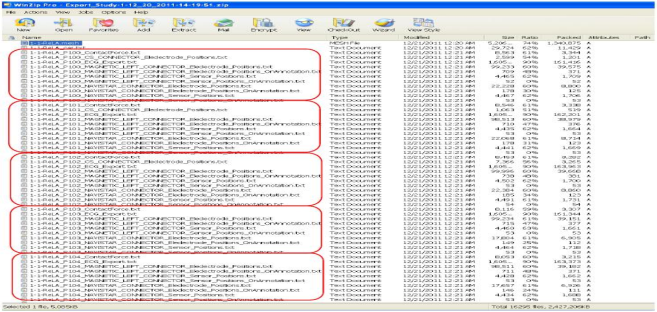


Figure : example of exported files with CARTO system

Postprocess CARTO data

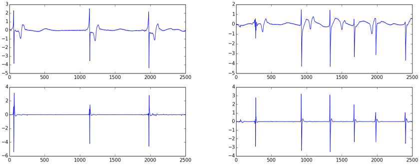


Figure : example of signals post-process from CARTO files

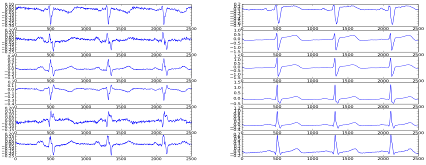
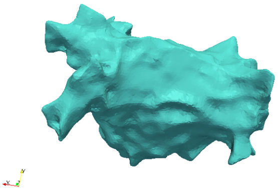
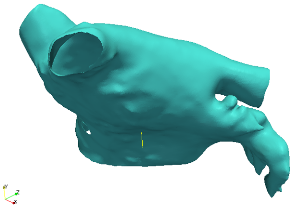


Figure : example of ECG post-process from CARTO files





What we use in practice ?

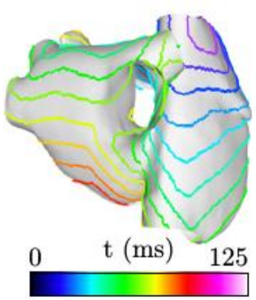


Figure : In silico activation map. A.Collin

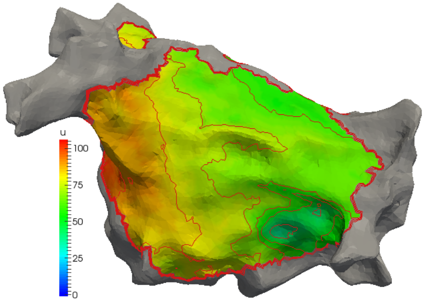


Figure : activation time from CARTO system

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] :

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

Bilayer Model

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- Average in depth

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

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] :

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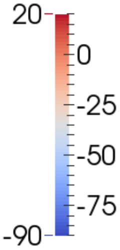
bilayer simulation



Luenberger observer for reaction-diffusion equations

Collin, Chapelle, and Moireau [2015]

Consider a simple reaction-diffusion equation :

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

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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}

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

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.

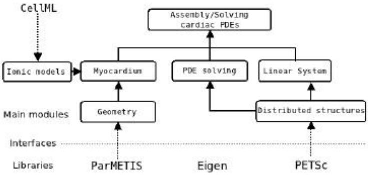
$$
\begin{cases}
A\Big(C\partial_t u^{(k)}+f(u^{(k)},w^{(k)})\Big)=\mathrm{div}(\sigma^{(k)}\nabla_x u^{(k)})+(-1)^k\gamma(u^{(1)}-u^{(2)}) \\
\qquad\qquad +\lambda\delta(\Gamma_u,x)(-(z-C_1(\Omega_u^{in}))^2+(z-C_2(\Omega_u^{in}))^2)\mathbb{1}_{\Omega^{(1)}}(x) \text{ on } \Omega^{(k)} \\
\partial_t w^{(k)}=g(u^{(k)},w^{(k)}) \text{ on } \Omega^{(k)} \\
\sigma^{(k)}\nabla_x u^{(k)}.n=0 \text{ on } \partial\Omega^{(k)} \\
u^{(k)}(0,x)=u_0^{(k)}(x), \quad w^{(k)}(x)=w_0^{(k)}(x) \quad x\in\Omega^{(k)}
\end{cases}
$$

Software

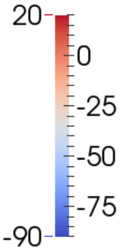
CEPS : Cardiac Electrophysiology Simulator

- 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)

Marc F.

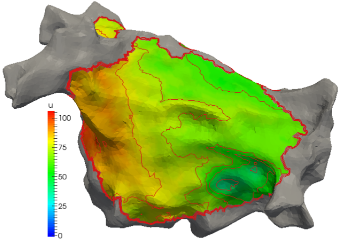


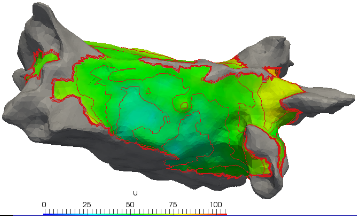
Square simulation



Pre-process patient data

postprocess
$\longrightarrow$





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)

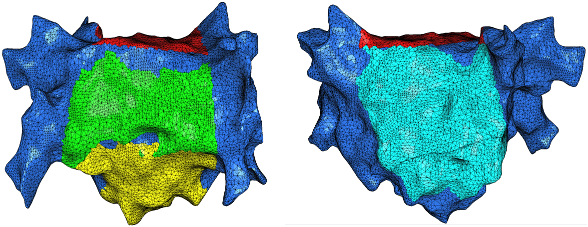
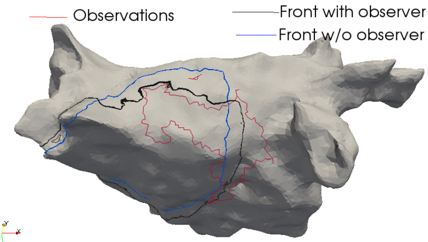
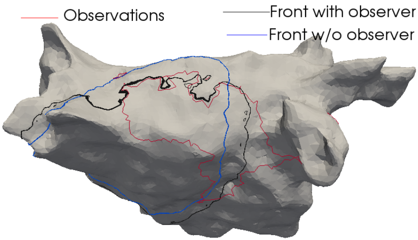


Figure : patch where we know fibers direction. (A.Collin)

Patient-data simulation





Application of observer on real data

- 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 model with front level-set data using topological gradient derivations. In *Functional Imaging an Modeling of the Heart*, pages 402–411. Springer, 2015.

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

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Thanks for your attention...