Intelligence artificielle pour l'analyse de la fonction cardiaque à l'échelle de populations

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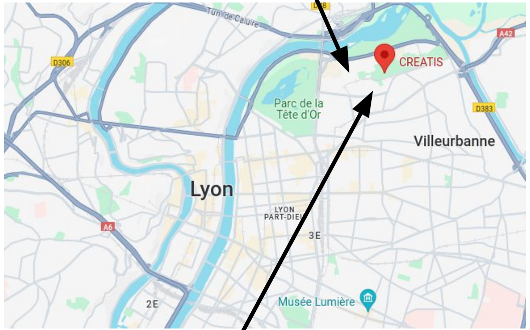
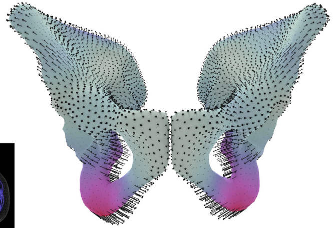
About

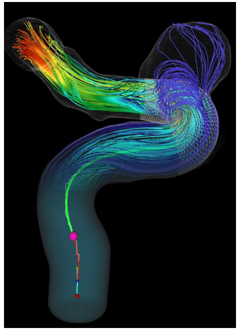
Génie Biomédical (3ª, 4ª, 5ª)

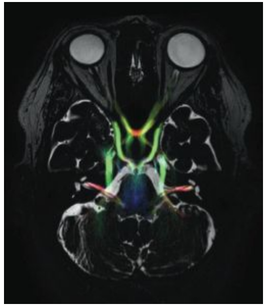
(informatique, traitement d'images)



- **Analyse d'images et modélisation**
- Imagerie ultrasonore
- Imagerie tomographique + radiothérapie
- Imagerie RMN + optique







IA ? machine learning ?

	Age	Taille	Fumeur	…
Patient #001	70	175	Oui	
Patient #002	72	180	Non	
Patient #003	65	168	Non	
…				

Q: quel problème à résoudre ?

Q: méthodes statistiques ? autre chose ?

IA ? machine learning ?

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…				

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MACHINE "LEARNING":

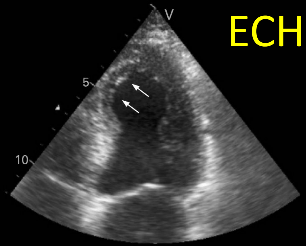
Tom Mitchell (1998)

On dit qu'un ordinateur:

- apprend par **experience E** = données ?
- par rapport à une **tâche T**
- et une mesure de **performance P**

Si sa performance pour faire T, mesurée par P, s'améliore avec l'expérience E.

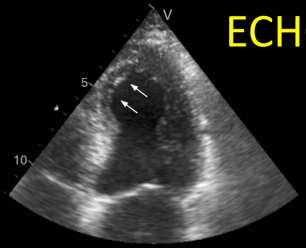
Imagerie = utile…



ECHO

IRM

Imagerie = utile…



ECHO

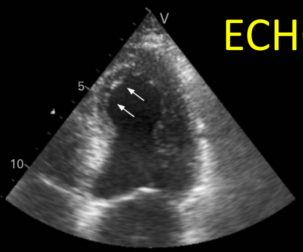
IRM

... mais analyse **“tronquée”** en clinique !

Mesures simples:

- Fraction d’éjection, GLS, …
- Taille de lésion, …

Imagerie = utile…



ECHO

IRM

… mais analyse **“tronquée”** en clinique !

<u>Mesures simples:</u>

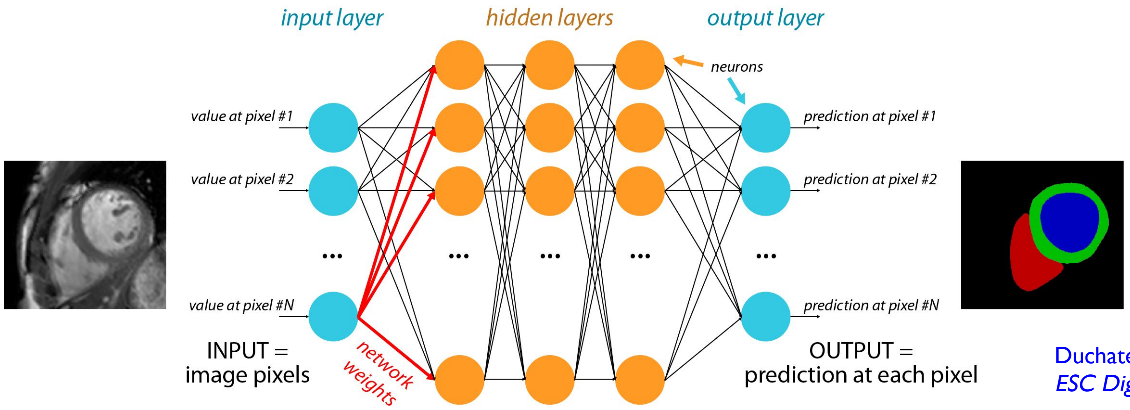
- Fraction d’éjection, GLS, …
- Taille de lésion, …

Que peut apporter l’IA ?

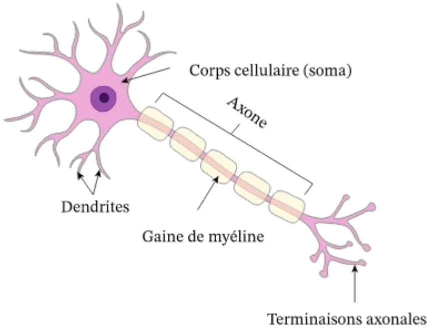
➔ Extraction **précise** de **biomarqueurs fins**

➔ Cadre d’analyse **pertinent statistiquement**

Réseaux de neurones

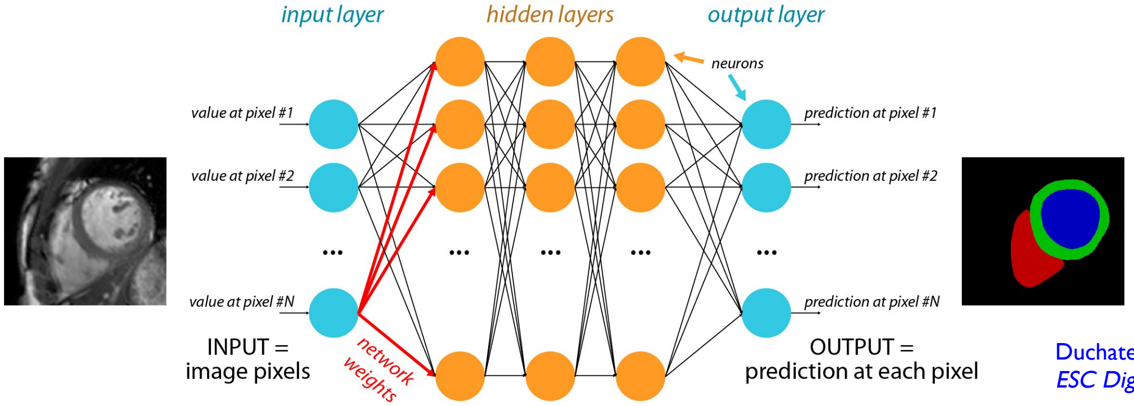


Duchateau & Bernard.
ESC Digital Health 2020

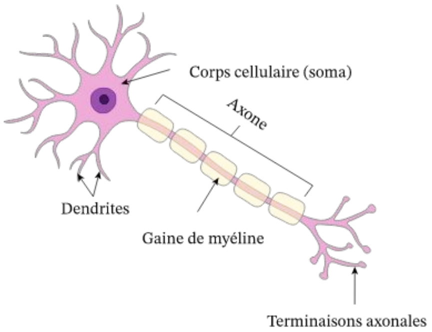


Neurone = combine + transmet l’information

Réseaux de neurones

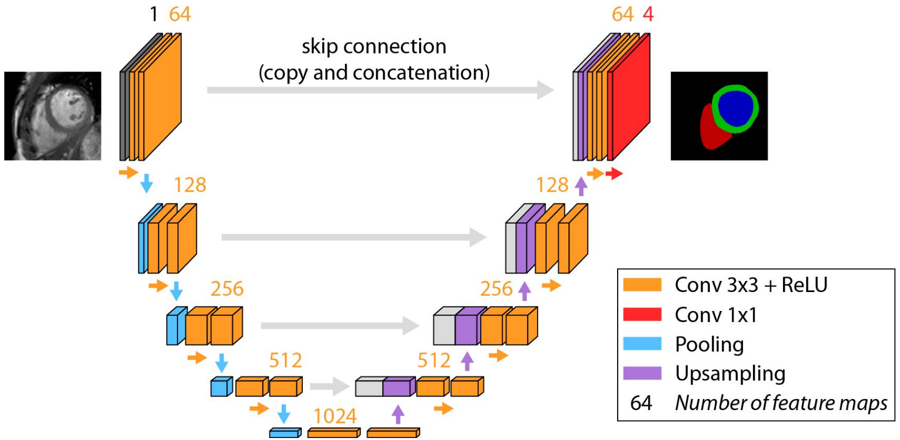


Duchateau & Bernard. *ESC Digital Health* 2020



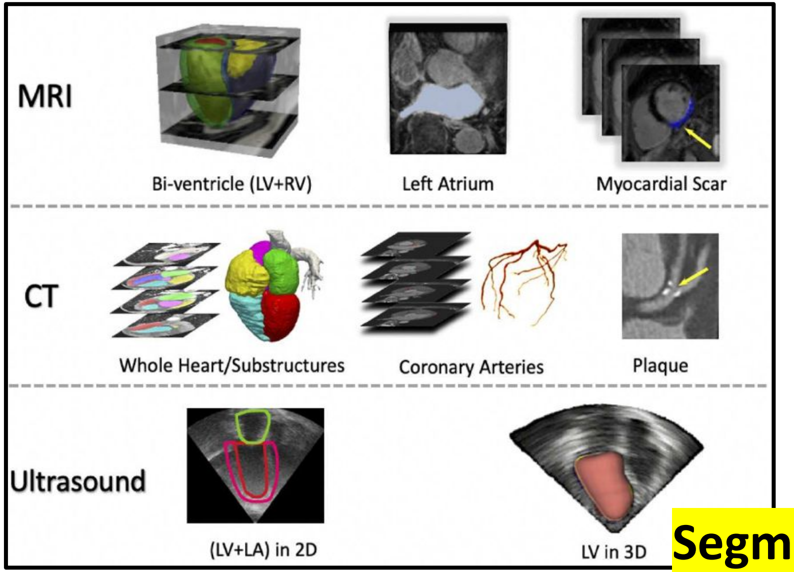
Neurone = combine + transmet l'information

En réalité = convolutions
= mieux pour images/signaux



Extraction de biomarqueurs

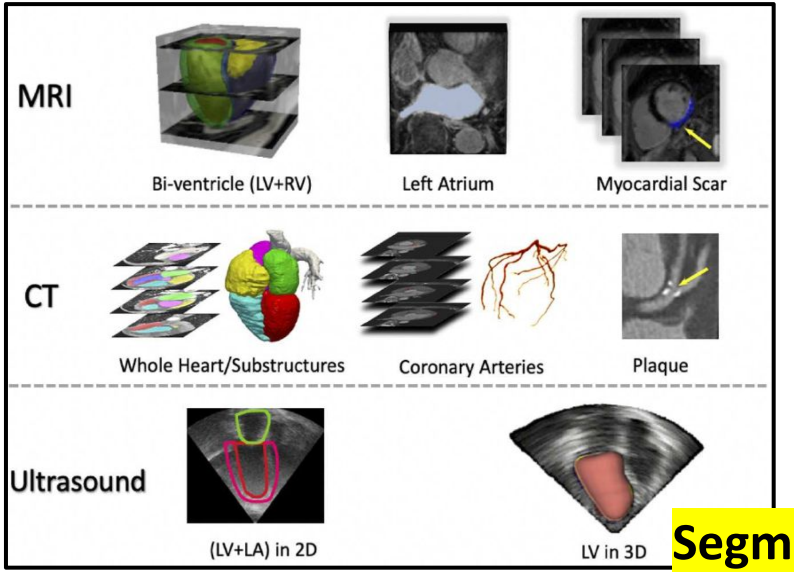
Extraction de biomarqueurs



Segmentation

Chen et al. Front Cardiovasc Med 2020

Extraction de biomarqueurs



Chen et al. Front Cardiovasc Med 2020

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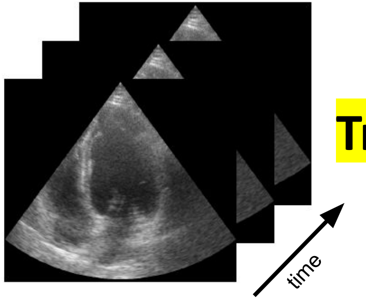
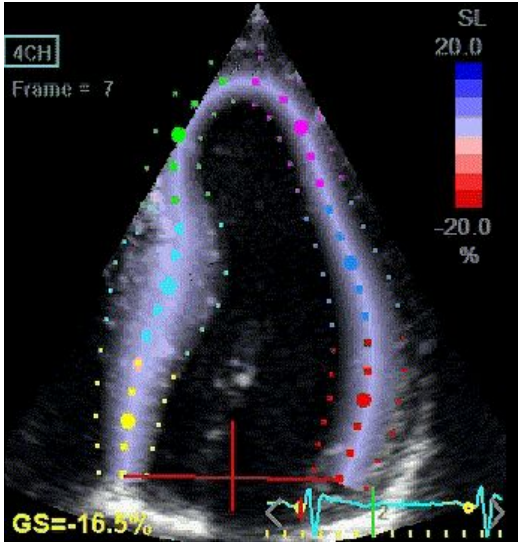
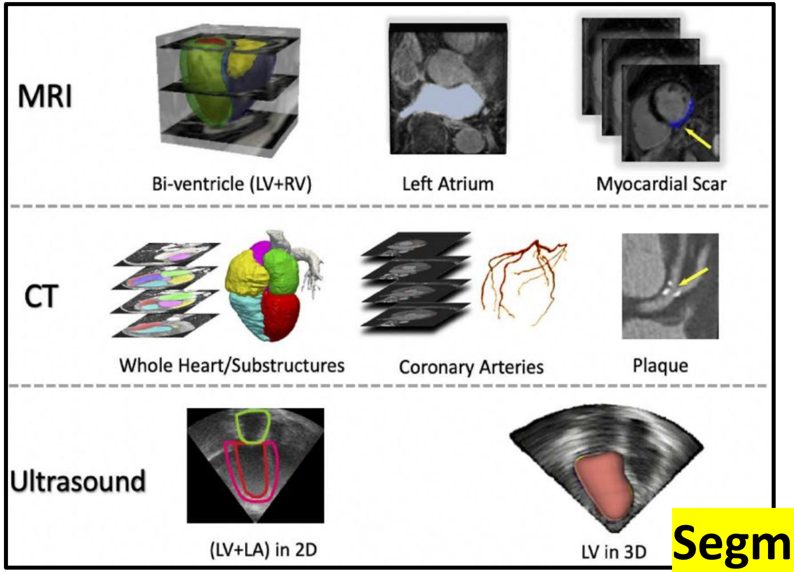


Tracking



Extraction de biomarqueurs



Chen et al. Front Cardiovasc Med 2020

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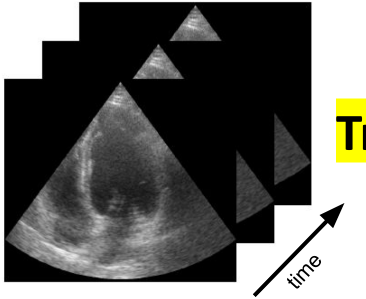
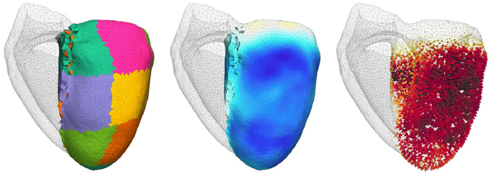


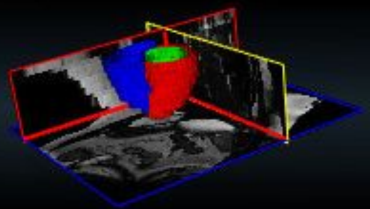
Tracking

Automatique ?
Reproductible ?



"Patterns" avancés ?

MRI & ECHO: segmentation



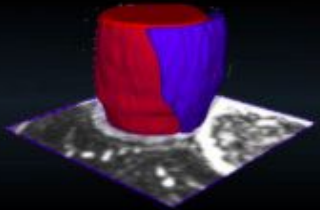
Automated Cardiac Diagnosis Challenge (ACDC)

Bernard et al. *IEEE T Med Imaging* 2018 [redacted]

CAMUS

Cardiac Acquisitions for Multi-structure Ultrasound Segmentation

Leclerc et al. *IEEE T Med Imaging* 2019 [redacted]



MYOcardial Segmentation with Automated Infarct Quantification

Ongoing work

MRI & ECHO: segmentation

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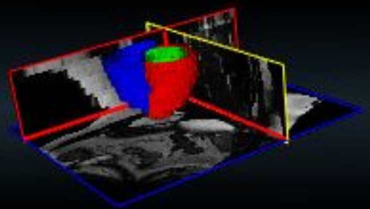
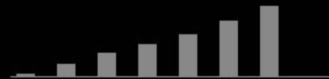


Automated Cardiac Diagnosis Challenge (ACDC)

Bernard et al. *IEEE T Med Imaging* 2018

Total citations Cited by 1831



IEEE Trans Med Imaging. 2018 Nov;37(11):2514-2525. doi: 10.1109/TMI.2018.2837502.
Epub 2018 May 17.

Deep Learning Techniques for Automatic MRI Cardiac Multi-Structures Segmentation and Diagnosis: Is the Problem Solved?

Olivier Bernard, Alain Lalande, Clement Zotti, Frederick Cervenansky, Xin Yang, Pheng-Ann Heng, Irem Cetin, Karim Lekadir, Oscar Camara, Miguel Angel Gonzalez Ballester, Gerard Sanroma, Sandy Napel, Steffen Petersen, Georgios Tziritas, Elias Grinias, Mahendra Khened, Varghese Alex Kollerathu, Ganapathy Krishnamurthi, Marc-Michel Rohe, Xavier Pennec, Maxime Sermesant, Fabian Isensee, Paul Jager, Klaus H Maier-Hein, Peter M Full, Ivo Wolf, Sandy Engelhardt, Christian F Baumgartner, Lisa M Koch, Jelmer M Wolterink, Ivana Isgum, Yeonggul Jang, Yoonmi Hong, Jay Patravali, Shubham Jain, Olivier Humbert, Pierre-Marc Jodoin

PMID: 29994302 DOI: 10.1109/TMI.2018.2837502

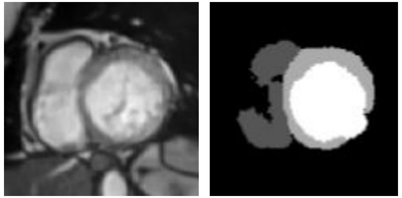
Left ventricle

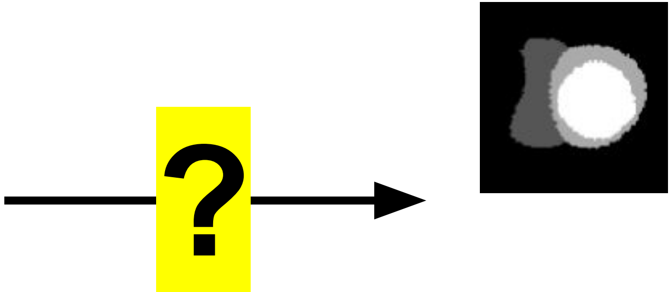
Rank	User	Mean DICE ED	Mean DICE ES	Mean Hausdorff ED	Mean Hausdorff ES	EF correlation	EF bias	EF standard deviation(std)	Volume ED correlation	Volume ED bias	Volume ED std
1	Georgios Simantiris	0.967	0.928	6.4	7.6	0.993	-0.4	2.7	0.998	2.0	4.6
1	Fabian Isensee	0.967	0.928	5.5	6.9	0.991	0.5	3.0	0.997	1.5	5.7
2	Clement Zotti	0.964	0.912	6.2	8.4	0.990	-0.5	3.1	0.997	3.7	5.1
3	Nathan Painchaud	0.961	0.911	6.1	8.3	0.990	-0.5	3.2	0.997	3.8	5.2
4	Mahendra Khened	0.964	0.917	8.1	9.0	0.989	-0.5	3.4	0.997	0.6	5.5
5	Christian Baumgartner	0.963	0.911	6.5	9.2	0.988	0.6	3.4	0.995	1.4	7.6

MRI & ECHO: segmentation

Cohérence anatomique

Painchaud et al. *IEEE T Med Imaging* 2020





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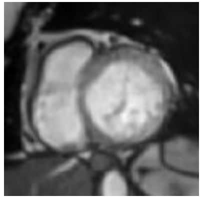
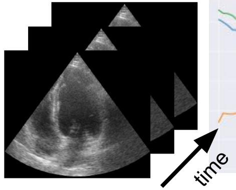
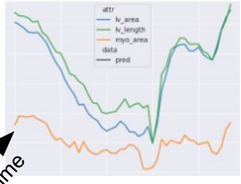
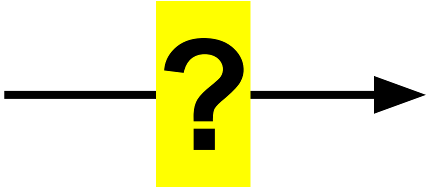


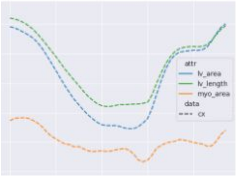
Cohérence temporelle

Painchaud et al. *IEEE T Med Imaging* 2022







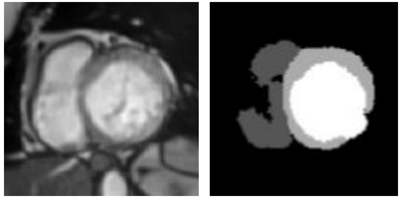


MRI & ECHO: segmentation

Représentation simplifiée

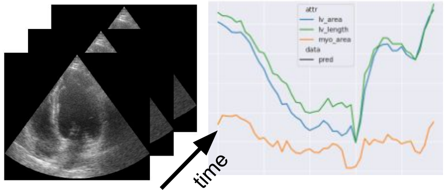
Cohérence anatomique

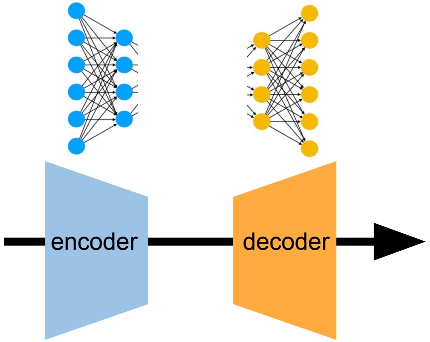
Painchaud et al. *IEEE T Med Imaging* 2020

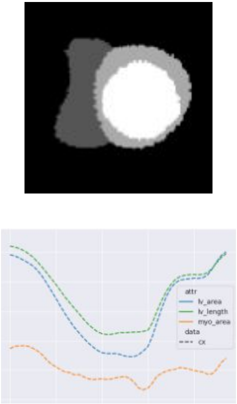


Cohérence temporelle

Painchaud et al. *IEEE T Med Imaging* 2022





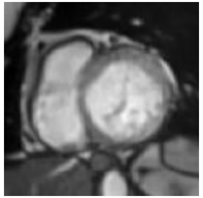


MRI & ECHO: segmentation

Représentation simplifiée

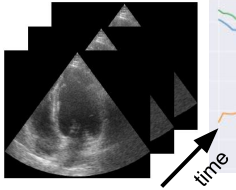
Cohérence anatomique

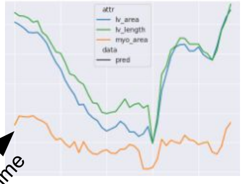
Painchaud et al. *IEEE T Med Imaging* 2020

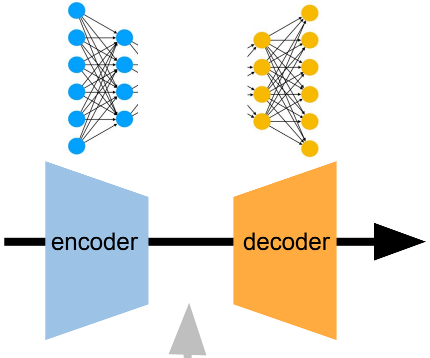


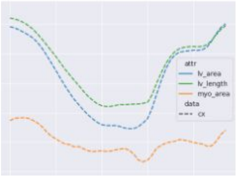
Cohérence temporelle

Painchaud et al. *IEEE T Med Imaging* 2022









ex: épaisseur

Propriétés

MRI & ECHO: segmentation

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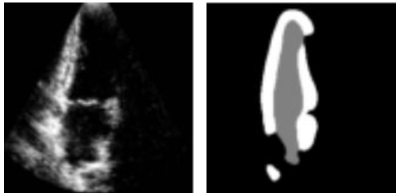
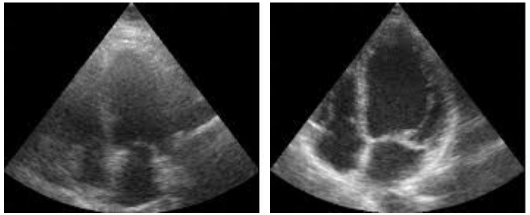
Cohérence anatomique



?



<u>Domaine source</u> = CAMUS:

- 2000 images annotées
- Bonne qualité

MRI & ECHO: segmentation

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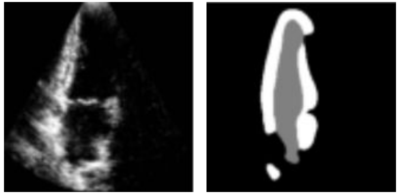
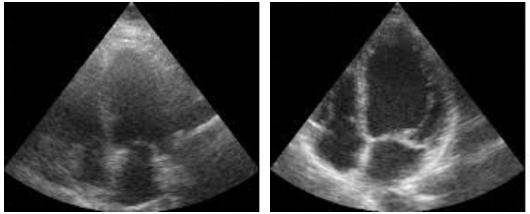
Cohérence anatomique



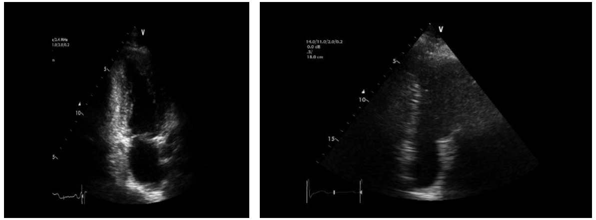
?



<u>Domaine source</u> = CAMUS:

- 2000 images annotées
- Bonne qualité

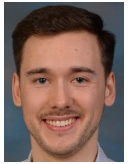
Généralisation à nouveau dataset <u>non annoté?</u>



<u>Domaine cible</u> = société ICardio:

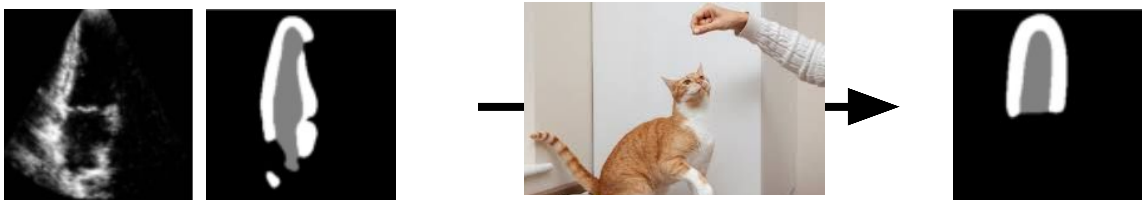
- 10 000 images sans annotation
- Qualité variable

MRI & ECHO: segmentation



Cohérence anatomique

Judge et al. *MICCAI* 2024



Inspiré du fonctionnement de ChatGPT =

1) Entrainement de politique

2) Entrainement de “reward”

3) Optimisation (renforcement)

état = image

action = segmentation

récompense = erreur

ECHO: tracking

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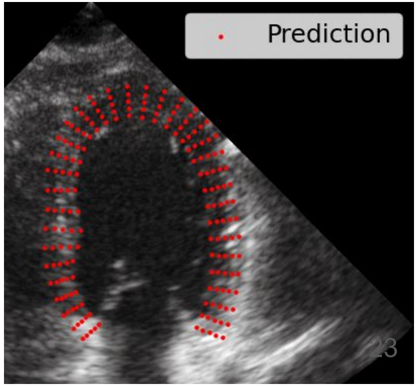
PhD T. Judge
Ongoing work

“Ground truth” pour le mouvement ?



ECHO: tracking

PhD T. Judge
Ongoing work

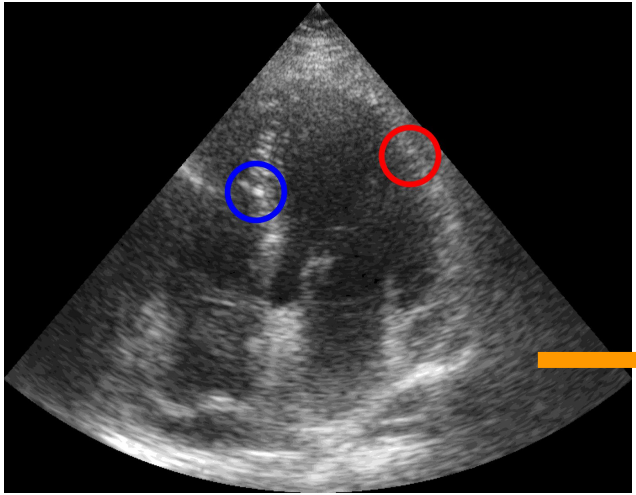
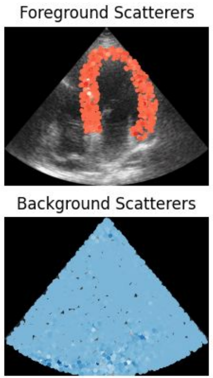


Image originale



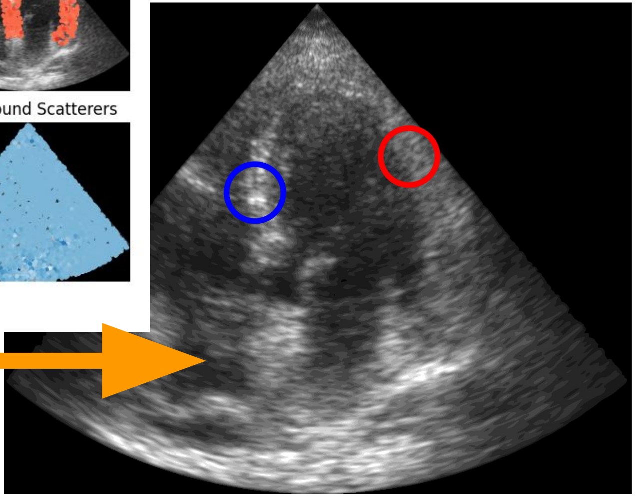
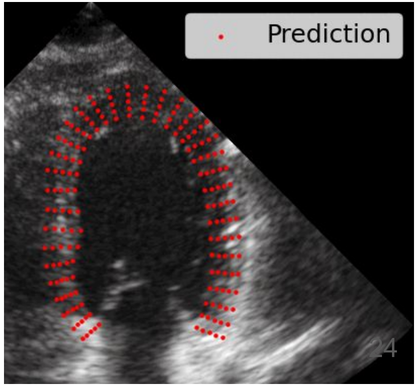


Image simulée
= vérité terrain connue
= pour entraîner IA !



Analyse de populations

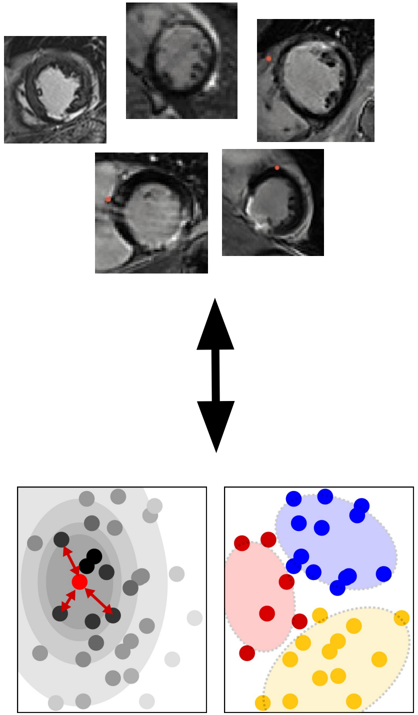
Analyse de populations

1) Représenter statistiquement ET simplement une population

2) Combiner des informations de différents types

Analyse de populations

1) Représenter statistiquement ET simplement une population



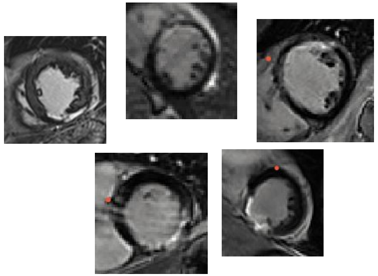
HAUTE DIMENSION

FAIBLE DIMENSION

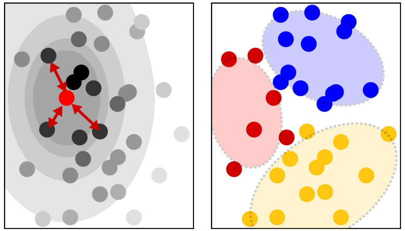
2) Combiner des informations de différents types

Analyse de populations

1) **Représenter** statistiquement ET simplement une population



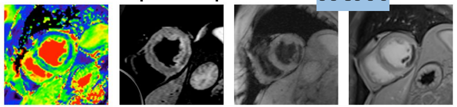
HAUTE DIMENSION



FAIBLE DIMENSION

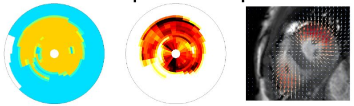
2) **Combiner** des informations de différents types

Multiple acquisitions **IRM**



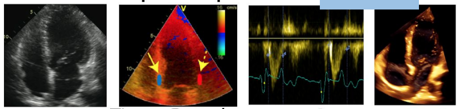
T2 map T2* weighted EGE LGE

Multiple descriptors



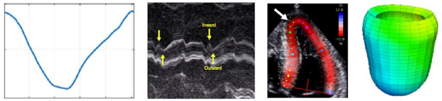
Geometry Transmurality Motion

Multiple acquisitions **ECHO**



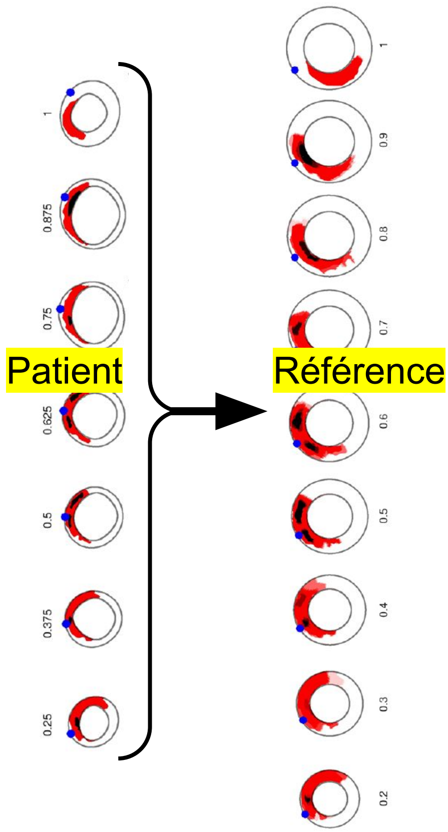
B-mode Tissue Doppler Valve flow 3D echo

Multiple descriptors



Volume Thickness 2D strain 3D strain

ex: “patterns” fins d’ischémie-reperfusion



Duchateau et al. *Front Card Med* 2023

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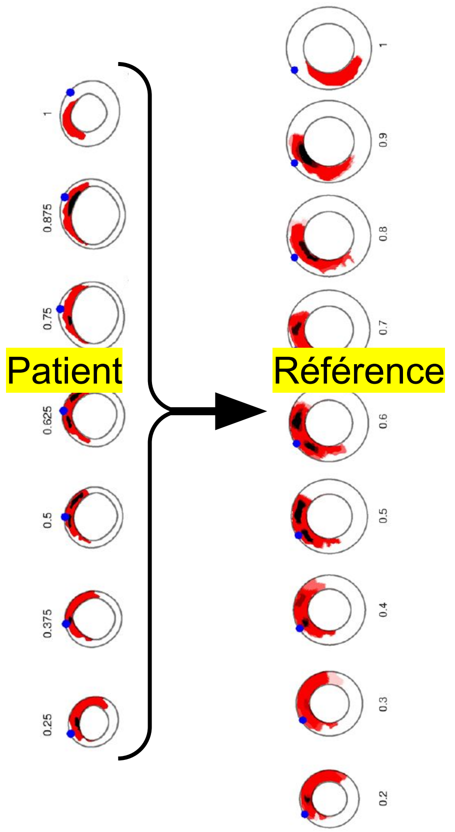
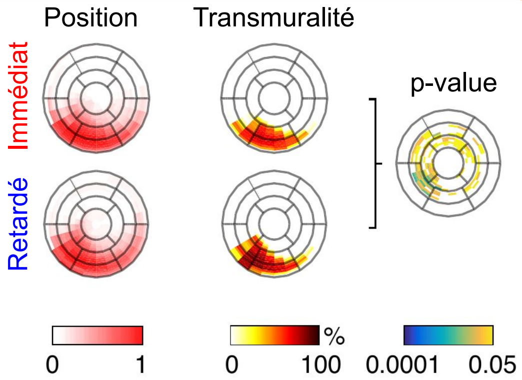


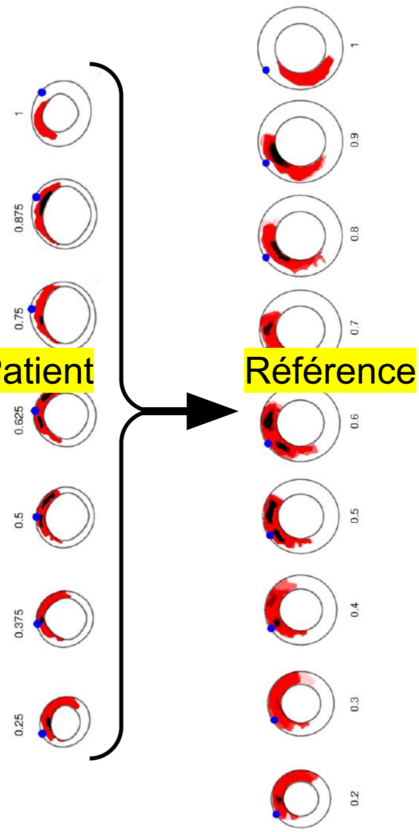
Statistiques “pixel-wise”

ex: sous-groupes vs. traitement



Duchateau et al. *Front Card Med* 2023

ex: “patterns” fins d’ischémie-reperfusion



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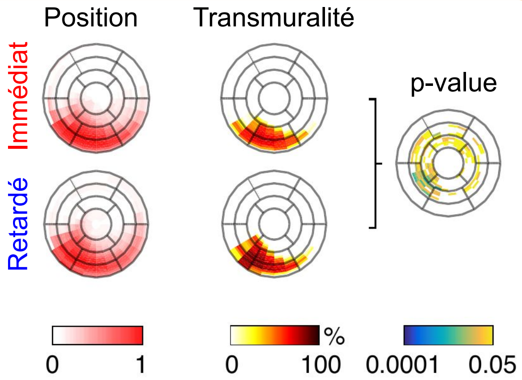
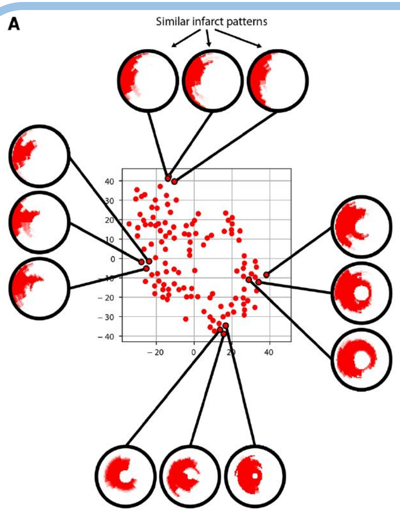
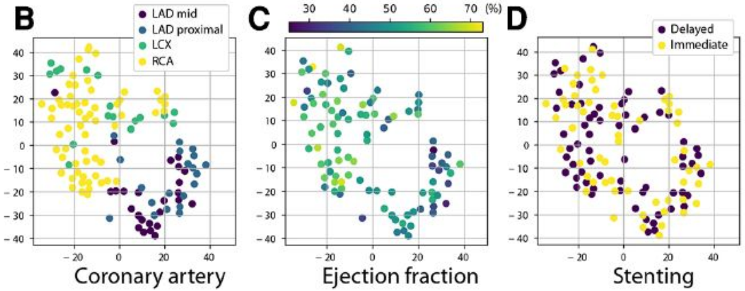


Statistiques “population-wise”





Duchateau et al. *Front Card Med* 2023

ex: contrôle qualité LGE/IRM

Choix du **TI optimal** (synthetic MAGIR)
vs. **LGE conventionnel**

PhD R. Deleat-Besson / ongoing work

ex: contrôle qualité LGE/IRM

Choix du **TI optimal** (synthetic MAGIR)
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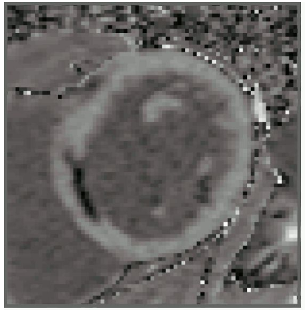
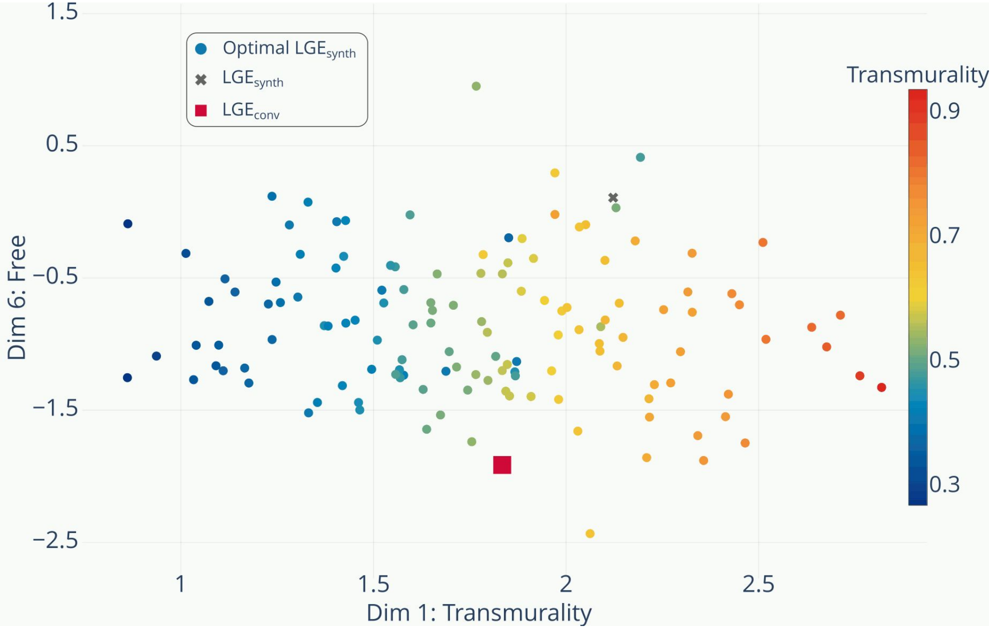
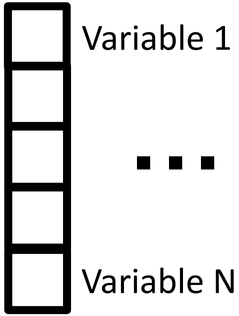




PhD R. Deleat-Besson / ongoing work

Données hétérogènes

Concaténation:



Données hétérogènes

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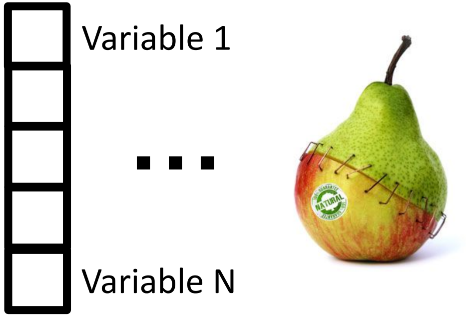
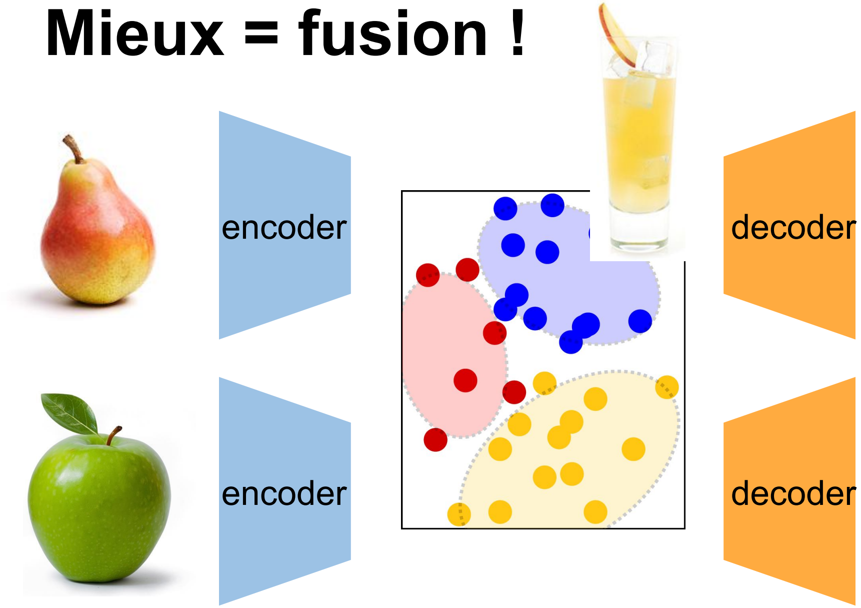


Mieux = fusion !

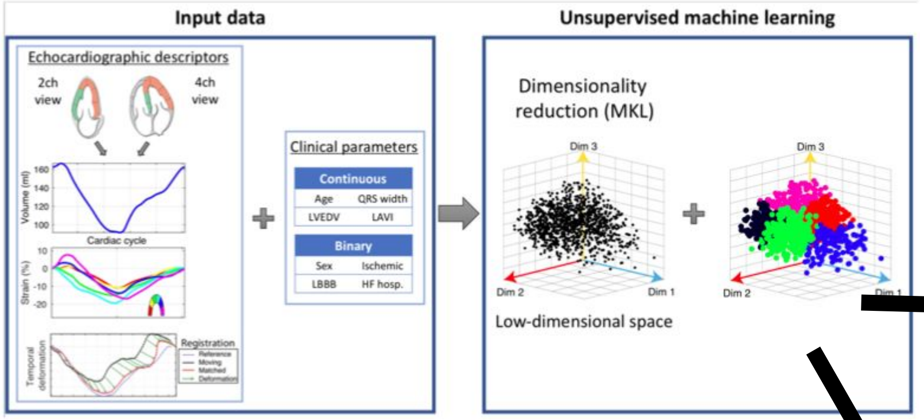


HAUTE DIMENSION

FAIBLE DIMENSION

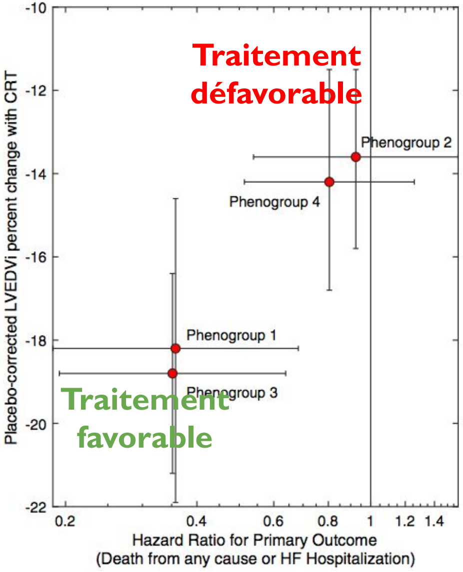
ex: réponse à la resynchronisation

Cikes et al. *Eur J Heart Fail* 2019

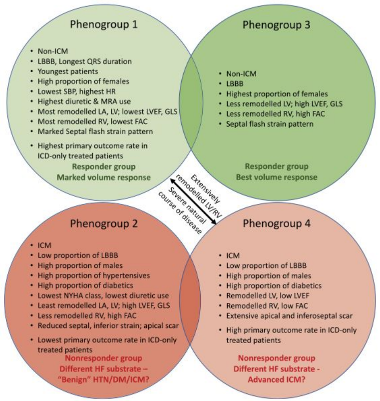


- 30% de non-répondeurs
- Mécanismes favorables?

Stratification de risque



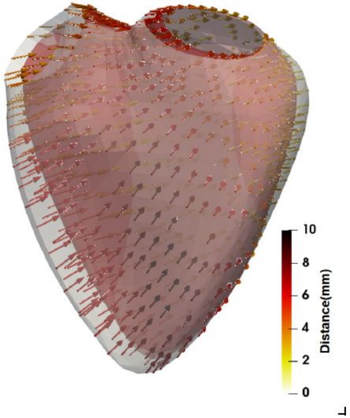
Phenotypage



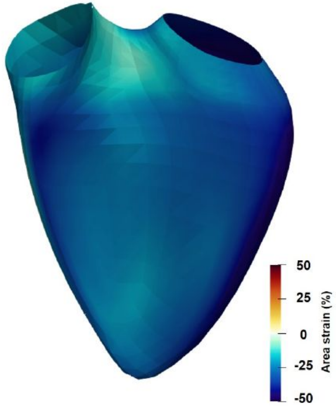
ex: forme et déformation

Moceri et al. *EHJCI* 2018
Di Folco et al. *Med Image Anal* 2022

Forme

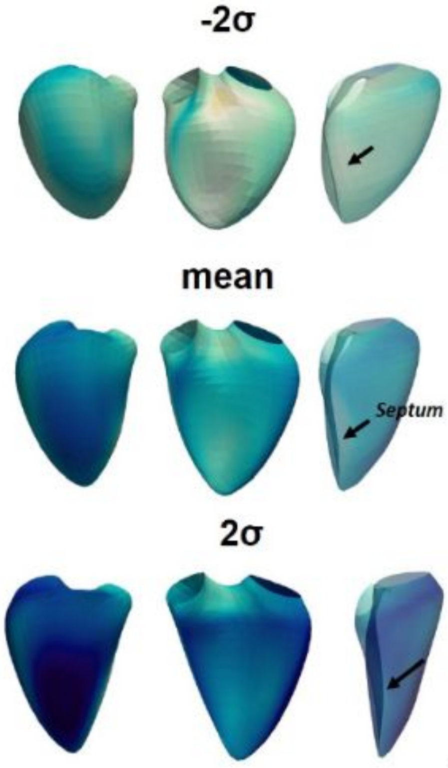


Déformation (strain)



Hypertension pulmonaire sévère

Normal

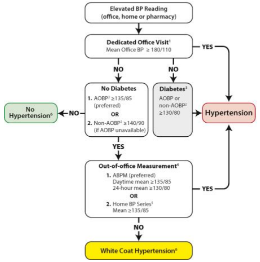


Mieux = éviter le mélange “tout en même temps” ?

Analyse clinique

eminence-based

evidence-based



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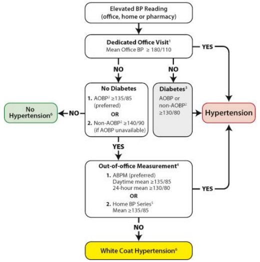
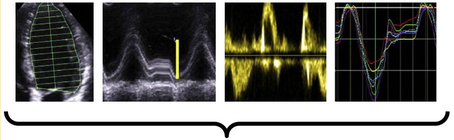
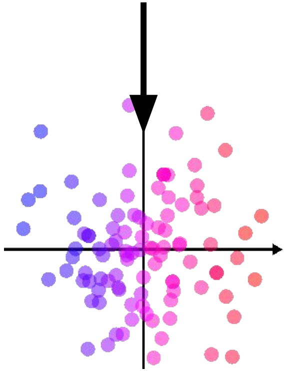


Analyse computationnelle





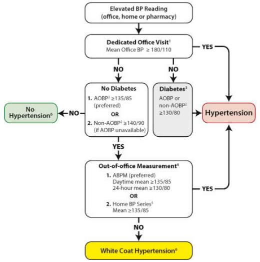
Approche “force brute”
= tout en même temps !

Mieux = éviter le mélange “tout en même temps” ?

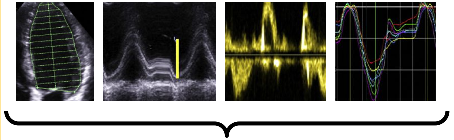
Analyse clinique

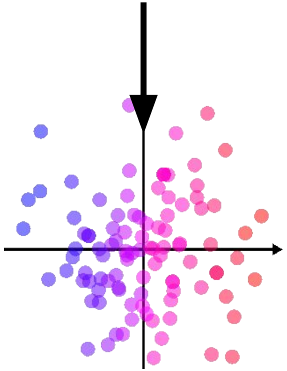
eminence-based

evidence-based



Analyse computationnelle





Approche “force brute”
= tout en même temps !

Objectif = Ordre optimal d’intégration des données ?

Niveaux simples

Niveaux élaborés

- **Hiérarchie imposée a-priori**

Mieux = éviter le mélange “tout en même temps” ?

Analyse clinique

eminence-based

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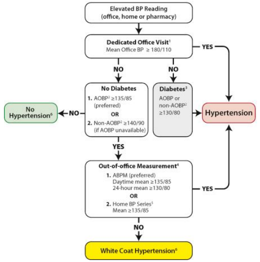
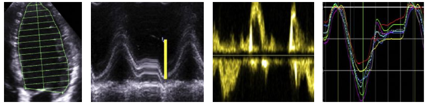
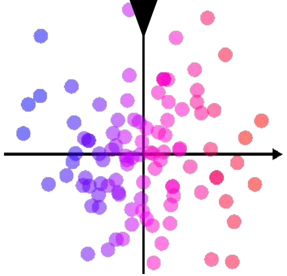


Analyse computationnelle





Approche “force brute”
= tout en même temps !

Objectif = Ordre optimal d’intégration des données ?

Niveaux simples

?

?

Niveaux élaborés

- **Hiérarchie imposée a-priori**
- **Hiérarchie apprise automatiquement**

Valeur explicative + Coûts { Calcul / Incertitudes / Economiques }

Hiérarchie imposée

ex: CelebA dataset

Niveau 0
= landmarks

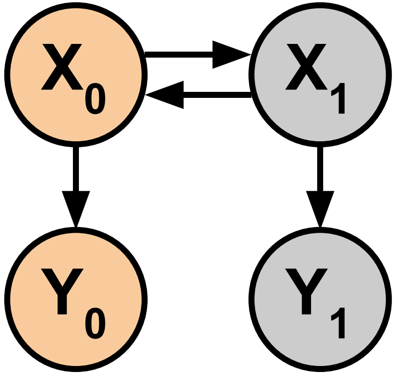
Niveau 1
= images

CREATIS

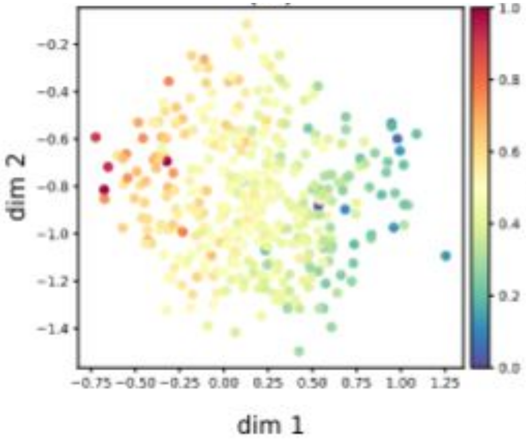
Freiche et al. *IEEE TMI* 2024

Représentation

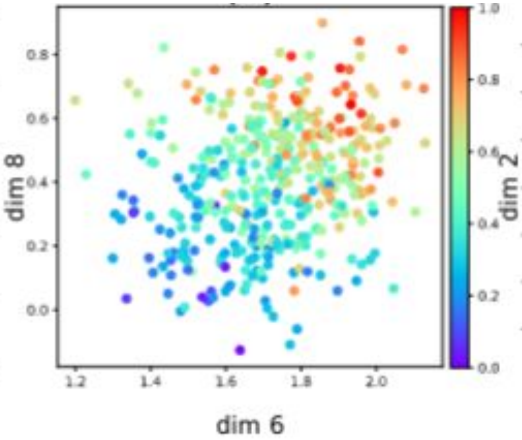
Observations



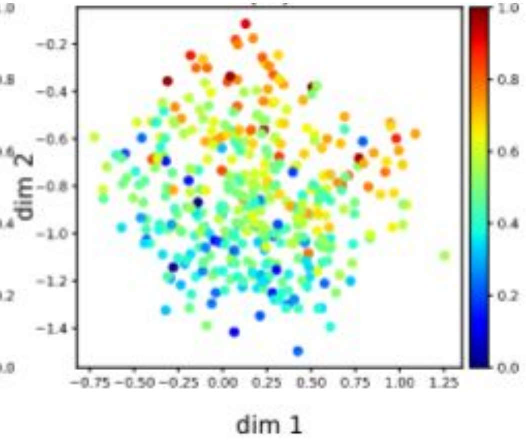
Orientation



Sourire



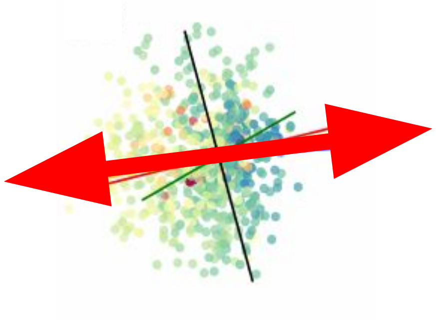
Intensité image

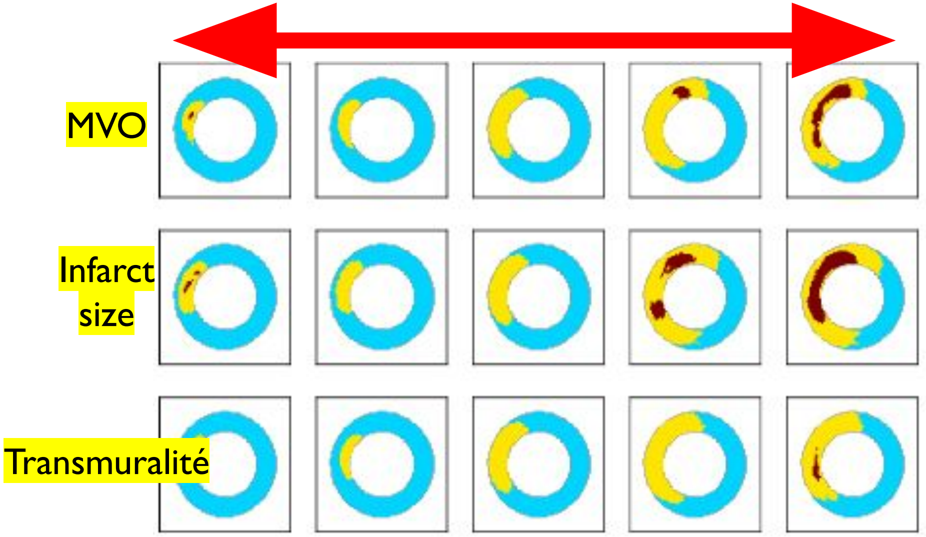


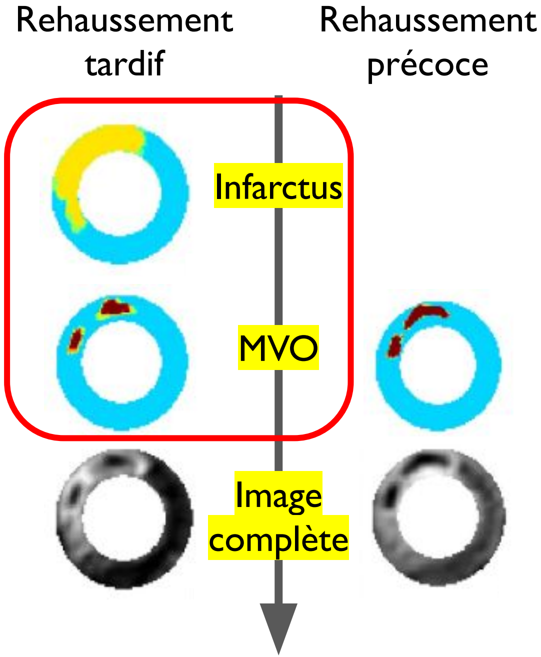
ex: infarctus + MVO + …

CREATIS

Freiche et al. *IEEE TMI* 2024





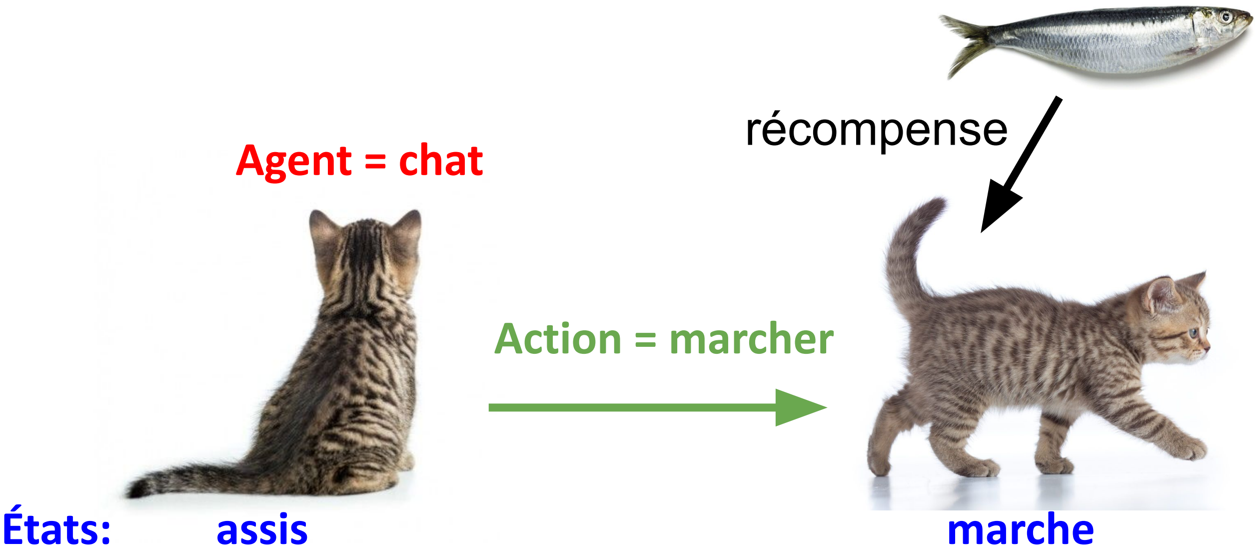


Hiérarchie apprise automatiquement

CREATIS
CLÍNIC BARCELONA Hospital Universitari

Bernardino et al. *MICCAI* 2022

Apprentissage par renforcement
- Pertinent pour chaînes de décisions
- Différentes décisions pour chaque patient



Hiérarchie apprise automatiquement

CREATIS
CLÍNIC BARCELONA Hospital Universitari

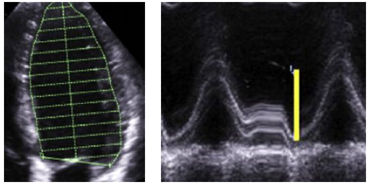
Bernardino et al. *MICCAI* 2022

Apprentissage par renforcement

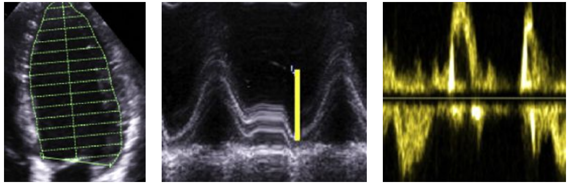
- Pertinent pour chaînes de décisions
- Différentes décisions pour chaque patient

récompense = précision - λ coût

Agent = clinicien



Action = rajouter acquisitions



États = modalités acquises

ex: hypertension artérielle / ECHO

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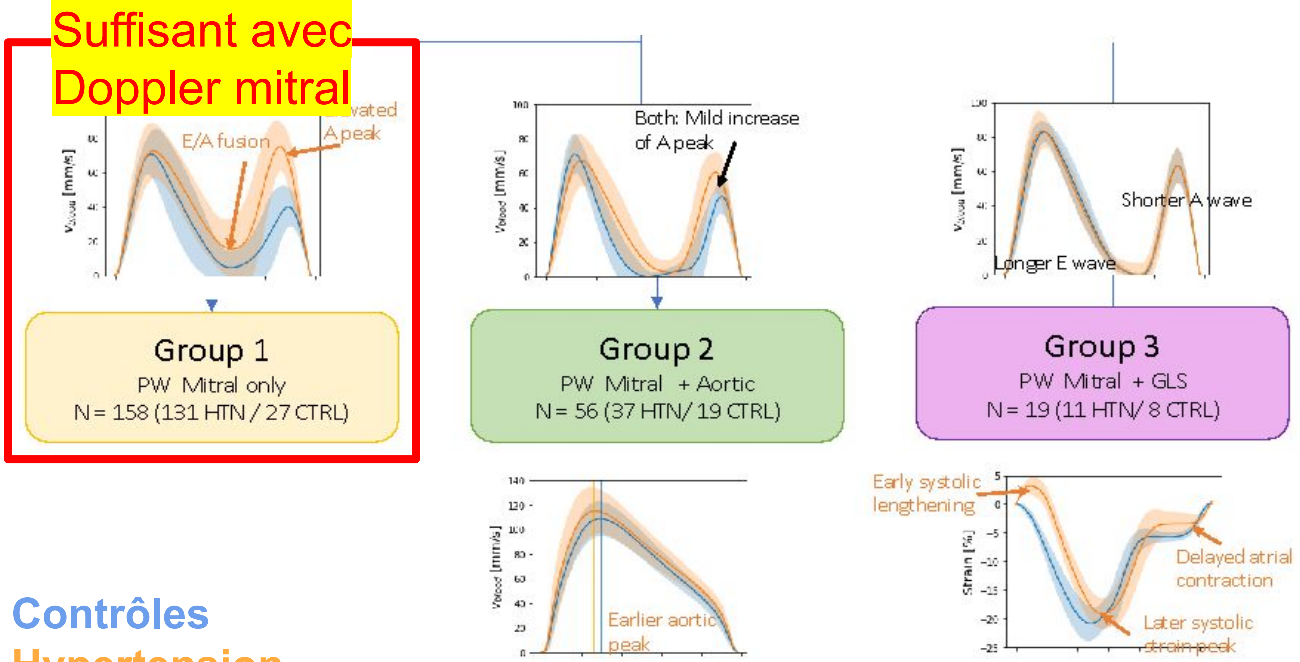
Bernardino et al. *MICCAI* 2022



Contrôles
Hypertension

ex: hypertension artérielle / ECHO

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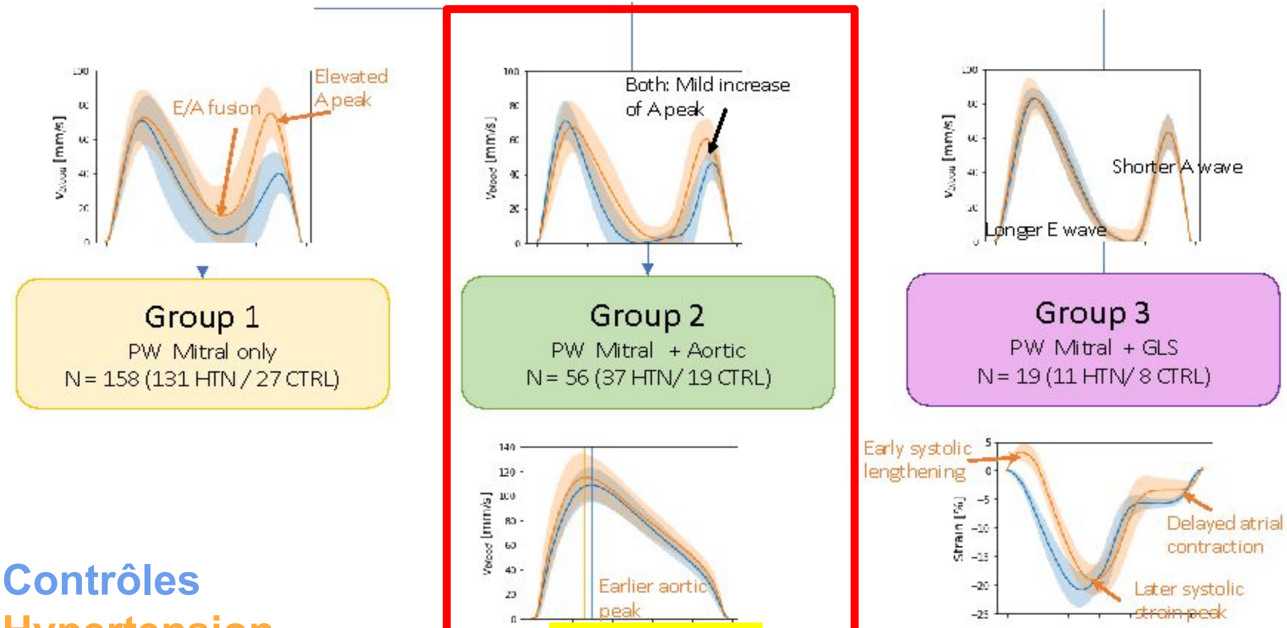
Bernardino et al. *MICCAI* 2022

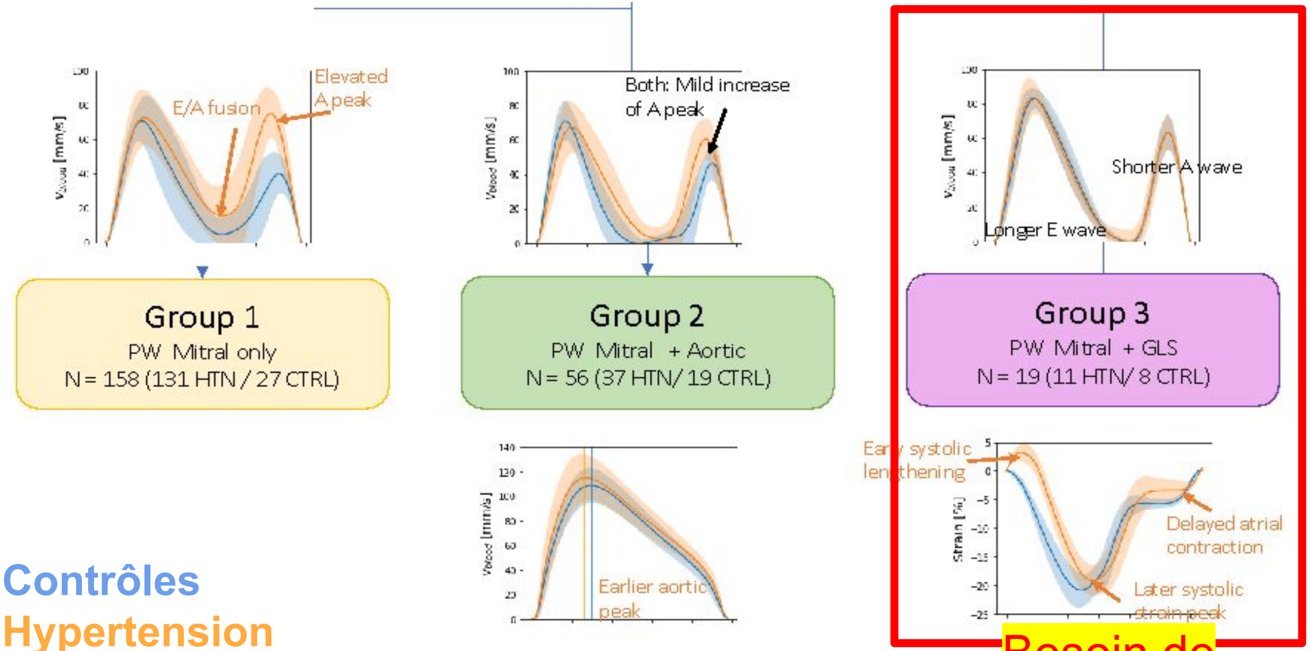


Contrôles
Hypertension

Besoin de Doppler aortique

ex: hypertension artérielle / ECHO

Bernardino et al. *MICCAI* 2022



Contrôles
Hypertension

Besoin de strain global (GLS)

IA: menace ou opportunité ?

Apprentissage « humain »:

- Apprendre par l'**expérience**
- **Lecture progressive et hiérarchique des données**
- **Contextualisation** = a-priori physiologique / physique
- **Raffiner** et **confirmer** les observations/diagnostic

IA: menace ou opportunité ?

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Approche algorithmique
= support quantitatif et objectif

- Grande quantité de données
- Comparaisons rapides et reproductibles
- Données complexes et diverses
- Nouveaux descripteurs et interactions ?

IA: menace ou opportunité ?

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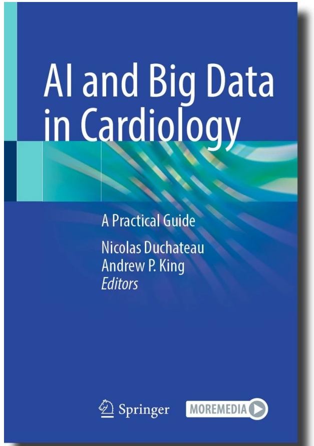
Approche algorithmique
= support quantitatif et objectif

- Grande quantité de données
- Comparaisons rapides et reproductibles
- Données complexes et diverses
- Nouveaux descripteurs et interactions ?

Bien observer et comprendre vos données !
Pas de magie = modèles = dépendent de ce que l'on met dedans

Merci… questions ?



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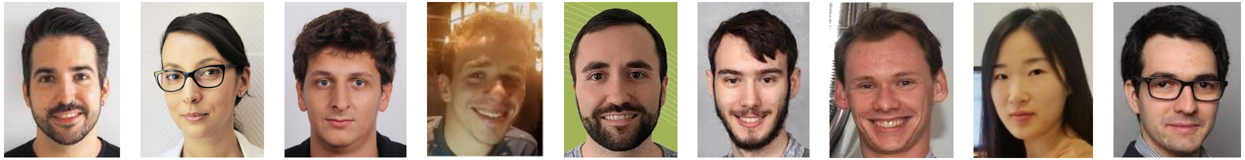
AI and Big Data in Cardiology

A Practical Guide

https://doi.org/10.1007/978-3-031-05071-8

https://deepimaging2023.sciencesconf.org/



nicolas.duchateau@creatis.insa-lyon.fr