LES RENCONTRES LYONNAISES DE CARDIOLOGIE
PRÉSIDENT DU CONGRÈS : Philippe CHEVALIER, Lyon
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LYON Hôtel Lyon Métropole

AI for ECG

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Introduction

Electrocardiogram (ECG): **time series**, observation of electrical functioning of the heart, useful in the detection of cardiac diseases.

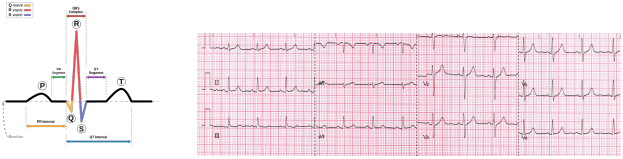
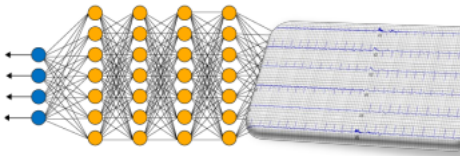


Image source: Wikipedia

This talk: A look at where are we with **AI 'understanding'**/making use of ECG?



. . . and perspectives for it being more accurate, interpretable, reliable (useful), . . .

- Human Expert: Direct and holistic study; expensive and time-consuming

- Signal Processing: Fourier/wavelet transformations; useful tools

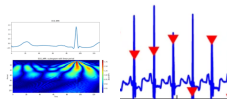
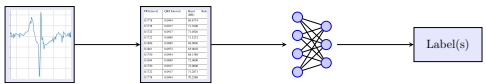
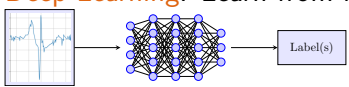


image src: [1]

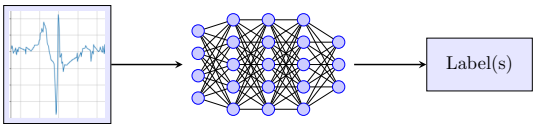
- Machine Learning: Feature engineering and preprocessing; difficult to generalise



- Deep Learning: Learn from raw signal; need much data and computation,

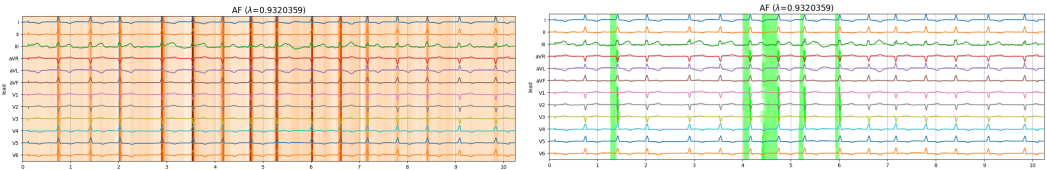


Automatic Classification of ECG Signals (Signal → Diagnoses)



Deep neural architectures[1] for multi-labelling of 12-lead ECG *are competitive*, but

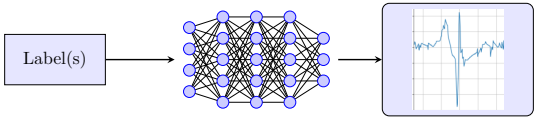
- Effective only on data from the same source (same hospital, equipment, . . .)
  vulnerable to noise (sensor issues, clinical/technical errors, . . .)
- Limited interpretability/explainability (requires medical + ML training)
  i.e., still needs to be validated by expert – lack of general applicability.



Post-hoc explainability (SHAP [left] and LIME [right]) of atrial fibrillation. Credits: Nhat Vo Duy, Ecole Polytechinque; Philippe Chevalier, Univ. Claude Bernard Lyon.

[1] e.g., Antônio H Ribeiro et al. "Automatic diagnosis of the 12-lead ECG using a deep neural network". In: *Nature communications* 11.1 (2020),

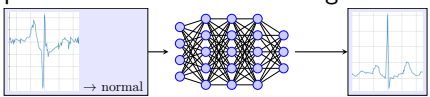
Automatic Synthetic Generation of ECG Signals (Diagnosis → Signal)



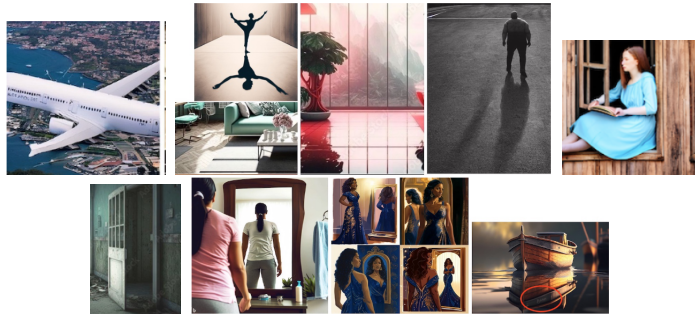
Generative models are much harder!

Why generation?

- Data augmentation (generate more data to train deep models)
- Verification of the internal model for ECG
- Interpretation (including for non-cardiologists);
  Example: If patient x's ECG demonstrates diagnosis y – generate ECG x' as similar as possible but that *not* suffering from diagnosis y (counterfactual generation).



Some examples of issues with image generation:

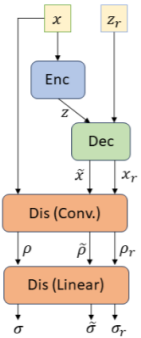


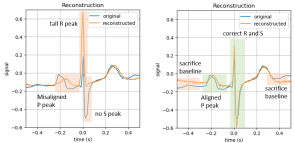
Images from: Borji, Qualitative Failures of Image Generation Models and Their Application in Detecting Deepfakes

(strong resemblance to real images, but *lacking* a complete underlying world-model).

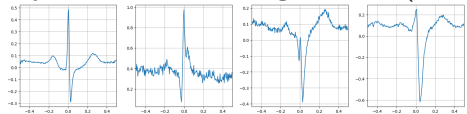
For ECG: need an underlying model of the heart, and anything relating to it.

Early results on ECG, our VAEGANE model:

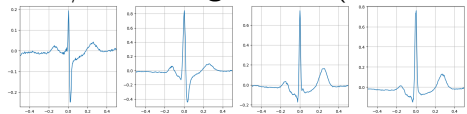




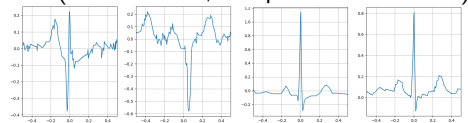
Inferior Myocardial Infarction – **generated** (VAEGANE):



Normal/Non-IMI – **generated** (VAEGANE):

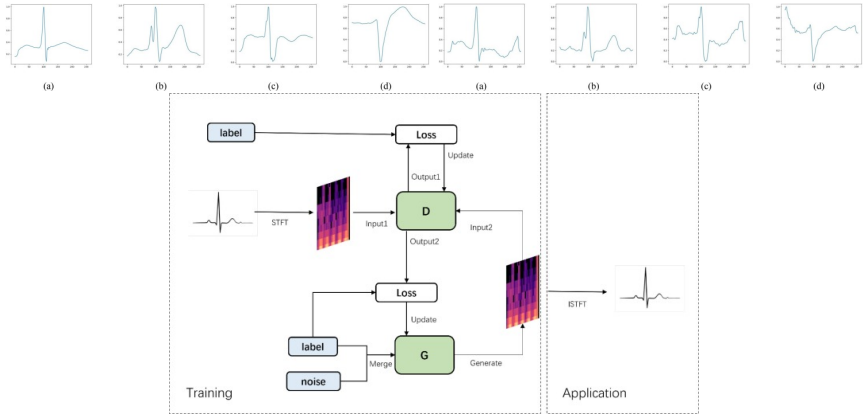


Real (for reference, sampled from dataset):



Duy Nhat Vo et al. *VAEGANE: Enhancing VAE with Feature-wise Loss for ECG Generation.*

Other results from the literature:



Note: single beat!

Yong Xia, Wenyi Wang, and Kuanquan Wang. "ECG signal generation based on conditional generative models". In: *Biomedical Signal Processing and Control* 82 (2023), p. 104587

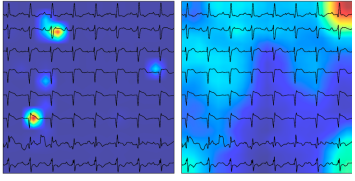
Success of Deep Learning for ECG?

Limited success of deep learning for ECG – especially, wrt needs of computation and data (remark: ECG data is often not public/easy to gather)

Foundation models for time series data is hard!

ECG signals are *periodic* – challenging for deep learning

Alternative: Use vision/language models instead?



Also promising: Diffusion Models, hybrid approaches, ...

(Our work: Eran Zvuloni et al. "On Merging Feature Engineering and Deep Learning for Diagnosis, Risk-Prediction and Age Estimation Based on the 12-Lead ECG". In: *IEEE Transactions on Biomedical Engineering* (2023). URL: https://ieeexplore.ieee.org/document/10025679);
Other references: Shereen Elsayed et al. "Do we really need deep learning models for time series forecasting?" In: *arXiv preprint arXiv:2101.02118* (2021); Akhil Vaid et al. "A foundational vision transformer improves diagnostic performance for electrocardiograms". In: *NPJ Digital Medicine* 6.1 (2023), p. 108

AI for ECG: Summary

- Classification performs well (for certain label concepts), but limited generalisation/transferrability and explainability
- Generation very rudimentary – indicating major limitations
- . . . because of particularities for ECG (and time series data),
- . . . or due to lack of data/attention (from AI community),
- . . . ?
- Are we at where language processing & computer vision was prior to 2010s? (success on particular datasets, via expert features, not very generalisable)
- New promising architectures constantly emerging
- Limitations: ECG analysis alone is insufficient – towards more holistic models?

Merci !

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...

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- Elsayed, Shereen et al. "Do we really need deep learning models for time series forecasting?" In: *arXiv preprint arXiv:2101.02118* (2021).
- Ribeiro, Antônio H et al. "Automatic diagnosis of the 12-lead ECG using a deep neural network". In: *Nature communications* 11.1 (2020), p. 1760.
- Vaid, Akhil et al. "A foundational vision transformer improves diagnostic performance for electrocardiograms". In: *NPJ Digital Medicine* 6.1 (2023), p. 108.
- Vo, Duy Nhat et al. *VAEGANE: Enhancing VAE with Feature-wise Loss for ECG Generation*.
- Xia, Yong, Wenyi Wang, and Kuanquan Wang. "ECG signal generation based on conditional generative models". In: *Biomedical Signal Processing and Control* 82 (2023), p. 104587.
- Zvuloni, Eran et al. "On Merging Feature Engineering and Deep Learning for Diagnosis, Risk-Prediction and Age Estimation Based on the 12-Lead ECG". In: *IEEE Transactions on Biomedical Engineering* (2023). URL: https://ieeexplore.ieee.org/document/10025679.