Artificial intelligence for ECG classification and prediction of the risk of death

Antônio H. Ribeiro

Uppsala University, Sweden

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Computerized electrocardiography analysis

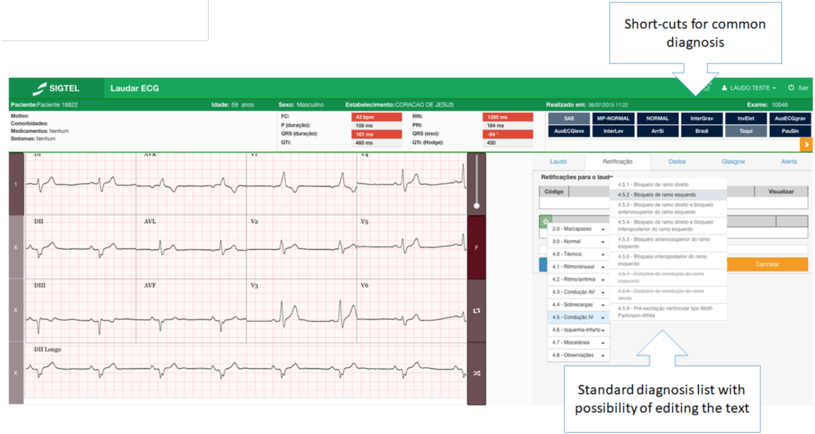
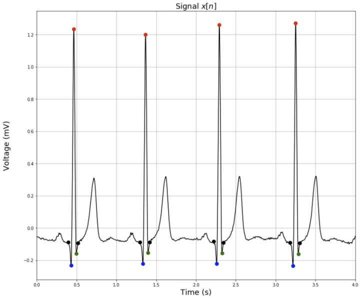
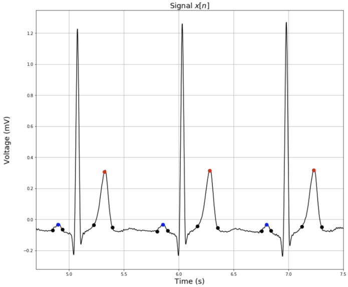


Figure: ECG displayed to the doctor in the Telehealth Network of Minas Gerais system

ECG segmentation



(a) QRS complex



(b) T and P waves

Figure: ECG segmented using signal processing

Classical ECG automated analysis

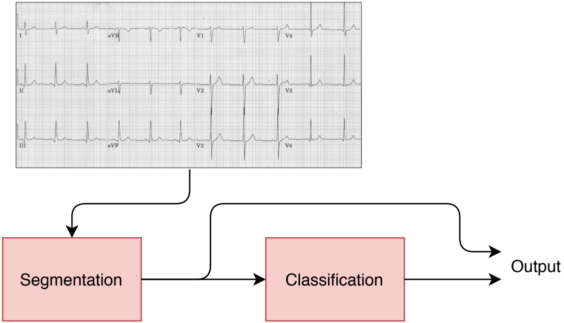
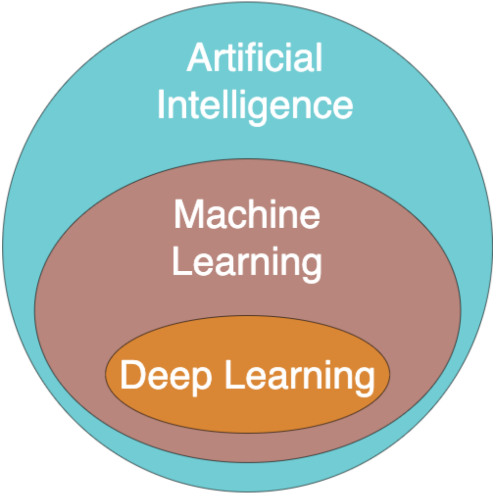


Figure: Two step procedure

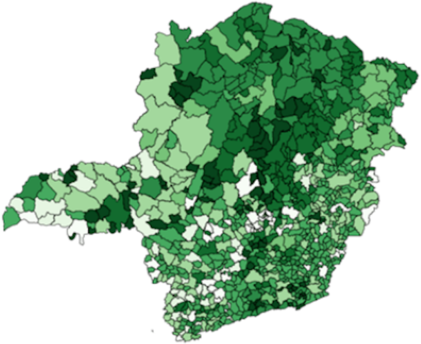
P. W. Macfarlane, B. Devine, and E. Clark, “The university of glasgow (Uni-G) ECG analysis program,” in *Computers in Cardiology*, 2005, pp. 451–454, ISBN: 0276-6574. DOI: 10.1109/CIC.2005.1588134.

Machine learning and artificial intelligence



Telehealth Network of Minas Gerais

Year	# Municipalities
2006	82
2007	102
2008	97
2009	328
2011	54
2013	106
2015	42
Total	811



M. B. Alkmim, R. M. Figueira, M. S. Marcolino, *et al.*, "Improving patient access to specialized health care: The Telehealth Network of Minas Gerais, Brazil," *Bulletin of the World Health Organization*, vol. 90, no. 5, pp. 373–378, May 2012, ISSN: 1564-0604. DOI: 10/f3x7px.

The CODE group

Figure: The CODE (*Clinical outcomes in eletrocardiography*) group was created to conduct clinical studies using storical data from the telehealth network.

Automatic ECG classification

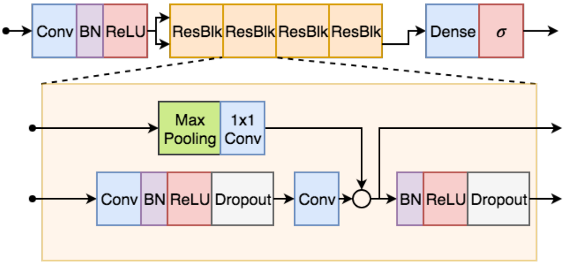


Figure: The uni-dimensional residual neural network architecture used for ECG classification.

Ribeiro, A.H., Ribeiro, M.H., Paixão G.M.M. et. al. (2020)
Automatic diagnosis of the 12-lead ECG using a deep neural network
Nature Communications (11), 1760.

The training dataset

- 2.3 million records 1.6 million distinct patients;
- Annotated by telehealth center cardiologist;
- Refined by comparing with University of Glasgow software results;
- 30 000 exams manually reviewed.

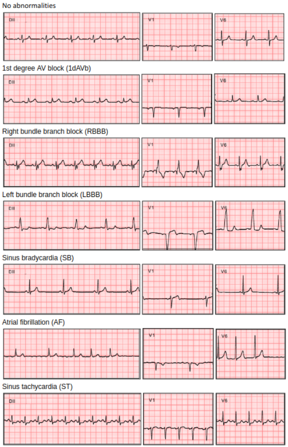


Figure: Abnormalities for the classification problem.

The testing dataset

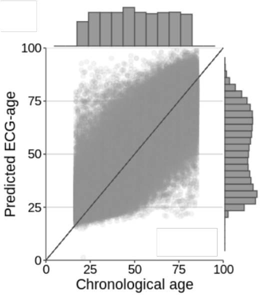
- 827 tracings from distinct patients;
- Annotated by 3 different cardiologists.

Results

	F1 Score			
	DNN	cardio.	emerg.	stud.
1dAVb	**0.897**	0.776	0.719	0.732
RBBB	**0.944**	0.917	0.852	0.928
LBBB	**1.000**	0.947	0.912	0.915
SB	**0.882**	**0.882**	0.848	0.750
AF	**0.870**	0.769	0.696	0.706
ST	**0.960**	0.882	0.946	0.873

Table: Performance indexes

Age-prediction model



Δ age = ECG-age - age

Figure: Predicted vs estimated age in 15% hold-out test set (n = 218,169 patients). Mean absolute error of 8.38 years.

E. M. Lima, A. H. Ribeiro, G. M. Paixão, *et al.*, "Deep neural network estimated electrocardiographic-age as a mortality predictor," *medRxiv*, Feb. 2021. DOI: 10.1101/2021.02.19.21251232.

ECG-age as a mortality predictor

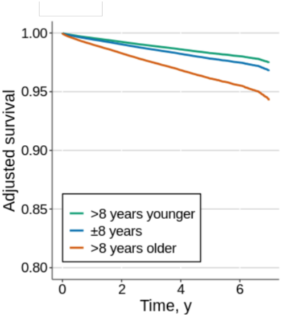


Figure: Adjusted survival analysis (CODE-15%

Table: Hazard ratio from Cox model

Adjusted by age and sex	
Δ age $<$ - 8 y	0.78
Δ age $>$ 8 y	1.79
Adjusted by age, sex and comorbities	
Δ age $<$ - 8 y	0.78
Δ age $>$ 8 y	1.78

Validation on ELSA-Brasil (and Sami-Trop)

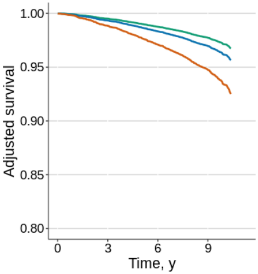


Figure: Adjusted survival analysis ELSA-Brasil

Table: Hazard ratio from Cox model

Adjusted by age and sex	
Δ age $<$ - 8 y	0.74
Δ age $>$ 8 y	1.75
Adjusted by age, sex and comorbities	
Δ age $<$ - 8 y	0.82
Δ age $>$ 8 y	1.57

Aquino, E. M. L., Barreto, S.M., Bensenor I.M., et. al. (2020)
Brazilian longitudinal study of adult health (ELSA-Brasil): Objectives and design
American Journal of Epidemiology 175 (4), 315-324.

Analysis on ECGs classified as normal

Table: Hazard ratio from Cox model

	CODE-15%	ELSA-Brasil
Adjusted by age and sex		
Δ age $<$ - 8 y	0.66	0.91
Δ age $>$ 8 y	1.53	1.63
Adjusted by age, sex and comorbities		
Δ age $<$ - 8 y	0.66	0.91
Δ age $>$ 8 y	1.52	1.42

Discussion

- Improved automatic classification using deep learning
  - Potential to improve tele-health service in short/medium term;
  - Screen more important exams;
  - Avoid medical mistakes and improve accuracy.
- AI to extend the potential of ECG for prognosis
  - Capability of identifying patterns that are not obvious for a cardiologist (double-edged aspect of it);
  - Extend ECG role in risk stratification.

Thank you!

Contact info:

antonio.horta.ribeiro@it.uu.se

@ahortaribeiro

antonior92.github.io

(github.com/antonior92)