ARTIFICIAL INTELLIGENCE(AI) AND INTERNET OF THINGS(IOT) TECHNOLOGIES FOR IMPROVING HEALTHCARE ACCESS FOR DISADVANTAGED COMMUNITIES

Engineering inspired by life: about heart, brain and AI

EMANUEL M. POPOVICI, ANDREEA FACTOR,

ANDRIY TEMKO, SERGI GOMEZ QUINTANA, FEARGAL O'SULLIVAN, TIEN VAN NGUYEN, GIUSEPPE CARRACCIOLO, VOLODYMYR SARANA, VIKTORIA SHELEVYTSKA

E.POPOVICI@UCC.IE

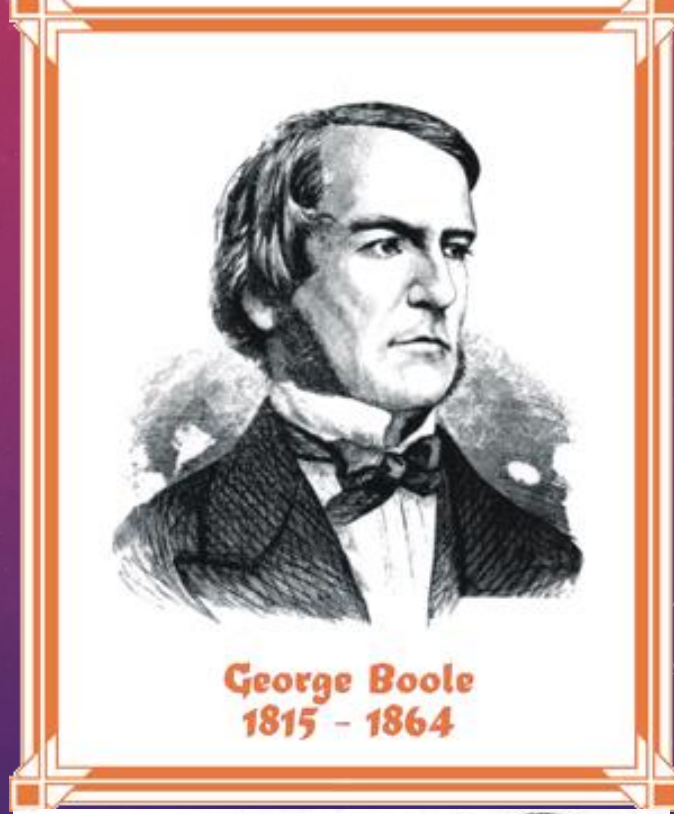
University College Cork, Ireland

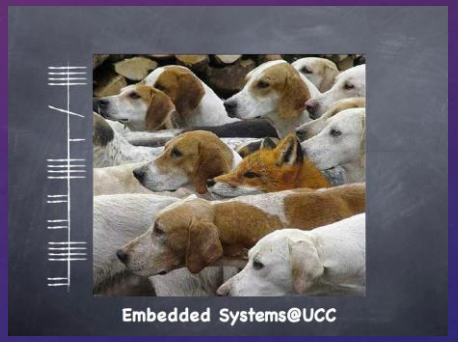
University College Cork, Ireland
Coláiste na hOllscoile Corcaigh

Embedded.Systems@UCC

University College Cork(1845)

- Alma Matter of Boolean Logic: the place where “To be or not to be” is always true
- Reference for Microelectronics in Ireland (NMRC, First and last Microelectronics Department, MIDAS, Tyndall, CEIA, Cork Tech Cluster, …)
- Embedded.Systems@UCC Home ;-)





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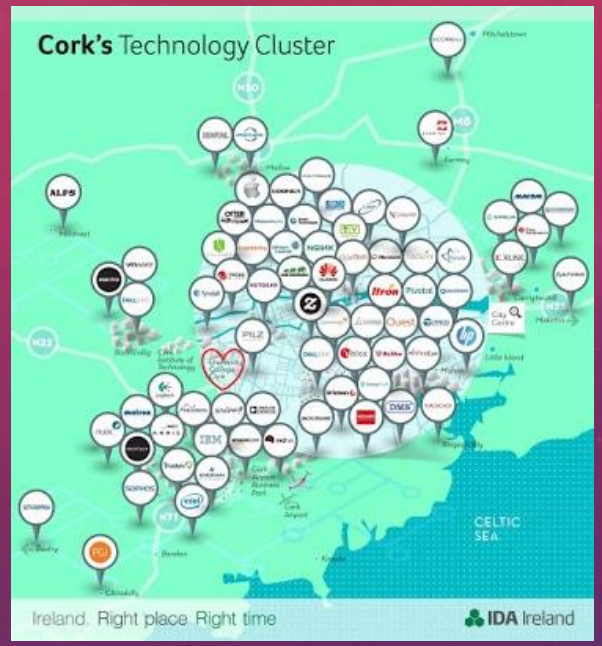
Celebrating 50+ Awards and Distinctions

EMBEDDEDING.BOOLEAN IN A CONNECTED UNIVERSITY



Mechanical Eng.

Agriculture

Palaeontology

Maths

Physics

Food Science

CS

BIS

EDA

Ecology

HW for ML

Digital IC

IoT

HW for Security

HW for Reliability

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Early Childhood Studies

Applied Psychology

Music

Civil Engineering

Energy Eng.

Medicine and Health

Biology

Anatomy & NeuroScience

Arts Architecture

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IMPACT IN RESEARCH











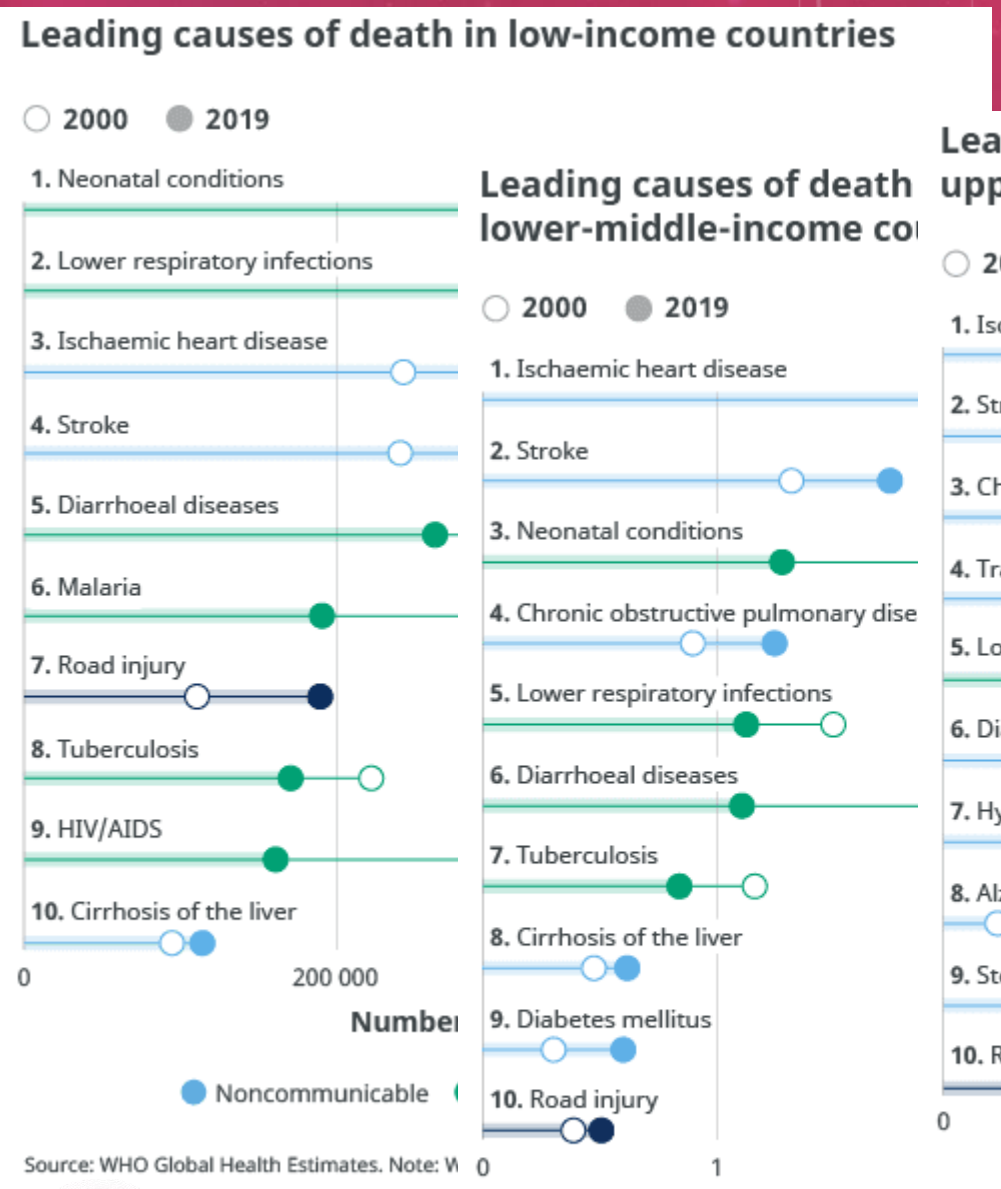


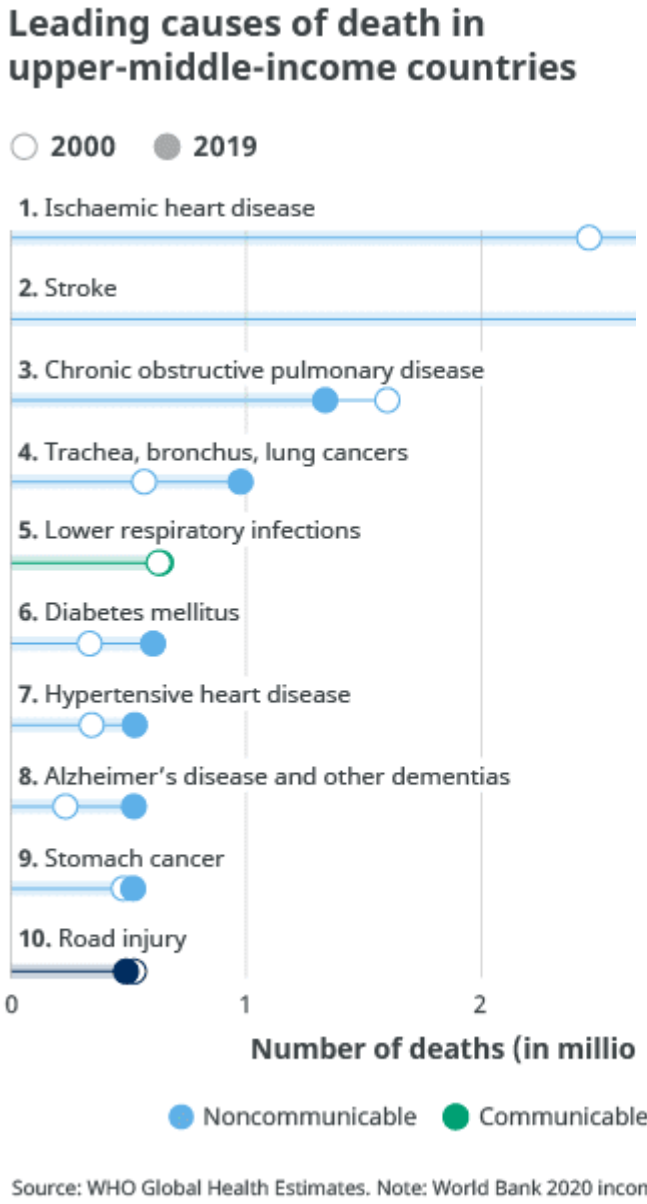


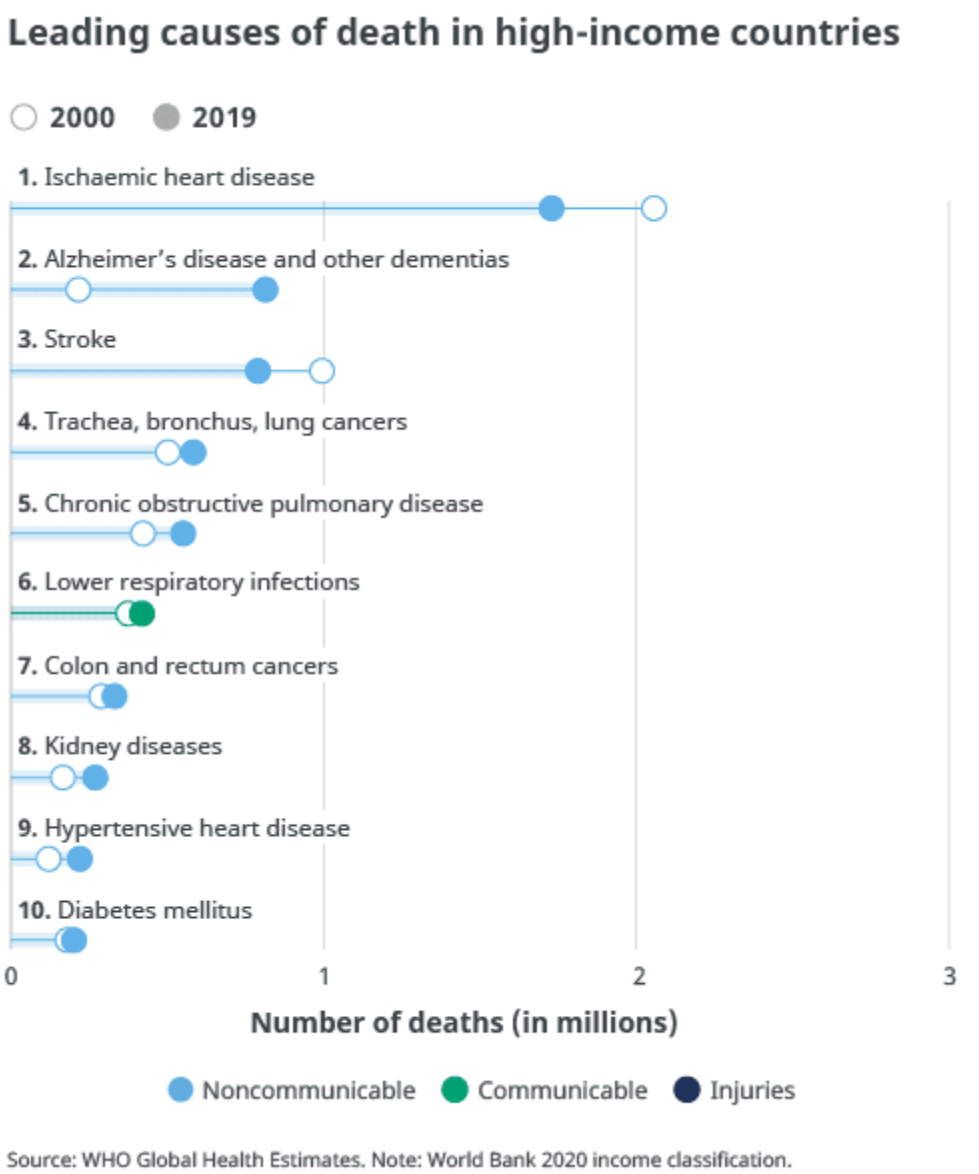




50+ Awards and Distinctions







Source: WHO Global Health Estimates. Note: World Bank 2020 income classification.

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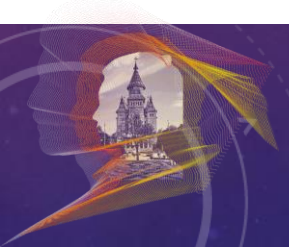


The top 10 causes of death (who.int)

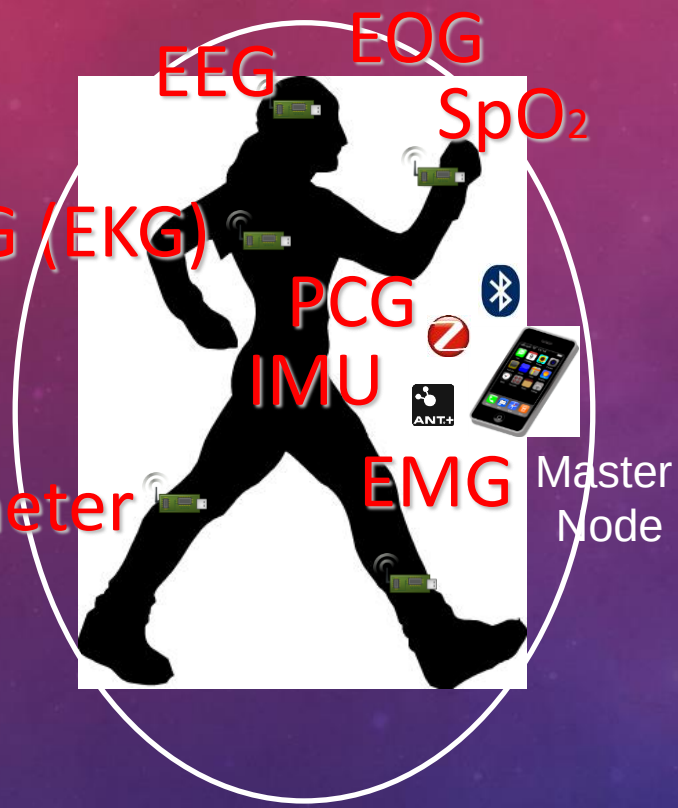
SOME OBSERVATIONS

Access to healthcare is non-uniformly distributed

Disadvantaged communities are disproportionately affected

Causes: availability of medical professionals; lack of expertise in key specialities; high cost of training; cost of equipment; lack of other key infrastructure (IT, power, etc)

TECHNOLOGY AND DATA SOURCES IN MEDICAL DOMAIN



Other sources of data:
- Imaging(CT, MRI, Hyperspectral, Ultrasound)
- Speech
- CO2
- Sweat
- …

Vital Signs:
- Respiratory Rate
- Blood Pressure
- Pulse rate
- Body Temperature

Pathology/Diseases:
- Seizure
- Congenital heart disease
- Concussion
- Allergies
- …

HEART AND BRAIN

Associated with some of the highest incidences of diseases

High social cost

Neonatal conditions are prevalent causes of death in low (to middle) income countries

- Oxygen depravation at birth leads to brain injury and 80% of seizures
- 1-3.5/1000 live births affected
- <10% of seizures detected through clinical signs
- >2.5 Million births affected Worldwide/Year
- > 1 million deaths or disabilities
- Low/middle-income countries disproportionately affected

- EEG Analysis is the gold standard
- Severe shortage of trained medical professionals for EEG analysis
- Even if available, not operating 24/7

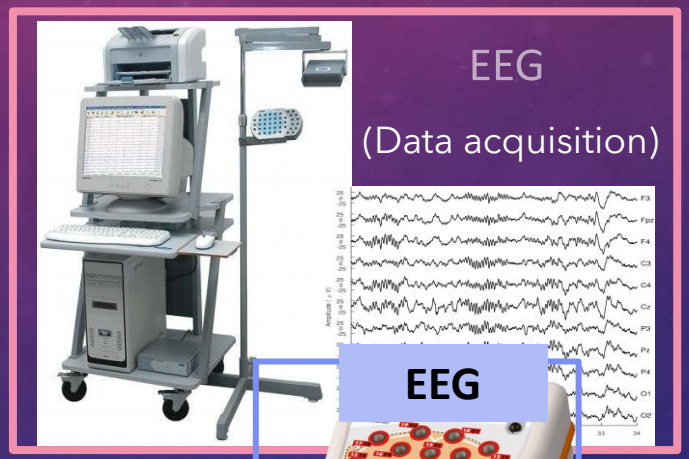
<u>Delay in diagnosis leads to increased morbidity and mortality</u>

ISSUES IDENTIFIED

- Lack of trained personnel
- Analysis taking long (>1/7th of the EEG recording)
- Report very late >24h
- Costly equipment
- Lack of IT infrastructure
- Power outages,...

Some System Specification:

- Have fast response time;
- Be accurate;
- Be easy to use and allow for quick review;
- Enable better monitoring and care in real-time in a remote location;
- Be low-cost, battery-operated, and plug and play.



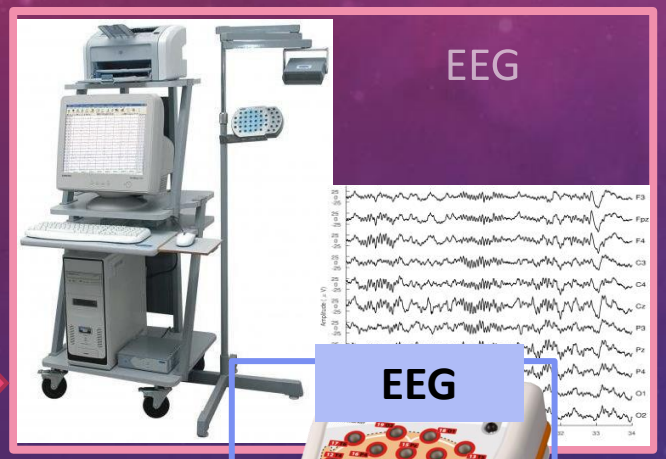
(J. Brogger et al Visual EEG reviewing times with SCORE EEG, 2018)

PROPOSED SOLUTION

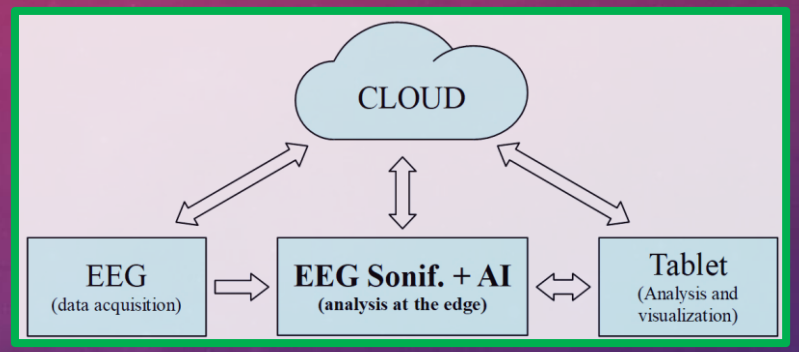
EEG analysis anytime, anywhere needed, pervasive to medical professionals

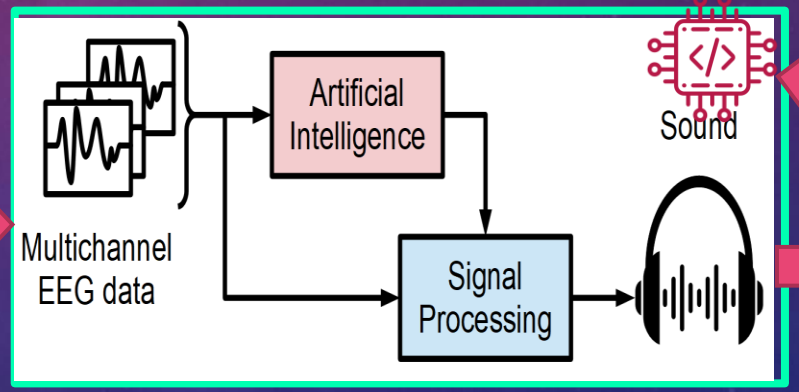
- **Scalable and interoperable**
- **Adaptable and flexible**
- **Expandable**

(Data acquisition)



(Aways-on AI and AI assisted sonification)





Review time less than 5s for an epoch of 2h ; Accuracy on par with experts

Why sonification?

- **Seizures evolve over time, the human ear is the most natural tool to sense that**

(Empowered medical professional)

PROOF OF CONCEPT

Edge/IoT

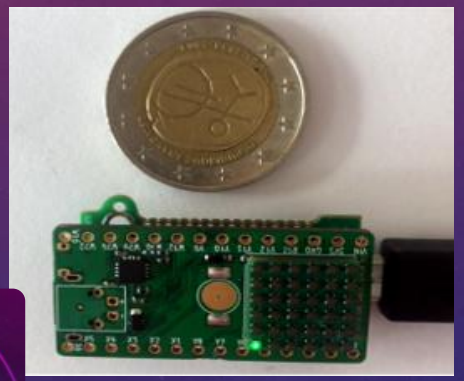
Mobile

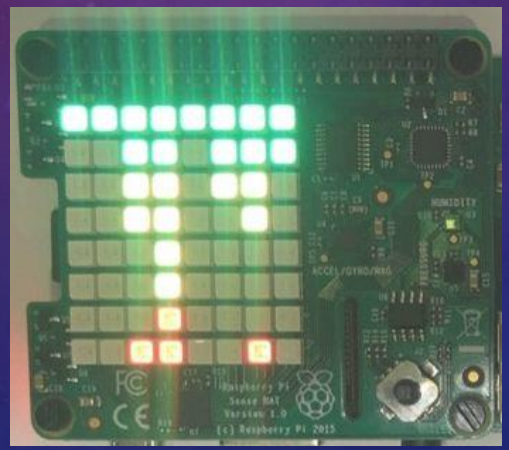
Early warning system (always on AI)

AI+Sonification
For seizure detection

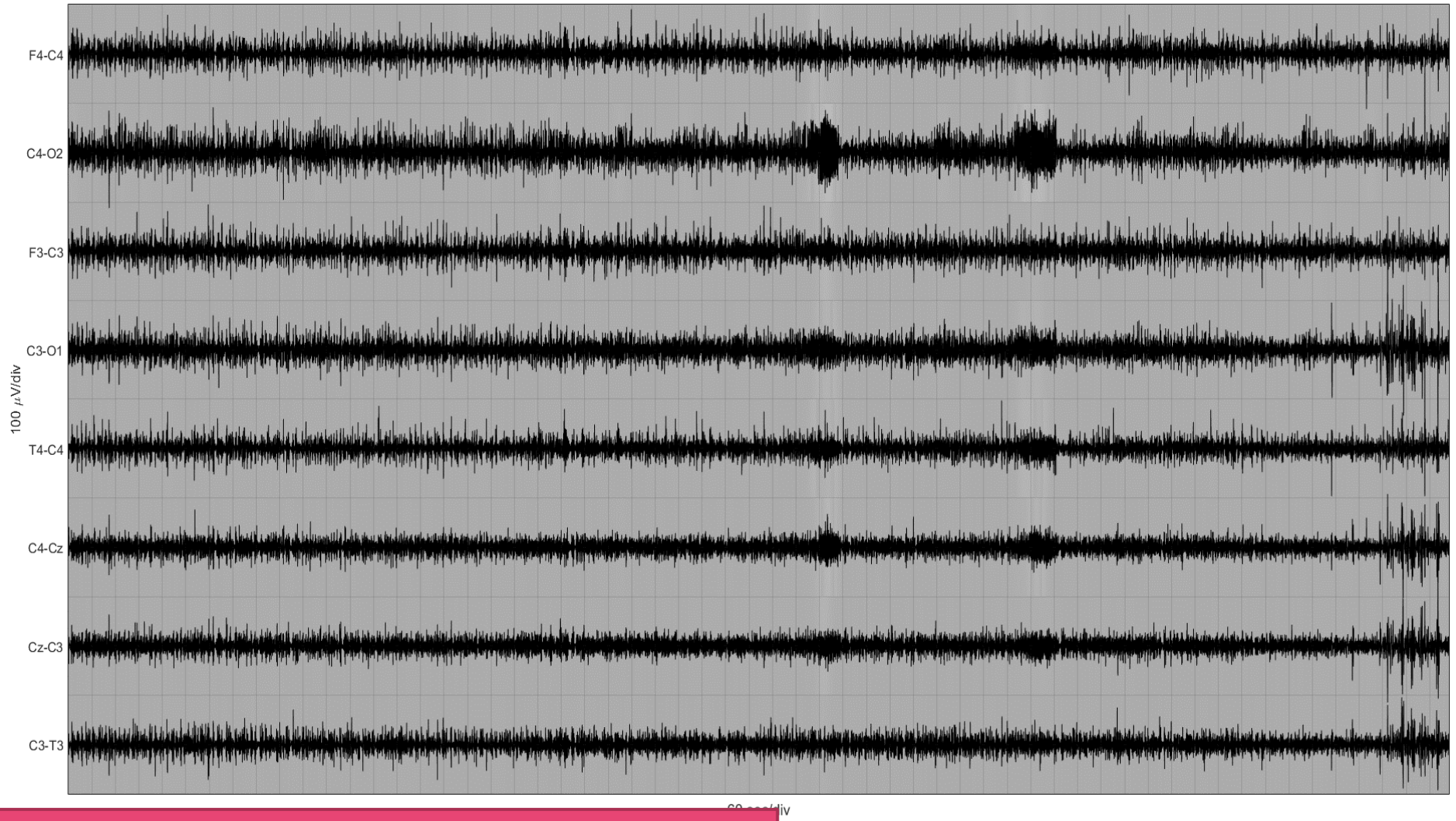
Ultra-fast, accurate review

Cloud





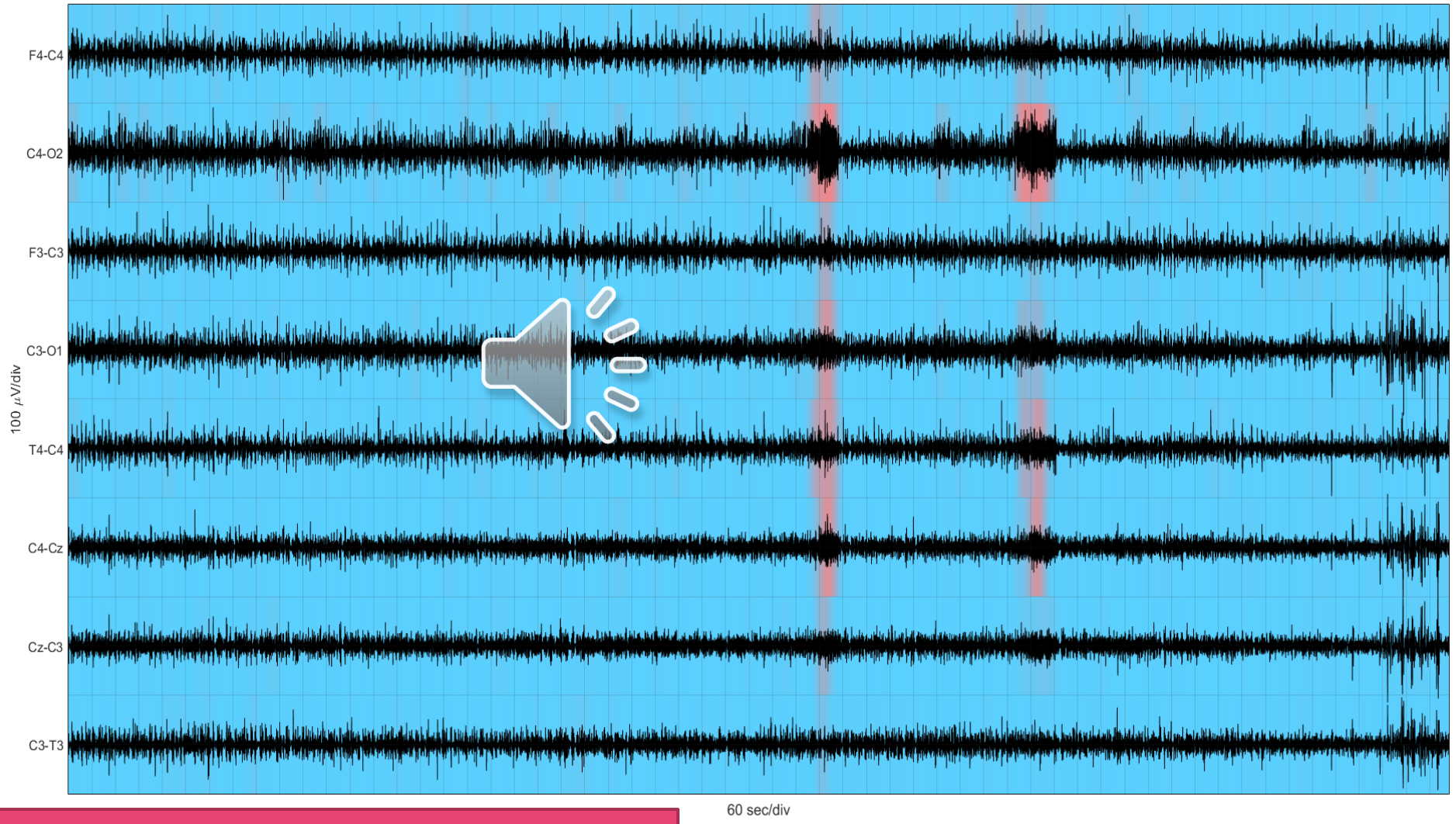
2 HOURS OF EEG = 360-720 WINDOWS TO SCROLL



- 22M EEG values in one day
- Seizures are rare events (once in many hours)
- Seizures can be as short as 10s
  - **1/7 to 1/2 of the recording time required for review**

Amplitude/duration/frequency/waveform/shape/…

DEMO 1: 2 HOURS OF EEG ANALYSED IN 3 SECONDS



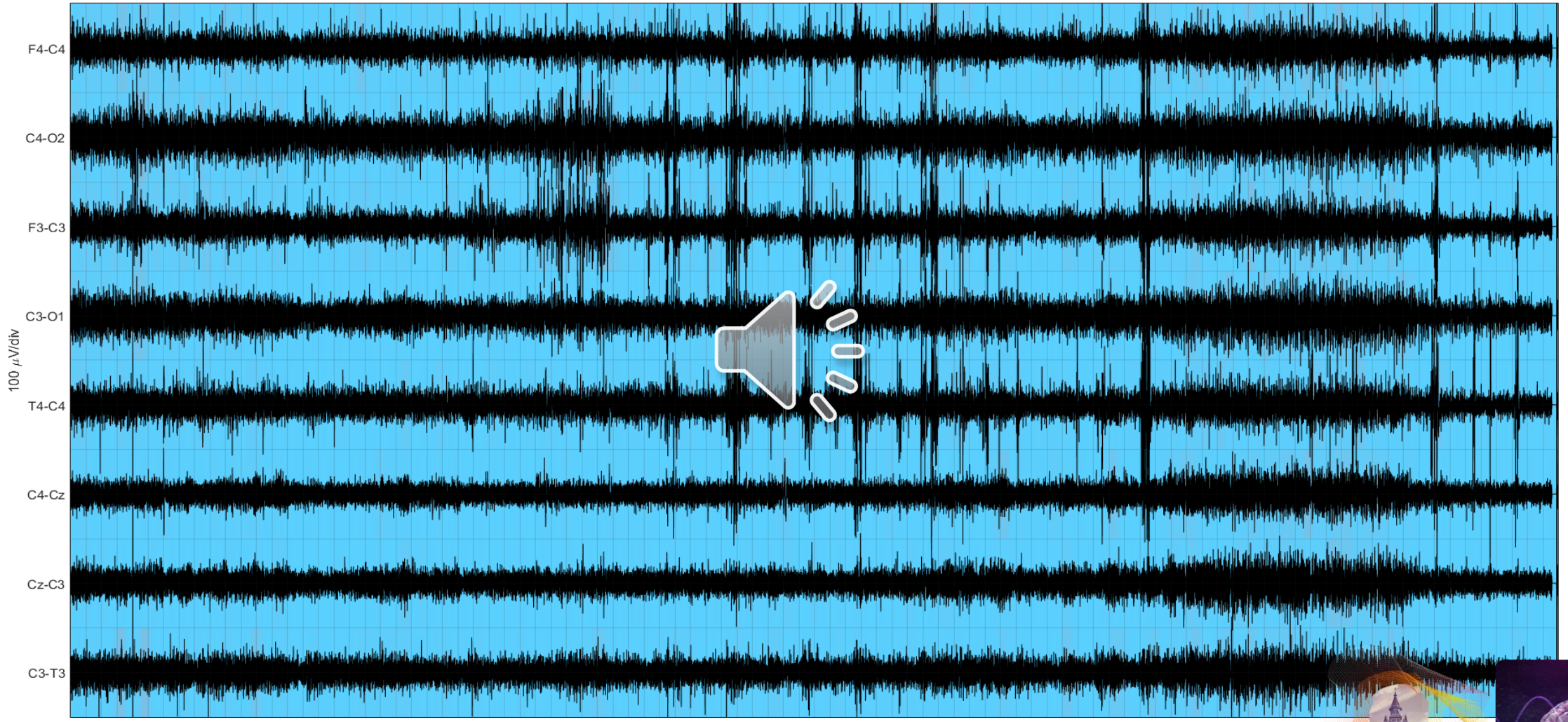
- AI allows an early warning
- AI allows identifying interesting segments, helps focusing attention

➢ 144h required to review 1 week-long EEG (6 babies) recording by an expert

➢ 0.6h required to review 1 week-long EEG (6 babies) recording by a non-expert medical professional

Seizure: high pitched sounds

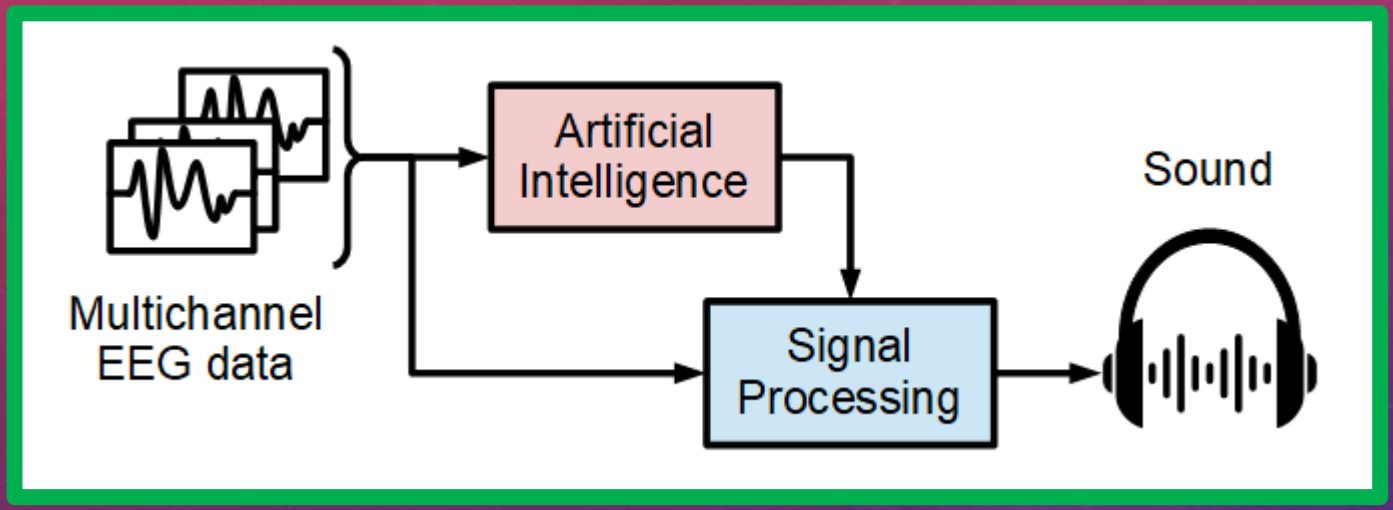
DEMO2: 2 HOURS OF BACKGROUND EEG IN 2 SECONDS

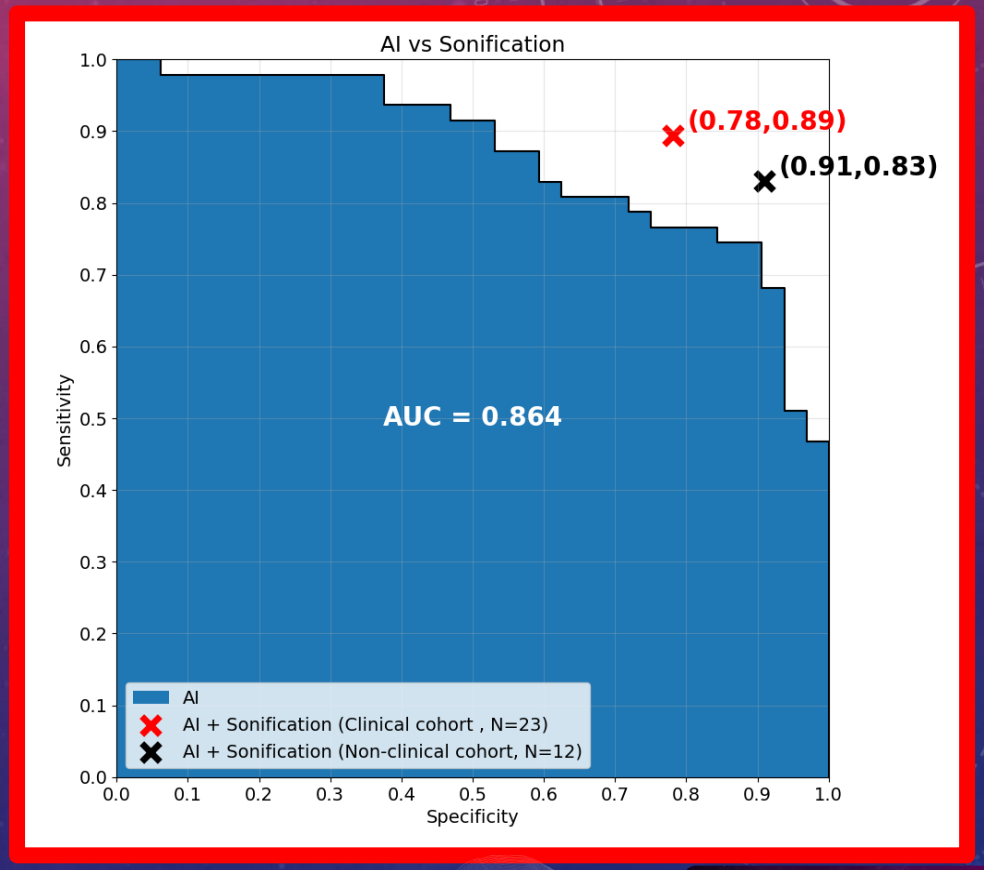


No seizures: quiet crackling, popping or hissing sounds

WANT TO LEARN MORE: AI-DRIVEN EEG SONIFICATION SURVEY/DEMO/PAPER

$$F = P + H^{AI}$$





https://sergigomezquintana.github.io/EEGsoundSurvey/

!!! Send us your own full demo/survey results to E.Popovici@ucc.ie

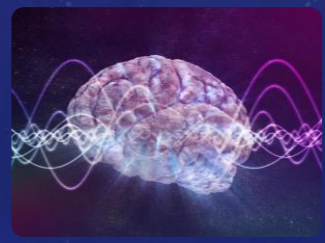
Gomez-Quintana, S., O'Shea, A., Factor, A. et al. A method for AI assisted human interpretation of neonatal EEG. Sci Rep 12, 10932 (2022). https://doi.org/10.1038/s41598-022-14894-4

VALUE PROPOSITION

A new explainable AI methodology to augment human natural senses

100-1000 times faster review than visual analysis; With NO accuracy loss; With no training

Expandable concept for the interpretation of biological signals



WHAT ABOUT THE HEART?

HEART DEFECTS

- Congenital heart defects (CHD)/ Patent ductus arteriosus (PDA)
- Incidence: 1-8/1000 births
  - Developing countries: 25/1000
  - Cause of mortality for 3% of all deaths

DIAGNOSIS

- Echocardiography
- Routine screening: multidimensional examination (e.g. auscultation, pulse oximetry)
- Alternative objective screening methods

Aims:

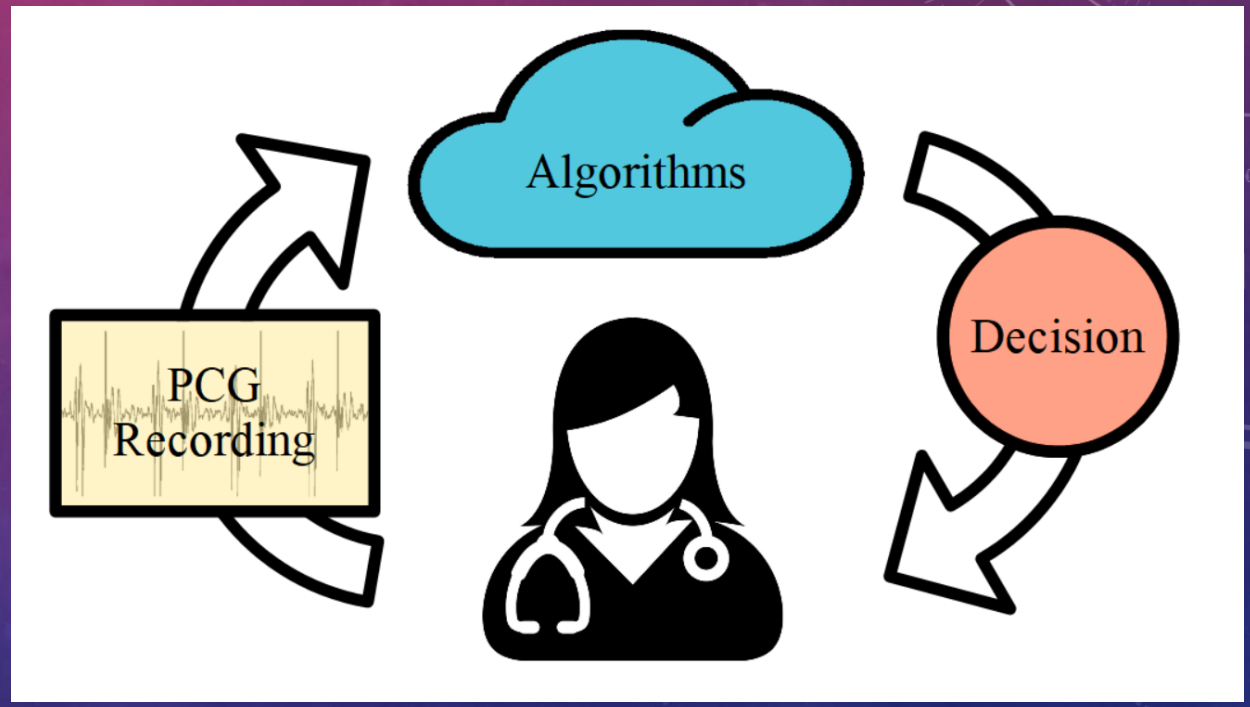
Developing and objective clinical decision support tool

Use AI-assisted auscultation to differentiate sounds with signatures of CHD/PDA

Implementations relevant to clinical settings: cloud and EDGE technologies

METHODS

- Recordings are taken using a digital stethoscope
- Pre-Processing, Segmentation, Feature Extraction
- AI model training PDA/CHD
- Cloud-based implementation
- EDGE-based implementation

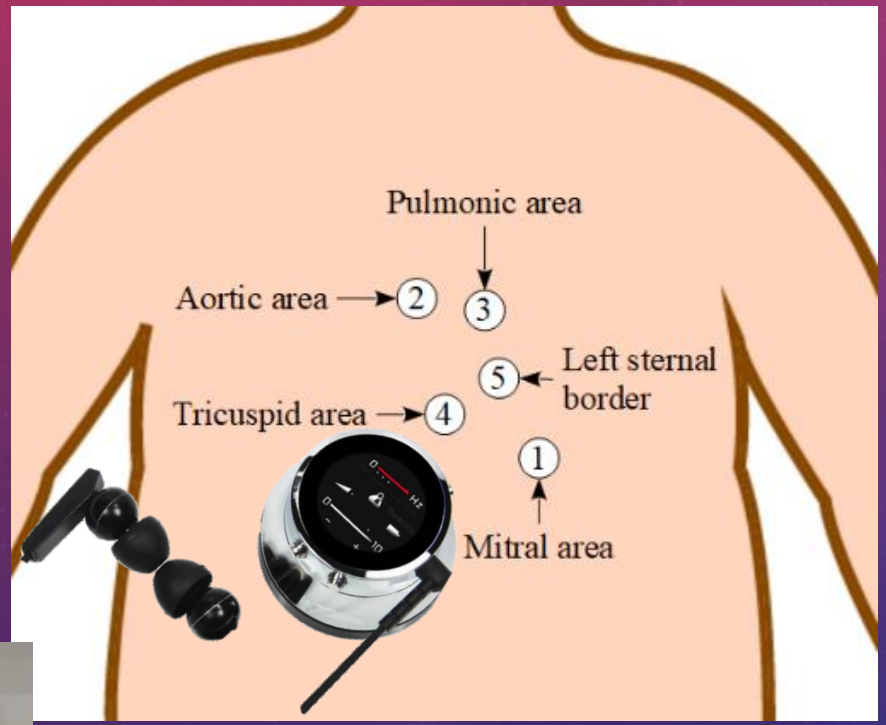


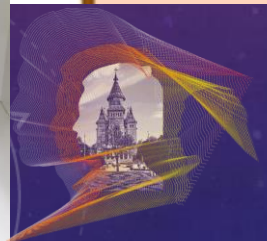
DATASET: THE PATIENTS

- Provided by our colleagues in Ukraine
- 265 neonates
- 242 neonates are term babies
- Ultrasound screening was used to confirm diagnostic (ground truth)

Sex	
Males	137 (52%)
Gestational age [weeks]	**Median 39, IQR 38-40**
Less than 37 weeks (preterm)	23 (9%)
37 weeks or more (term)	242 (91%)
Postnatal age [hours]	**Median 48, IQR 30-64**
Less than 24h	29 (11%)
From 24 to 48h	95 (36%)
From 48h to 72h	87 (33%)
More than 72h	54 (20%)
Diagnostics	
Healthy	137 (52%)
PDA	89 (33%)
CHD	39 (15%)
Total number of patients	**265**

DATASET: THE RECORDINGS



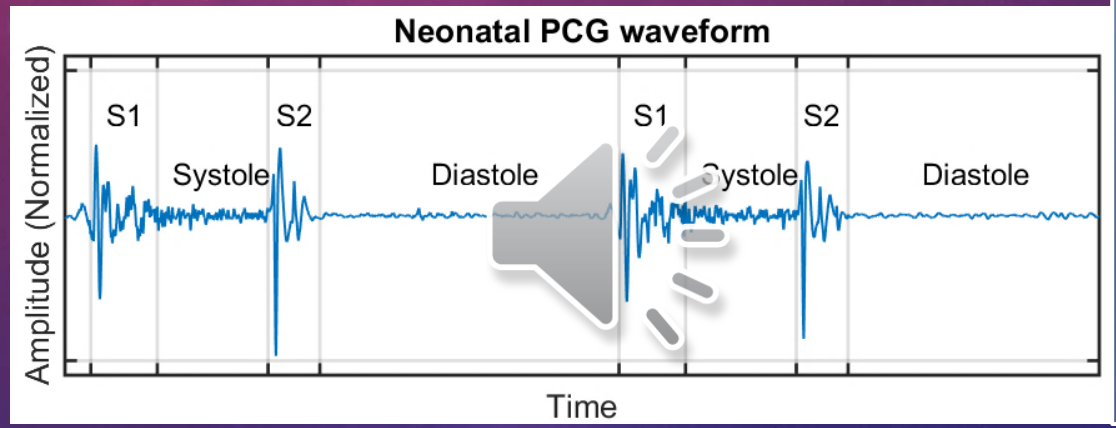


- A digital stethoscope was used to acquire PCG recordings
- 5 different auscultation areas
- Manual annotations

Total number of recordings	1325
Recordings per patient	5
Total number of annotated cycles	**5904**
Annotated cycles per recording	Median 5, IQR 4-5
Annotated cycles per patient	Median 23, IQR 21-25
Total hours recorded	**7h 48min**
Total annotated	47min 53s

INTERPRETATION OF HEART SOUNDS

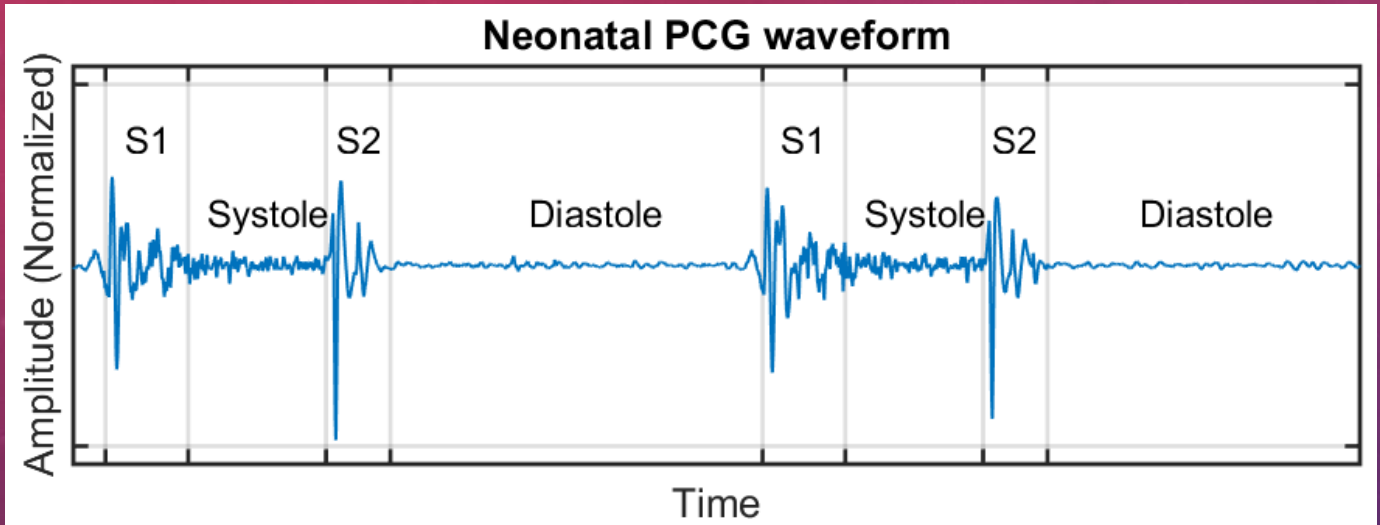
- Heart cycle consists of two fundamental heart sounds S1 & S2 (beats)
- In between, other sounds might occur (murmurs)
  - Some murmurs are pathological
  - Others are physiological (innocent): ductus arteriosus



Complex problem for neonates
➔ ML approach

+ External artifacts (scratches, noises, vocalizations, etc…)

SEGMENTATION ALGORITHM DEVELOPMENT

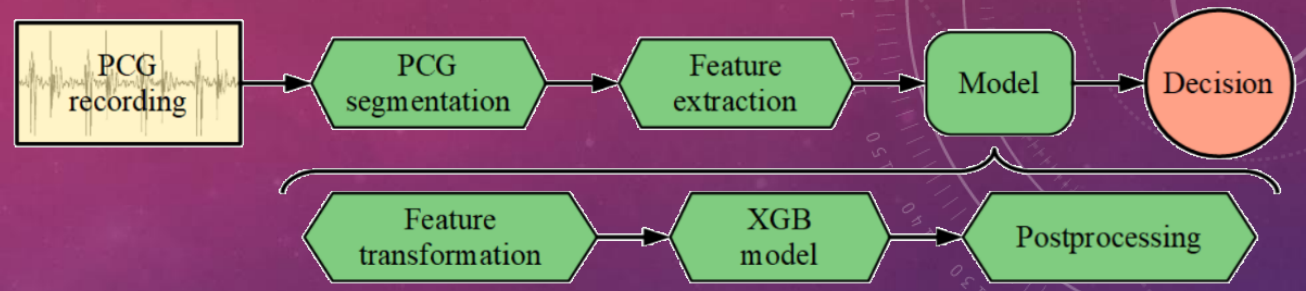


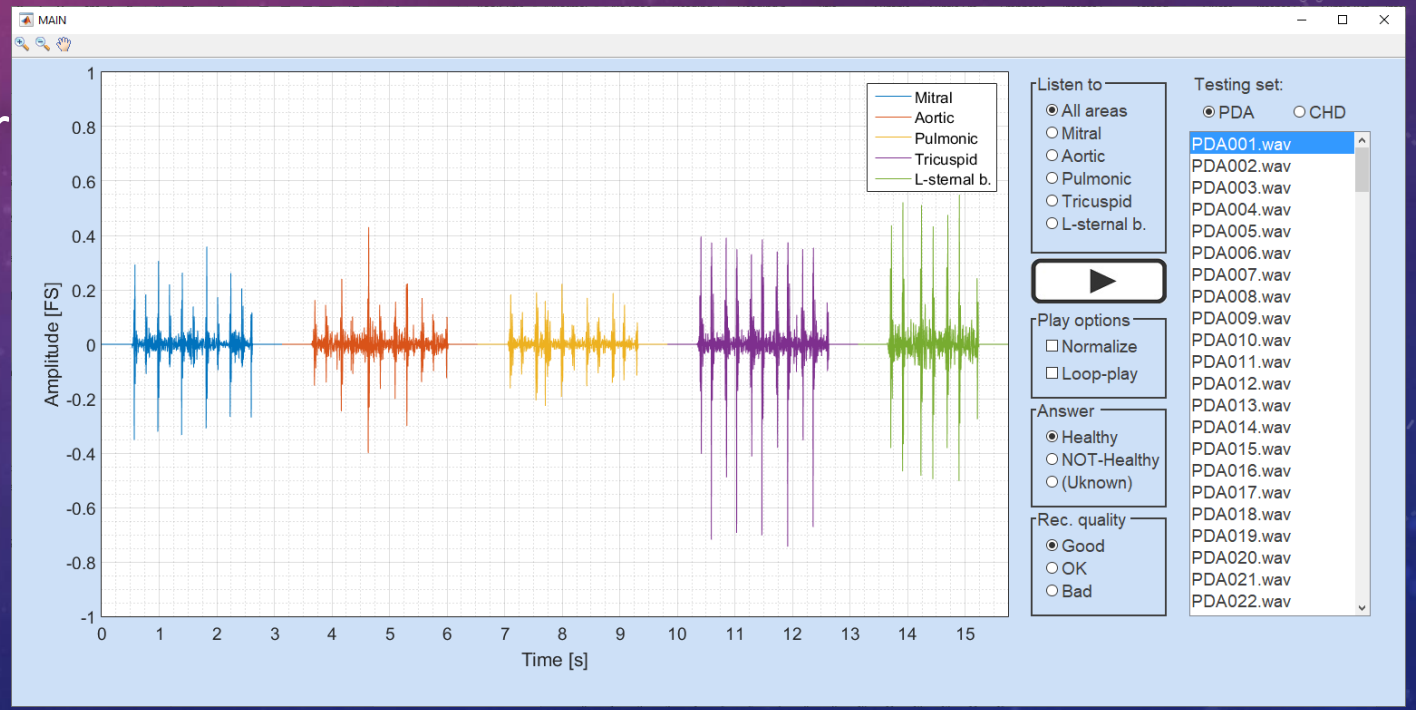
S. Gómez-Quintana et.al.,"Automatic segmentation for neonatal phonocardiogram," *2021 IEEE Engineering in Medicine & Biology Society (EMBC)*, 2021, pp. 135-138

- Only 10% of the collected dataset was manually segmented
  - Manual segmentation is a tedious task to perform
- Automatic segmentation can increase the data availability
  - More data may lead to train better models
- Accurate algorithm based on DSP and XGBoost (F1 Score 0.94)

ALGORITHM & DESIGN OF THE EXPERIMENTS

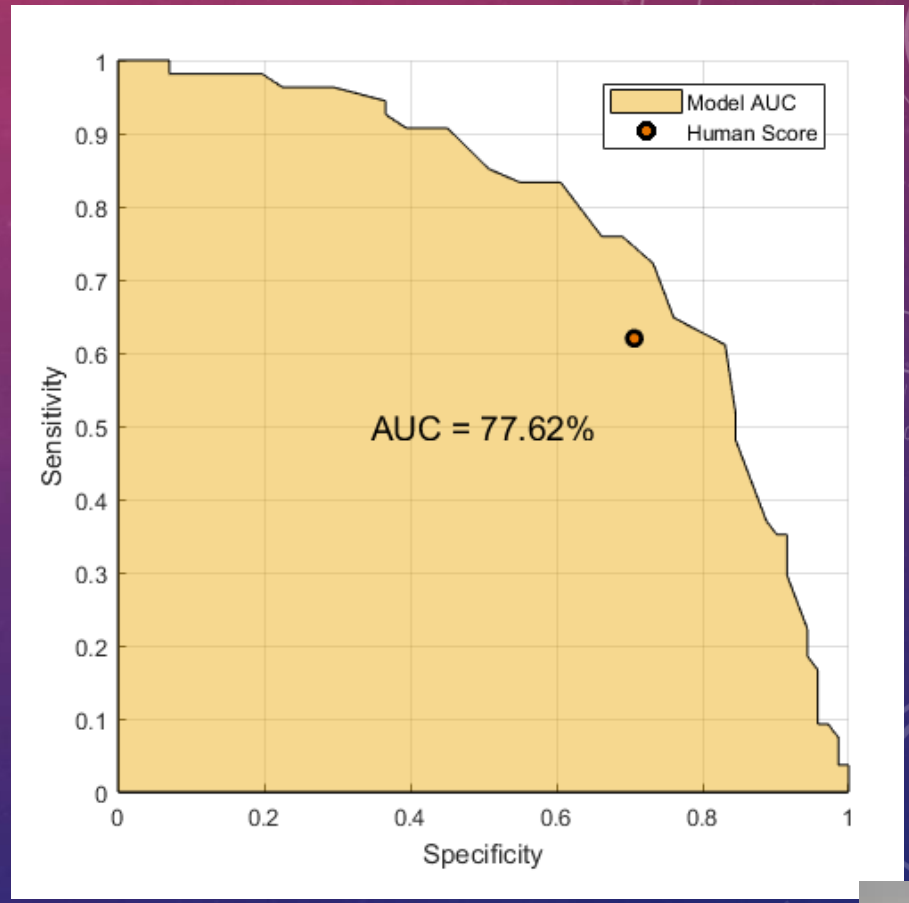
- PDA vs CHD: two models based on the same framework
- Feature importance analysis & selection
- Survey design
  - Comparison with a trained doctor





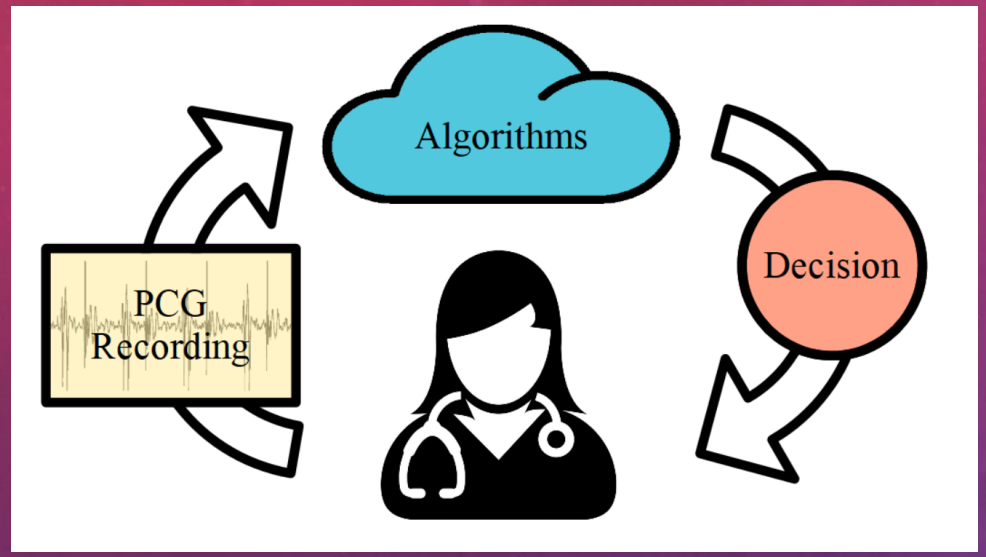
AI RESULTS

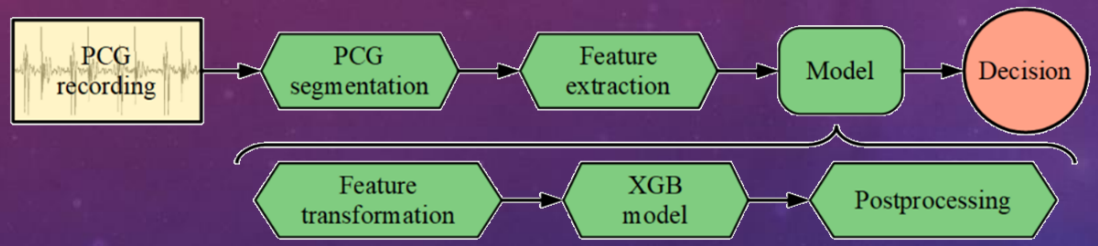
- PDA-Algorithm's performance: 77% AUC
- CHD-Algorithm's performance: 78% AUC



Gómez-Quintana, et. al., "A Framework for AI-Assisted Detection of Patent Ductus Arteriosus from Neonatal Phonocardiogram" *Healthcare* **2021**, *9*, 169. https://doi.org/10.3390/healthcare9020169

CLOUD INTEGRATION





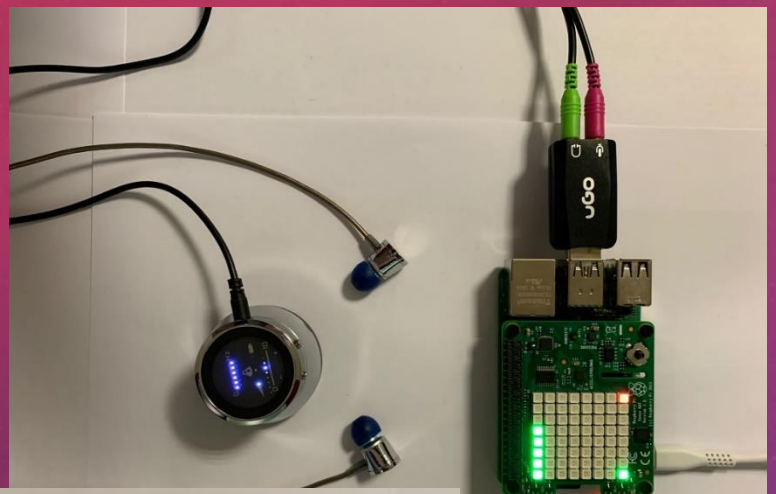
- Data-rate reduction:

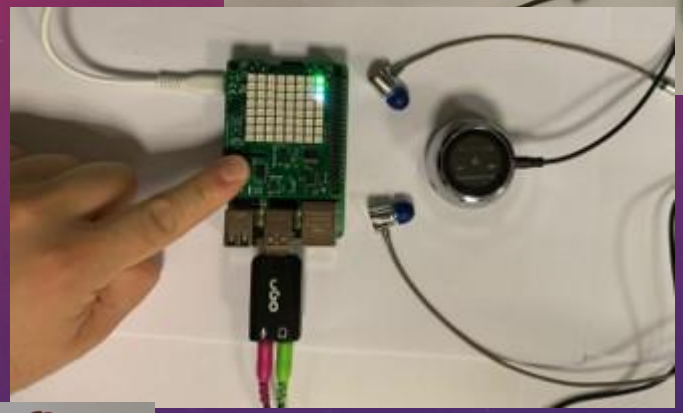
Compression on the edge	Compression (%)	RMSE (%)
MP3 112kbps (lossy)	7.942	10.224
WAV @2kHz (lossless)	4.535	1.361

- Execution times (s):

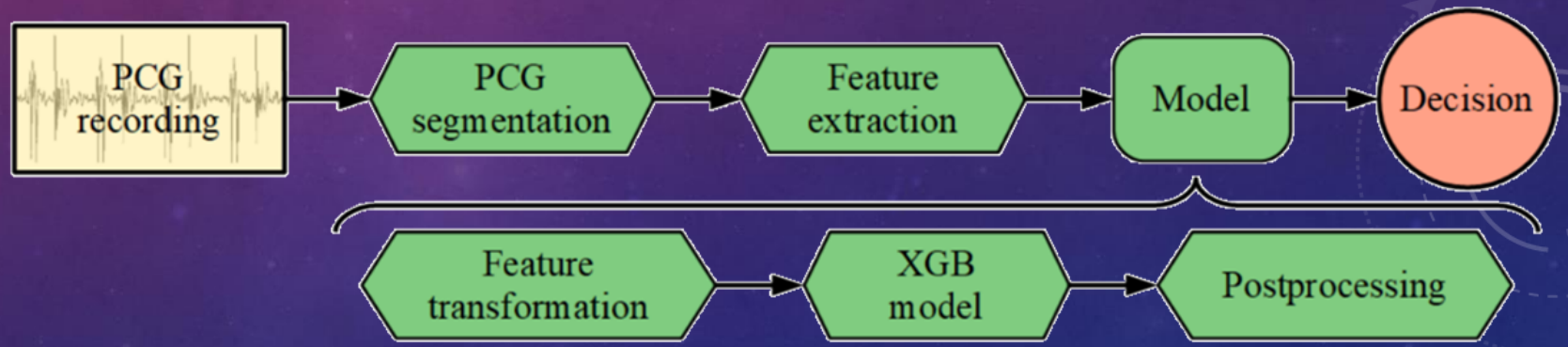
PCG length (s)	*10*	*20*	*60*	*120*
Segmentation	0.438	0.831	2.612	5.913
Batch size (# cycles)	*25*	*150*	*300*	*450*
Feature extraction	1.018	5.629	10.294	16.753
Classification	0.145	0.159	0.158	0.158

EDGE IMPLEMENTATION



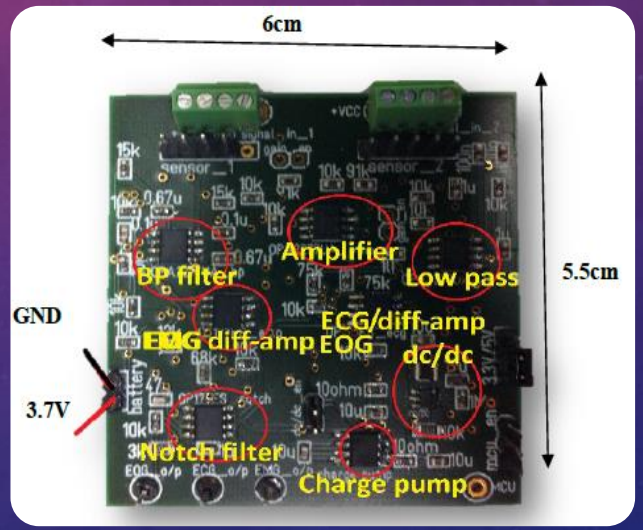


Raspberry Pi 4.0	1 (71.4 s – 143 cycles)
SEG and FE	18.543
Sound Classification	0.205
Rearranging And Avg.	0.0514
Final Classification	0.753



TOWARDS A UNIVERSAL STETHOSCOPE

- Back to the future: StarTrek Tech (Tricorder)
- A single (handheld) device for any ExG signals
- A single (handheld) stethoscope for any ExG/PxG signals
- Ultra low power AI on a microcontroller
- Smart sensing using EDGE computing
- Open Data



Other Projects

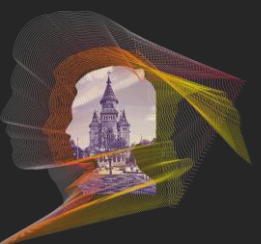
- IoT for smart lighting systems (70% reduction in power)
- Nano-watt Wake-up radio receivers(270nW): wearables, smart harvesters, etc
- Cycling and sensors for air quality monitoring
- Capacitive sensing for BAN
- Security and electronics
- Monitoring horses
- Radars for tractors
- Floating PV farms
- DC Lab
- IoT and machine condition monitoringtoring/etc
- Large-scale environmental monitoring
- Hardware Accelerators for Multi-Asset Option Pricing (European/American)
- EDA tools for ML and ML for EDA tools
  - Digital circuits as ANN: from decomposition to performing synthesis differently
- Towards zero power inference for biomedical applications
- Stochastic Computing and ML
- QUANTUM Computing/EDA and ML
- Ultra low power Asynchronous Charge Sharing Logic in ML inference (decoupling power consumption from input data)
- Adiabatic Logic and ML at the edge

Evolution and Future

$$F = P + NI^{(AI)},$$

where F=Future/Fun, P= Present, NI=Natural Intelligence, AI=Artificial Intelligence

(Note: AI could be interchanged with M=Money)



ACKNOWLEDGEMENTS

Funding: SFI Insight, CRT-AI, Philanthropic(Qualcomm, Dell, Analog Devices), Grand Challenges Canada and Wellcome Trust

Data:

- PCG: Provided by HearTone research group in Kriviy Rih, Ukraine
- EEG: Provided by University of Helsinki

All the data used in this study was ethically approved.

Thank you!

Embedded.Systems@UCC

Any Questions?

http://sites.google.com/site/embedded0101

Youtube: Embedded.Systems@UCC

e.popovici@ucc.ie

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