

# — MyPreHealth: Predicting Episodic Disorders with Health Companions



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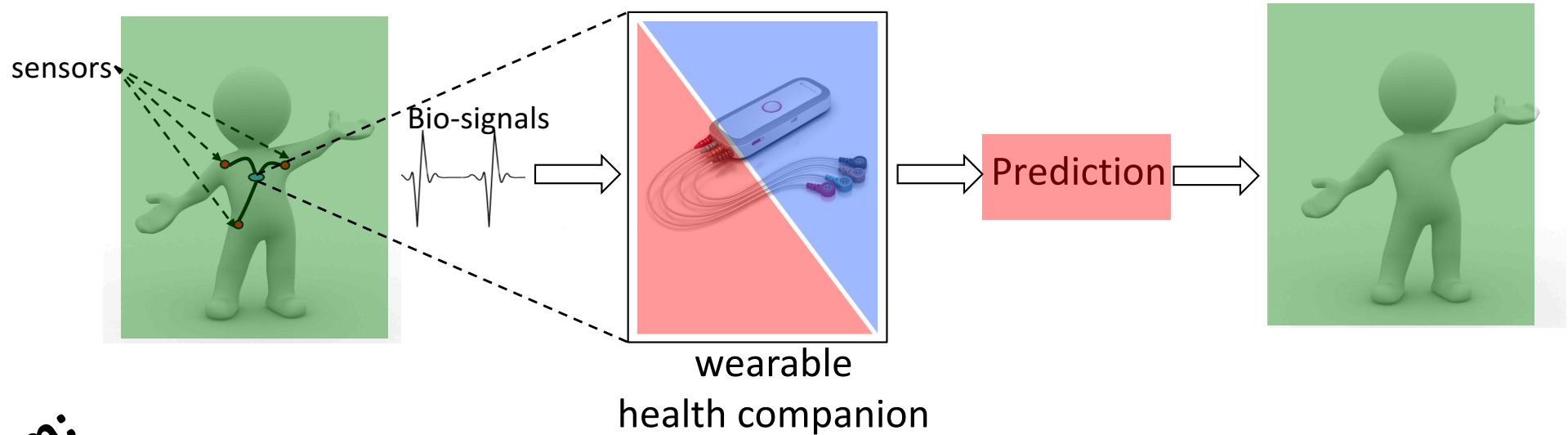


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# Project challenge



## Aim:

To devise wearable and autonomous monitoring solutions in order to predict epilepsy and migraine episodes relying on real-time analysis of bio-signals events on ultra-low-power devices

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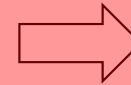
Prof. Philip Ryvlin  
CHUV

## WP1



### Predictive DSP

- Data interpretation
- Low-energy software



- features extraction
- labelling
- self-aware DSP

## WP2



### Domain-specific computing

- System-level
- Component-level



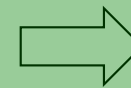
- Virtual platform
- Approximate  
Logic Synthesis

## WP3



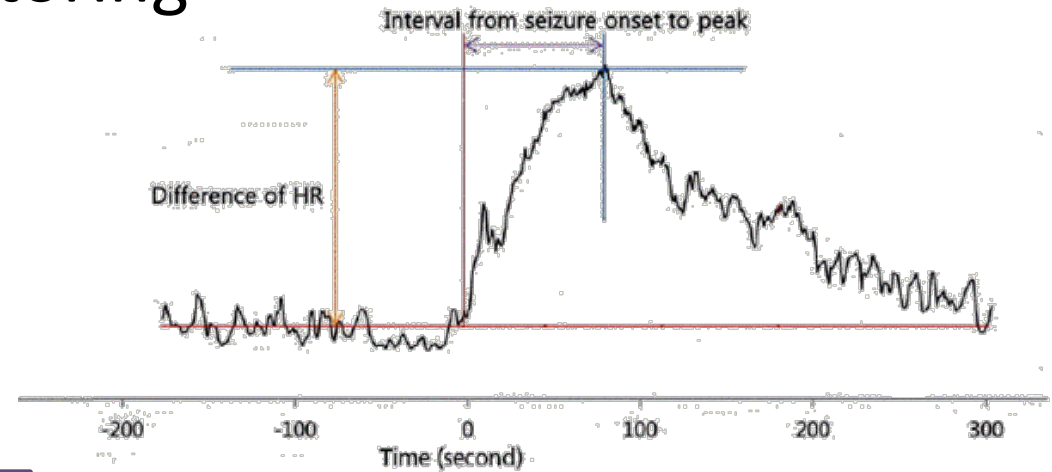
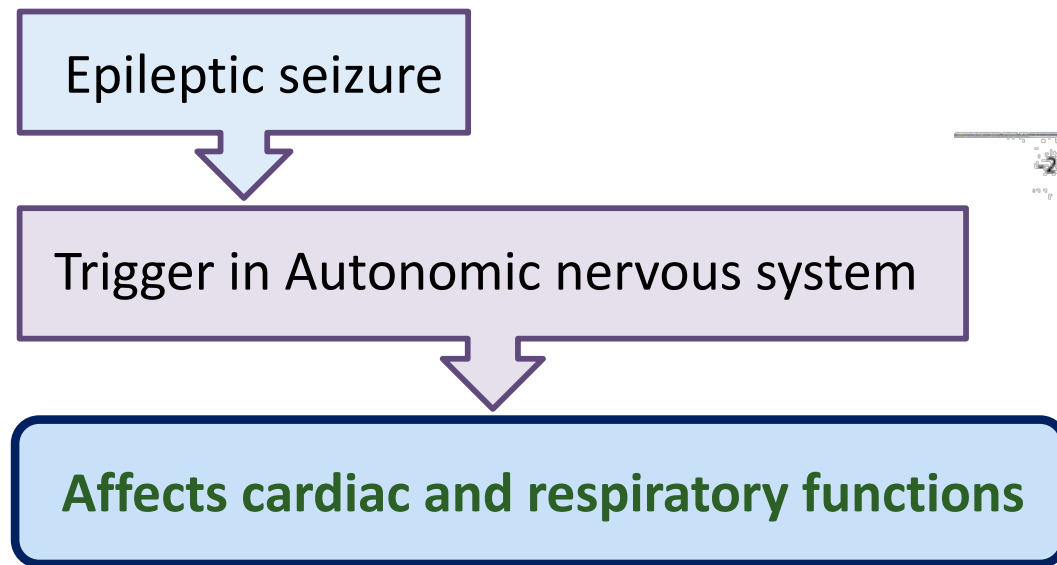
### Observational studies

- migraine and epilepsy
- experts annotations



- multimodal  
bio-signals DBs

## Multi-Modal Epilepsy Monitoring



**Cardiac function is not enough!**

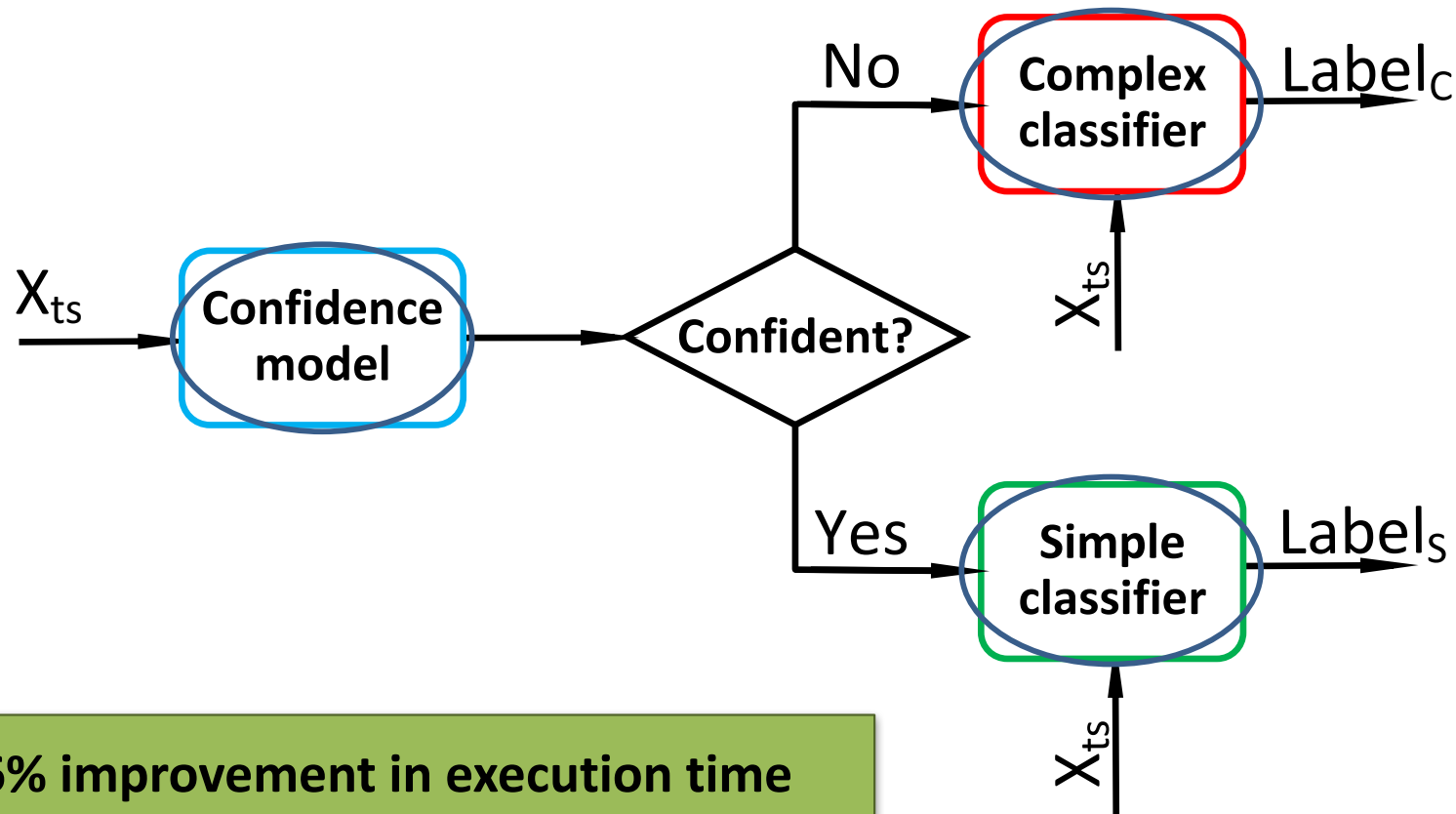


**Multi-modal detection system**

**11.92% improvement in performance**



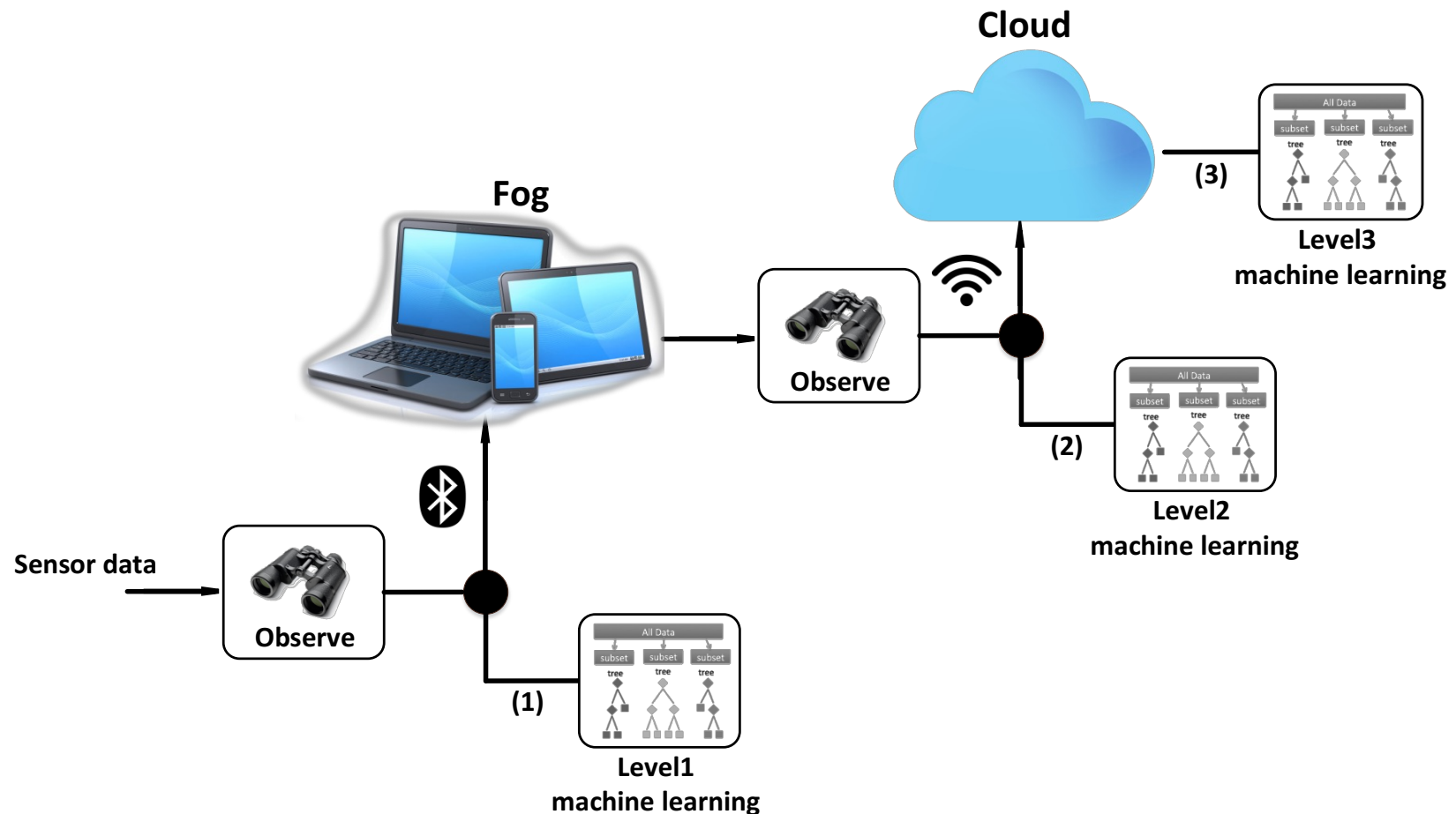
## Self-Awareness: Two-Level Classification



**36% improvement in execution time**

Forooghifar, F., Aminifar, A. and Atienza D., "Self-aware wearable systems in epileptic seizure detection." Euromicro Conference on Digital System Design (DSD), 2018, pp. 426-432.

## Self-Awareness: Distributed Monitoring



**17-86 days improvement in battery execution lifetime**

## Self-Learning: Lack of Labeled EEG Data

Why is it an issue?

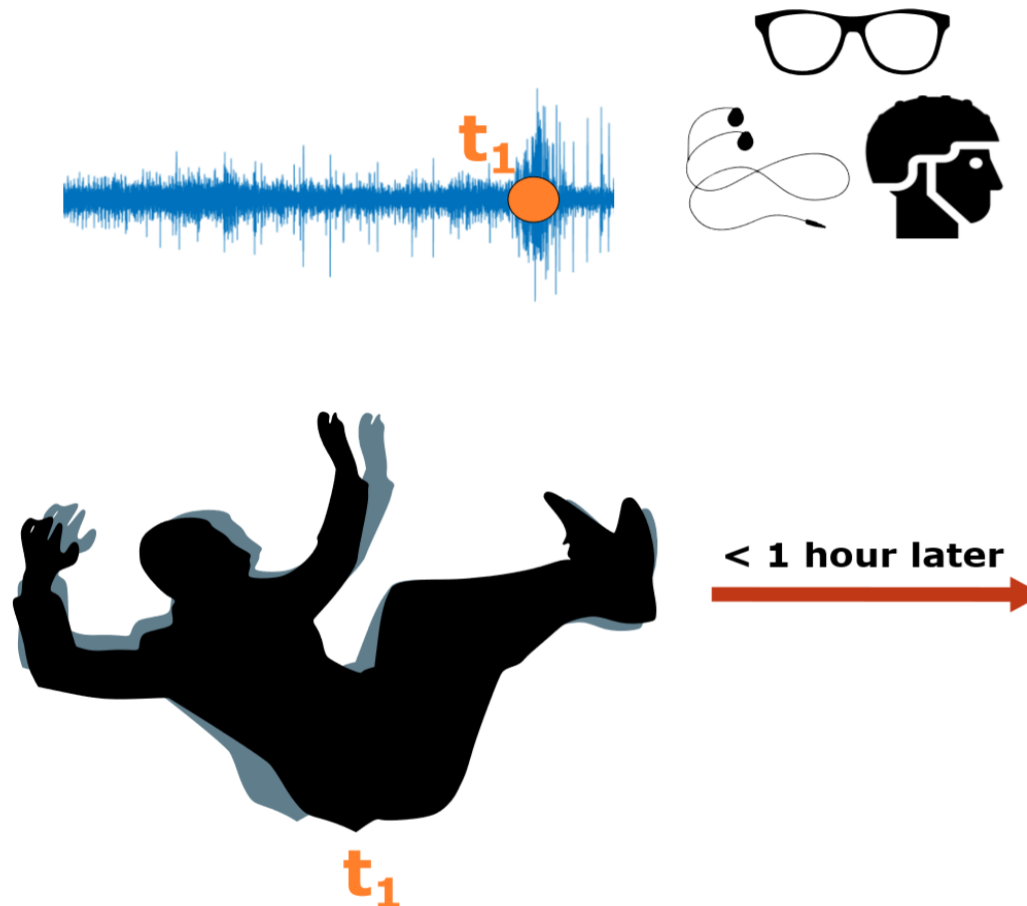
- State-of-the-art: **Supervised Learning**

Why does it lack?

- Labeled by **experts**
- EEG variability: Need **personalized data**

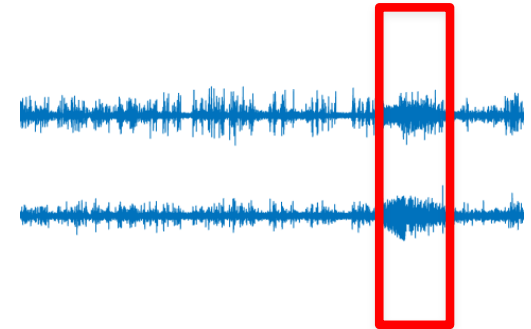
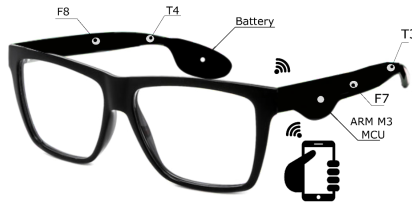
**What if we could label our own data at the edge?**

## Self-Learning (Setting):

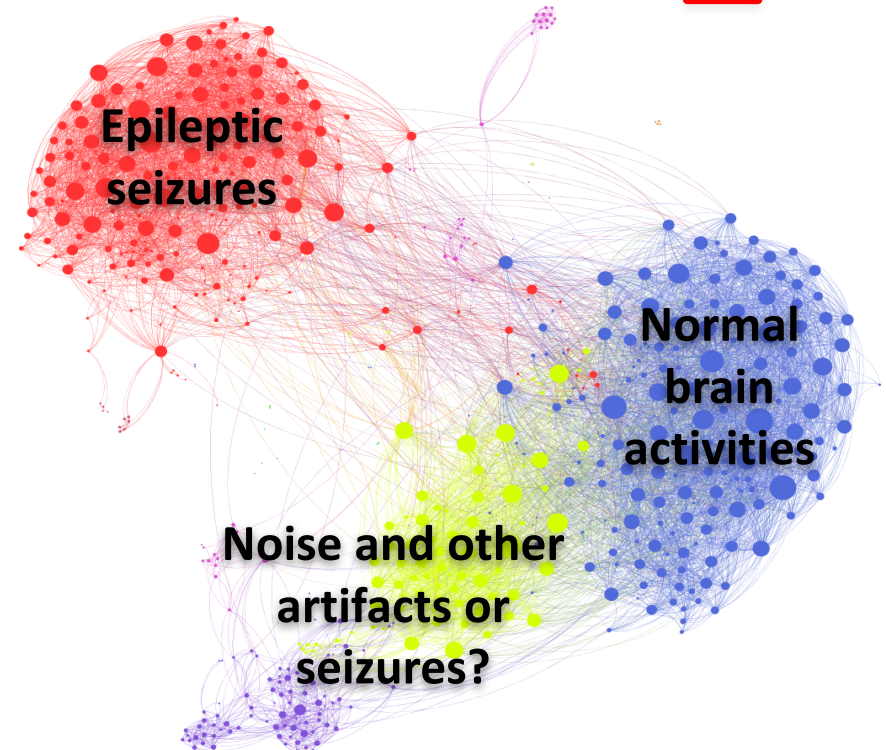


93.3% labels  $< 1 \text{ min}$  from reference

## Self-Learning: User Informs Using Smartwatch

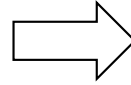


**Our minimally-supervised seizure detection reaches 92.6% geometric mean between the sensitivity and specificity.**



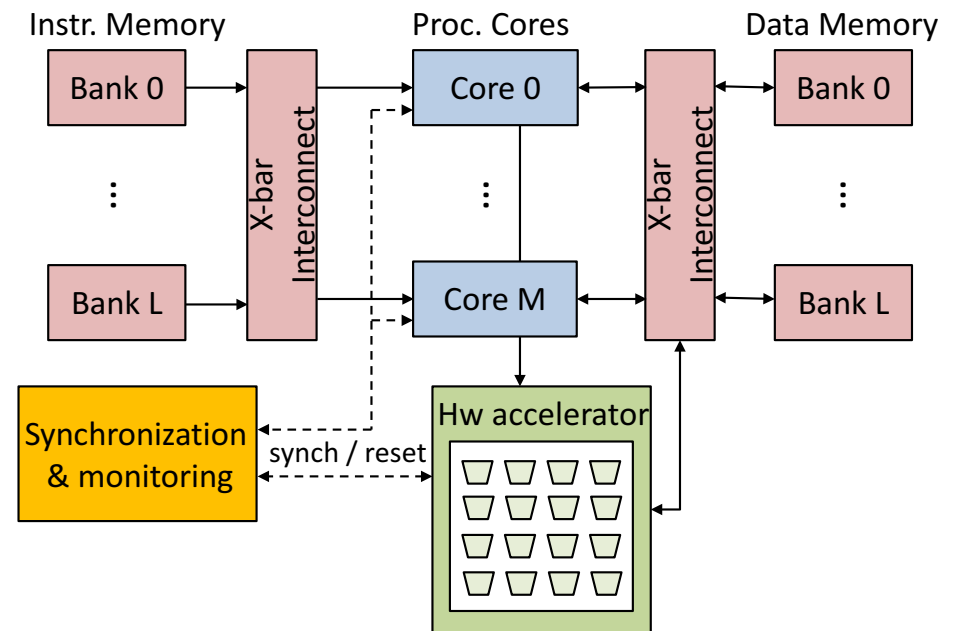
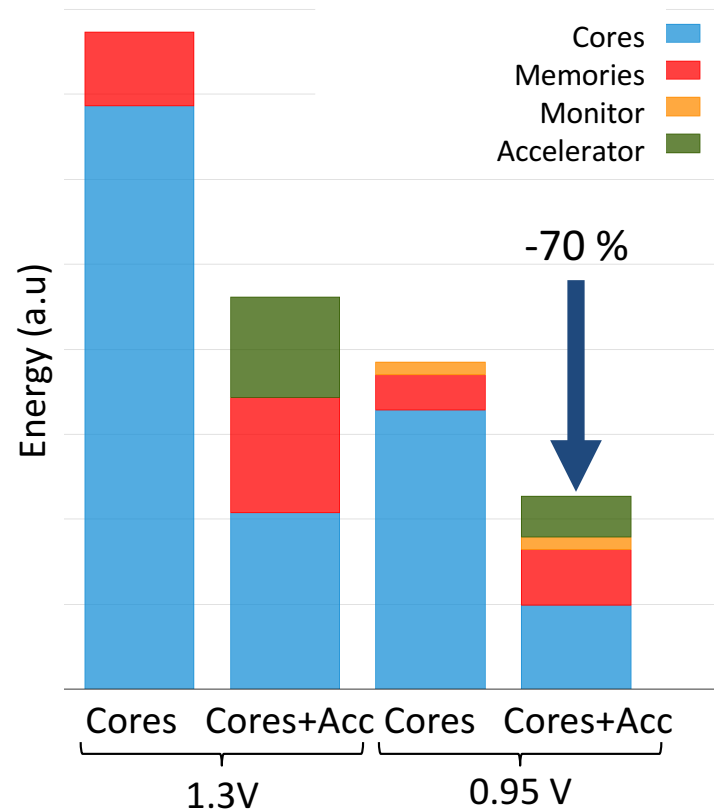
## Characteristics of apps

- task-level parallelism
- computational hotspots
- error-tolerance



## Domain-specific architecture [1]

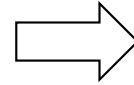
- multi-core
- reconfigurable accelerator
- ultra-Low VDD + error monitoring



[1] Basu S, Duch L, Peón-Quirós M, Atienza D, Ansaloni G, Pozzi L. "Heterogeneous and Inexact: Maximizing Power Efficiency of Edge Computing Sensors for Health Monitoring Applications." IEEE International Symposium on Circuits and Systems (ISCAS), May 2018.

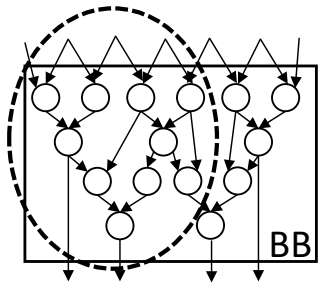
## Hotspot identification & selection

- Control Flow Regions
- Call Graph AccelCands

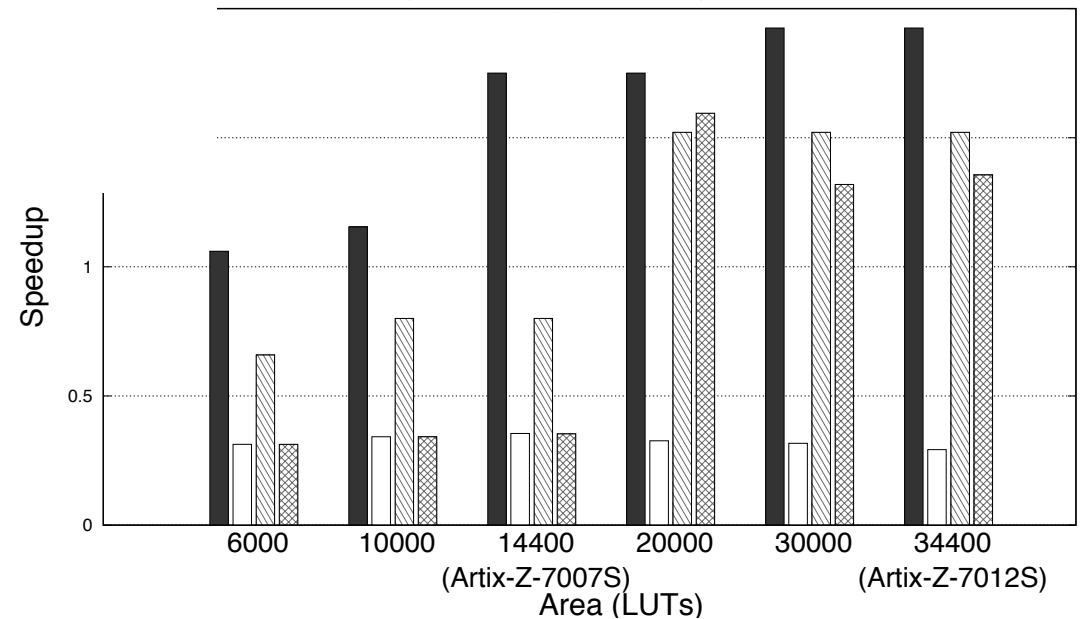


- RegionSeeker [1]
- AccelSeeker [2]

## Basic Block



AccelSeeker gprof1 gprof2 gprof3

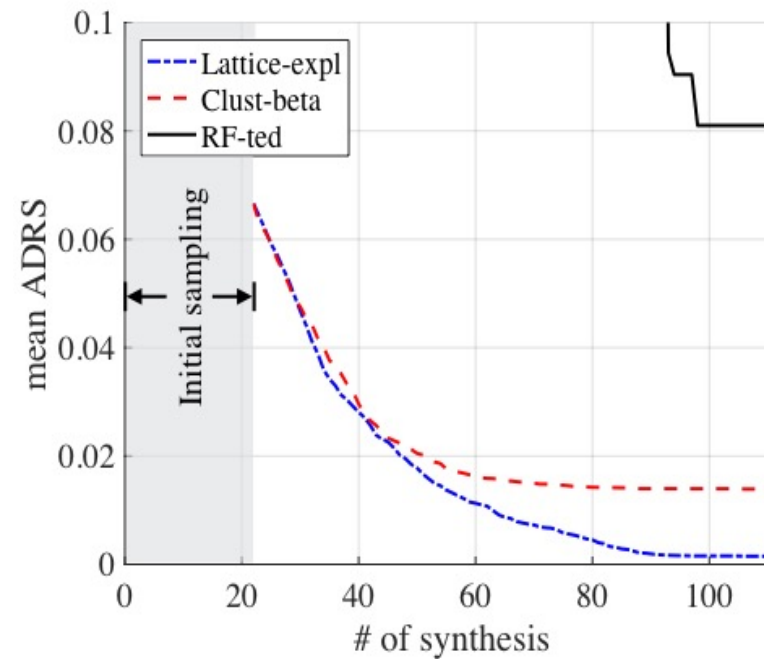
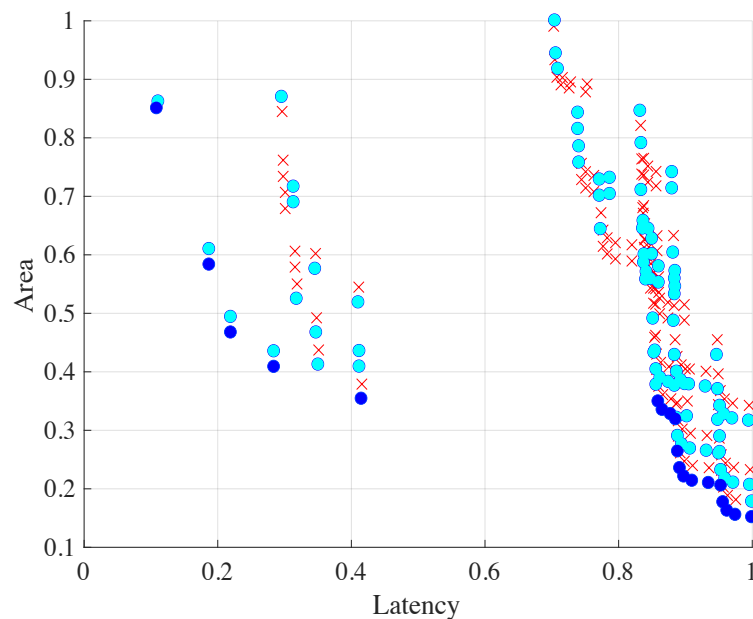


[1] Zacharopoulos G, Ferretti L, Giaquinta E, Ansaloni G, Pozzi L. "RegionSeeker: Automatically Identifying and Selecting Accelerators from Application Source Code." IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems (TCAD). March 2018.

[2] Zacharopoulos G, Di Guglielmo G, Ansaloni G, Carloni L, Pozzi L. "Compiler-Assisted Selection of Hardware Acceleration Candidates from Application Source Code" IEEE International Conference on Computer Design (ICCD), November 2019.

## Hotspots implementation with HLS

- Focus on regions of interest
  - Traversing a multi-dimensional representation
- ⇒
- Cluster-based heuristic [1]
  - Lattice-based heuristic [2]



[1] [Ferretti L](#), [Ansaloni G](#), [Pozzi L](#). "Cluster-Based Heuristic for High Level Synthesis Design Space Exploration." IEEE Transactions on Emerging Topics in Computing (TETC). January 2018.

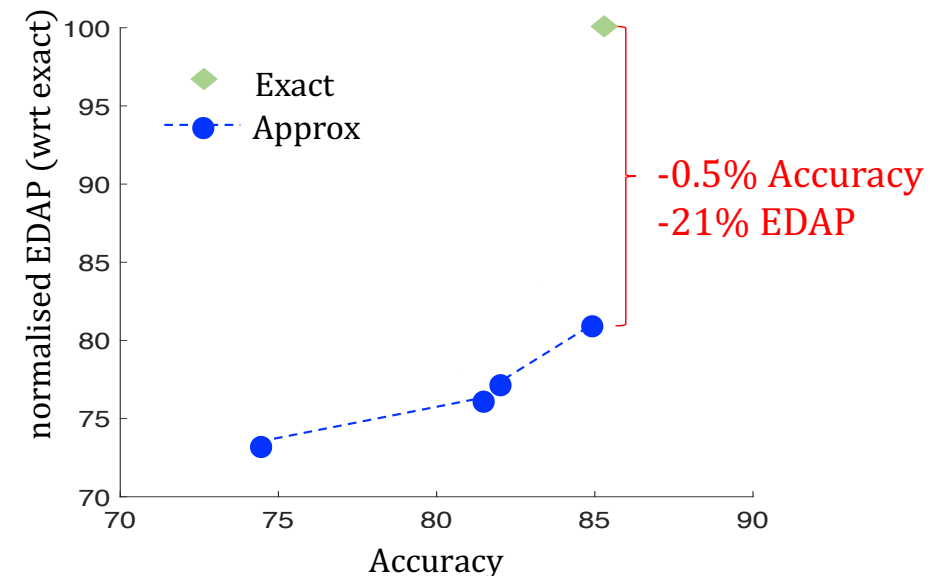
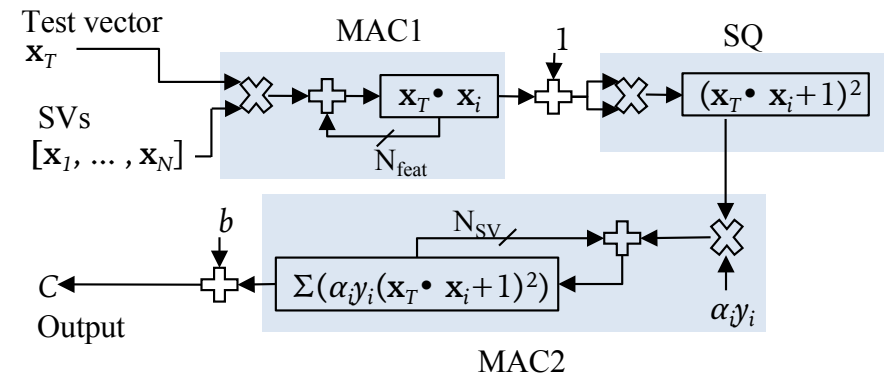
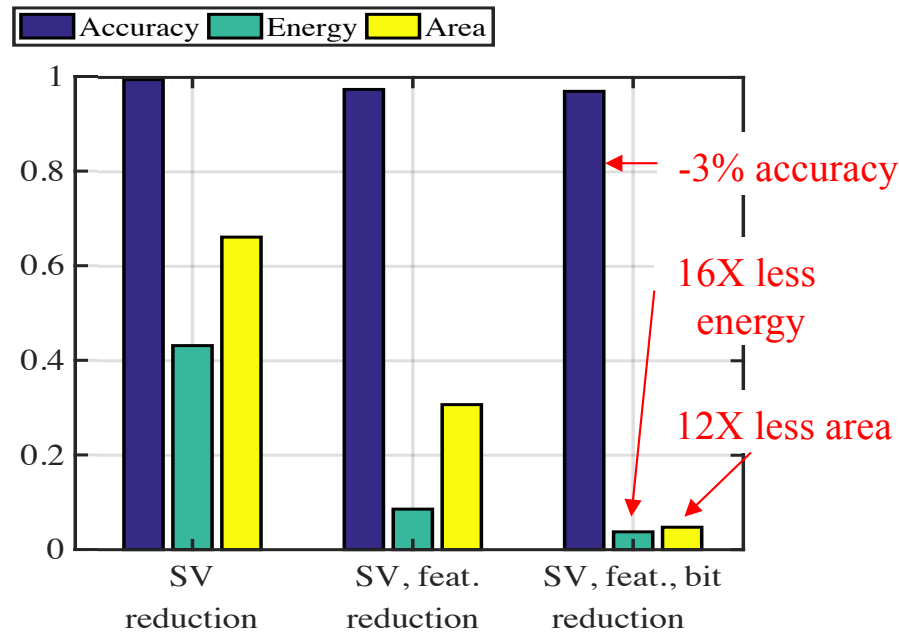
[2] [Ferretti L](#), [Ansaloni G](#), [Pozzi L](#). "Lattice-Traversing Design Space Exploration for High Level Synthesis." IEEE International Conference on Computer Design (ICCD). October 2018.



Hotspots implementation with inexact optimizations

→ test case: quadratic SVM  
for seizure detection from ECG

- Bit truncation & algorithmic simplification [1]
- Approximate Logic Synthesis [2]



[1] Ferretti L, Ansaloni G, Pozzi L, Aminifar A, Atienza D, Cammoun L, Rylvlin P. "Tailoring SVM Inference for Resource-Efficient ECG-Based Epilepsy Monitors." Design, Automation & Test in Europe Conference & Exhibition (DATE), March 2019.

[2] Ansaloni G, Scarabottolo I, Pozzi L. "Judiciously Spreading Approximation among Arithmetic Components with Top-Down Inexact Hardware Design." submitted to Design, Automation & Test in Europe Conference & Exhibition (DATE), March 2020.

## Detecting epileptic seizures

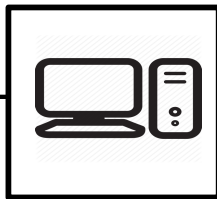
- Seizures appear at random moments, can result in accidents, and impact key social and socioeconomic aspects
- Evaluating the seizure frequency is the most important parameter used to adjust anti-epileptic treatment [i.e. 1]
- Patients fail to report 85.8% of night time and 30-50% of day-time seizures [2]
- Successful seizure detection integrating sensors for accelerometry and extracerebral biosignals [3-5]

### Limits

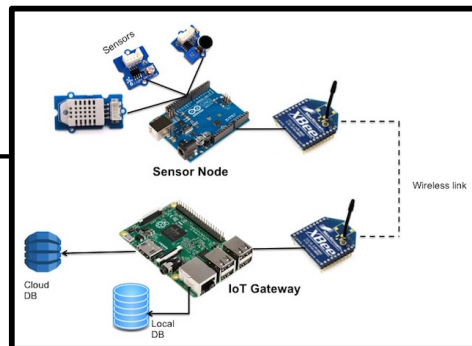
- Studies should be performed with the EEG gold standard
- Lack of combining multiple biosignals
- Data is processed offline and not in real-time
- New for closed-loop systems

## Clinical epilepsy studies-CHUV

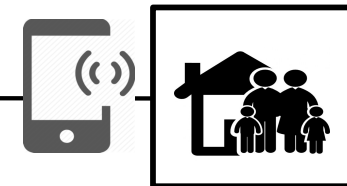
Pilot with long-term  
video EEG



Clinical trial  
with long-term video EEG



Clinical trial  
in ambulatory  
context

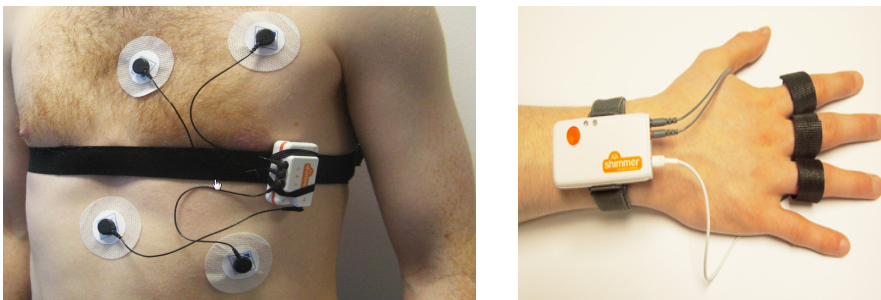


**MyPreHealth observational pilot study: Machine learning based focal and secondary GTC seizure detection algorithm using a multimodal approach in epilepsy patients.**

*Develop a multimodal automatic seizure detection algorithm based on extracerebral symptoms*

- *Classify features from ACC, ECG, PPG, SpO2, and EDA in accordance with the Video-EEG based onset of seizures*
- *Validity (sensitivity and specificity)*
- *Time course of biosignals for the preictal, ictal and postictal periods*

Shimmer ECG and GSR



Video-EEG

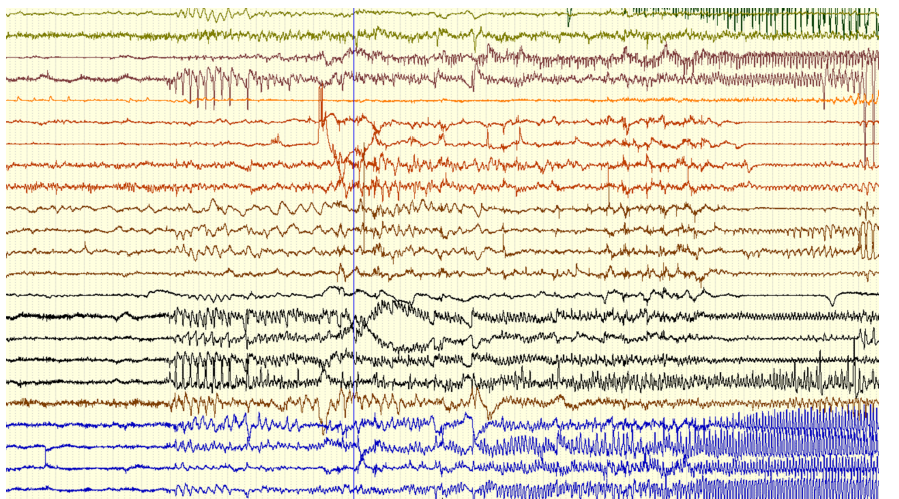


**Project population:**

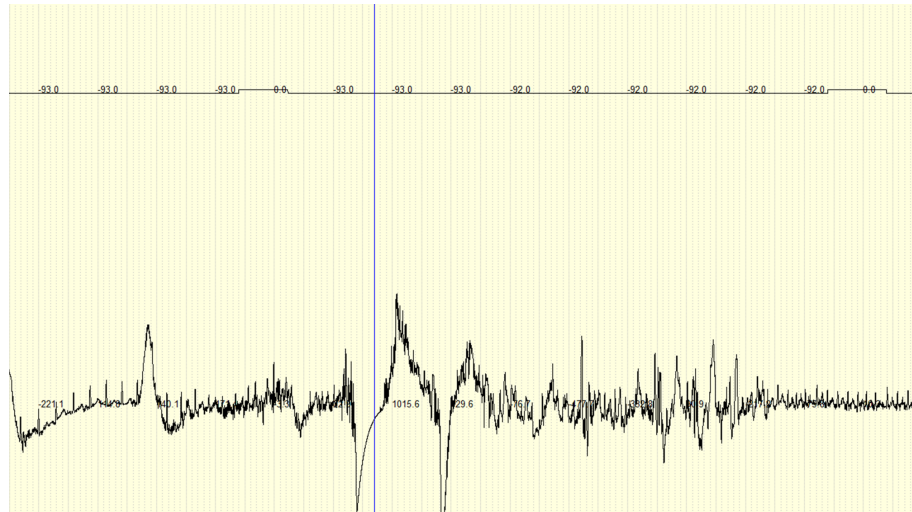
- 3/13 adult patients undergoing Video-EEG monitoring in the Monitoring Unit
- focal seizures and generalized convulsion
- 34 seizures recorded

## MyPreHealth observational pilot study: Machine learning based focal and secondary GTC seizure detection algorithm using a multimodal approach in epilepsy patients

EEG:



ECG:



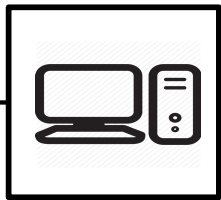
- Single patient
- Analysis of ECG signal
- **Bagged tree classifier** for automated seizure detection
- Windows of 3 min before and 3 min after seizure
- **93%** detection rate with wearable ECG

## Predicting migraine attacks

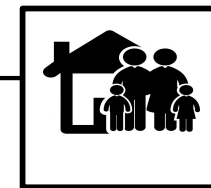
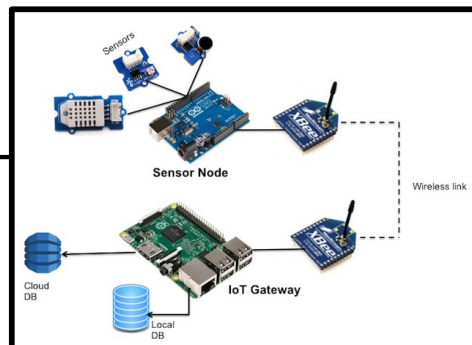


- Acute migraine treatment is encouraged as early as possible after a migraine episode has been detected

Pilot in  
ambulatory context



Clinical trial in ambulatory context



## MyPreHealth observational pilot study II: Wearable device and electronic diary study for early detection of migraine onset

- To detect and illustrate the time course of changes of biometric variables before, during, and after the occurrence of migraine pain*
- Evaluate the effect of the average time lapse between symptom onset and drug administration*

E4 wristband



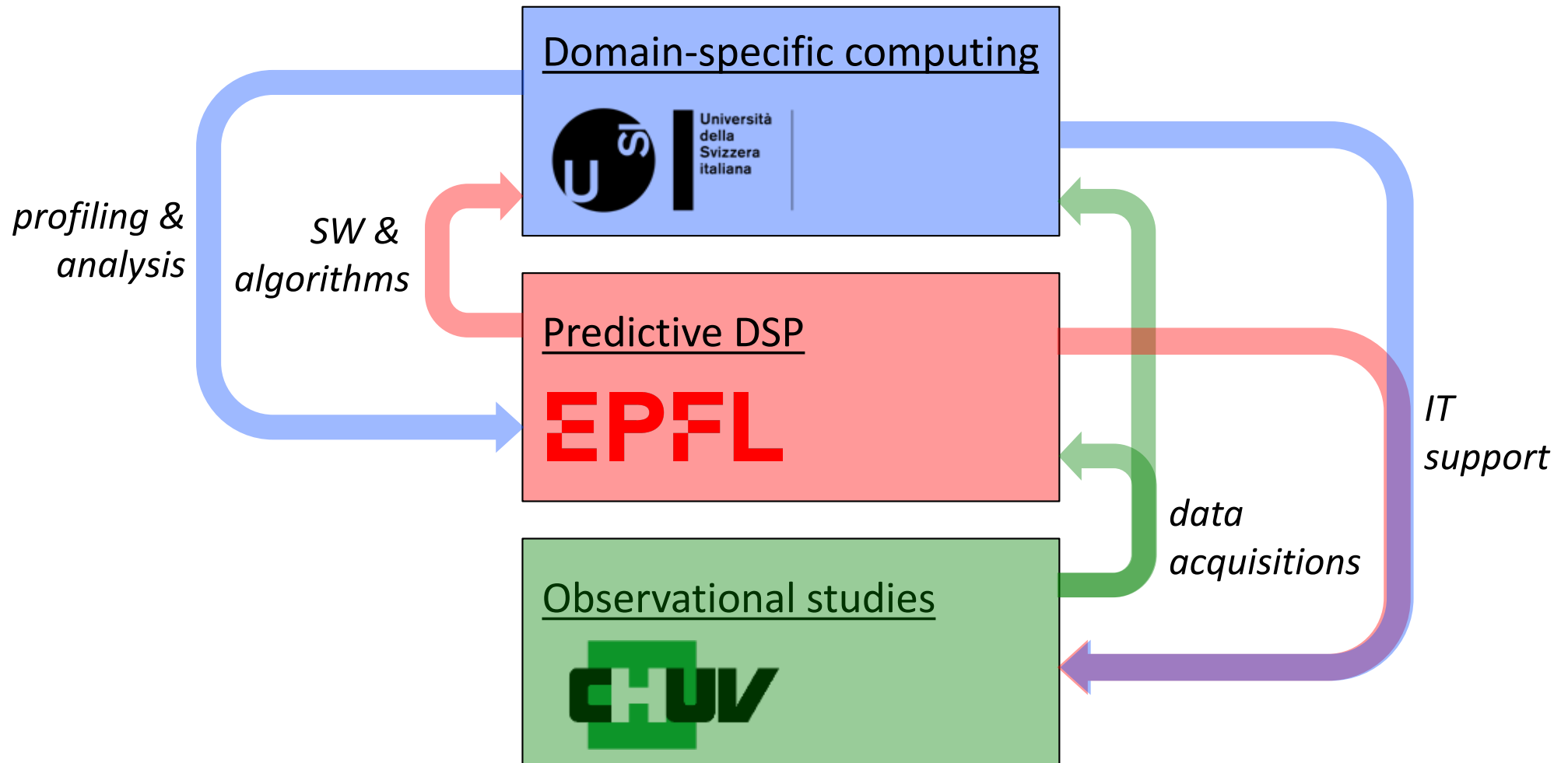
My PreHealth migraine diary app



### *Project population:*

- 20 patients*
- Chronic migraine*
- At least two migraine attacks per month*

# A collaborative effort





4 Journal and 10 conference papers in all fields targeted by MyPreHealth

- Bio-signals processing and analysis
- Low-power architectures for health monitoring
- Inexact computing for health applications

## Journal articles:

[j1] Duch L, Basu S, Peón-Quirós M, Ansaloni G, Pozzi L, Atienza D. “i-DPs CGRA: An Interleaved-Datapaths Reconfigurable Accelerator for Embedded Bio-signal Processing.” IEEE Embedded Systems Letters, June 2018.

[j2] Zacharopoulos G, Ferretti L, Giaquinta E, Ansaloni G, Pozzi L. “*RegionSeeker: Automatically Identifying and Selecting Accelerators from Application Source Code.*” IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems (TCAD). March 2018.

[j3] Ferretti L, Ansaloni G, Pozzi L. “*Cluster-Based Heuristic for High Level Synthesis Design Space Exploration.*” IEEE Transactions on Emerging Topics in Computing (TETC). January 2018.

[j4] Forooghifar F, Aminifar A, Cammoun L, Wisniewski I, Ciumas C, Ryvlin P, Atienza D. “*A Self-Aware Epilepsy Monitoring System for Real-Time Epileptic Seizure Detection.*” Mobile Networks and Applications, 2019.

## Conference papers:

- [c1] Basu S, Duch L, Peón-Quirós M, Atienza D, Ansaloni G, Pozzi L. *"Heterogeneous and Inexact: Maximizing Power Efficiency of Edge Computing Sensors for Health Monitoring Applications."* IEEE International Symposium on Circuits and Systems (ISCAS), May 2018.
- [c2] Scarabottolo I, Ansaloni G, Pozzi L. *"Circuit carving: A methodology for the design of approximate hardware."* IEEE Design, Automation & Test in Europe Conference & Exhibition (DATE). March 2018.
- [c3] Forooghifar F, Aminifar A, Atienza D. *"Self-Aware Wearable Systems in Epileptic Seizure Detection."* Euromicro Conference on Digital System Design (DSD). August 2018.
- [c4] Sopic D, Aminifar A, Atienza D. *"e-Glass: A Wearable System for Real-Time Detection of Epileptic Seizures."* International Symposium on Circuits and Systems (ISCAS). May 2018.
- [c5] Scarabottolo I, Ansaloni G, Pozzi L. *"Work-in-Progress: A Partitioning Strategy for exploring Error-Resilience in Circuits."* International Conference on Compilers, Architecture and Synthesis for Embedded Systems (CASES), September 2018.
- [c6] Ferretti L, Ansaloni G, Pozzi L. *"Lattice-Traversing Design Space Exploration for High Level Synthesis."* IEEE International Conference on Computer Design (ICCD). October 2018.
- [c7] Scarabottolo I, Ansaloni G, Pozzi L. *"Partition and Propagate: an Error Derivation Algorithm for the Design of Approximate Circuits."* Design, Automation Conference (DAC), June 2019.
- [c8] Ferretti L, Ansaloni G, Pozzi L, Aminifar A, Atienza D, Cammoun L, Rylvlin P. *"Tailoring SVM Inference for Resource-Efficient ECG-Based Epilepsy Monitors."* Design, Automation & Test in Europe Conference & Exhibition (DATE), March 2019.
- [c9] Pascual D, Aminifar A, Atienza D. *"A Self-Learning Methodology for Epileptic Seizure Detection with Minimally-Supervised Edge Labeling."* In Design, Automation & Test in Europe Conference & Exhibition (DATE) (pp. 764-769), 2019.
- [c10] Zacharopoulos G, Di Guglielmo G, Ansaloni G, Carloni L, Pozzi L. *"Compiler-Assisted Selection of Hardware Acceleration Candidates from Application Source Code"* IEEE International Conference on Computer Design (ICCD), November 2019.

## WP1

- Refinement of the detection/prediction algorithms based on multi-modal data acquired in WP3
- Automatic per-person DSP tuning



## WP2

- Concurrent accelerators selection and implementation
- Design of accelerators-rich virtual platforms for bio-signal analysis



## WP3

- Completion of acquisitions from migraine and epilepsy patients
- Publication of anonymized database



## WP1

- Fog computing and federated ML at the edge for personalized health monitoring
- Interpretable AI for the co-design of epilepsy detection and prediction algorithms



## WP2

- Self-aware QoS tuning strategies via hardware approximation
  - System and component (accelerator) levels



## WP3

- Transfer Learning: combining retrospective epilepsy database and acquired data from wearable to improve detect/predict episodes



Thank you!!