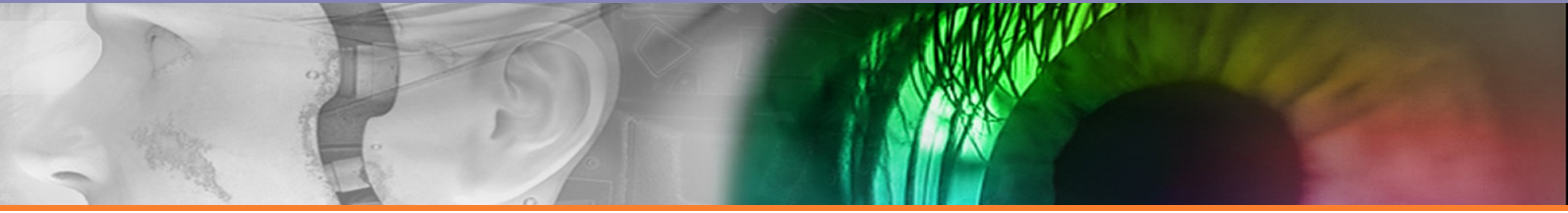


AI for Health and Well-Being @SI-Lab

Andrea Carboni, Claudia Caudai, Sara Colantonio, Danila Germanese, Massimo Magrini, Massimo Martinelli, Davide Moroni, Paolo Paradisi, Maria Antonietta Pascali

http://www.isti.cnr.it

IVI-CNR Meeting

September 5, 2023

CNR Research Campus in Pisa

Institute of Information Science and Technologies

SI-Lab in a nutshell

The Team

Competences

- Computer vision
- Artificial intelligence & intelligent systems
- Statistical signal processing
- Topological data analysis
- Human-computer interaction
- Inclusion & Accessibility

Application fields

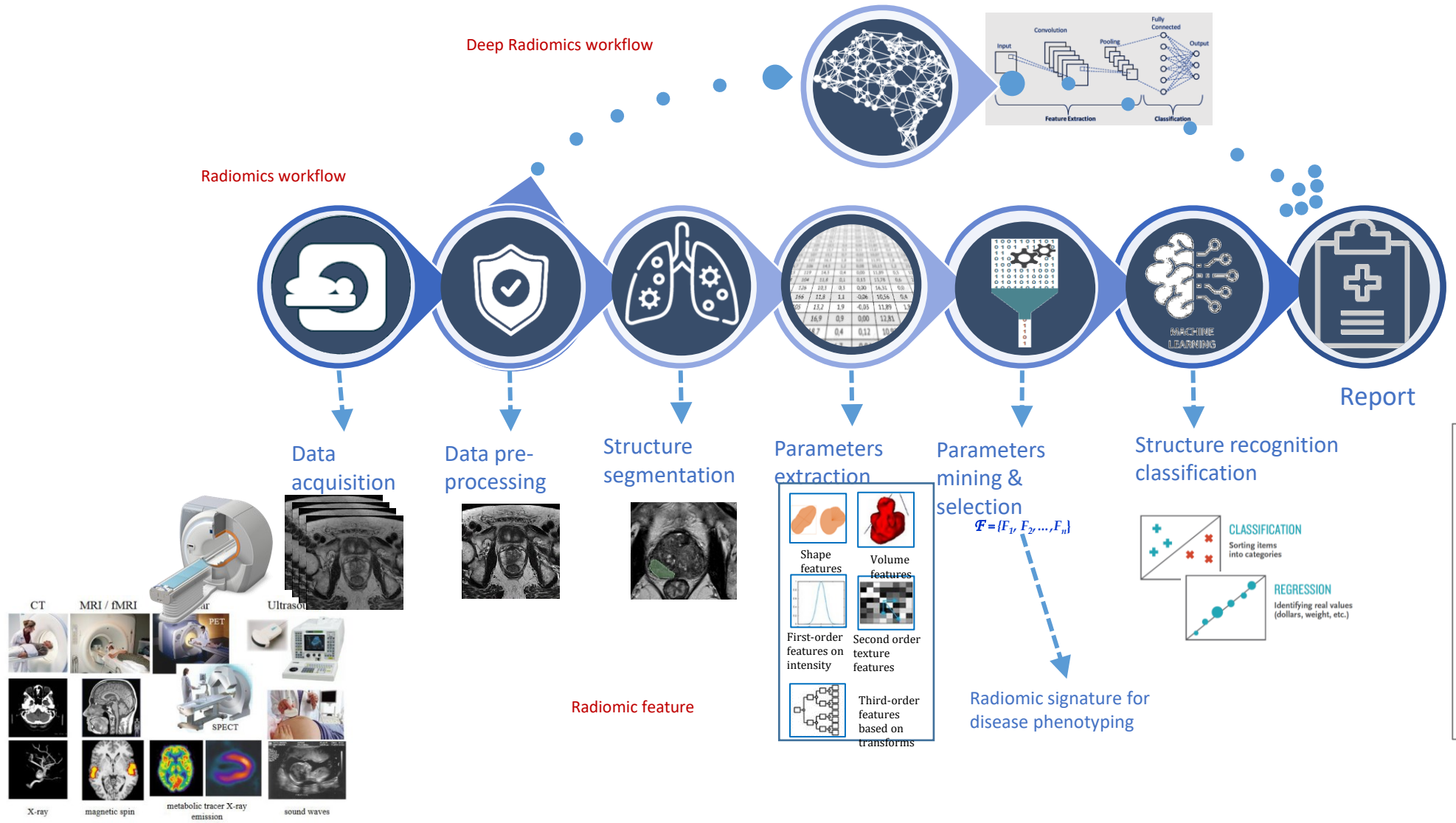
- Industry 4.0 — Smart Converting 4.0, COMPTO-NIM
- Blue Growth — NAUTILOS
- Mobility & Smart Cities — MobiWallet, space, ICSI, SCIADRO
- Cultural Heritage — MOSCARDO, ARROWS
- Internet of Everything — PlatformUptake.eu
- Health & Wellbeing — ProCAncer-I, ACTIVAGE PROJECT, NAVIGATOR, SEMEOTICONS, fAIth, TI ASSISTO

AI for Health and Well-Being @SI-Lab

- Quantitative radiology
  - Radiomics
  - Precision Radiology
  - Deep Ensembling
- Unobtrusive monitoring & physiological computing
  - AI-powered smart devices for risk prediction
  - Smart cameras for ambient assisted living
  - Event-based signal processing of EEG and brain complexity
  - Infrared imaging and thermography
- Topological Data Analysis
- Interactive systems for training and rehab
- Monitoring solutions and IoT
- AI-based Telemedicine & Telecare
- Personal and Clinical Decision Support Systems
- …

AI in quantitative radiology: radiomics and deep radiomics

- Support radiologists' work by quantifying information relevant for diagnosis (e.g., extracting relevant biomarkers)



Working to ensure:

- Robustness (e.g., Variational AutoEncoders)
- Reproducibility and generalizability (e.g., IBSI, validation techniques)
- Usability, transparency and traceability (e.g., MLOps, in-production monitoring, model passport)

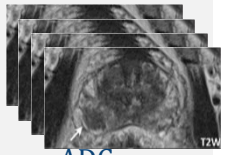
Precision radiology

- Attention-based deep neural networks

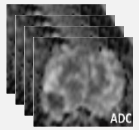
Prostate Cancer Aggressiveness based on MRI

85 cases – 100 lesions on MRI scans

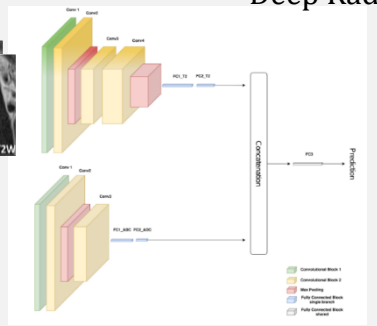
T2W

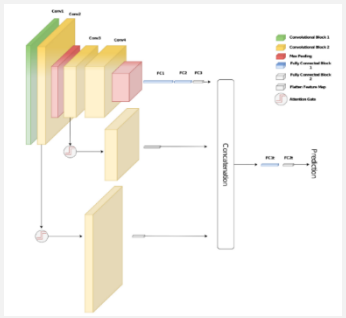


ADC

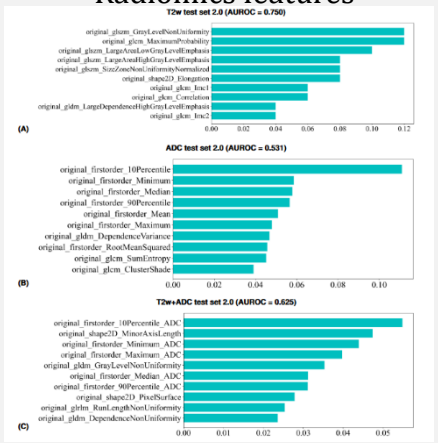


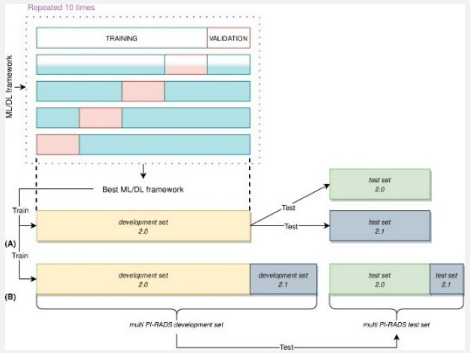
Deep Radiomics models





Radiomics features

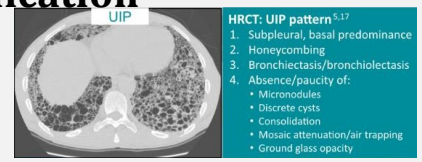


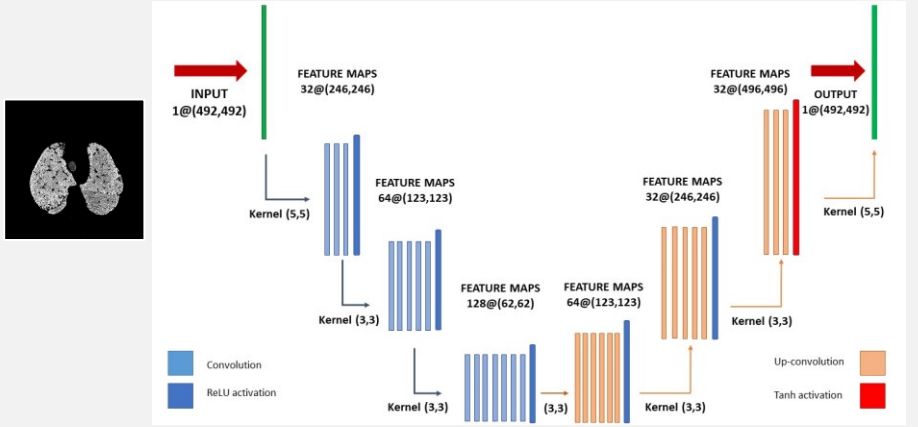


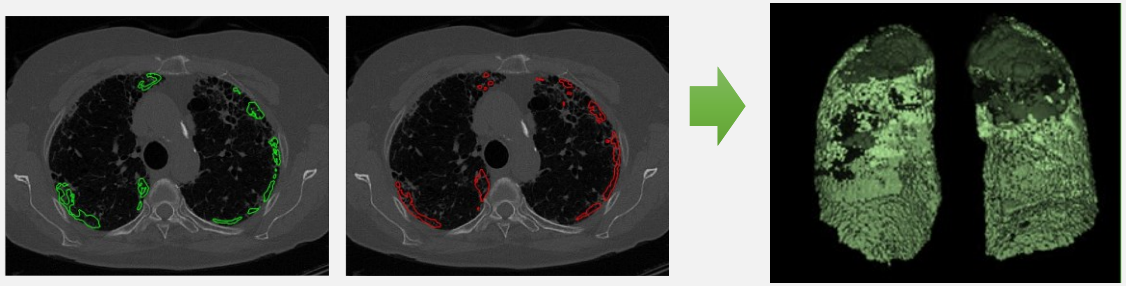
Nested & stratified cross-validation

COVID-19 and Usual Interstitial Pneumoniae pattern segmentation and quantification

20 IPF patients – CT volumetric scans
Training/Test 13/7 cases
56 COVID-19 patients CT scans
Training/Test 36/20 cases



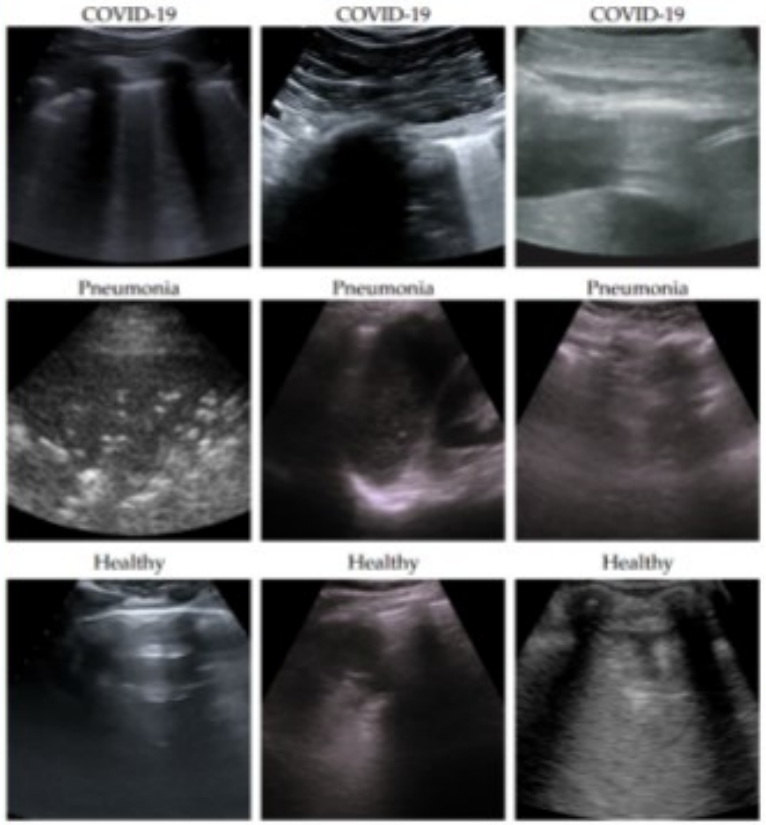




Dice score 86,5%± 12,7% Jaccard score 83,5%±15,1% 2,0%

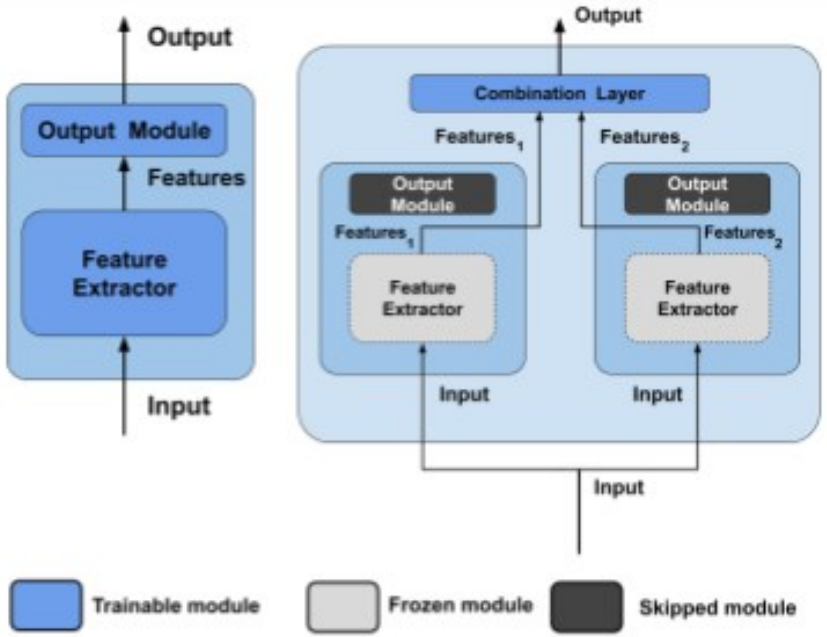
Deep Ensembling for lung ultrasound classification

Dataset



Class	Videos	Frames
COVID-19	64	1024
Pneumonia	49	704
Healthy	66	1326

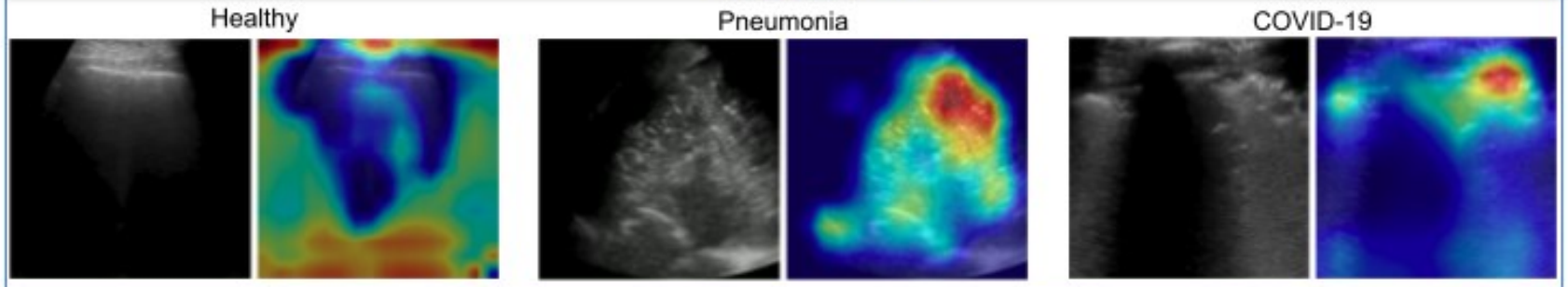
Model



Results

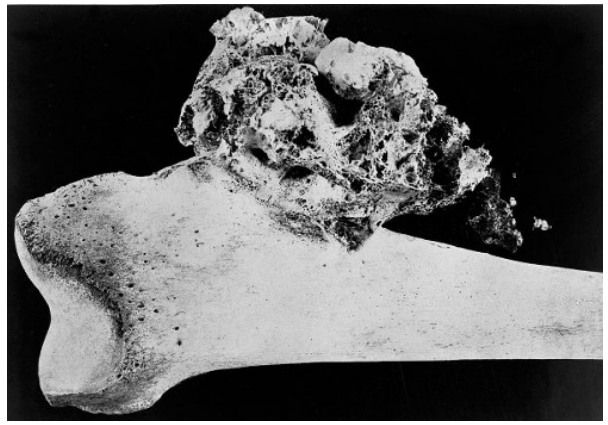
	Class	Recall	Precision	F1-Score
VGG[25]				
Acc.: 87.8% (87.1%)	COVID-19	0.88±0.07	0.90±0.07	0.89±0.06
#Param.: 14.7M	Pneumonia	0.90±0.11	0.81±0.08	0.85±0.08
FLOPs: 15.3G	Healthy	0.83±0.11	0.90±0.06	0.86±0.08
InceptionV3[23]				
Acc.: 89.1% (89.3%)	COVID-19	0.864±0.036	0.901±0.031	0.880±0.030
#Param.: 23.9M	Pneumonia	0.908±0.025	0.842±0.037	0.871±0.025
FLOPs: 6G	Healthy	0.907±0.026	0.918±0.021	0.911±0.021
DenseNet-201[24]				
Acc.: 90.4%	COVID-19	0.892	0.918	0.905
#Param.: 20M	Pneumonia	0.903	0.610	0.728
FLOPs: 4.29G	Healthy	0.850	0.842	0.846
Weak model				
Acc.: 98.7% (98.3%)	COVID-19	0.984±0.004	0.993±0.004	0.990±0.004
#Param.: 5M	Pneumonia	0.997±0.005	0.991±0.006	0.991±0.007
FLOPs: 0.39G	Healthy	0.999±0.003	0.993±0.003	0.995±0.004
Ensemble				
Acc.: 100% (100%)	COVID-19	1.000±0.000	1.000±0.000	1.000±0.000
#Param.: $10M^2$	Pneumonia	1.000±0.000	1.000±0.000	1.000±0.000
FLOPs: $0.78G^3$	Healthy	1.000±0.000	1.000±0.000	1.000±0.000

Explainability



Bruno, A., Ignesti, G., Salvetti, O., Moroni, D., & Martinelli, M. (2023). Efficient Lung Ultrasound Classification. Bioengineering, 10(5), 555.
Bruno, A., Moroni, D., & Martinelli, M. (2023). Efficient adaptive ensembling for image classification. Expert Systems, 1–12. https://doi.org/10.1111/exsy.13424

Deep Learning Approach to Human Osteosarcoma Cell Detection & Classification



Osteosarcoma aggressive malignant neoplasm of bones

Different cell populations were cultured on glass slides:

i) Undifferentiated Mesenchimal Stromal Cells (MSC)

ii) **Osteosarcoma** cells. MG-63 (human osteosarcoma cell line ATCC CRL-1427)

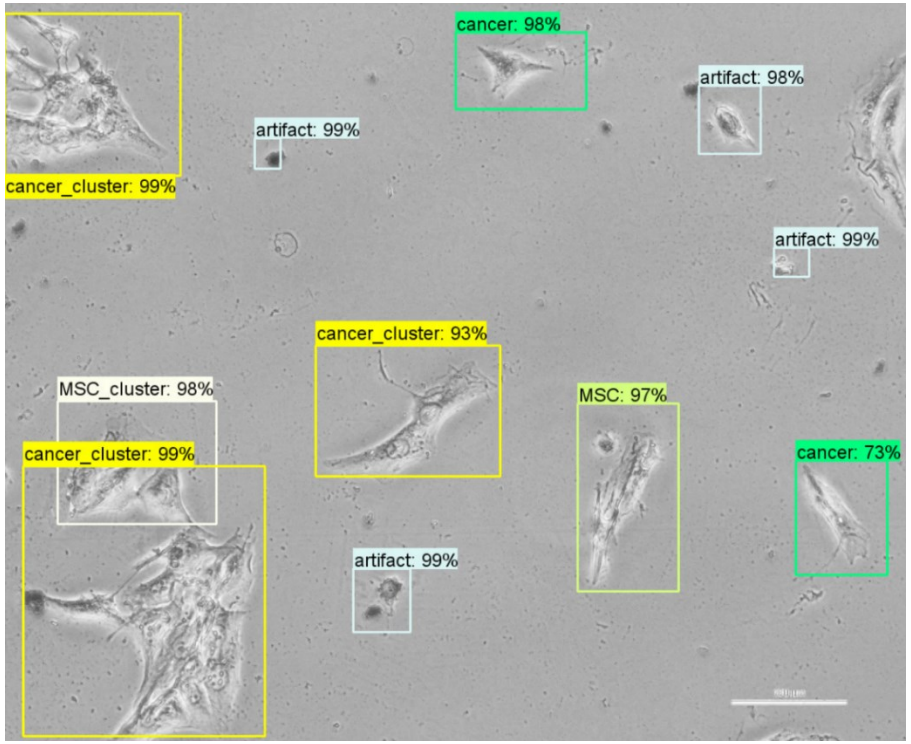
iii) **Mixed** cancer and normal cells

Images recorded with an optical microscope

DL applied to identify and classify single cells:
trained a Faster R-CNN

229 objects used for training
Training / Validation: 80% / 20%

Results:
classification accuracy of **0.97**

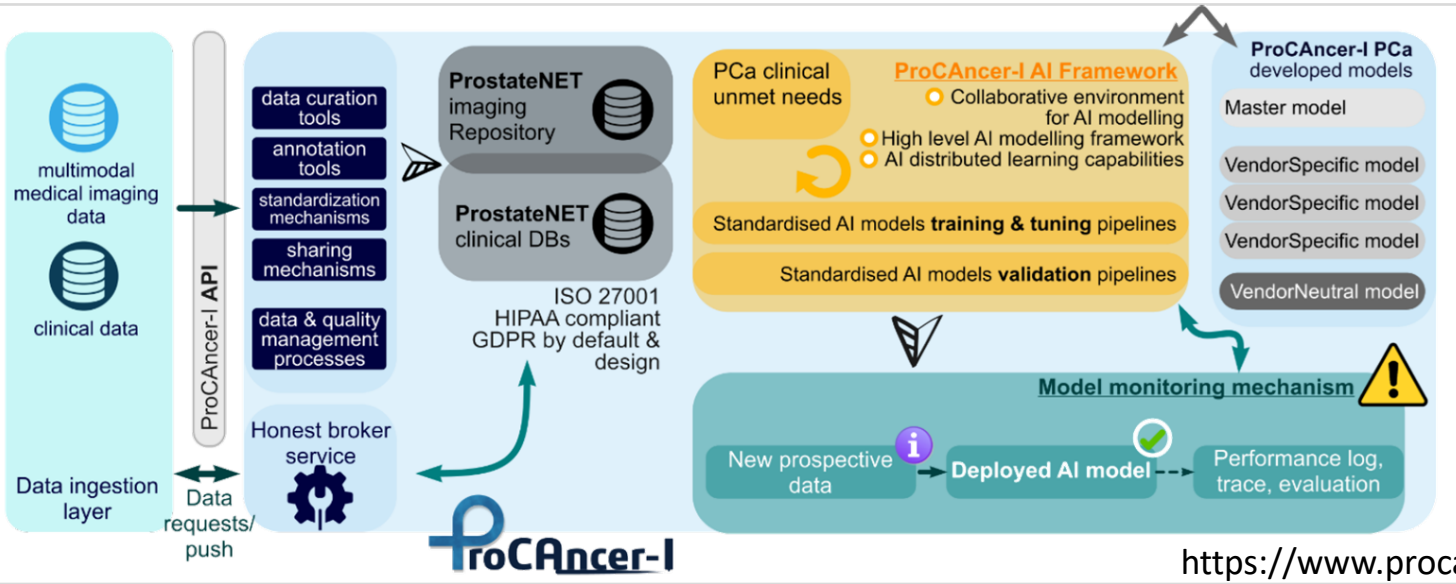


D'Acunto, M., Martinelli, M., & Moroni, D. (2019). From human mesenchymal stromal cells to osteosarcoma cells classification by deep learning. Journal of Intelligent & Fuzzy Systems, 37(6), 7199-7206.

Imaging research environments and bio-banks

ProCAncer-I

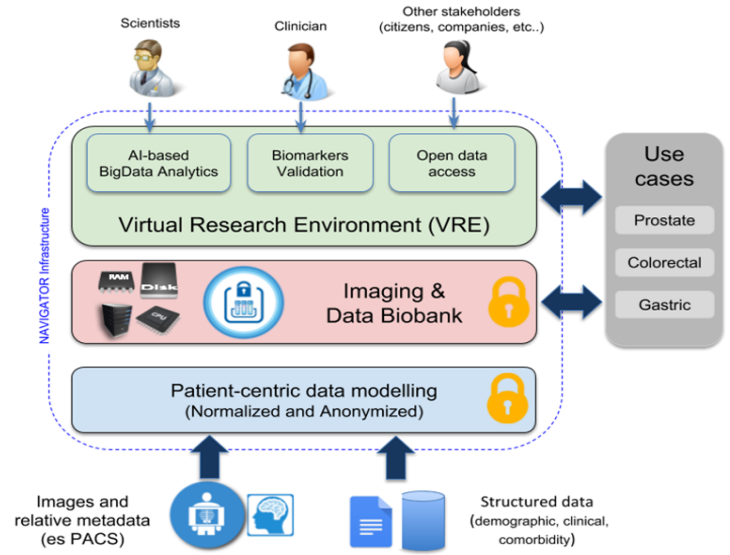
A sustainable **AI cloud-based platform** for the **development, verification** and **validation** of **trustworthy,** and **reliable AI models** for addressing **unmet needs** in the clinical management of **Prostate cancer**



https://www.procancer-i.eu/

NAVIGATOR

An **open imaging Biobank**, augmented with an **open-science oriented, Virtual Research Environment**, available for medical researchers and general clinical stakeholders, for ***radiomics analyses*** and **digital patient models** in oncology



HPC lab
infroscience

http://navigator.med.unipi.it/

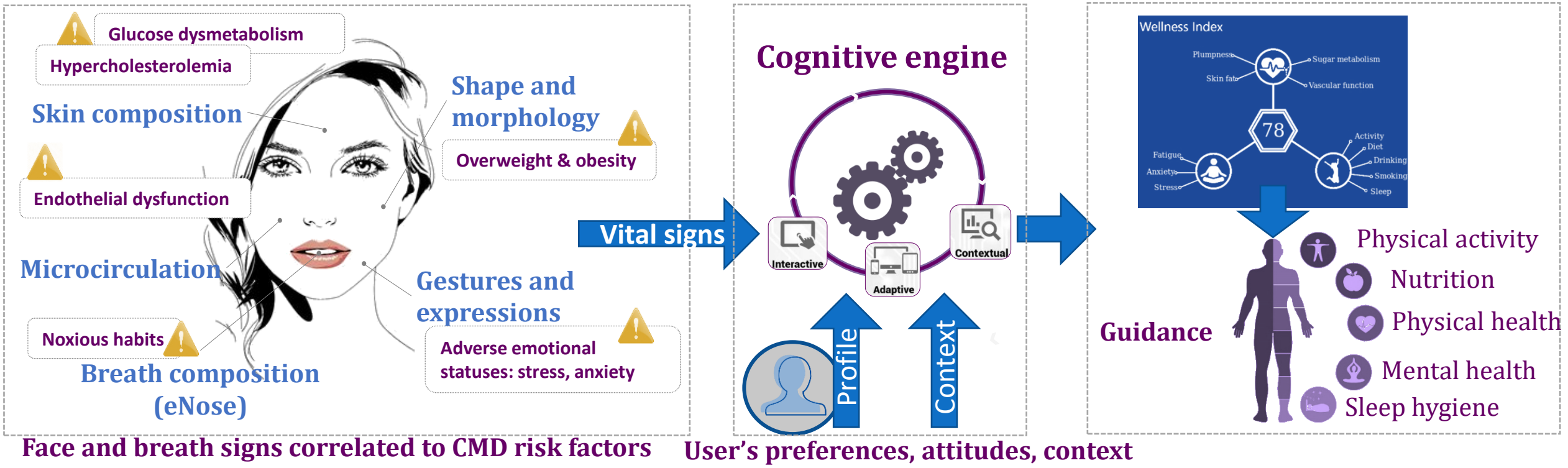
AI-powered smart devices for risk prediction

Real use case: SEMEOTICONS

Objective:

- Prevention of **cardio-metabolic diseases (CMD)**
- Evaluation of vital signs from **face analysis**
- **Sensorised mirror** easily fitting daily life routines
- **Personalised guidance** with an empathic assistant

https://www.youtube.com/watch?v=oUWGg2Hsu6I

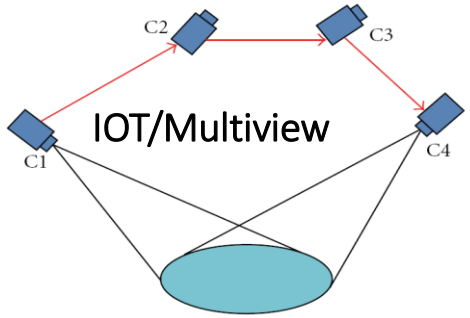


Giorgi, D., Bastiani, L., Morales, M. A., Pascali, M. A., Colantonio, S., & Coppini, G. (2022). Cardio-metabolic risk modeling and assessment through sensor-based measurements. International Journal of Medical Informatics, 165, 104823.

Smart cameras for ambient assisted living

A smart camera is a camera equipped with an AI component.

It can be regarded as a smart sensors in the IoT perspective



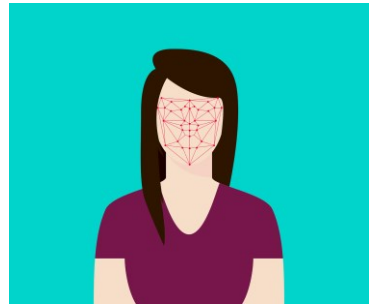
<u>Advantages</u>:

- Distributed visual intelligence
- Pervasive approach
- Robustness & fault tolerance
- Autonomy
- Adaptability / Extensibility
  - New AI component can be developed for custom visual tasks
  - Deep learning - Machine learning approach

<u>Experience:</u>

- Technology tested in smart cities project in indoor and outdoor scenarios in surveillance and urban mobility

Object detection



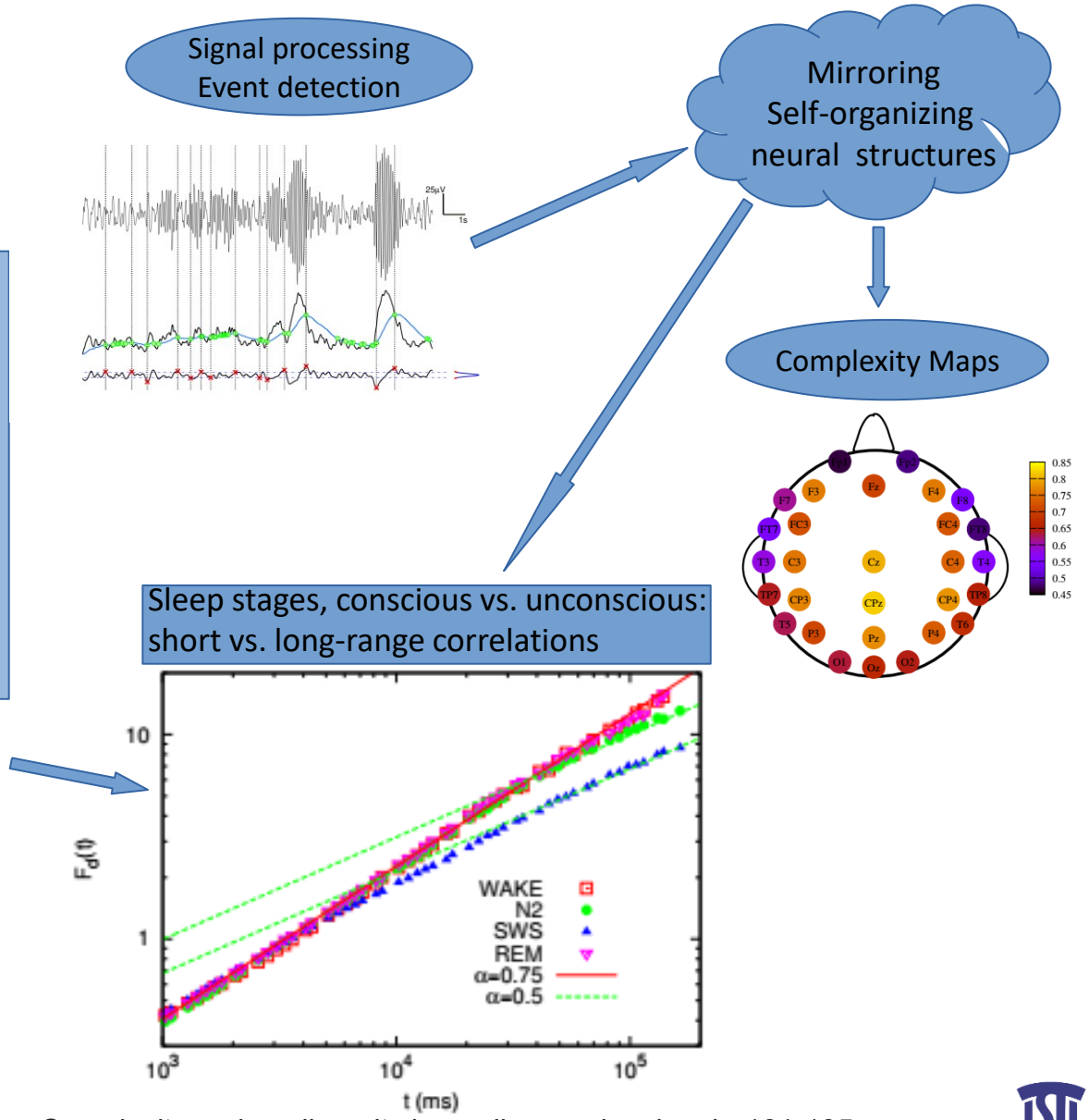
People identification & re-identification

Anomalous event detection

Activity recognition for context-aware applications

Event-based signal processing of EEG and brain complexity

- Brain waveforms ⟹ Brain events
- Events: birth-death of self-organized states (coherent/synchronized states)
- Event-based connectivity measures (multi-channel events)
- Functional, causal connectivity:
  - Avalanche size distribution
  - Degree distribution
  - Scaling analysis, long-range correlations
- Potential applications to disorders of consciousness and
- neurological diseases



Paradisi, P., & Allegrini, P. (2017). Intermittency-driven complexity in signal processing. *Complexity and nonlinearity in cardiovascular signals*, 161-195.

Learning in bio-inspired neural network models

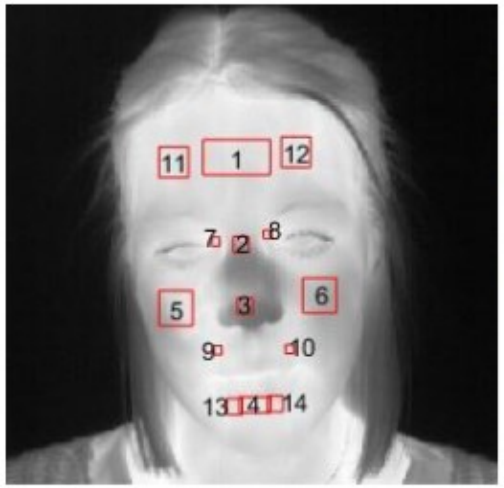
- A modeling/theoretical study: from single neurons to neural populations (analogy with local field potential)
- Role of network topology on the complexity of the neural system [self-organization features]
- Evolution of complexity features during learning
- Application to biomedical signal processing (EEG)

- Project “Future Artificial Intelligence Research” (FAIR), [funded by National Recovery and Resilience Plan]

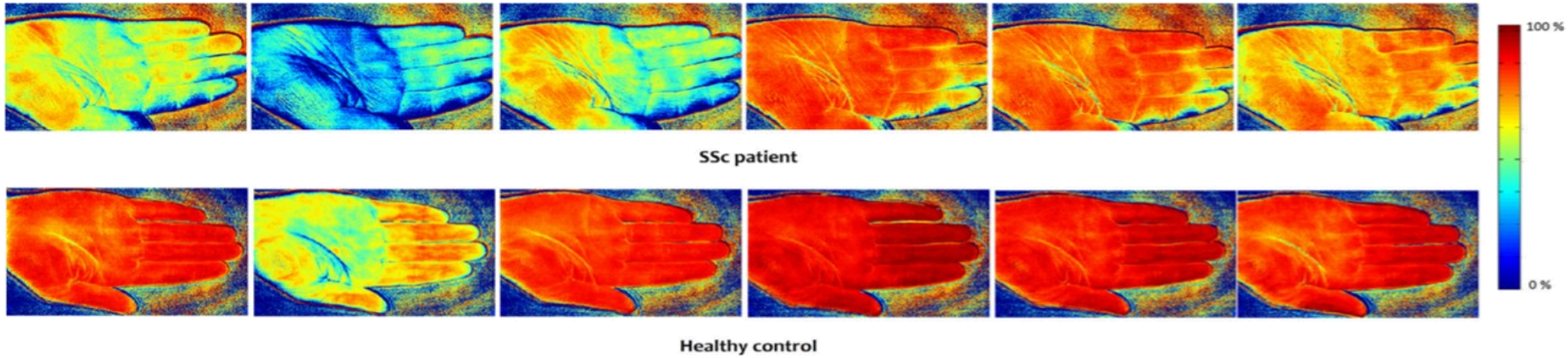
- Research Task: Self-organization and complexity in bio-inspired models of neural networks during learning processes

AI & computer vision for Infrared imaging and thermography in biomedical applications

- Image processing and computer vision methods for infrared image analysis
  - Response to physiological stimuli
  - Stress analysis and physiological computing
    - Noninvasive contactless measurement
  - HR analysis and Heart Rate Variability (Near-infrared)
- Applications to:
  - Obesity
  - Anorexia Nervosa and Horticultural Therapy
  - Generative art



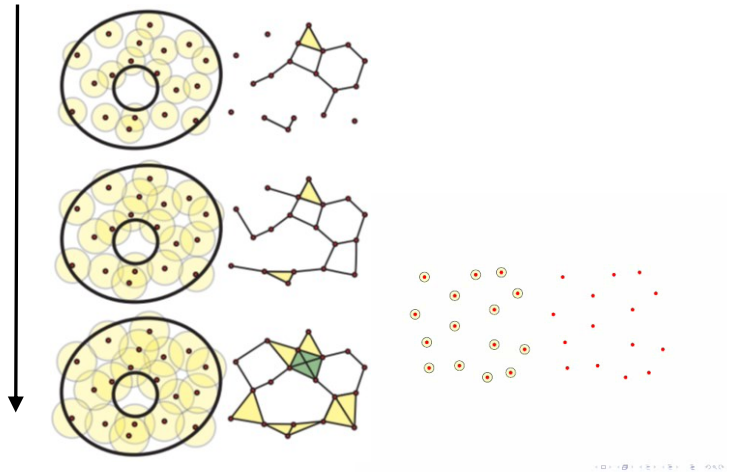
1. Forehead
2. Nasal Septum
3. Nose Tip
4. Chin
5. Left Cheek
6. Right Cheek
7. Left Periorbital
8. Right Periorbital
9. Left Maxillary
10. Right Maxillary
11. Left Forehead
12. Right Forehead
13. Left Chin
14. Right Chin

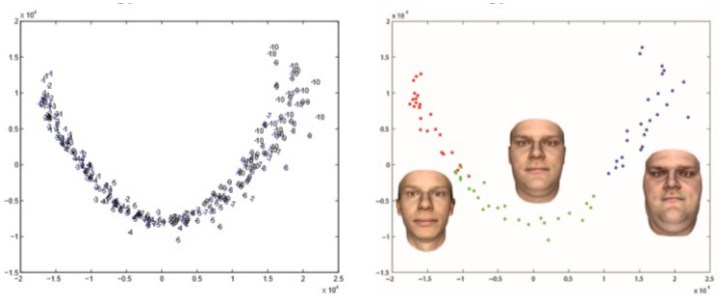


Jalil, B., Hartwig, V., Moroni, D., Salvetti, O., Benassi, A., Jalil, Z., ... & Guiducci, L. (2019). A pilot study of infrared thermography based assessment of local skin temperature response in overweight and lean women during oral glucose tolerance test. Journal of Clinical Medicine, 8(2), 260.
Curzio, O., Billeci, L., Belmonti, V., Colantonio, S., Cotrozzi, L., De Pasquale, C. F., ... & Maestro, S. (2022). Horticultural Therapy May Reduce Psychological and Physiological Stress in Adolescents with Anorexia Nervosa: A Pilot Study. Nutrients, 14(24), 5198.

Topological Data Analysis (TDA) & Machine Learning for Health and Well Being

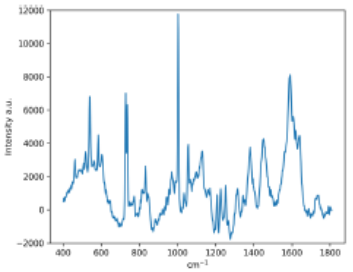
- Topological Data Analysis (a mathematical theory) provides tools for gaining insigth into topological and geometric structure of patterns
  - Computable, multiscale and informative feature
  - It can be thought informally as a (powerful) generalization of the number of connected components, loops and voids (Betti numbers)
- Our research themes:
  - Interplay of TDA with Machine Leaning
    - Provide trainable topological layers to allow neural networks to deal with topological information
    - Understanding deep learning with TDA-based approaches
- Applications: image processing, statistical shape analysis, time series, finance, protein folding, sensor coverage….
  - 3D faces and correlation with obesity [GPH+2017]
  - Raman spectra classification
    - Chondrosarcoma grading (histology) [Sci.Rep.2023]
    - Alzheimer disease detection (cerebrospinal fluid) [AITA2023]

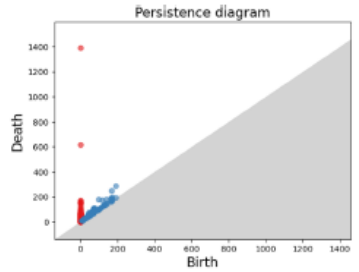




(1-homology, Euclidean filtration)

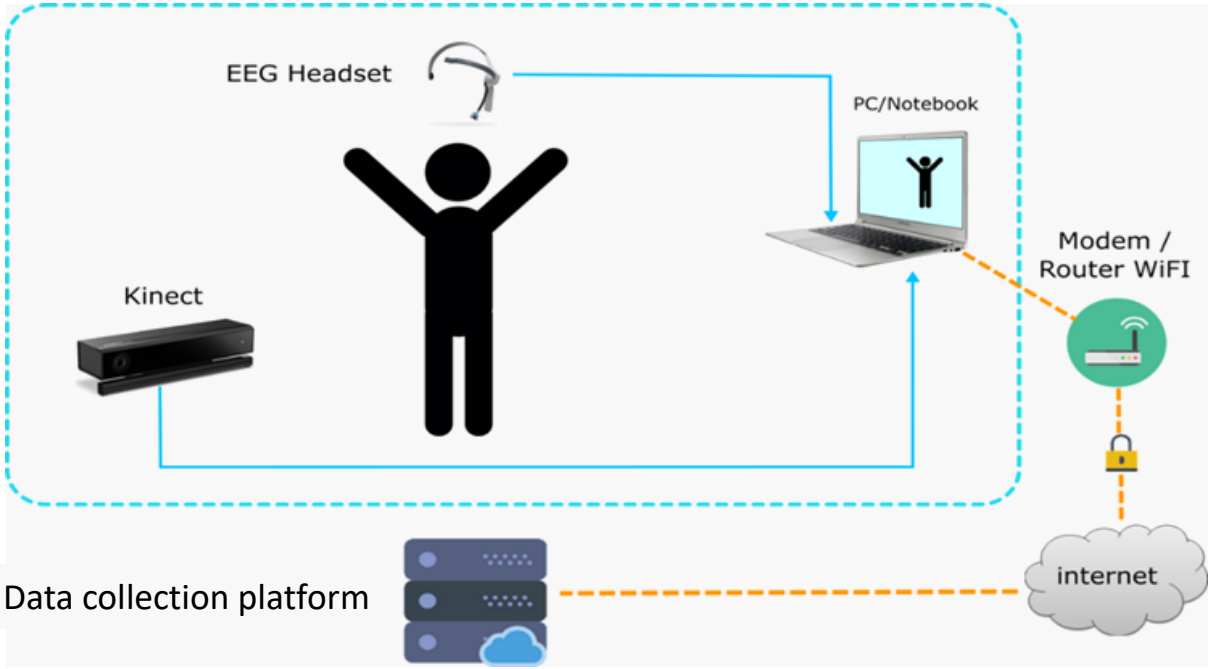
(1-homology, Euclidean filtration)





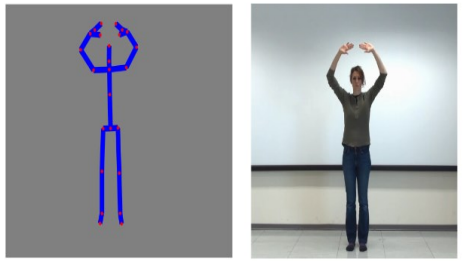
Moroni, D., & Pascali, M. A. (2021). Learning topology: bridging computational topology and machine learning. *Pattern Recognition and Image Analysis*, *31*(3), 443-453.

Assistive tecnologies for physical and cognitive training

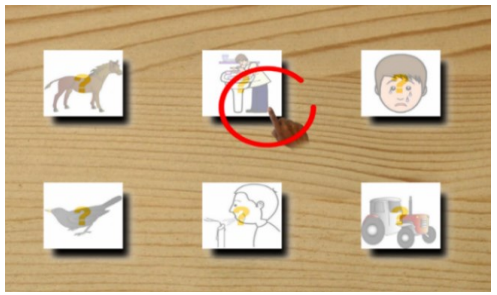


Microsoft Kinect
Gesture and movement monitoring – whole body and hands

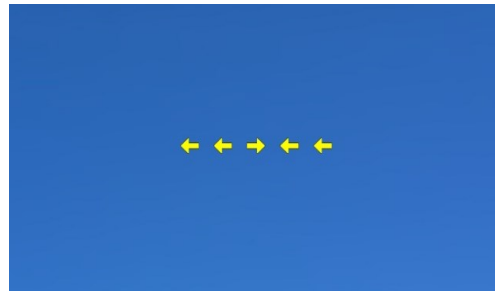
EEG wireless sensors
Detects brain actvity without any need gel



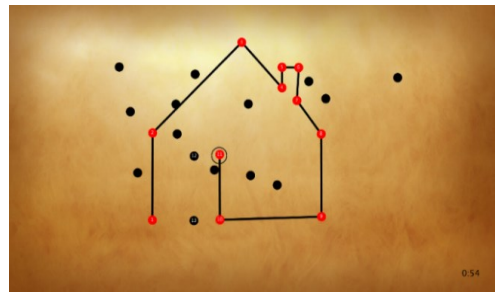
Tailored physical activity
guided and monitored automatically



Exergame with gestural control:
«choose the tail corresponding to the sound»



Attention tests
(ANT) based on gestural control, integrated with EEG monitoring

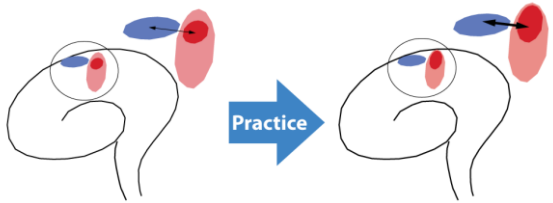


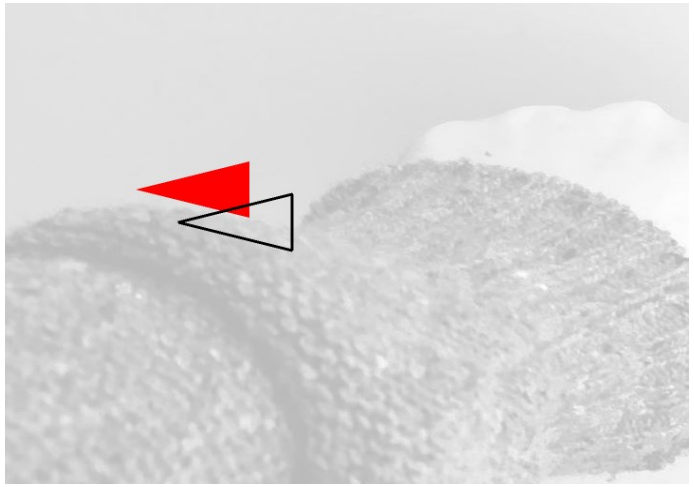
Exergame with gestural control:
«join the dots to disclose the picture»

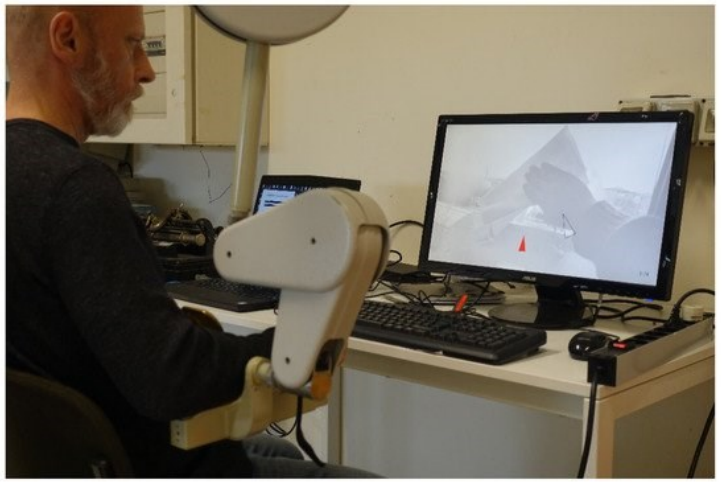
Track-Hold: AI-powered system for neuromotor rehabilitation based on a passive robotic aid

15 million people are affected by cardiovascular pathologies 10-20% of the cases had experience of cerebrovascular disease or cerebral stroke (stroke = **2nd cause of mortality**)

The physiological presupposition of neurorehabilitation is represented by the phenomenon of **Neuroplasticity** and the **consequent learning** and **motor control process:**
the ability of the brain to modify its structure and functions according to the activities of its neurons, related for example to somato-sensory stimuli.







Track-Hold (by Wearable Robotics) is a passive robotic arm designed to record the movements of the upper limbs of human beings:

- Execution of exercises in a "weightless" mode
- Purely neurological exercise

Exercises are dictated by a **functional basis**. *Daily life* movements, performed by manipulating the device, are broken down into sub-movements, which consist in **reaching a keypoint** characterized by a precise angle and 3D position.

- **Data analysis & intelligent services for performance evaluation**

Righi, M., Magrini, M., Dolciotti, C., & Moroni, D. (2022). A case study of upper limb robotic-assisted therapy using the track-hold device. Sensors, 22(3), 1009.

Thank you for your attention

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