ISPR Final Lecture

INTELLIGENT SYSTEMS FOR PATTERN RECOGNITION (ISPR)

DAVIDE BACCIU – DIPARTIMENTO DI INFORMATICA - UNIVERSITA' DI PISA

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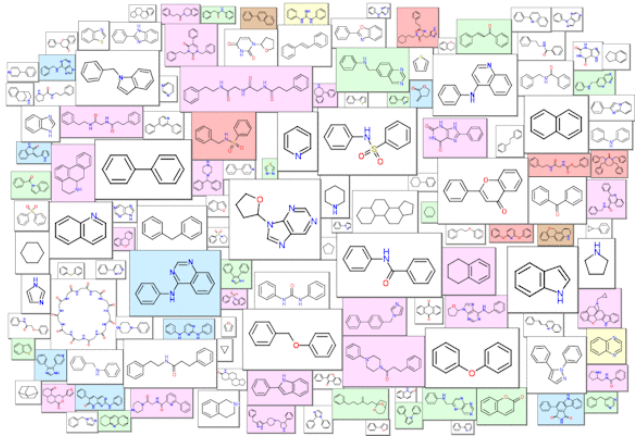
Lecture Outline

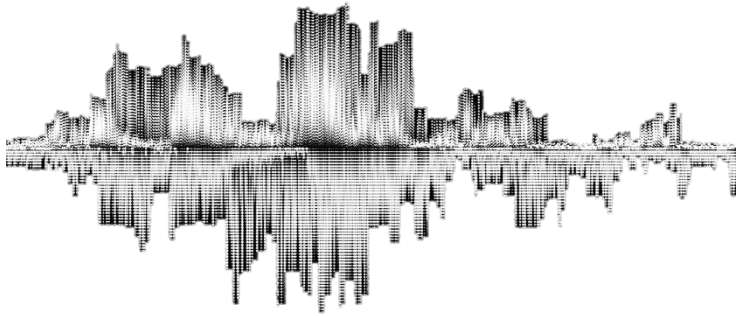
- Course wrap-up
  - A-posteriori view of the course
  - Final take home messages
- Overview of ML research @UNIPI
  - Groups and laboratories
  - Research themes and projects
  - Opportunities
- ISPR Final exam
- Conclusions & Discussion

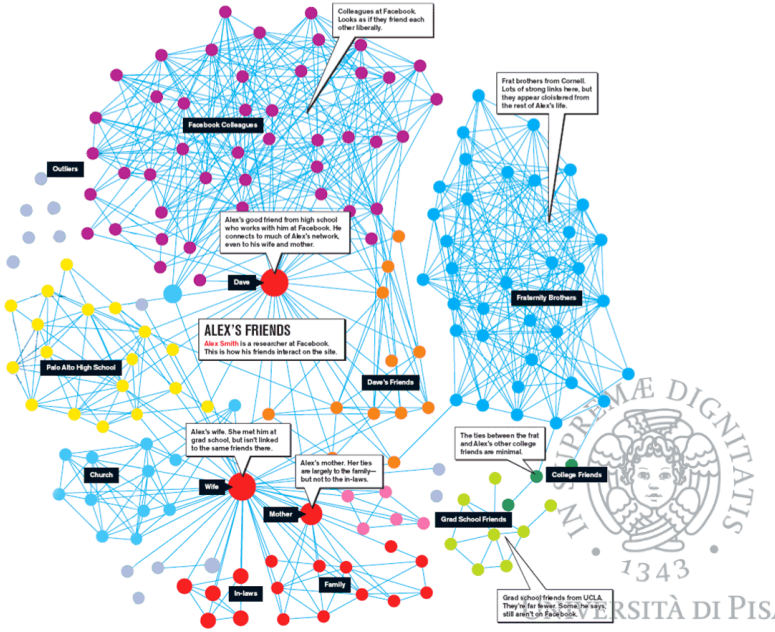
A Modern View on Pattern Recognition (I)

Dealing with complex data

- Large scale
- Multimodal
- Information in context
- Raw and noisy



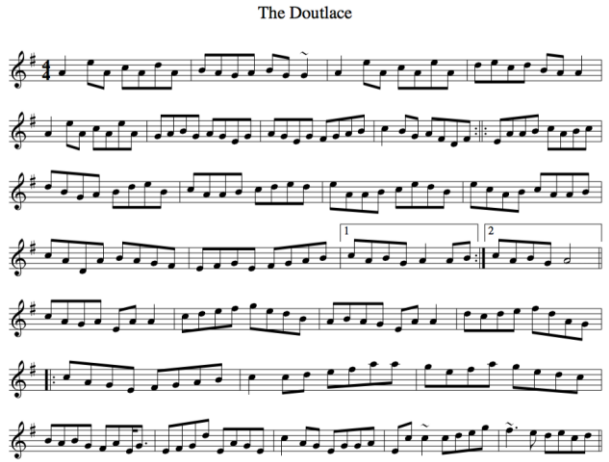


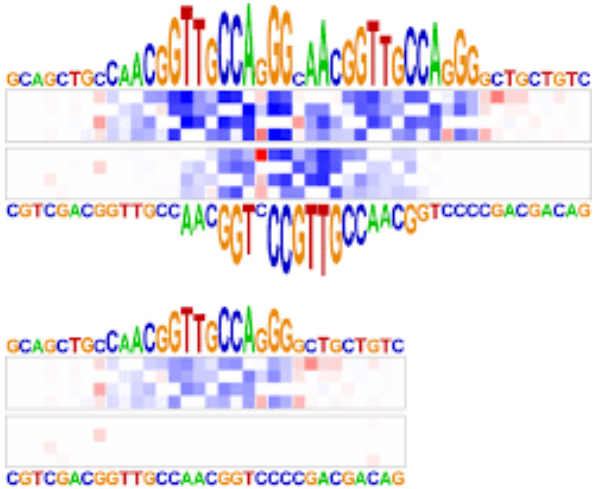


A Modern View on Pattern Recognition (II)

The goals are well past recognition

- Understanding, reasoning and explaining
- Generation
- Creativity
- Search & strategize





The Course in 1-Slide

- Old-school pattern recognition
  - Building blocks: convolution, filters, spectral analysis
- Probabilistic models
  - Infer knowledge rather than just predict
  - Introduce prior knowledge
  - How to approximate distributions
  - How to sample distributions
- Deep Neural Network
  - Efficient and high predictive performance
  - Non-parametric and non-linear
  - Work on noisy, raw and heterogeneous data
- Deep Generative models
  - Learn a generative process
  - How to approximate complex distributions
  - How to sample complex distributions

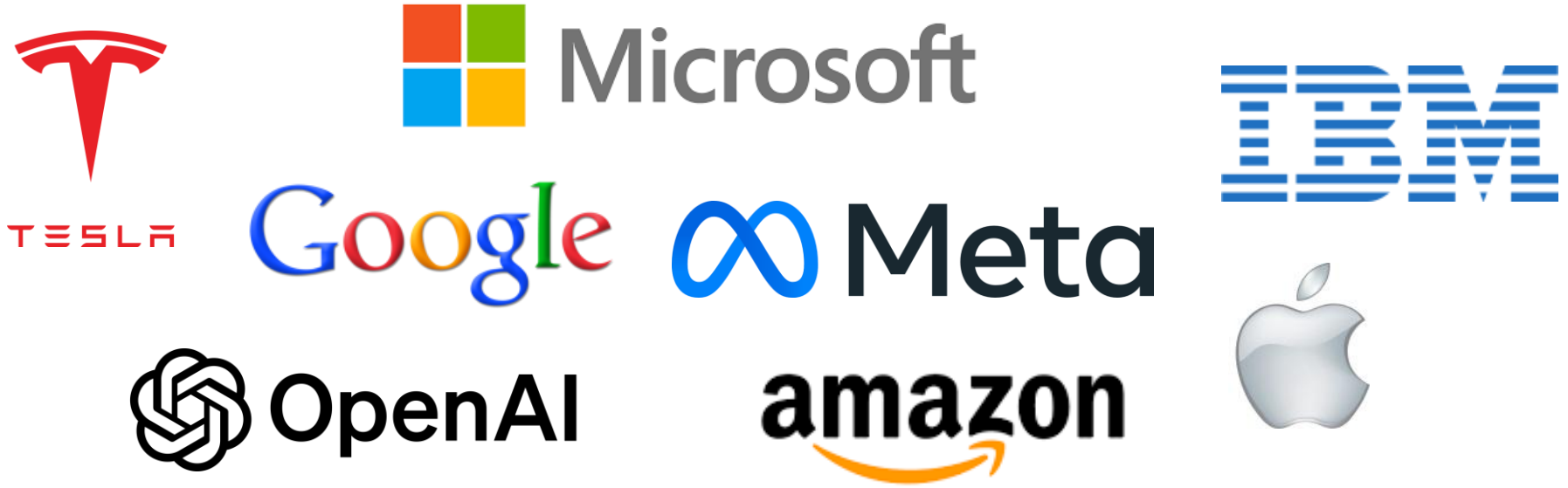
A Convergence of Neural-Generative Paradigms

- Need the efficacy and efficiency of neural models with the interpretability and generative ability of probabilistic-based models
- Modular approach
  - E.g. CRF on the top of CNN for semantic segmentation
  - Easily incorporate prior knowledge
- Inbreeding of paradigms
  - CRF as discriminative-generative-energy based models
  - Variational and generative DL
- Mutual support
  - Causal learning

After Completing This Course, Hopefully…

- Know which learning paradigms and models are best to start with for addressing a given PR problem
- Know what challenges your model will need to solve to realize a PR application
- Know a bag of tricks to modify a model to suit your needs
  - Message passing, variational approximations, sampling, latent representations, feature functions, diffusion processes, change of variable and flows,
  - Batch normalization, pretraining, end-to-end differentiability, distribution learning with NN, enhancing memory, attention, adversarial learning, invertible neural layers, on the importance of gaussian noise
  - Randomized NNs, alternatives to backprop, learning with graphs, causal Vs observational models

Machine Learning is the New Algorithmics



Can you derive EM for GMM?

When do you need to check you gradient?

Implement a Gaussian/edge filter

Research Groups

Computational Intelligence & Machine Learning Group (CIML)

- https://ciml.di.unipi.it/
- Coordinated by Alessio Micheli
- Focus on pure Machine Learning

Pervasive Artificial Intelligence Laboratory (PAI Lab)

- pai.di.unipi.it
- A joint initiative by Dipartimento di Informatica @ UNIPI and Istituto Scienza e Tecnologia dell'Informazione @ CNR
- Coordinators – Davide Bacciu and Patrizio Dazzi
- >15M Euro EU grants
- Focus on AI & Pervasive Computing

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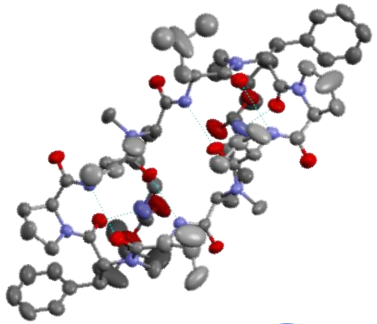
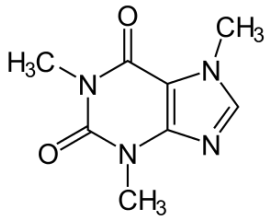
Research Overview





- Learning for graphs & structured data
- Deep learning and neural networks, generative models, RL, causality
- Pervasive AI (distributed, embedded, morphological/neuromorphic, continual)

CoEvolution

EMERGE

TEACHING

TU Delft

DeepMind

H&M

MONTE DEI PASCHI DI SIENA
BANCA DAL 1472

DELL

THE UNIVERSITY OF EDINBURGH

UNIVERSITY OF CAMBRIDGE

Funded by Italian, European and industrial projects

APTUS.AI
shaping knowledge

QUANTABRAIN

stm

CONTINUALIST

CORNELIS NETWORKS

intel

enel

USI/SUPSI
IDSIA

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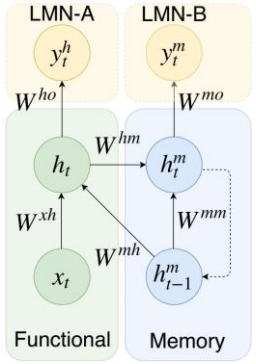
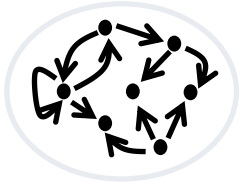
Topics of current research (I)



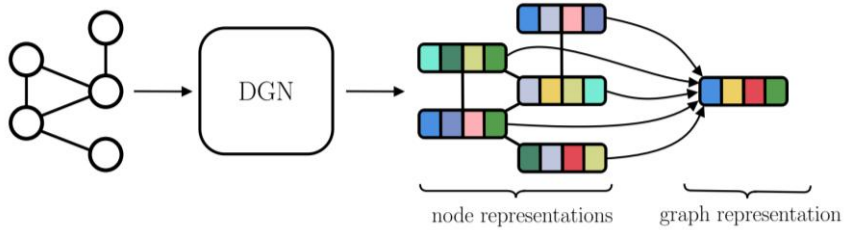
Recurrent neural networks

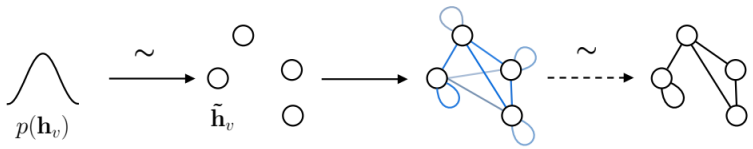


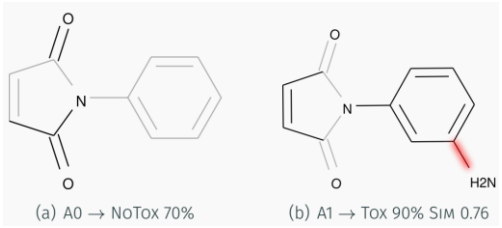
- (Deep) Reservoir computing and randomized networks
- New paradigms of dynamic memory
- (Neuro)morphic computing and dynamical systems

Deep learning for graphs

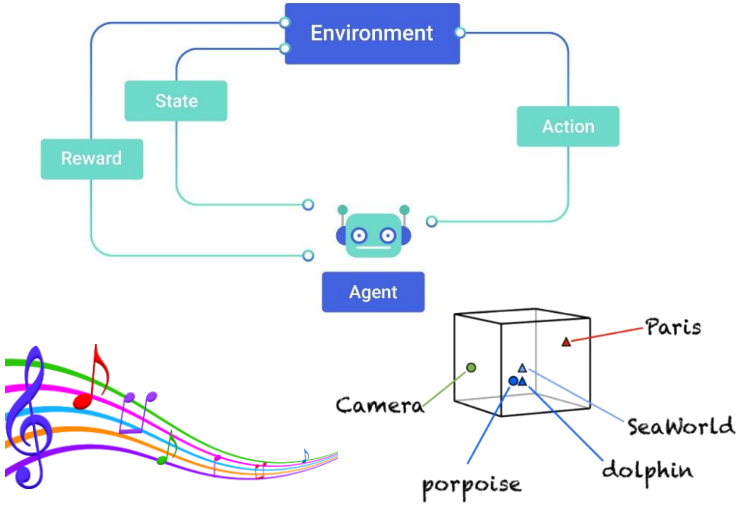
- Algorithmic reasoning
- Efficient neural diffusion
- AI for science
- Graph generation







Topics of current research (II)



Learning Fundamentals

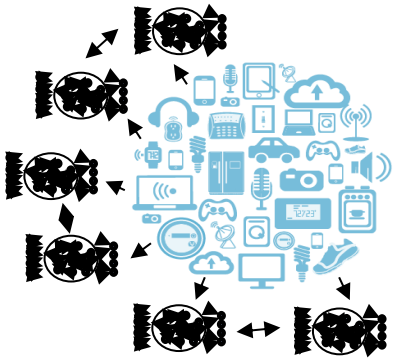
- Continual learning
- Federated learning
- (chemical, physical, *) Informed NNs
- Learning-symbolic integration & reasoning
- Reinforcement learning and learning under weak/self/noisy supervision
- Theoretical properties of deep NNs

FEDRAY

Avalanche

Pervasive AI

- Distributed learning
- In-silico embedded intelligence
- AI on GPU/FPGA/Cluster computing
- ML as a service & ML-based application development
- Trustworthy & human-centered learning



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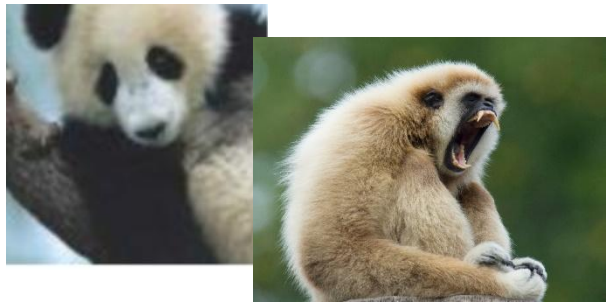
Topics of current research (III)



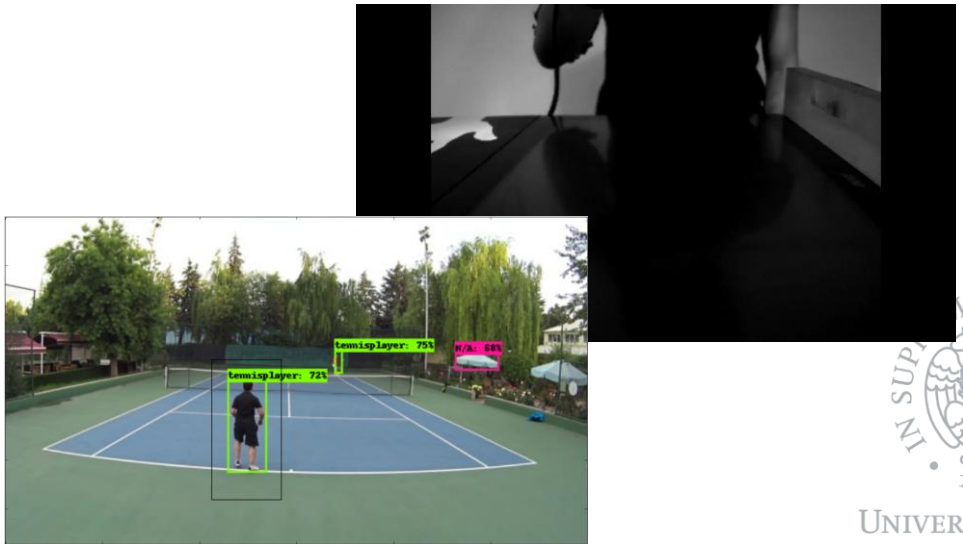
Applications of learning systems

- Machine vision & multimedia
- Bioinformatics & Chemistry
- Robotics & Autonomous Vehicles
- Physio-signal processing

Contact if interested in M.Sc. and Ph.D. projects

Causal learning & Trustworthy AI

- Robust, safe and secure deep learning
- Learning causal models
- Continual learning for robustness



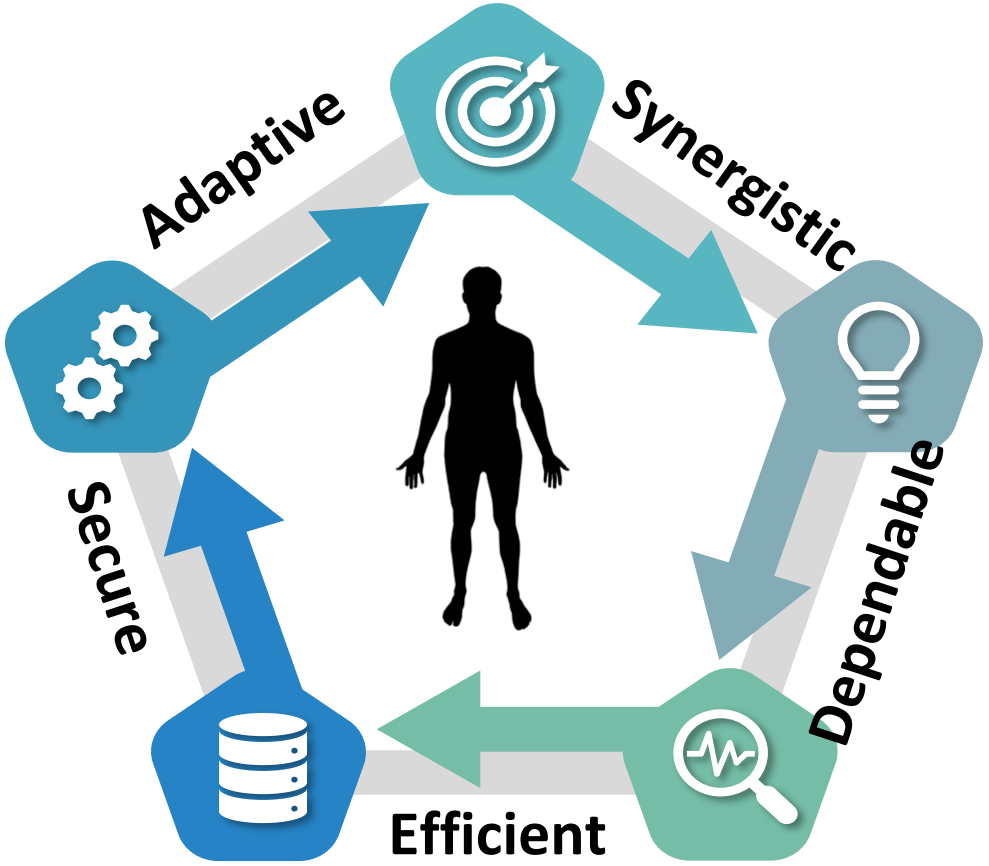
Recent Projects & Initiatives

- EU HorizonEU CoEvolution: Trustworthy Framework for Connected ML and (2024-2027)
- EU EIC Pathfinder EMERGE: Emergent awareness from minimal collectives (2022-2026)
- EU H2020 TEACHING: A computing Toolkit for building Efficient Autonomous appliCations leveraging Humanistic INtelliGence (2020-2023)
- FAIR AI research network: Continual learning transversal project & deep learning for graphs (2022-2025)
- EU H2020 TAILOR: Trustworthy AI Integrating Learning, Optimization and Reasoning (2020-2023)
- MIT-UNIPI international project on deep learning for optimization problems
- H&M Industrial collaboration on Deep Learning for Graphs
- Cornelis Network industrial collaboration on Pervasive AI
- Startups: Aptus AI, ContinualIST, QuantaBrain

TEACHING - Motivation & Vision

A human-centric perspective on autonomous CPSoS applications

TEACHING - Motivation & Vision



A human-centric perspective on autonomous CPSoS applications

Paradigmatic shift needing support at computing and system level

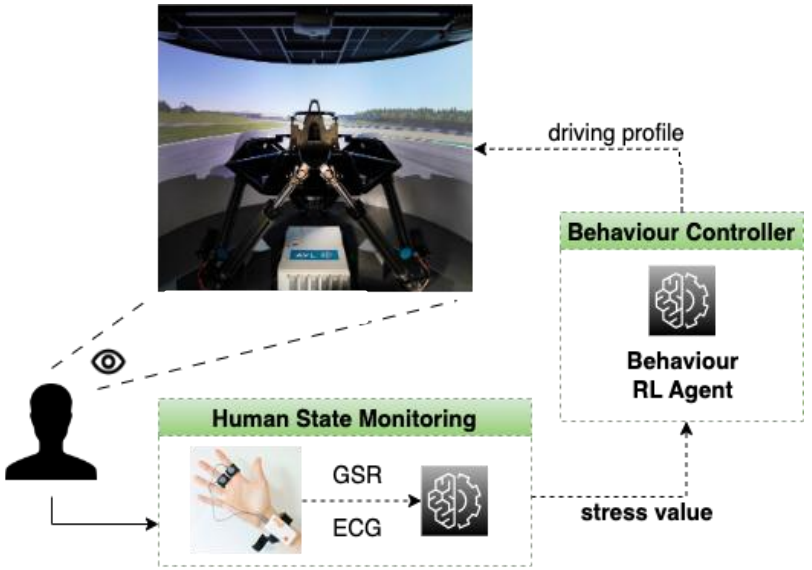
TEACHING – Autonomous Driving App

Vehicles

iMX8

Raspberry PI

Available HW



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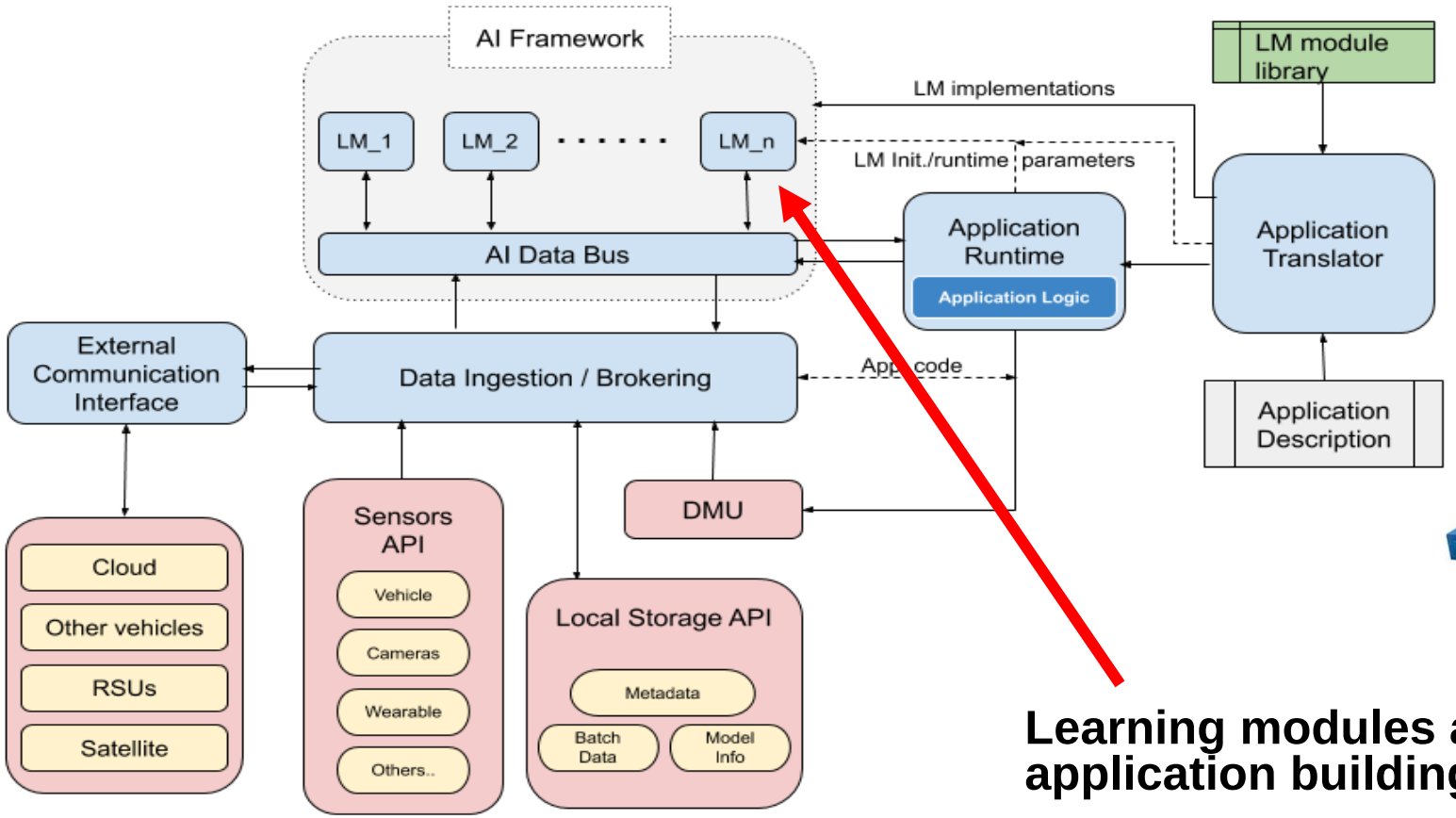
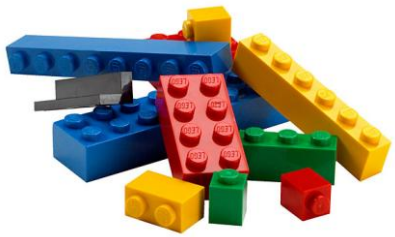
TEACHING Driving Platform @ PAILAB

Human state estimation

TEACHING – AI as a Service for Safe Adaptive Distributed Applications



https://github.com/EU-TEACHING



Learning modules as application building blocks

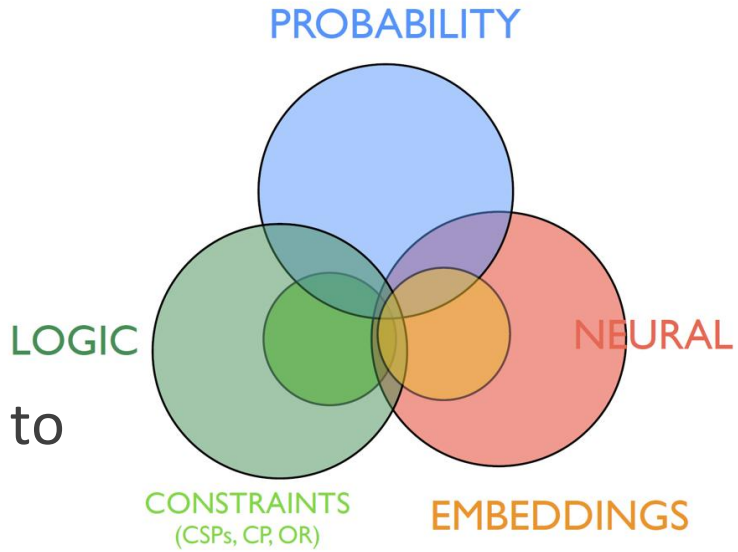
H2020 TAILOR (2020-2024)

TAILOR

Trustworthy AI - Integrating Learning, Optimisation and Reasoning

ICT-48 Network of research excellence centres on foundations of Trustworthy AI

- 55 partners; >75 affiliated labs
- Research program to address grand challenges
- Connectivity fund for active dissemination to the larger AI community
- Network collaboration activities (exchanges, events, joint supervisions)



tailor-network.eu

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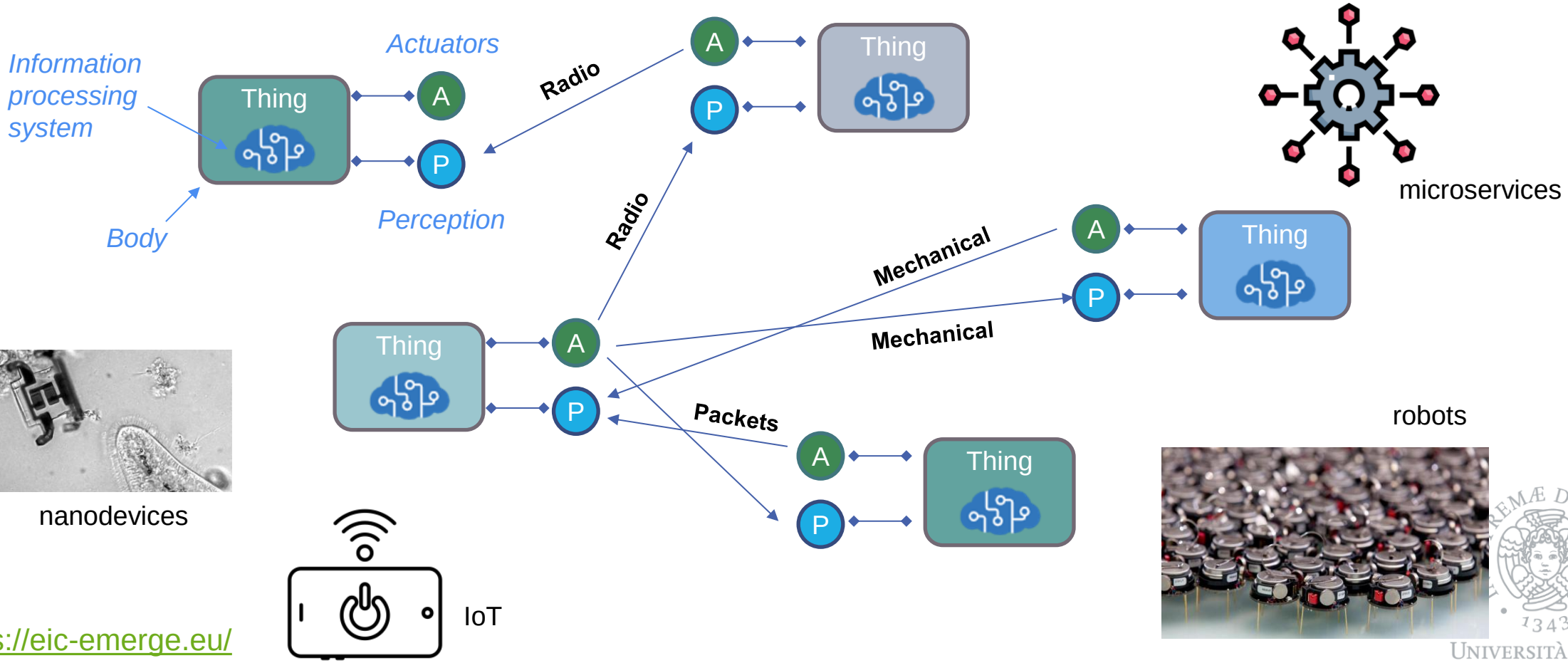
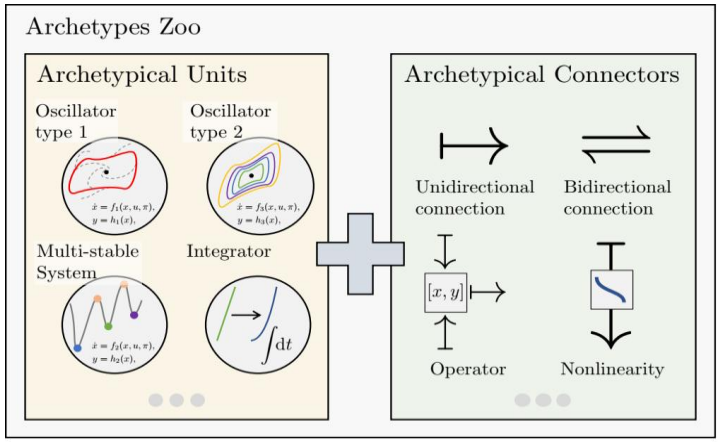
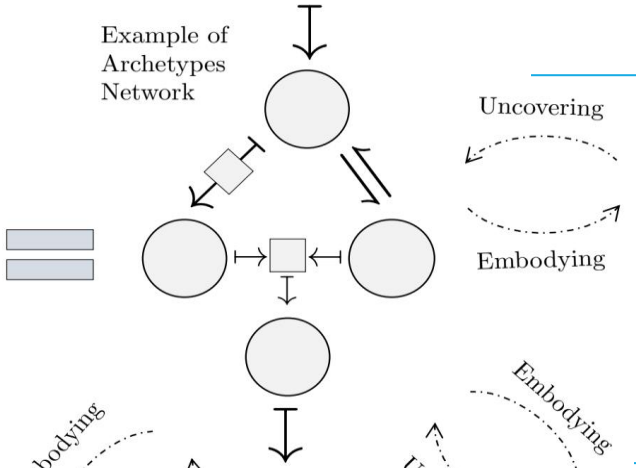
EMERGE – Awareness of Minimal Collectives

EMERGE – Aware Minimal Collectives

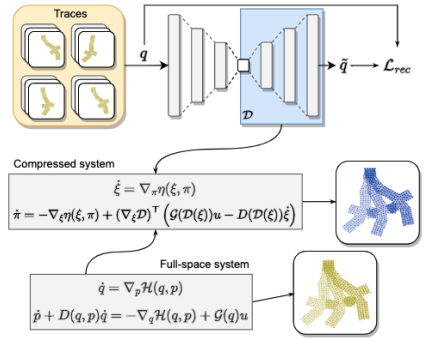


Novel Neural Computing Framework

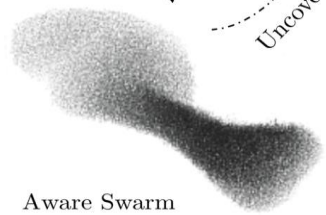


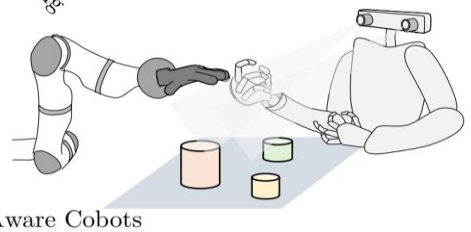


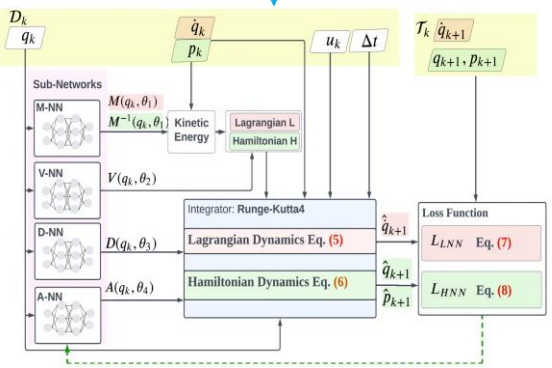
Latent compressed representations for control



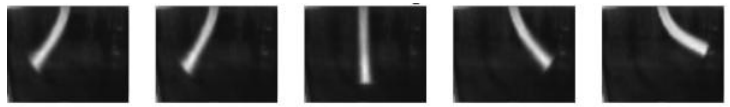
Learning physically-consistent dynamics of manipulators



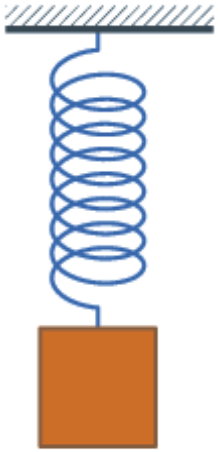




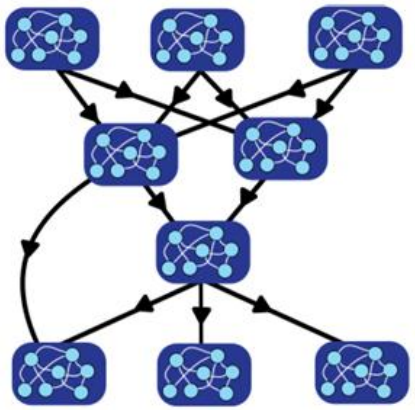
Learning soft-object dynamics from perceptions

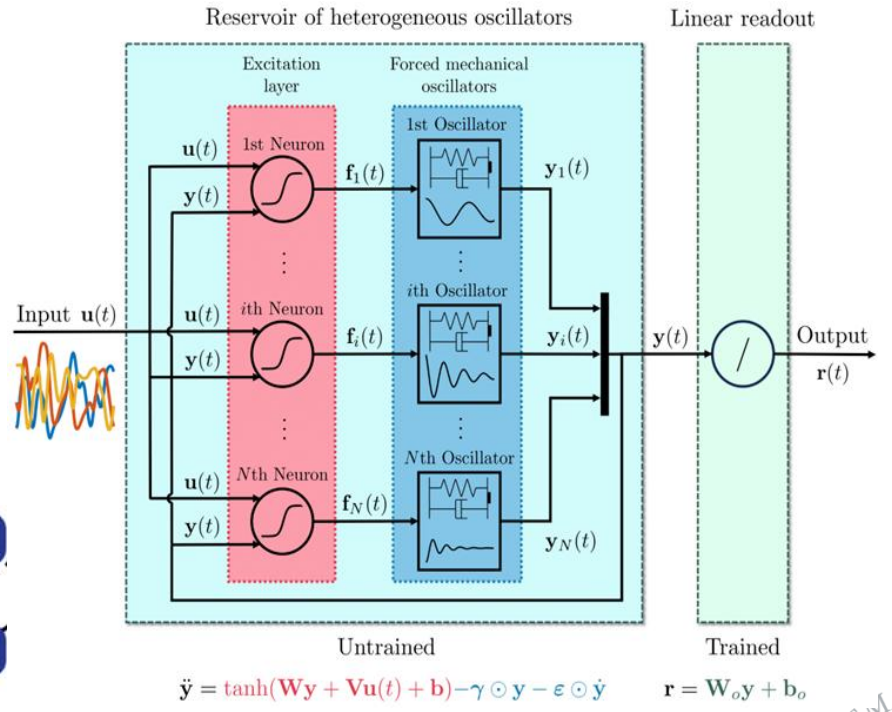


Neural Computing on Dynamical Systems



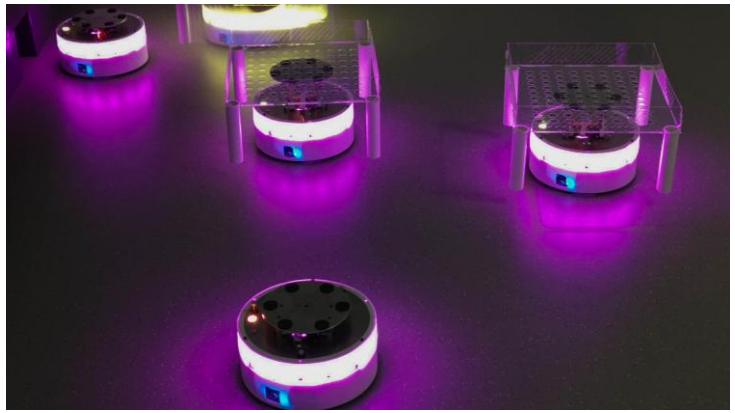
- Neural processing on **multi-stable harmonic oscillators**
- Family of **efficient and expressive neural networks** for dynamical data
- Physically implementable Neural Networks
- Neural Networks of Neural Networks





EMERGE – Use Cases

- Modular soft robots - Dynamic addition of components
- Robotic swarms - Large scale minimal collective
- Cobots - Marketable use case where interoperability is a need



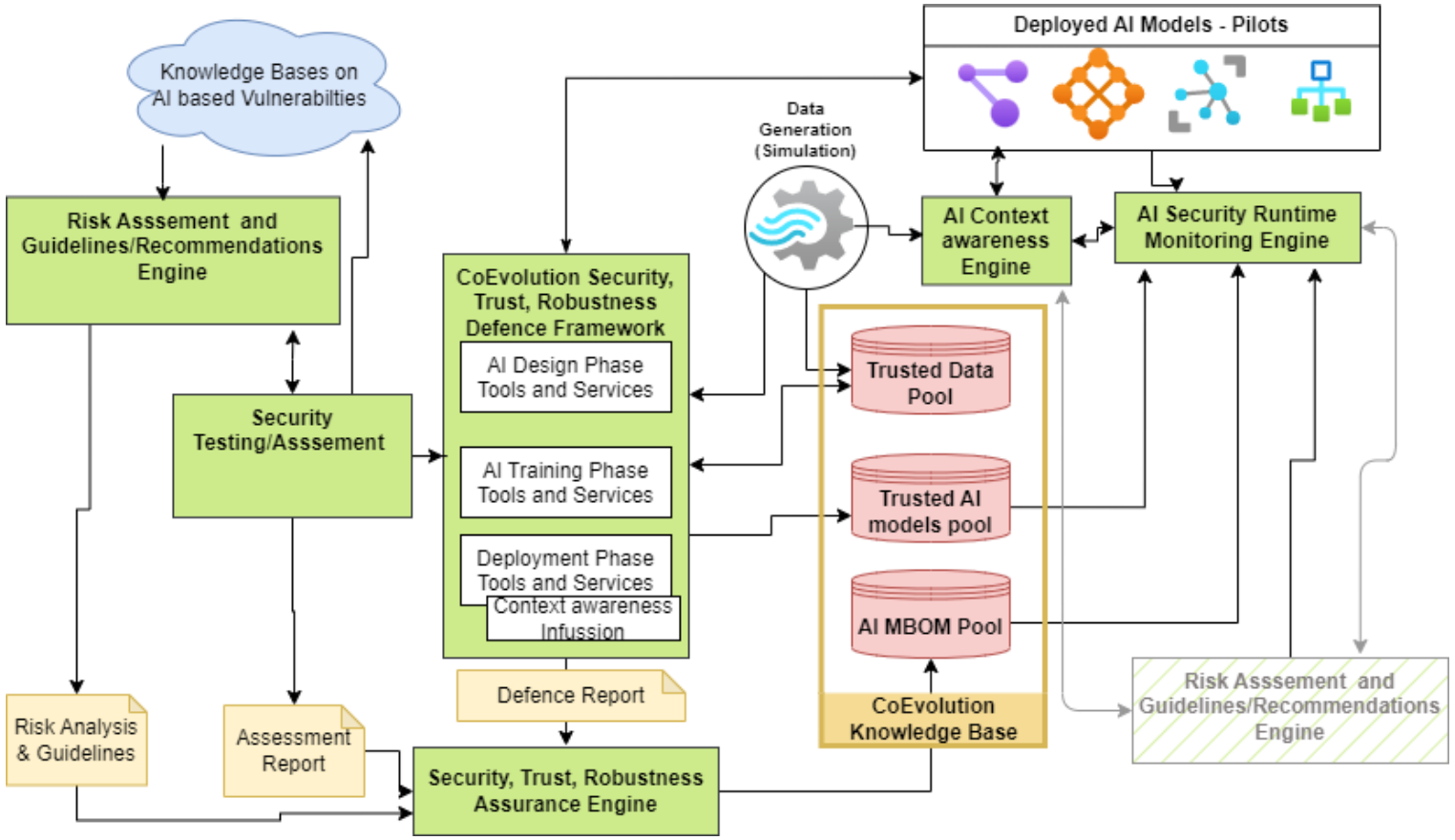
EMERGE

The **EMERGE** consortium:

Funded by the European Union

Funded by the European Union under Grant Agreement 101070918

CoEvolution



Post-deployment security and robustness through incremental and continual learning

Midterm 4 – RL & Advanced Models

- Format
  - Read 1 paper on a course topic
  - From a list of referenced papers
  - Prepare an 8 slides presentation with the following (rough) content
    - Introduction to the problem
    - Model description
    - Key catch of the model, represented by a commented equation
    - Key (empirical) result
    - Comment on novelties, strong points and weaknesses
- Deliver the presentation by the 27-06-2025
- Unless you are going for first appello: then deadline 04-06-2025

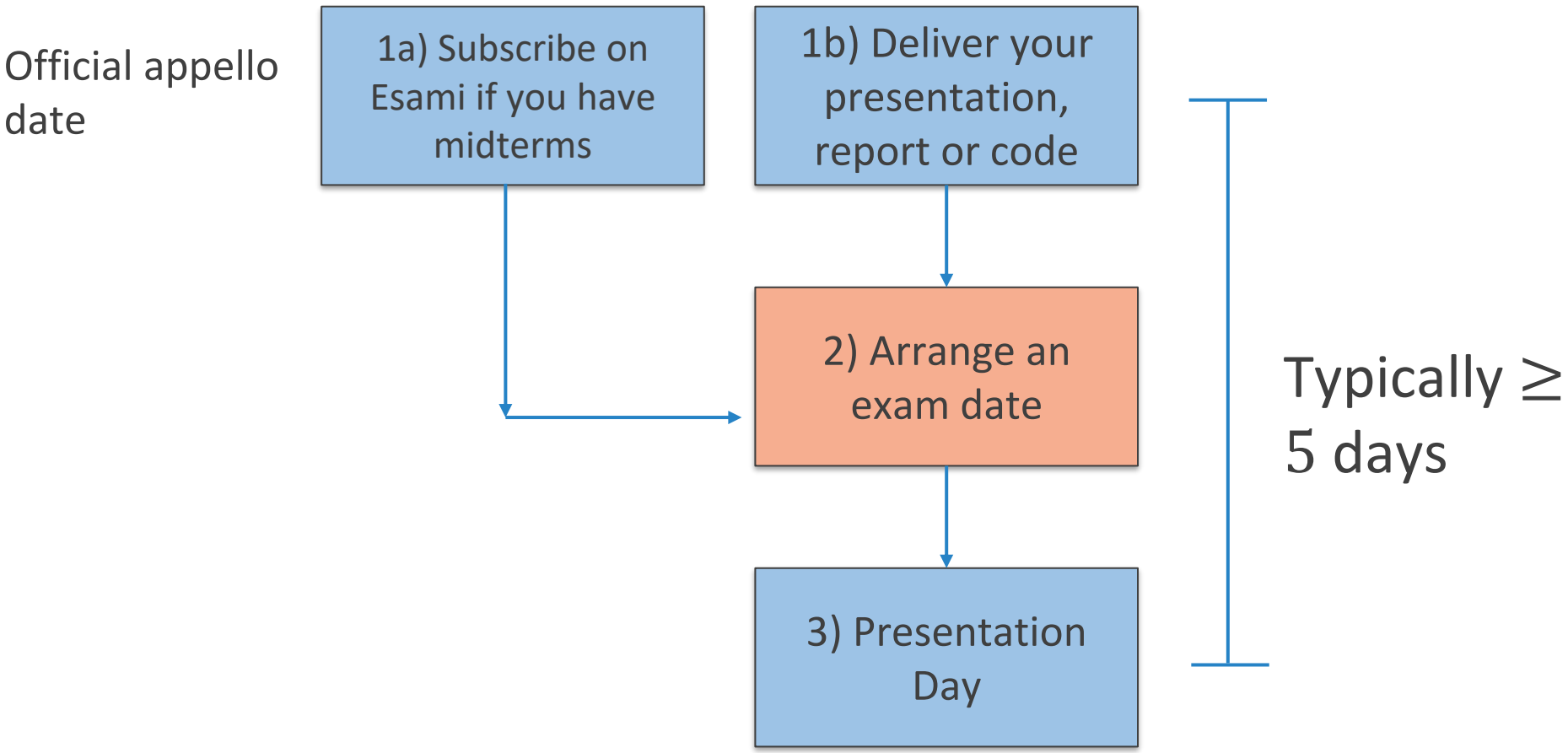
Final Projects (Alternative to MIDTERMS)

- **Survey**
  - Read at least 3/4 relevant papers on a topic
  - Prepare 10 pages report + 1 presentation (for oral day): not a simple summary but find connections between the works and highlight open problems
- **Software**
  - Develop a software implementing a non-trivial learning model, and/or an application relevant for the course, and/or documenting a solution for an ML challenge available on the web
  - Prepare a presentation (for oral day) describing the software/challenge and its validation/results

Final Projects – What to Deliver?

- Two things need to be delivered (by the Appello deadline)
  - A written report or the code for the project
  - A presentation on the project (for either type)
- Presentation will last 15 minutes and will be given on the oral day
- Presentation tips
  - (Survey) Summarize the ideas, models and results
  - (Software) Describe the implemented model, the library and the experimental validation
  - My suggestion is to keep the number of slides around 15 (tops)

Final Exam Timeline



Presentation, Report & Code Delivery

Fixed and strict deadlines for handling the presentation, report and/or code to me

1. 04/06/2025 h. 18.00
2. 27/06/2025 h. 18.00
3. 17/07/2025 h. 18.00

Delivery through the ISPR moodle

- Submit presentation, report or code in a single archive file (no data!!!!)

On the Oral-Presentation Day

- Oral exams will be held in-person
  - Check for room information and dates on the Moodle
  - All students are welcome to attend
- Non-midterm students will first deliver their presentation
- All students will be subject to an oral exam on models, algorithms and applications discussed during the course lectures
  - Deep learning for graph II: Advanced models lecture is not part of exam materials

FAQs

- What is the language for the report and the presentation?
  - Both need to be written in English, but the presentation can be given in either Italian or English
  - The oral exam can be in either Italian or English (your choice)
- How long do midterms last?
  - Until September exams (included)
  - Yes, I will keep them even if you give the exam and fail it (not if you fail it because of plagiarism though)
- Other questions?