ISPR Final Lecture
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
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
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/](https://ciml.di.unipi.it/)
- Coordinated by Alessio Micheli
- Focus on pure Machine Learning

**Pervasive Artificial Intelligence Laboratory (PAI Lab)**
- [pai.di.unipi.it](http://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
Research Overview

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

Funded by Italian, European and industrial projects
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

Learning with structured data
- Deep learning for graphs
- Graph generation
- Algorithmic reasoning
- Efficient neural diffusion
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

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
Topics of current research (III)

Causal learning & Trustworthy AI
- Robust, safe and secure deep learning
- Learning causal models
- Continual learning for robustness

Applications of learning systems
- Recommendation systems
- Machine vision & multimedia
- Bioinformatics
- Chemistry
- Robotics
- Autonomous Vehicles
- Physio-signal processing
And many other things...

- Generative and unsupervised deep learning
- Computational creativity: music generation and style transfer; visual arts
- Medical imaging
- Robotics & embodied intelligence
- ...

Contact if interested in M.Sc. and Ph.D. projects
Active 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
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
- Raspberry Pi
- iMX8
- Available HW
- Driving profile
- Behaviour Controller
  - Human State Monitoring
    - GSR
    - ECG
  - Behaviour RL Agent
  - Stress value
TEACHING Driving Platform @ PAILAB

Human state estimation
TEACHING – AI as a Service for Safe Adaptive Distributed Applications

Learning modules as application building blocks

https://github.com/EU-TEACHING
H2020 TAILOR (2020-2024)

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
EMERGE – Awareness of Minimal Collectives

Emergent awareness from minimal collectives
EMERGE – Aware Minimal Collectives

Information processing system

Actuators

Perception

Radio

Packets

Mechanical

IoT

microservices

robots

nanodevices

https://eic-emerge.eu/
Novel Neural Computing Framework

Learning physically-consistent dynamics of manipulators

Latent compressed representations for control

Learning soft-object dynamics from perceptions

Archetypes Zoo

Archetypical Units

- Oscillator type 1
- Oscillator type 2
- Multi-stable System
- Integrator

Archetypical Connectors

- Unidirectional connection
- Bidirectional connection
- Operator
- Nonlinearity

Example of Archetypes Network

Uncovering

Embodying

Aware Soft Robot

Aware Swarm

Aware Cobots

Spines

Compressed system

\[ 0 = \nabla_h(x, t) + \nabla \Phi(x) + (W^n)(\Phi(x) - \Phi|x|) \]

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
The **EMERGE** consortium:

- Università di Pisa
- TU Delft
- University of Bristol
- LMU Ludwig-Maximilians-Universität München
- Da Vinci Labs

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CoEvolution (Kickoff Nov 2024)

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 19-06-2024

○ Unless you are going for first appello: then deadline 28-05-2024
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

1a) Subscribe on Esami if you have midterms
1b) Deliver your presentation, report or code
2) Arrange an exam date
3) Presentation Day

Typically ≥ 5 days
Presentation, Report & Code Delivery

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

1. 28/05/2024 h. 09.00
2. 19/06/2024 h. 09.00
3. 15/07/2024 h. 09.00

Delivery through the ISPR moodle

- Submit presentation, report, 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
  - A. Ceni, A. Cossu, W. Meira and R. Massidda lectures are not part of the exam programme
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?
Concluding

○ I hope you have enjoyed the course
○ I will be out of my office:
  ● 10 June-12 June
  ● 26 Jun-11 Jul
  ● 12-30 August

Enjoy the rest of your AI curriculum