Introduction to the ISPR Course

INTELLIGENT SYSTEMS FOR PATTERN RECOGNITION (ISPR)

DAVIDE BACCIU – DIPARTIMENTO DI INFORMATICA - UNIVERSITA’ DI PISA

DAVIDE.BACCIU@UNIPI.IT
Objectives

Train machine learning (ML) specialists capable of
- designing novel learning models
- developing pattern recognition applications using ML
- developing intelligent agents using Reinforcement Learning (RL)

Focus on challenging and complex data
- Machine Vision: noisy, hard-to-interpret, semantically rich information
- Structured data: relational information (sequences, trees, graphs)

Lectures do not cover Natural Language Processing as there is a dedicated course
Expected Outcome

Methodology-oriented outcomes

○ Gain in-depth knowledge of advanced machine learning models
○ Understand the underlying theory
○ Be able to individually read, understand and discuss research works in the field

Application-oriented outcomes

○ Learn to address modern pattern recognition problems
○ Gain knowledge of ML, PR and RL libraries
○ Be able to develop an application using ML and RL models
Prerequisites

- Knowledge of machine learning fundamentals
  - Pass the ML course or.. come discuss your ML skills with me
- Mathematical tools for ML
  - Algebra and calculus
  - Optimization
  - Probability and statistics
- Programming experience in Python (helpful)

...and, above all, a disposition not to get (easily) scared by math!
Organization

The course covers five themes

- Introduction to Pattern Recognition
- Probabilistic (Generative) Models
- Deep Learning
- Generative Deep Learning
- Advanced models and applications

An incremental approach: from old school pattern recognition to state-of-the-art deep learning
Guest Lectures

Guest seminars by researchers and Ph.D. students on (tentative):

- Practical lectures on deep learning frameworks (PyTorch, TF/Keras, Ray)
- Reservoir computing
- Alternative to backprop
- Neural xDE framework
- Short seminars on hot research topics by guest lecturers
- ...

DAVIDE BACCIU - ISPR COURSE
Topics (I)

- **Introduction to Pattern Recognition**
  - Introduction to signal processing
  - Introduction to image processing

- **Probabilistic (Generative) Models**
  - Graphical models
  - Bayesian networks and causality
  - Hidden Markov Models
  - Markov Random Fields
  - Bayesian learning and variational inference
  - Sampling
  - Boltzmann machines
Topics (II)

- Deep Learning (DL) fundamentals
  - Deep autoencoders
  - Convolutional architectures
  - Gated recurrent networks
  - Transformers and encoder-decoder architectures
  - DL toolset: dropout, batch normalization, residual connections, attention
  - Neural memories
  - Deep learning with Pytorch and Keras-TF

- Generative deep learning
  - Exact likelihood models
  - Variational AE
  - Generative adversarial networks
  - Normalizing flow
  - Diffusion models
Topics (III)

- **Advanced topics and applications**
  - Reservoir computing
  - Dynamical systems and neural networks
  - Alternatives to backprop
  - Deep learning for graphs
  - Reinforcement learning
  - Machine vision, multimodal learning, BioInformatics, robotics, ...
  - ...

Course Instructor

Davide Bacciu

- Email – davide.bacciu@unipi.it
- Tel - 050 2212749
- Office - Room 331O, Dipartimento di Informatica
- Office hours - Thursday 16-18 (email me!)
Course Schedule

Weekly Timetable:

<table>
<thead>
<tr>
<th>Day</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tuesday</td>
<td>11.00 - 12.45</td>
</tr>
<tr>
<td>Wednesday</td>
<td>16.15 - 18.00</td>
</tr>
<tr>
<td>Thursday</td>
<td>14.15 - 16.00</td>
</tr>
</tbody>
</table>

Talk now if there are incredibly worrisome issues with the schedule!

Course comprises **35-36 lectures**

- Course will be given *in-person* and *streamed online on Teams* for Ph.D. students
- Video recording of the lectures will be available (to everybody) on Teams
Course Homepage

Reference Webpage on Moodle:

https://elearning.di.unipi.it/course/view.php?id=278

Here you can find

○ Course information
○ Lecture slides
○ Articles and course materials
○ Midterms and final project assignments

Subscribe to the course to receive feeds and news
Reference Books (changing this year)

For pattern recognition refer to slides (and additional material)

Previous years

Probabilistic learning reference (free pdf):
David Barber, Bayesian Reasoning and Machine Learning, Cambridge University Press (2012)

Deep learning reference (free pdf):

Starting this year

Deep learning (free pdf):
Simon J.D. Prince, Understanding Deep Learning, MIT Press (2023)

Probabilistic & deep learning (free pdf):

I will keep reference to both sets of books for this year
The Origins of Pattern Recognition (PR)

**Duda and Hart, 1973**

Machine recognition of meaningful regularities in noisy or complex environments

A variety of approaches to realize it

- Statistical PR
- Clustering
- Rule-based systems (fuzzy)
- Signal processing
- Logic and reasoning
- Structural and syntactic PR
- ...and of course, machine learning!
The Viola-Jones Algorithm

Consider the following two hand drawn pixel masks

Sum pixels in the white area and subtract those in the black portion

- VJ1 is large in the eye region
- VJ2 is large on the nose stripe

VJ algorithm positions the masks on the image and combines the responses (≈ 5K hand aligned examples)
PR Stages – An historical View

1. Identification of distinguishing attributes of the object/entity (feature detection)
2. Extraction of features for the defining attributes (feature extraction)
3. Comparison with known patterns (matching)

Basically, lots of sleepless nights **hand-engineering** the best data features
PR Stages - A Modern View

Pattern recognition after the deep learning revolution

Apparently, a single stage process with a data crushing-and-munching neural monster spitting out predictions
AlexNet kills the ImageNet 2012 competition outperforming runner-up by over 10%
Then.. Things Started Going Offhand

GoogleNet

ResNet

DenseNet
CNN Evolution
Long Short Term Memory

Processing sequences and rescuing gradients since 1996
The Deep Learning Lego

Creating application by putting together various combinations of CNN and LSTM modules
Autonomous Driving
Teaching Robots to Manipulate
Teaching Robots to Manipulate

Top primitive:
the object is approached from the top with palm down parallel to the table. Object center is approximatively at the level of middle phalanx. When contact is established all fingers are simultaneously closed, achieving a firm power-like grasp.
Generative Adversarial Networks

At the roots of the generative deep learning wave
Early bedroom uses…
...and Psychedelic Pacman
Starting to get better at face generation
Face Swapping in Back to the Future
Or in any other clip you like
Variational Deep Learning

First attempts at bridging deep learning with generative models
Learning Entities and Relations from Images

- Numbers
- Clothing
- Addition
- Multiplication
But nowadays nobody cares because we have...

...diffusion models!
Graph Neural Networks

An exploding field in Deep Learning
Drug Repurposing

![Diagram showing drug repurposing with nodes and edges representing drug-protein interactions and side effects.]

- **Drug** (△)
- **Protein** (●)
- **Node feature vector**
- **Drug-protein interaction** (△●)
- **Protein-protein interaction** (●●)

- **r₁** Gastrointestinal bleed side effect
- **r₂** Bradycardia side effect

- **Polypharmacy side effects**
Generating Molecules
Incorporating Knowledge Graphs
Neural Algorithmic Reasoning

Abstract input (FF) \[ f \]

Processor

Abstract output (FF) \[ g \]

Natural input (brain-vessel graph) \[ \hat{f} \]

Natural output (brain-vessel graph) \[ \hat{g} \]
Learning intelligent agents
The Course Philosophy

○ Start from traditional PR approaches
  ● Introduce problems and tasks
  ● Learn some useful techniques

○ Learn how old-school stuff has been reused in a modern way

○ Understand how probability is fundamental to machine-deep-reinforcement learning

○ Connect the dots between traditional PR, generative and deep learning

A practical approach with code complementing theory when possible
On probabilities and pains of the sort

- From student anonymous advices (some 2 years ago)
  - Too much attention on probabilistic models, which are not state of the art....
  - The course should only briefly mention probabilistic models and focus on state-of-the-art models...
Machine Learning – A Probabilistic Perspective
Reference Languages

Reference language for the course is Python (but some Matlab might pop-up)

- Students of the AI curriculum should be already familiar with
- Easy-to-learn language enhanced by reasonable editors and graphical environments
- Lots of library support for signal processing, image processing and machine learning

For the final project there is some reasonable flexibility in which language you can use (no deep learning in Pascal, please!)
Exams – M.Sc. Students

M.Sc. students following the course lecture can complete the exam by

**Midterm Assignments** - A total of 4 short assignments on experiences related to course topics

**Oral Exam** - An examination on the course program

The *alternative* way (for working students, those who fail or don’t like the other way)

**Final Project** - A written report on a topic of interest for the course, a software implementing a PR application, ....

**Oral Exam** - A 15 minutes *presentation* of the final project *plus* examination on the course program
Exams – Ph.D. Students

Let’s find a topic that is of interest for you, maybe part of your research project, and that is consistent with the course topics.

Several options possible:

- **Essay** – A research technical report on the topic of interest
- **Code** – A software exploring/implementing some research model/experiment/benchmark
- **Anything else that makes sense for research**...

No oral exam needed
Midterm Assignments

○ Delivery of a notebook/colab or a very short slide deck (e.g. 10 slides) on
  ● A quick and dirty (but working) implementation of a simple pattern recognition algorithm
  ● A report concerning the experience of installing and running a demo application realized using available libraries
  ● A summary of a recent research paper on topics/models related to the course content

○ Timeline
  ● One midterm every 3-4 weeks
  ● Should be doable with a couple of afternoons’ work
  ● Midterm published: early March, late March, late April, mid May
  ● Midterm delivered: late March, mid April, mid May, late May
Final Project (I)

○ Choose from a set of suggested topics or propose your own topic of interest
○ Timeline
  ● Suggested topics list published: mid May
  ● Choose project: email me to arrange a topic
  ● Report (10 pages, for survey type) or code (for SW type) and presentation (for all) delivery: by the standard exam date (appello) (strict)
Final Project (II)

Possible project types

- **Survey** - Read at least five relevant and distinct papers on a topic, prepare a presentation and write a report: not a simple summary, rather try to find connections between the works and highlight interesting open problems.

- **Software** - Develop a tested and commented software implementing a non-trivial learning model and/or a pattern recognition application relevant for the course. Prepare a presentation describing code and its validation.
Oral Exam

○ (Give your **presentation** on the final project (15 minutes))
  ● Discuss it in front of me and anybody interested
  ● Be prepared to answer my **questions on the presentation**

○ An **oral exam** with questions **covering the course contents**
  ● Lectures whose content is not relevant for the final exam will be clearly marked as such

○ Remember to upload the presentation/report/code on Moodle by the appello deadline

Only for those who did not do the midterms
How to get past this course?

Grading (with midterms)

- Midterms only wave the final project and oral presentation: there is no vote for them, only pass/fail
- The exam vote is given by the oral examination grade

Grading (alternative way) \( \frac{(G_P + G_O)}{2} \)

- \( G_P \in [1, 32] \) is the project grade
- \( G_O \in [1, 30] \) is the oral grade
Introduction to Pattern Recognition

An introduction to the fundamental PR problems in signal and image processing and a summary of the old-school techniques to address them.

Topics
- Pattern recognition in time/spatial and spectral domain
- Timeseries and image analysis
- Convolution and correlation operators
- Visual feature descriptors
- Visual feature detectors
- Image segmentation
Next Lecture

Introduction to Signal Processing

- Timeseries
- Convolution and correlation
- Spectral analysis
Changes to next week schedule!

- Tuesday 27 February – Cancelled
- Wednesday 28 February - Cancelled
- Thursday 29 February - Cancelled

Extra (recovery) lectures
- Friday 01 March – Room L1 h14-16 (confirmation pending)
- Friday 08 March – Room L1 h14-16
- Friday 15 March – Room L1 h14-16
Onboarding

Remember to register on the course Moodle

https://elearning.di.unipi.it/course/view.php?id=278

Within the end of this week please signup on this shared spreadsheet

- Your email address for the course mailing list
- Name and curriculum/course
- Note the different sheet for M.Sc./Ph.D.

When you send me an email include tag [ISPR] (or may end up in thrash)

Questions?