UNIVERSITÀ DI PISA

DIPARTIMENTO DI INGEGNERIA DELL'INFORMAZIONE

Dottorato di Ricerca in Ingegneria dell'Informazione

Doctoral Course

Perspectives on Transfer Learning: From Gradient Flow to NTK Regimes

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Short Abstract:

Knowledge transfer learning is an advanced learning paradigm that focuses on transferring the knowledge acquired by a complex model to a simpler or more specialized one. The central idea is to enable a lightweight model to mimic the behavior and decision boundaries of a more complex model, often referred to as the teacher model. This is achieved by training the student model on the soft labels or probabilistic outputs generated by the teacher, rather than on the original hard labels of the dataset. The student model not only replicates the predictive capability of the teacher but also inherits its generalization capacity, often leading to faster convergence and improved performance on related but distinct tasks. Such techniques have proven effective in scenarios involving heterogeneous information sources, semi-supervised and unsupervised learning, and distributed or federated environments where direct access to raw data is limited.

In addition to traditional transfer learning, the course introduces the emerging and complementary concept of knowledge unlearning as part of the broader field of knowledge management in artificial intelligence. Unlearning refers to the adjustment of previously acquired knowledge from a model without requiring complete retraining. It is particularly relevant in contexts where data privacy, fairness, or regulatory compliance necessitate the forgetting of specific information or biases. When integrated with transfer learning, unlearning can be viewed as a technique for selective knowledge transfer, enabling systems to retain only the most relevant and reliable information from the source model while discarding outdated or undesirable patterns.

Despite the wide adoption of transfer learning in many domains such as computer networking, decision support systems, and natural language processing, the underlying theoretical foundations of the method remain underdeveloped. Current approaches often rely heavily on empirical performance without a rigorous understanding of why knowledge transfer works effectively across different domains and architectures. This gap underscores the need for formal design techniques and mathematical frameworks capable of explaining and predicting the behavior of transfer

learning systems. For these reasons, in this course, we introduce an exploration of the mathematical tools suitable for the theoretical analysis of transfer learning, with particular emphasis on spectral analysis methods. Spectral techniques enable a detailed examination of how information propagates through different layers and representations, revealing insights into the mechanisms of knowledge compression, regularization, and generalization.

Course Contents in brief:

- Introduzione alle NN e al regime di NTK [1] [2]
- Analisi shallow NN in regime di NTK [3] [4]
- Analisi Deep NN in regime di NTK [5] [6] [7]
- Metodi per l'analisi spettrale delle NN in regime NTK (Teoremi di Gershgorin, Fisher-Courant) [8] [12]
- Introduzione al Transfer Learning: Knowledge distillation [9] [10] [11]
- Analisi Knowledge distillation in regime NTK [9] [10]
- Analisi Unlearning in regime NTK [13] [14] [15]

Total # of hours of lecture: 16

References:

[1] Jacot et all; Neural Tangent Kernel: Convergence and Generalization in Neural Network

[2] He; On Kernel and Feature Learning in Neural Networks (thesis)

[3] Du et all; GRADIENT DESCENT PROVABLY OPTIMIZES OVER-PARAMETERIZED NEURAL NETWORKS

[4]Arora et all; Fine-Grained Analysis of Optimization and Generalization for Overparameterized Two-Layer Neural Networks

[5] Cao; Generalization Bounds of Stochastic Gradient Descent for Wide and Deep Neural Networks

[6] Du; Width Provably Matters in Optimization for Deep Linear Neural Networks

[7] Generalization Error Bounds of Gradient Descent for Learning Over-parameterized Deep ReLU Networks

[8] The Asymptotic Spectrum of the Hessian of DNN Throughout Training

[9] Panahi; Analysis of Knowledge Transfer in Kernel Regime

[10] Phuong; Towards Understanding Knowledge Distillation

[11] Gou; Knowledge Distillation: A Survey

[12] Xiao;Disentangling Trainability and Generalization in Deep Neural Networks

[13] Nazanin Mohammadi, Mila Vincent Dumoulin Eleni Triantafillou, Gintare Karolina Dziugaite; Data Selection for Transfer Unlearning

[14] Sadhika Malladi, Alexander Wettig, Dingli Yu, Danqi Chen, Sanjeev Arora; A Kernel-Based View of Language Model Fine-Tuning

[15] Zibin Pan, Zhichao Wang, Chi Li, Kaiyan Zheng, Boqi Wang, Xiaoying Tang, Junhua Zhao; Federated Unlearning with Gradient Descent and Conflict Mitigation

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CV of the Teacher

Pietro Cassarà received his M.Sc. degree in Telecommunication and Electronic Engineering from the University of Palermo in 2005 and his PhD degree in 2010, jointly with the State University of New York. Nowadays, he is a senior researcher of the Institute of Science and Information Technologies (ISTI) at the National Research Council (CNR) and a permanent member of the National Inter-University Consortium for Telecommunications (CNIT), Pisa, Italy. From 2017 to 2020, he was a temporary staff member of the CMRE lab at the NATO of La Spezia; from 2019, he has been leading the group research in machine learning for communication.

His research interests include optimized automatic controls and machine learning theory for wireless sensor networks, distributed cyber-physical systems, and distributed learning architectures for networking. As part of his research activities, he has had the opportunity to participate in and coordinate activities in European and Nationally funded projects and international projects funded by the European Space Agency and NATO.

He has been Co-Chair of the National IPv6 Council since 2021 and Vice-Chair at the European Telecommunications Standards Institute for the IPE and ENI activities related to 5G systems and NTN, and from 2025 is a co-founder of the Intent Based Networking topic at the Internet Research Task Force (IRTF).

Since 2022, he has been coordinating the activities of the joint CNR-Huawei laboratory for research related to AI for networking.

He has been involved in teaching activities at the University of Pisa (Mathematics and Computer Science) on the topic of analytical analysis of AI architectures with networking applications.

He has been involved in many activities in organizing conferences, workshops, and round tables, and in activities as an editor.

He has been participating in the IEEE ComSoc and VTS committees and is involved in the IEEE Machine Learning for Communications ETI activities.

Final Exam:
A project where candidates will analyze a neural network with the methodologies discussed during the class, involving numeric techniques based on tools such as MATLAB and Python.

Room and Schedule

Room: *Aula Riunioni del Dipartimento di Ingegneria dell'Informazione, Via G. Caruso 16, Pisa – Ground Floor*

Schedule:

From 16 April 2026

Day1 – [16:18]

Day2 – [16:18]

Day3 – [16:18]

Day4 – [16:18]

Day5 – [16:18]

Day6 – [16:18]

Day7 – [16:18]

Day8 – [16:18]

The course is in the framework of the educational activities of IEEE Student Branch at the University of Pisa	IEEE STUDENT BRANCH – UNIVERSITY OF PISA