UNIVERSITÀ DI PISA

DIPARTIMENTO DI INGEGNERIA DELL'INFORMAZIONE

Dottorato di Ricerca in Ingegneria dell'Informazione

Doctoral Course

"Cognitive models in robotics"

Prof. Giovanni L.C. Masala, Dr. Ioanna giorgi
University of Kent, School of Computing - UK
G.Masala@kent.ac.uk, I.Giorgi@kent.ac.uk

Local coordinator: Prof. Mario G.C.A. Cimino, mario.cimino@unipi.it

Short Abstract:

Cognitive models play a central role in advancing autonomous and adaptive behavior in robotics by providing computational accounts of perception, memory, language, and decision-making. Rather than relying solely on task-specific control architectures, cognitively inspired systems aim to reproduce general mechanisms underlying human cognition, enabling learning, reasoning, and flexible interaction with the environment. This course introduces key principles of cognitive modeling in robotics, with particular emphasis on neural and symbolic–subsymbolic approaches. As a representative example, we consider the ANNABELL (Artificial Neural Network with Adaptive Behavior Exploited for Language Learning) model, which implements language acquisition and use through biologically inspired neural mechanisms and working-memory structures. ANNABELL illustrates how complex cognitive functions can emerge from the interaction of simple neural components, offering insights into scalable, brain-inspired architectures for cognitive robotics.

Course Contents in brief:

- Introduction to cognitive robotics and cognitive architectures
- Biological and cognitive inspirations for robotic intelligence
- Neural-based cognitive models and learning mechanisms
- Symbolic and hybrid approaches to cognition in robots
- Working memory, attention, and executive control
- Language acquisition and processing in cognitive systems
- The ANNABELL model: structure, neural mechanisms, and language learning
- Applications, simulations, and relevance to autonomous robotic systems
- Open research problems and future directions in cognitive robotics
- Open Science approaches

Total # of hours of lecture: 8

References:

Golosio, B., Cangelosi, A., Gamotina, O., & Masala, G. L. (2015). A cognitive neural architecture able to learn and communicate through natural language. *PloS one*, *10*(11), e0140866.

Giorgi, I., Golosio, B., Esposito, M., Cangelosi, A., & Masala, G. L. (2020). Modeling multiple language learning in a developmental cognitive architecture. *IEEE Transactions on Cognitive and Developmental Systems*, *13*(4), 922-933. IEEE TCDS Outstanding Paper Award

Giorgi, I., Cangelosi, A., & Masala, G. L. (2021). Learning actions from natural language instructions using an on-world embodied cognitive architecture. *Frontiers in Neurorobotics*, *15*, 626380.

Giorgi, I., Golosio, B., Esposito, M., Cangelosi, A., & Masala, G. L. (2023). Conceptual development from the perspective of a brain-inspired robotic architecture. *Cognitive Systems Research*, *82*, 101151.

Asaduzzaman, M., Giorgi, I., & Masala, G. L. (2025, March). Filtering hallucinations and omissions in Large Language Models through a cognitive architecture. In *2025 IEEE Symposium on Computational Intelligence in Natural Language Processing and Social Media (CI-NLPSoMe Companion)* (pp. 1-5). IEEE.

Mirolli, M., & Parisi, D. (2009). Language as a cognitive tool. *Minds and machines*, *19*(4), 517-528.

Mirolli, M., & Parisi, D. (2011). Towards a Vygotskyan cognitive robotics: The role of language as a cognitive tool. *New Ideas in Psychology*, *29*(3), 298-311.

Kotseruba, I., & Tsotsos, J. K. (2020). 40 years of cognitive architectures: core cognitive abilities and practical applications. *Artificial Intelligence Review*, *53*(1), 17-94.

Sussman, A., & Hollander, J. (2021). *Cognitive architecture: Designing for how we respond to the built environment*. Routledge.

Cangelosi, A., & Schlesinger, M. (2018). From babies to robots: the contribution of developmental robotics to developmental psychology. *Child Development Perspectives*, *12*(3), 183-188.

CV of the Teacher

Dr Giovanni Masala is a Senior Lecturer in Computer Science at the University of Kent, School of Computing, where he leads the Cognitive Robotics and Autonomous Systems Lab. His research spans artificial intelligence, robotics, human–robot interaction, medical imaging, and language processing, with a strong publication record and an established international profile. He has held lead and co-investigator roles on multiple funded research projects exploring the application of AI and robotics to real-world domains, including healthcare, industry, and assistive technologies. Dr Masala has extensive experience in academic–industry collaboration, technology transfer, and the supervision of doctoral research in cognitive and embodied AI. He is a Senior Member of the IEEE Computational Intelligence Society and serves as Associate Editor for *Frontiers in Robotics and AI*. In the area of language understanding, he contributed to the development of large-scale neural cognitive architectures, achieving significant scientific and public impact.

Dr Ioanna Giorgi is a Lecturer in Artificial Intelligence at the University of Kent, School of Computing. She holds a PhD in Computer Science from the University of Manchester. Her research focuses on cognitive modelling, developmental cognitive robotics, and human–robot interaction, with particular emphasis on language as a computational mechanism for building high-level cognitive representations and abstraction. Her doctoral work introduced a novel cognitive modelling approach for multilingual language learning and received international recognition through the IEEE TCDS Outstanding Paper Award. She also extensively researches autonomous and social robots. Her work aims to combine symbolic and neural AI, cognitive architectures, embodied robotics and modern deep learning to develop scalable, human-centred intelligent systems.

Final Exam: Multiple-choice question test.

Room and Schedule

Room: Meeting Room DII – Polo A, Largo L. Lazzarino 1

Schedule:

Day 1 – March 24, 2026 – h. 11.00-13.00

Theoretical foundations

Hour 1 – Cognitive Robotics

Introduction to cognitive robotics and cognitive architectures

Biological and cognitive inspirations for robotic intelligence

Hour 2 – Learning and Representation

Neural-based cognitive models and learning mechanisms

Symbolic and hybrid approaches to cognition in robots

Day 1 – March 24, 2026 – h. 14.00-18.00

Core cognitive mechanisms, Models, Applications, and Research Outlook

Hour 3 – Cognitive Control and Language

Working memory, attention, and executive control

Language acquisition and processing in cognitive systems

Hour 4 – Case Study: ANNABELL

The ANNABELL model: structure, neural mechanisms, and language learning

Examples of training in ANNABELL

Hour 5 – From Models to Robots

Learning objects and actions in the real world. Tutor-based and scaffolded learning.

Experimental investigation of high-level skills in robots: learning, categorisation, abstraction and cognitive control.

Hour 6 – Future Directions

Open research problems and future directions in cognitive robotics

Day 2 – March 27, 2026 – h 8.00-10.00: Final exam.