Tutorial
(IEEE ICDL-EPIROB, Sept. 18, Lisbon, Portugal)
Introduction of Predictive Coding to Developmental Robotics

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***Abstract*— this tutorial aims to deepen understanding of how predictive and reflective minds of robots can be developed by using predictive coding as the organizing principle of the systems. The tutorial begins with the basics of predictive coding and free energy minimization principle followed by their implementation into different types of recurrent neural network (RNN) models based on both deterministic dynamics and stochastic one using variational Bayes. A set of robotics experiments using those models are reviewed through which we examine how compositionality can be developed by forming necessary functional hierarchy in visuo-motor processing and how such functions and structures developed can be used for active inference of on-going context or intention of others. Particular focuses will be given to emergent phenomena observed in the robotic experiments and their possible correspondences to phenomenological issues as well as to psychiatric disorders.**

***Index Terms*— Predictive coding, Developmental robotics, Recurrent neural network,**

I. INTRODUCTION

This tutorial provides basic ideas on how to use the predictive coding principle [1-3] for development of cognitive minds of robots. It has been considered that the mind is comprised of emergent phenomena, which appears via intricate and often conflictive interactions between the top-down intention for acting on the external world and the bottom-up recognition of the resultant perceptual reality [4, 5]. It is presumed that the skills for generating complex actions, knowledge and concepts for representing the world can naturally develop by allowing entangling interactions between these two processes of predicting future and reflecting the past.

This thought can be evaluated by conducting synthetic robotic experiments by using the predictive coding principles. This is because the aforementioned dense interaction between the top-down and the bottom-up processes can be effectively carried out by using the predictive coding principle in which cognitive processes of generating actions, recognizing the perceptual consequences, and learning the causality from action to perception can be performed rationally under a unified principle of prediction error minimization. It is also speculated that the principle can contribute to gaining understanding for phenomenological problems including consciousness and free will by closely examining the autonomy in the above mentioned interactions.

The tutorial starts with introduction of predictive coding by taking two different formations, one from deterministic dynamic system and the other from Bayesian probabilistic modeling based on free energy minimization principle [3]. Then, these two different formulations are arbitrated by introducing a particular RNN model, so-called the variational Bayes predictive coding RNN (VBP-RNN) [6, 7]. This part of tutorial will cover basics of nonlinear dynamic systems and stochastic dynamic systems as well as Bayesian probabilistic modeling.

A set of robotics experiments using such predictive coding type RNN models are introduced by which we examine how necessary spatio-temporal hierarchy can be developed, how such hierarchy can support generation of diverse complex actions while adapting to on-going environmental situational changes by performing active inference on the situational changes. Furthermore, the lecture introduces possible extensions of the study applied to computational psychiatry in which the underlying mechanisms for schizophrenia as well as autism are investigated with hypothesizing that these diseases might be caused by certain malfunction of predictive coding mechanism assumed in the patients' brains.

Finally, the tutorial introduces results from recent synthetic robotic experimental studies which can possibly explain how

free will can be originated and how it can become consciously aware by considering difference in the information process developed between deterministic and probabilistic ones as arbitrated by a certain meta-prior.

II. CONTENTS

The tutorial is provided in a form of a half day lecture course. The detailed contents are shown as itemized in the following.

1 Introduction of foundation of predictive coding
  - 1.1 Deterministic dynamic model
  - 1.2 Bayesian probabilistic model (free energy principle)

2 Implementation of predictive coding into RNN models
  - 2.1 Multiple spatio-temporal scales RNN
  - 2.2 Variational Bayes predictive coding RNN with meta-prior

3 Synthetic robotic experiments using predictive coding
  - 3.1 Development of hierarchy in learning compositional visuo-motor patterns
  - 3.2 Active inference of intentions of others in human-robot interaction
  - 3.3 Reconstruction of pathology of schizophrenia and autism in robot experiments

4 Approaches to subjective experience by predictive coding
  - 4.1 Possible accounts for free will and consciousness from robot experiment
  - 4.2 Prediction and postdiction

III. Target audience

The audiences could be both of graduate students and researchers from wide-ranged background including robotics, neural network modeling, neuroscience, machine learning, developmental psychology, and philosophy of minds.

IV. Lecturer

The tutorial lecture will be given by Jun Tani, director of Cognitive Neurorobotics at Okinawa Institute of Science and Technology in Japan. Jun Tani has studied cognitive neurorobotics by using predictive coding framework more than two decades. He recently published a book, *"Exploring Robotic Minds: Actions, Symbols, and Consciousness as Self-Organizing Dynamic Phenomena"* from Oxford University Press. by summarizing his past studies related to the topics.

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