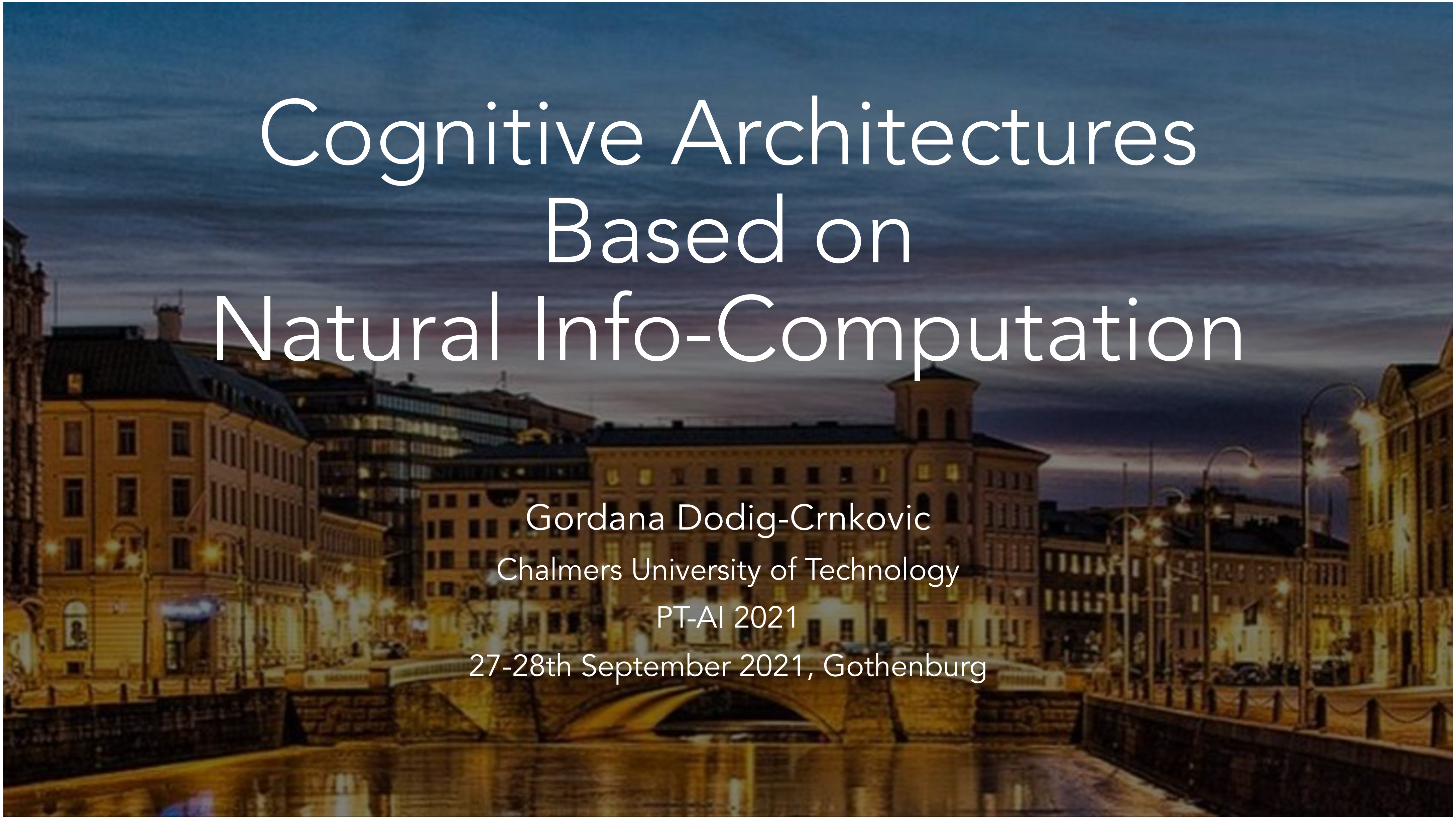

Cognitive Architectures Based on Natural Info-Computation

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Cognitive Architectures: Core Cognitive Abilities and Practical Applications

Recent comprehensive overview of 40 years of research in cognitive architectures, (Kotseruba and Tsotsos 2020), evaluates modelling of the core cognitive abilities in humans, but only briefly mentions biologically plausible approaches based on natural computation.

However, there is an important development of biologically inspired computational models in the recent past that can lead to the development of biologically more realistic cognitive architectures.

Unlike vast majority of cognitive architectures, that consider human cognition, we would like to focus on the development and evolution of the continuum of natural cognitive architectures, from basal cellular to human-level cognition.

Cognitive Architectures in a Continuum from Unicellular to Human-level Social Cognition.

We use evolutionary info-computational framework, where natural/ physical/ morphological computation leads to evolution of increasingly complex cognitive systems.

Forty years ago, when the first cognitive architectures have been proposed, understanding of cognition, embodiment and evolution was different.

So was the state of the art of information physics, bioinformatics, information chemistry, computational neuroscience, complexity theory, self-organization, theory of evolution, information and computation.

Cognitive Architectures:
Antecedents of Human Cognition

Novel developments support a constructive interdisciplinary framework for cognitive architectures in the context of computing nature, where interactions between constituents at different levels of organization lead to complexification of agency and increased cognitive capacities. We identify several important research questions for further investigation that can increase understanding of cognition in nature and inspire new developments of cognitive technologies. Recently, basal cell cognition attracted a lot of interest for its possible applications in medicine, new computing technologies, as well as micro- and nanorobotics. Bio-cognition of cells connected into tissues/organs, and organisms with the group (social) levels of information processing provides insights into cognition mechanisms that can support the development of new AI platforms and cognitive robotics.

Computing Nature – Natural Computationalism
Universe that Computes

"And how about the entire universe, can it be considered to be a computer?
Yes, it certainly can, it is constantly computing its future state from its current state, it's constantly computing its own time-evolution!

And as I believe Tom Toffoli pointed out, actual computers like your PC just hitch a ride on this universal computation!"

(Chaitin 2006)

* https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.414.4009&rep=rep1&type=pdf What is Computation? (How) Does Nature Compute? David Deutsch in A Computable Universe by Hector Zenil

*http://www.gordana.se/work/PUBLICATIONS-files/2007-Epistemology%20Naturalized.pdf

Information as a Substrate of Natural Computation

If Nature computes, what is the substrate on which computation is performed?

It is INFORMATION (as developed in Floridi's Informational Structural Realism)

Here we distinguish two kinds of information:

- Ontological (information as the case, what universe is)
- Epistemological (information as the basis of knowing)

Cognitive Architectures
Based on Natural Info-Computation

Naturalist computationalism (Computing nature) framework makes it possible to describe all cognizing agents (living organisms and artificial cognitive systems) as informational structures with computational dynamics [Dodig-Crnkovic, 2006-2020].

Morphological computation in this framework is a process of creation of new informational structures, as it appears in nature, living as non-living. It is a process of morphogenesis, which in biological systems is driven by development and evolution.

Cognitive architectures generated by natural (morphological) computation are realized in the substrate of matter/energy [Dodig-Crnkovic, 2012].

Cognition in living systems/agents constitutes life-organizing, life-sustaining goal-directed processes, while in artifactual systems, cognition is engineered process based on sensors, actuators and computing units designed to mimic biological cognition (bio-mimetic design).

PRE-NEURAL BIOCOMPUTATION

Work of Michael Levin suggests broad range of applications for nature-inspired cognitive architectures based on biological cognition connecting genetic networks, cytoskeleton, neural networks, tissue/organ, organism with the group (social) levels of information processing.

Levin shows how biology has been computing through *somatic memory* (information storage) and *biocomputation/decision making* in *pre-neural bioelectric networks*, before the development of neurons and brains.

Insights from biocognition can help the development of new AI platforms, applications in targeted drug delivery, regenerative medicine and cancer therapy, nano-technology, synthetic biology, artificial life, and much more.

Cognitive Architectures Based on Natural Info-Computation

Unlike self-organized natural cognitive agents, engineered cognitive computational agents are essentially dependent on human-made infrastructure for their existence and maintenance.

Types of physical/morphological computation in solid-state inanimate matter used for computers today are not capable of self-organizing cognitive agency that is fundamental feature of living organisms. Their cognition is governed by language-based information processing without ‘8real-time) intrinsic connection with autonomous agency which all living creatures have.

Engineered cognitive systems can still learn a lot from living agents, even from the simple ones like unicellular organisms.

Cognitive Architectures Based on Natural Info-Computation

Natural info-computational model of reality for an agent includes agent itself and the world as it appears for the agent (Umwelt). Computation is information processing (Burgin, 2005).

Computation is natural information transformation [Rozenberg, Back, Kok, 2012] [Stepney et al., 2005, 2006; Stepney, 2008] and [MacLennan, 2004], on different levels of organization (physics, chemistry, biology, cognition) [Dodig-Crnkovic, 2017a-c] [Burgin and Dodig-Crnkovic, 2015).

Cognitive Architectures Based on Natural Info-Computation

Evolutionary process in living organisms, in the sense of extended evolutionary synthesis [Jablonka, Lamb, Zeligowski, 2014], [Laland et al. 2015] unfolds as a result of interactions of living agents with the environment, including other living agents.

It starts with the first simplest pre-biotic structures and leads to more complex forms such as viruses and bacteria, continuing up in complexity through the evolution of species, from single cells to humans, [Dennett, 2018] [Dodig-Crnkovic, 2015].

Cognitive Architectures Based on Natural Info-Computation

This framework is treating cognition as an open-ended process of self-organization where computation for the most part proceeds as signal processing in natural systems, and only under special circumstances it takes form of symbol manipulation and language-based communication [Ehresmann, 2012].

Both living and engineered info-computational artifacts possess various degrees of cognitive capacities [Dodig-Crnkovic, 2018; 2017a-c].

Cognitive Architectures Based on Natural Info-Computation

Mechanisms of cognition, based on natural computation/ morphological computation are far more sophisticated than the machine-like classical computationalist models based on abstract symbol manipulation [Kampis, 1991].

They conform to the view expressed by [Witzany, 2000] and [Witzany and Baluska, 2012] that rule-based machines are not good enough models of natural cognition of highly complex living organisms.

Embodiment is the fundamental characteristics of cognition, which implies that senses, feelings and emotions must be taken into account as constitutive of cognition [Dodig-Crnkovic, 2017a].

Info-computational approach incorporates our best current scientific knowledge about the processes in nature, translating them into language of natural info-computation.

Cognitive Architectures Based on Natural Info-Computation

The aim of this approach to cognition is to increase understanding of cognitive processes in diverse types of agents, biological and synthetic, including their ability of learning, and learning to learn (meta-learning) [Dodig-Crnkovic, 2020], as well as their communications and mutual interactions.

The focus is on the understanding of the fundamental mechanisms of cognitive processes based on natural information and morphological computation, which boils down to the study of the structures and their dynamics at different levels of organization.

Cognitive Architectures Based on Natural Info-Computation

As the development of increasingly sophisticated artificial intelligent cognitive computational systems rapidly progresses, a framework that can seamlessly connect the natural with the artificial is useful for learning in both directions – from the natural system to the model and back.

Some Open Questions of Cognitive Architectures and Natural Info-Computation

- Biomimetic Design of Cognitive Architectures. How “Biologically Plausible” is Enough?
- Cognitive Behaviors and their Simulation, Emulation and Engineering

  Two open questions that run in parallel, providing an opportunity for two-way learning between computing and neuroscience (Rozenberg and Kari 2008).

  - how cognition works and develops in nature, and
  - how we can simulate, emulate and engineer it.

- Computational Efficiency of Natural Computing

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