A3 Afternoon Session 3: (25 min) Michele Braccini, Paolo Baldini and Andrea Roli
An investigation of graceful degradation in Boolean network robots subject to online adaptation

Supporting links:

https://www.unive.it/pag/fileadmin/user_upload/centri/ECLT/documenti/Programme_WIVACE_23.pdf

https://arxiv.org/pdf/2006.02367.pdf : Online adaptation in robots as biological development provides phenotypic plasticity (Michele Braccini 1 , Andrea Roli1,2, and Stuart Kauffman 3)

https://www.mdpi.com/1099-4300/24/10/1368 : On the Criticality of Adaptive Boolean Network Robots (Michele Braccini 1,* , Andrea Roli 1,2 , Edoardo Barbieri 1 and Stuart A. Kauffman 3)

On_the_Criticality_of_Adaptive_Boolean_Network_Rob.pdf
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Online adaptation in robots as biological development provides phenotypic plasti...
PDF Document · 548 KB

Abstract:
- The ability of responding to environmental stimuli with appropriate actions is a property shared by all living organisms: This statement introduces the concept of organisms being able to react to their environment in a way that benefits their survival.
- and it is also sought in the design of robotic systems: This suggests that the ability for robots to respond appropriately to their environment is desirable and sought after in the field of robotics.
- Phenotypic plasticity provides a way for achieving this property as it characterizes those organisms that, from one genotype, can express different phenotypes in response to different environments, without involving genetic modifications: Here, phenotypic plasticity is described as a mechanism that allows organisms to adapt to different environments without changing their genetic makeup.
- In this work, we study phenotypic plasticity in robots that are equipped with online sensor adaptation: The text specifies that the focus of the work is on

studying phenotypic plasticity in robots that can adapt their sensors to their environment in real-time.

- We show that Boolean network controlled robots can attain navigation with collision avoidance by adapting the coupling between proximity sensors and their controlling network without changing its structure: This line indicates that the study demonstrates that robots using Boolean networks as controllers can achieve navigation and collision avoidance by adjusting the connection between their sensors and control network without modifying the network's core structure.
- In other terms, these robots, while being characterized by one genotype (i.e., the network) can express a phenotype among many that is suited for the specific environment: It clarifies that despite having a fixed genetic makeup (represented by the network), these robots can exhibit different behaviors suited to their current environment.
- We also show that the dynamical regime that makes it possible to attain the best overall performance is the critical one, bringing further evidence to the hypothesis that natural and artificial systems capable of optimally balancing robustness and adaptivity are critical: This suggests that the study identifies a particular dynamic state in robots that leads to optimal performance, supporting the idea that both natural and artificial systems need to balance robustness and adaptability to be successful.

Introduction:

- evolutionary theories have focused mainly on the role of selection acting on randomly generated genetic material in the origination of phenotypic diversification—and finally speciation: It explains that traditional evolutionary theories have emphasized the role of natural selection acting on randomly generated genetic variations in the development of diverse phenotypes and the emergence of new species.
- It describes how the NeoDarwinian Synthesis or Modern Synthesis placed a strong emphasis on genetic material as the primary driver of evolutionary innovation.
- So, the differential survival and reproduction success of biological organisms has been ascribed to genotype: This line reinforces that in traditional evolutionary thought, differences in survival and reproduction success are attributed to an organism's genetic makeup.
- Parallel to the development of “Modern Synthesis”, Mayr argued that: “[...] it is the phenotype which is the part of the individual that is visible to selection”: Here, the text introduces the idea that Ernst Mayr challenged the traditional view, proposing that it's the phenotype (observable traits) that is subject to selection.
- Mayr’s argument, together with Waddington’s work on the Epigenetic Landscape, has paved the way for the formulation of a theoretical framework according to which the phenotype—and not the genotype—, the environment and above all the development process play a primary role in

the origin of the novelty from an evolutionary point of view: This explains that Mayr's argument, along with Waddington's work on the Epigenetic Landscape, laid the foundation for a theoretical framework where phenotype, environment, and development process are considered more important than genotype in explaining evolutionary novelty.

- The epigenetic landscape metaphor, which finds a formal basis in dynamical systems theory, stresses the concept for which there is no trivial deterministic mapping between genotype and phenotype: It introduces the concept of the epigenetic landscape metaphor and how it highlights the idea that there isn't a simple one-to-one mapping between an organism's genotype and its phenotype.
- It is the dynamics of the complex network of interaction among genes, and between genes and the environment, which will determine the stable expression patterns and so ultimately will affect the phenotype determination: This states that the dynamics of interactions between genes and their environment play a critical role in determining stable expression patterns and, consequently, the traits expressed by an organism.
- Therefore, the ensemble of dynamics than can be generated by the genes composing the organism’s genetic code represents a source of diversification that can explain the birth of new phenotypes and, consequently, their affirmation on the evolutionary scale: This suggests that the diversity of dynamics generated by an organism's genes can lead to the emergence of new traits and their success in evolution.
- It is important here to emphasize the role of the environment in constraining and shaping these actual dynamics: This highlights the significance of the environment in influencing and shaping the dynamics of gene interactions.
- **In biology, the capacity of a genotype to produce different phenotypes depending on the environment in which it is located is defined as phenotypic plasticity, developmental plasticity if differences emerge during development: This introduces the definitions of phenotypic plasticity and developmental plasticity, where an organism's genotype can result in different phenotypes based on environmental conditions.**
- The specific dynamics that shapes an organism’s phenotype during its development is indeed the response to various influences, among which we inevitably find the external environment, other organisms, and noise: It states that an organism's phenotype during development is influenced by a variety of factors, including the external environment, interactions with other organisms, and random noise.
- More in general, these external agents influence the process of regulation so that they might destabilize reached (meta)stable patterns of gene expression and induce a network dynamics reconfiguration, able to accommodate and possibly give appropriate responses to the new state of the external environment: This explains that external factors can disrupt stable gene expression patterns and trigger changes in network dynamics to adapt to a new environment.
- In other words, they stimulate the process of construction of a new internal

model of the external world: This describes how these external factors prompt the organism to create a new internal representation of the external environment.

- Biologists call this process developmental recombination; in the works, reasons and evidences why this process is held responsible for the origin of differences between species are presented: It introduces the term "developmental recombination" and suggests that this process is responsible for the generation of differences between species. The text also hints at evidence supporting this claim in referenced works.
- **a hypothesis that phenotypic plasticity could allow organisms to traverse fitness valleys in the evolutionary landscape, which would be difficult for mutation-driven evolution because the intermediate phenotypes in these valleys might be disadvantageous.**
- **Therefore, even if mutations (random or not) contribute to the creation of diversification, by modifying the gene regulatory networks topology and therefore the constraints imposed on its dynamics, they are not necessary conditions for phenotypic plasticity and, in the light of the previous discussion, assume a role of supporting actors: This states that while mutations can contribute to diversity by altering gene networks, they are not essential for phenotypic plasticity, which is more influenced by network dynamics.**
- They are, however, implicated in the genetic accommodation process, that is the process following the selection of the phenotypic variant with a genetic component; or when a reorganization of the genotype allows individuals of subsequent generations to reach the same phenotype at a lower cost, in terms of time, resources, etc.: This explains that **mutations play a role in genetic accommodation, a process that occurs after the selection of a phenotypic variant with a genetic component**. It can also facilitate individuals of future generations in reaching the same phenotype more efficiently.
- **Steps: Begin > Initial population > Calculate the fitness value > Selection > Crossover > Mutation.**

Para 2:

The text introduces the viewpoint of cybernetics (the study of communication and control in animals and machines) and its relevance to understanding phenotypic plasticity. It emphasizes that the ability to create an internal model of the external world through phenotypic plasticity is highly significant. Here, it abstractly describes how phenotypic plasticity allows an organism to condense the vast amount of information it receives from the external environment into an internal model that prioritizes information critical for the organism's survival. This explains that the organism uses its internal model to guide its actions, primarily focusing on maintaining homeostasis, which is the stable internal

state that keeps essential variables within a healthy physiological range. phenotypic plasticity is not only essential for living organisms but also holds significant potential for artificial systems (such as robots or AI). It poses a critical question about identifying the generic properties that enable organisms to demonstrate the observed phenotypic plasticity during their development, leading to effective adaptability. It poses a critical question about identifying the generic properties that enable organisms to demonstrate the observed phenotypic plasticity during their development, leading to effective adaptability. This suggests that discovering these properties could offer insights into how organisms adapt during their development. It also explains that understanding these properties might help elucidate how the development process influences evolutionary changes and the differences and shared characteristics among species. This suggests that looking for generic properties is an alternative to costly and less generalizable comparative studies among different species. It acknowledges the successes of such studies in discovering genes like homeobox and Pax6 but highlights their limitations. An approach based on generic properties provides an alternative to the comparative studies between different species, which although have led to great results (see above all the discoveries of homeobox and Pax6 gene, have the limitation of being highly costly and not being easily generalizable.
Homeobox - https://en.wikipedia.org/wiki/Homeobox
Pax6 - https://en.wikipedia.org/wiki/PAX6

Para 3:
Provides a detailed overview of the evidence and theories regarding the presence of criticality in biological systems, particularly in gene networks and the brain. It also explores the potential implications of criticality for biological organisms, including the idea that criticality may foster phenotypic plasticity, robustness, and adaptivity. The passage begins by stating that numerous research papers have suggested that biological cells, particularly their gene networks, operate in a critical dynamic regime. The passage provides an example where researchers used microarray gene expression data and compared it to models (random Boolean networks) to determine that the genetic regulatory network of HeLa cells operates in an ordered or critical regime, rather than a chaotic one. It mentions a study by Aldana and others that discusses how biological genetic networks modeled as Random Boolean Networks (RBNs) in a critical regime exhibit robustness and evolvability simultaneously. Critical systems are noted for their ability to respond reliably to inputs while having a broad range of possible responses. The passage explains why this functionality is crucial for organisms, as they need to process and respond to environmental information vital for their survival. Whether criticality could promote the development of phenotypic plasticity and whether this might also be responsible for the establishment of the robustness and adaptivity traits observed in organisms as a result of both evolution (phylogenesis) and individual development (ontogenesis). the research's objective of exploring the potential relationship between dynamical criticality and phenotypic plasticity. It

explains that if a link is found between criticality and phenotypic plasticity, it could provide additional support for the criticality hypothesis. Furthermore, it could help illuminate the connection between phenotypic plasticity, criticality, and the processes of evolution.

Epigenetic adaptation and epigenetic autonomy are concepts related to the field of epigenetics, which explores heritable changes in gene expression or cellular phenotype that do not involve changes to the underlying DNA sequence. Let's define these terms:

- *Epigenetic Adaptation:*
  - *Epigenetic adaptation refers to the process by which organisms or populations can adapt to changes in their environment through epigenetic modifications. These modifications involve alterations in gene expression patterns without changes to the DNA sequence itself.*
  - *For example, when an organism experiences environmental changes, such as changes in temperature or food availability, its epigenetic marks (e.g., DNA methylation, histone modifications) may be modified in response. These epigenetic changes can lead to changes in gene expression that help the organism better cope with the new environmental conditions.*
  - *Epigenetic adaptation is considered a mechanism that allows organisms to exhibit phenotypic plasticity, where the same genotype can produce different phenotypes in response to environmental cues.*
- *Epigenetic Autonomy:*
  - *Epigenetic autonomy is a concept that suggests that epigenetic changes can have a degree of independence or autonomy from the genetic information encoded in an organism's DNA.*
  - *In other words, epigenetic modifications can sometimes exert significant control over an organism's traits or behaviors, even overriding the genetic instructions. This concept highlights the dynamic and regulatory role of epigenetic mechanisms.*
  - *Epigenetic autonomy can be seen in cases where the epigenetic state of specific genes or regions plays a crucial role in determining an organism's phenotype, irrespective of the underlying genetic sequence.*

In summary, epigenetic adaptation involves using epigenetic modifications to respond to environmental changes and adapt to new conditions, while epigenetic autonomy emphasizes the ability of epigenetic mechanisms to *influence traits independently of the genetic code. Both concepts underscore the importance of epigenetics in understanding how organisms respond to their environment and develop specific traits.*

Some examples of phenotypic plasticity in real organisms:

- **Arabidopsis thaliana**: This small flowering plant can exhibit different growth patterns and leaf shapes depending on factors like light intensity, temperature, and nutrient availability.
- **Peppered Moth (Biston betularia)**: This moth species is known for its color variation. The color of their wings can change in response to industrial pollution, with darker moths becoming more prevalent in areas with soot-covered trees.
- **Salmon**: Salmon undergo dramatic morphological changes as they migrate from freshwater to the ocean and back. They change from being streamlined and silver in the ocean to developing a hooked jaw and vibrant colors in freshwater.
- **Daphnia**: These small aquatic crustaceans can develop different body armor and spine structures in response to the presence of predators. This is a classic example of predator-induced phenotypic plasticity.
- **Coral Reefs**: Coral polyps can change their growth forms and colors in response to changes in water temperature, light, and nutrient levels. This can affect the overall structure and health of coral reefs.
- **Tadpoles**: Many species of tadpoles can exhibit phenotypic plasticity in response to the presence or absence of predators. They may develop different tail shapes and behaviors for better survival.
- **Ants**: In some ant species, the development of worker ants can be influenced by factors such as nutrition and environmental conditions, leading to different worker castes with specialized roles.
- **Cress (Lepidium sativum)**: Like Arabidopsis, cress plants can exhibit phenotypic plasticity in response to environmental conditions, altering their leaf shape and growth patterns.
- **Horned Beetles (e.g., Onthophagus taurus)**: Male horned beetles can develop larger or smaller horns depending on the availability of resources and competition for mates.
- **Platypus**: Male platypuses have venomous spurs on their hind limbs, but the size and potency of these spurs can vary among individuals, possibly influenced by environmental factors.

Rest of the experimental details are read from the paper.