Late Breaking Abstracts booklet
Artificial Life
Conference 2016

Edited by
Carlos Gershenson, Tom Froese, Jesus M. Siqueiros,
Wendy Aguilar, Eduardo J. Izquierdo and Hiroki Sayama

Table of Contents

Jitka Cejkova, Dominik Svara, Martin M. Hanczyc and Frantisek Stepanek
Shape changing multi-armed droplets 1

Oliver López-Corona and Pablo Padilla
The emergence of cooperation from entropic principles and sustainability 2

Elvia Ramírez-Carrillo, Oliver López Corona, Fernando de León-González, Gilberto Vela Correa and Alejandro Frank
Soil Respiration as a Proxy for Ecosystem Health 4

Hye Jin Cho, Kyu Cheol Lee and Changduk Yang
PVDF-g-PtBA Copolymers for Triboelectric Nanogenerators with High Dielectric Constant 5

Francesco Corucci, Nicholas Cheney, Hod Lipson, Cecilia Laschi and Josh Bongard
Evolving swimming soft-bodied creatures information 6

Hiroki Sayama, Ali Jazayeri and J. Scott Turner
A Finite State Machine-Based Approach for Detecting Interactions among Individuals with Different States in a Biological Collective 7

Maitri Mangal, Graham Wilcox, Haashim Shah, Hiroki Sayama and Carol Reynolds
How Old Should You Be To Become a Father? Reconstructing the Fitness Function over Paternal Age 8

Chiara Picchi, Fabrizio Cinelli, Rodrigo Rubio and Francesco Corucci
Artificial Life inspired Architecture: a sustainable and adaptive treehouses ecosystem in the Chilean forest 9

Erick Pérez and Tom Froese
A network model of the appearance of biologically irresolvable conflict in prehistoric hunter- gatherer groups 10

Matthew Dale, Julian Miller, Susan Stepney and Martin Trefzer
Modelling and Training Unconventional in-Materio Computers using Bio-Inspired Techniques 11

Yuliya Betkher, Vitor Santos and Nuno Nabais
Impact of ALife Simulation of Darwin's and Lamarck's Theories of Evolution on Life and Society 12

Rob Mills, Martina Szopek, Michael Bodi, Thomas Schmickl and Luís Correia
On the timescale of interactions in bio-hybrid systems 15

Reiji Suzuki
Complex systems approach to temporal soundscape partitioning in bird communities 17

Marco Montalva Medel, Fabiola Lobos, Thomas Ledger and Eric Goles
Expanding the limits of bistability modelling: a Boolean-based continuous representation of the lac operon regulation dynamics 19

Nathanael Aubert-Kato, Olaf Witkowski, Erik Hoel and Nicolas Bredeche
Agency in Messy Chemistries: Information-Theoretic Measures vs. Strategies Case Study in a Reaction-Diffusion Model 20

Jorge Ivan Campos Bravo and Tom Froese
Multiple action switching in embodied agents evolved for referential communication 22

Alexandra Penn, Inman Harvey, Erik Hom and Claudio Avignone Rossa
Emergent Homeostasis in a Synthetic Mutualism: modelling the interplay of abiotic and biotic interactions in an experimental proto-ecosystem 23

Eneas Aguirre-Von-Wobeser, Juan Toledo-Roy, Ana Leonor Rivera, Valeria Souza and Alejandro Frank
Complex modelling of bacterial interactions using an agent-based model 25

Dobromir Dotov and Tom Froese
A set theoretic analysis shows different forms of closure in autopoietic theory, computational autopoiesis, and (M,R)-systems 27

Eiko Matsuda and Takashi Ikegami
Synesthesia in Artificial Life 29

Leticia Cruz and Tom Froese
An Evolutionary Robotic Model of Explicit Agency Detection 31

Mario A. Zarco-López and Tom Froese
Can we incorporate sleep-like interruptions into evolutionary robotics? 33

Shape changing multi-armed droplets

Jitka Cejkova, Dominik Svara, Martin M. Hanczyc and Frantisek Stepanek

Abstract:
Artificial cells are engineered objects that mimic one or many functions of biological cells and could be embodied as solid particles, lipid vesicles or droplets. Our work is based on using decanol droplets in aqueous solution of sodium decanoate in the presence of salt. A decanol droplet under such conditions bears many qualitative similarities with living cells, such as the ability to move chemotactically, divide and fuse, or change a shape. In short-time-scales these droplets perform oriented movement in salt gradients, mimicking chemotaxis behavior of living cells. This behavior includes maze solving. In the long-time-scale, during the evaporation of water from the decanoate solution, the droplets perform fantastic shape changes, when the originally round decanol droplets grow into branching patterns and mimic the axon growth of neuronal cells.

At the beginning of an experiment, the decanol droplets have a round shape. Later, first small spikes appear on the droplets' periphery, they bulge and also retract. Few minutes after, several spikes dominate over the others and start to prolong and grow. The droplets have a star shape and their tips get longer and form tentacles. Then holes in the tentacles appear and after that the tentacles disintegrate and their fragments shrink, coalesce and make small droplets again. In the end of an experiment, after the evaporation of water from the decanoate solution is completed, the glass slide substrate is covered by several pieces of gelled decanol and unstructured dry decanol/decanoate leftovers.

We observe extensive shape changes in our droplet systems, with bifurcation and branching patterns that are at least superficially similar to biological neuronal architectures. However, in this moment we cannot speak about functional similarity, because the electrical conductivity of the surrounding bulk electrolyte is now much higher than the conductivity of decanol, so this is the opposite of what happens in neuronal networks. In order to simulate neuronal connections and some signal propagation, we would need the tentacles to conduct electricity better than the surrounding solution. Also, the tentacles now seem to be "self-avoiding", so we would need to somehow convince them to make connections. Anyway we hope our multi-armed droplets could represent "artificial neurons" in future, so in addition, spiking-type behavior in our system will be tested. A chemistry-based artificial neuron would provide embodiment of unit and population-based self-organization, intercommunication and emergent higher order phenomena that can be fully characterized in terms of chemistry.

The emergence of cooperation from entropic principles and sustainability

Oliver López-Corona and Pablo Padilla

Abstract:
Assessing quantitatively the state and dynamics of a social system is a very difficult problem. It is of great importance for both practical and theoretical reasons such as establishing the efficiency of social action programs, detecting possible community needs or allocating resources. In this paper we propose a new general theoretical framework for the study of social complexity, based on the relation of complexity and entropy in combination with evolutionary dynamics to asses the dynamics of the system. Imposing the second law of thermodynamics, we study the conditions under which cooperation emerges and demonstrate that it depends of relative importance of local and global fitness. As cooperation is a central concept in sustainability, this thermodynamic-informational approach allows new insights and means to asses it using the concept of Helmholtz free energy. Finally we introduce a new set of equations that consider the more general case where the social system change both in time and space, and relate our findings to sustainability.

Entropy, unfortunately, became associated with disorder, the antithesis of complexity and so how was it possible that biological or social systems appeared to increase their complexity (i.e. by cooperate) and reduce disorder, when the second law demanded its destruction?

Considering a more abstract definition of entropy, given a string of characters X, composed by a sequence of values or symbols x which follow a probability distribution $P(x)$, information (according to Shannon) is defined as $I = -\sum p(x)\log p(x)$, which has the same functional form of the physical entropy. Therefore, in this work we shall talk about entropy (S) or information (I) as the same. Then the maximum entropy S_{max} is the system total information capacity while the observed entropy (S_{obs}) is the actual information content. The macroscopic constraints are the macroscopic information and the historical constraints are the information historically excluded.

Even more, Gershenson and coworkers (Gershenson et al, 2012) have proposed that complexity (C) may be directly measured as $C = aI_{out}(1 - I_{out})$, where a is a normalization constant and I_{out} is the system information after all computations have occurred. In an entropic formulation $C = aS_{obs}(1 - S_{obs}) = aS(1 - S)$.. In this form we may measure the complexity of a system by measuring its entropy.

In this work we will present a simple computation in the context of game theory as applied to the social sciences that poses some interesting questions. Essentially we show that if social interactions are described by a game and we compute the associated entropy, then there are some cases in which it will increase monotonically. More precisely, assume for simplicity and without loss of generality that individuals in a society can adopt two strategies A or B and let x_A and x_B denote the proportion of the population choosing strategy A and B respectively. So we have $x_A + x_B = 1$. Since they are both positive, we can interpret them as probabilities. We assume, in the standard context of game theory that they satisfy the replicator equations and introducing the relation of Entropy as Information we get that the entropy production is

$$\frac{dS}{dt} = -\sum x_i \left(f_i - \phi\right) \ln x_i.$$

Most interesting is that from the thermodynamic stand point (Michaelian-2000), sustainability (understood as the capacity of a system to reach states of greater longevity) is attained by minimizing the Helmholtz free energy $F = U - TS$ which we show is only possible with positive entropy production and that is related with to the sign of ($f_i - \varphi$).

Finally considering a more general case where the interaction may change in time and space and using the López-Padilla equations (Lopez-Corona et al, 2013), we get that the entropy production is

$$\frac{d}{dt}\Omega\int S(r_j,t)dr_j = -\sum \Omega \int \left\{div\left[e_i(r_j,t)\nabla x_i(r_j,t)\right]\ln x_i\right\} dr_j.$$

The analysis of this new equation for a specif social set, could help us to understand the emergence of cooperation (a prerequisite for sustainability) with a full space-time description.

Soil Respiration as a Proxy for Ecosystem Health

Elvia Ramírez-Carrillo, Oliver López Corona, Fernando de León-González, Gilberto Vela Correa and Alejandro Frank

Abstract:
Soil is recognized as the largest terrestrial reservoir of organic carbon and its alteration significantly impacts the carbon concentration in the atmosphere (Stockmann et al. 2013). In fact, global soil organic carbon (SOC) contains more carbon than the atmosphere or terrestrial vegetation (Fischlin et. Al. 2007). We present a time series analysis for soil respiration data acquired with automated chambers in a half an hour basis for an Oregon forest in the US, in the central area of Cascade Mountains.

The weather in this zone for August of 2003 gave place to a thunderstorm followed by local temperatures ranged from 27 to 33 °C and high wind, which created extreme fire conditions, resulting into the called the B&B complex fire to denote two independent simultaneous fires that together burned 368 km2 of forest. We use data from AmeriFlux research consortium for 2001 (unburned condition) and 2004 (burned condition).

For the unburned condition both Fourier and DFA analysis shows a pink noise signal for the soil respiration fluctuations, with scaling exponent of 1.22 and 1.32; and for the burned conditions we obtained values of 1.52 and 1.53, corresponding to brown noise signal. As soil is a system that emerge from the interaction of the biosphere, the atmosphere, hydrosphere and geosphere over time on a particular geomorphology, then we consider that soil respiration time series integrate information from all this systemic components, taking a global character even due the very local measurement emplacement.

Then we use a metaphor of soil respiration as a physiological process of a "live like" system and relate the type of noise to different health status. We take the presence of pink (1/f) noise as a fingerprint of a dynamic critical state of the system, which may be associated with a healthy state meanwhile a brown noise, where the system becomes more "rigid" by gaining correlation, is a sign of health loss (López-Corona et al, 2013 ; Rivera et al, 2016).

PVDF-g-PtBA Copolymers for Triboelectric Nanogenerators with High Dielectric Constant

Hye Jin Cho, Kyu Cheol Lee and Changduk Yang

Abstract:
In addition to alternative energy sources such as solar, power, and geothermal, many mechanical energy sources that occur by friction and contact are being overlooked. This research focused on the triboelectric effect to harvest charged energy through friction and contact, motivated by synthetically modifying polymers used as negative charged bodies in a generator to obtain higher outputs. It is important to develop energy harvesting technology in a synthetic way. Previous triboelectric nanogenerators (TENGs) have been developed using polymer materials as negative charge substrate without synthetic modification by just the changing structure and operation principle of the generator. However, this article takes a different, non-structural, approach by modifying synthetically polymer substrates of the TENG with other materials with good electric characteristics. As more poly (tert-butylacrylate) (PtBA) with high dielectric constant is grafted in poly (vinylidene fluoride) (PVDF), it is predicted that friction surface charge density of the graft copolymer thin film will be increased. According to increasing graft concentration of the PtBA in the PVDF, dielectric constant and friction surface charge density of the TENG are improved, resulting in more than 3 times the output current of raw PVDF TENG. TENGs harvest energy by using friction. Above all, the synthetic TENG in this work can generate electric energy anywhere friction and contact occur in a wide range of natural and human environments. Thus, the TENG of the modified polymer substrate can be utilized in real life practically, such as in insole of shoes, pedals, floor material, coastal buoys, backpacks, and so on. It can convert usually wasted mechanical energy into electricity. This sort of TENG can be changed and has enormous potential for development of generator and modification methods according to the diverse range of synthetic polymer substrate materials. These modified TENGs with less environmental pollution, low cost, high energy efficiency, and accessible processes harvest energy and improve energy technology.

Evolving swimming soft-bodied creatures information

Francesco Corucci, Nicholas Cheney, Hod Lipson, Cecilia Laschi and Josh Bongard

Abstract:
Robotic and fluid dynamics studies suggest that flexibility can be advantageous for organisms living in water [Alben et al., 2002, Bergmann et al., 2014, Shelley and Zhang, 2011, Giorgio-Serchi et al., 2016, Giorgio-Serchi and Weymouth, 2016], which would partly explain the abundance of soft-bodied creatures produced by natural evolution in this environment. A new setup is introduced that allows further investigations on this issue from an evolutionary perspective. The effects of a fluid environment on the evolution of soft morphologies will be investigated. Other efforts will be directed to studying the evolutionary transitions water↔land, and how these affect the evolution of successful morphologies and behaviors. Soft creatures are simulated in the VoxCAD simulator [Hiller and Lipson, 2014], empowered with a mesh-based fluid drag model. A local drag force is computed for each facet of the deformable mesh, and added up as an additional force experienced by the underlying voxel. Neutral buoyancy is assumed. Complex phenomena such as turbulences are overlooked by this model, which might limit the range of life-like locomotion strategies that can be simulated. Robots are evolved using a multi-objective implementation of CPPN-NEAT [Corucci et al., 2016, Cheney et al., 2015]. Two CPPNs are evolved: the first one (CPPN1) determines the morphology of the robot, the second one (CPPN2) determines its control. Queried at each voxel of a cubic workspace, they both take as inputs the 3D location of the voxel (x, y, z), the polar radius (d), and a bias (b). CPPN1 has two outputs, determining whether a voxel should be full or empty, actuated or passive. The outputs of CPPN2 dictate the frequency and phase offset of the sinusoidal actuation. The task consists in locomotion, and four objectives are defined: 1) Maximize the traveled distance 2) Minimize the actuation energy (% of actuated voxels) 3) Minimize the number of voxels 4) Minimize the age of each individual [Schmidt and Lipson, 2011]. In a first experiment robots are evolved in water only. Additional experiments are then performed by starting evolution in water, then switching to land halfway (and viceversa). A sample of the evolved morphologies can be observed in the accompanying video (https://youtu.be/4ZqdvYrZ3ro). The system is able to evolve diverse and life-like morphologies and locomotion strategies. Preliminary results also encourage the investigation of environmental transitions.
[Please see the accompanying video: https://youtu.be/4ZqdvYrZ3ro]

A Finite State Machine-Based Approach for Detecting Interactions among Individuals with Different States in a Biological Collective

Hiroki Sayama, Ali Jazayeri and J. Scott Turner

Abstract:
Motion tracking and behavioral modeling of biological collectives has been actively studied in behavioral ecology and artificial life. Earlier studies were mostly focused on modeling individual behaviors, i.e., how each individual moves in response to local situations, such as the positions and velocities of nearby individuals. An implicit assumption that was commonly made was that such behavioral rules were homogeneously applicable to all individuals over time, i.e., that those individuals would not change their behavioral rules. Few studies considered detection of interactions among individuals with different states in the collective.

Here we develop a computational method to extract information about interactions among individuals with different states in a biological collective from their spatio-temporal trajectories. Our method analyzes each individual's position and its local environmental condition, which may include other individuals and other environmental constraints (e.g., obstacles placed in the space, etc.). Our objective is to computationally convert these observational data into a more dynamical, rule-based description of the collective behavior, with possible interactions among the individuals also adequately captured. To facilitate this challenging task, we adopt a finite state machine assumption, i.e., that the states of individuals in the collective are discrete and finite, and that they can change dynamically according to the input coming from their local environment.

The proposed method first detects discrete behavioral states of those individuals, and then constructs a model of their state transitions, taking into account the positions and states of other individuals in the vicinity. Because of the large amount of stochasticity typically present in the observational data, we assume that the transition rules are described in the form of state transition probabilities. Partly based on our earlier work on morphogenetic swarm chemistry, we modeled these state transition probabilities in a simple linear matrix form. This simplification makes model construction a simple least squares estimation task. The final result of this task is given as a m x m x n tensor, where m and n are the numbers of behavioral states and environmental input variables for state transition, respectively.

We have been testing the proposed method through applications to two real-world biological collectives: termites and pedestrians (the former is functional; the latter is still under development). Significant interactions were detected between nearby termite individuals with different states, illustrating that the proposed method can provide quantitative information about how individuals with various behavioral states interact with each other, and how strong such interactions are. Prospects of the pedestrian modeling and the potentials of future applications will also be discussed.

H.S. thanks financial support from the US National Science oundation (1319152). J.S.T. thanks financial support from the Human Frontiers Science Program (HFSP) (RGP0066/2012).

How Old Should You Be To Become a Father? Reconstructing the Fitness Function over Paternal Age

Maitri Mangal, Graham Wilcox, Haashim Shah, Hiroki Sayama and Carol Reynolds

Abstract:
Every parent deals with the dilemma of deciding when to have a child. Is there a best age to have a child? Older parents are more educated and likely have higher incomes. A parent with a higher educational attainment is more likely to have a child who also achieves a high level of education. These factors can subsequently predict the education and income of their children.

We have studied how the age of a parent (a father, in particular) could have impacts on the future success of their child (the child's salary). We have collected a large amount of demographic statistics data from the US Census data and other literature, and have constructed a "fitness function" that predicts child income from paternal age to demonstrate these impacts. There was no data available for a direct link between paternal age (PA) and the income of the child (CI), so we had to create it through indirect means. First, PA was connected to the paternal education level (PEL), then we connected PEL to child education level (CEL), and finally CEL was connected to CI. Each connection was estimated using a different statistical data set, in which the output was calculated as a weighted average of the dependent variable using frequencies of observed values as weights, for each value of the independent variable.

A smooth functional curve of CI versus PA was created using numerical interpolation. The result showed that 33 years old is the estimated optimal age to become a father. After the age of 33, the general level of the child's income remains, more or less, constant, with a slight negative slope. However, it is also known that as a father gets older there is a higher chance of the child having mental disorders, so our result may imply that it is favorable to have a child as early as possible after the age of 33. When paternal age is less than 33, there is a steep positive slope on the CI vs PA plot. This means that there is a negative effect on having a child before that age on the child's future success, at least in our current social environment.

The actual average age of fatherhood in the United States is 32.5 years currently. Our result for the ideal paternal age in terms of child income is very close to this average age. This may be a result of social evolution of humans. Namely, we can hypothesize that humans, through social evolutionary processes, have begun to have children at an optimal age as to maximize their child's financial success. An interesting extension of this research would be to measure other metrics of success, such as IQ and the number of children (biological fitness), in terms of paternal age. That way we can see from an evolutionary standpoint which metric of success society is currently leaning towards, based on the average paternal age.

Artificial Life inspired Architecture: a sustainable and adaptive treehouses ecosystem in the Chilean forest

Chiara Picchi, Fabrizio Cinelli, Rodrigo Rubio and Francesco Corucci

Abstract:
A project is presented in which ideas from Artificial Life are used to inform Architecture. The case study is the design of an ecotourism treehouses complex in the Chilean forest. The region of interest is located in the south-central Chile (Villarica, Araucania Region), characterized by natural landscapes (native forests, lakes, volcanoes). The forest represents the main entity to deal with in our design process, and an important source of inspiration: a living macro-organism hosting many individual ecosystems (most notably, trees). Accordingly, we view our treehouses complex as an organism of self-sufficient but networked cells: the housing units. The whole complex lives in a symbiotic interaction with the forest. Each unit is self-sufficient, but connected with others in order to share resources (water, energy) harvested from the environment, forming a macro-organism. Units are to be scattered in the area of interested, with an equilibrium between dispersion and aggregation. To devise their spatial distribution, the use of Cellular Automata (CA) is being investigated. CA are being evolved so that the final, emergent, planning accommodates different requirements. As biological cells, units are considered living and adaptive organisms. They depend on the forest for energy supply, shelter and structural support. The design process of the houses is performed within physical simulations, and is based on evolutionary and developmental processes. Each cell borns as a plastic entity, positioned at a predefined location. It then grows according to a developmental process guided by environmental stimuli, the parameters of which are devised by evolution. The living unit will try to reach out the open sky, finding its way amid the tree branches in order to maximize incoming sunlight and water, while establishing connections with nearby entities in order to exchange resources. A support structure will develop similarly to the cytoskeleton of living cells, exploiting trees as external structural support. Appendages withstanding mechanical load will be kept and strengthened, while others will be removed. Housing units will be made of sustainable materials: wood coming from the forest itself represents an optimal choice (no transport costs and pollution). The addition of other biodegradable materials is being considered as well, such as textiles (covering) and cellulose (insulation). Each unit is thus temporary and biodegradable. Digital fabrication methodologies will be put in place in order to build them on site (CNC machines, robotic arms). The living houses will maintain their adaptivity even once deployed in the actual environment, during their lifetime. Some parts of the houses will be able to move and adapt to stimuli in order to maximize efficiency and improve self-sustainability. They will orient towards sunlight, maximize the amount of collected water, adapt their shape to minimize wind resistance, and react to actions and habits of the visitors by adjusting both the interiors and the exteriors. The control required by these adaptive mechanisms will exploit the house itself as a computational resource (morphological computation). All this will bring integration and sustainability to unprecedented levels, with this living architectural complex representing an additional attraction for the visitors.

A network model of the appearance of biologically irresolvable conflict in prehistoric hunter-gatherer groups

Erick Pérez and Tom Froese

Abstract:
According to Gamble et al.(2014), human groups consist of multiple layers of relationships that build up to create ever-larger communities. They propose the following group sizes: 5, 15, 50, 150, 500, and 1500, which in the case of hunter-gatherers refer to intimate groups, foraging groups, bands, communities, mega-bands, and tribes, respectively. A key problem is to explain the maintenance of cooperation in these different groups. Gamble et al. claim that modern humans biologically evolved to cooperate within groups of maximally 150 individuals (also known as Dunbar's number), such that the appearance of larger group sizes during the early Neolithic period led to constraints that required the emergence of new cultural mechanisms of conflict mediation. Examples include religion, hierarchy, and warfare, with the latter two finding support in detailed agent-based simulations(Turchin et al., 2013). We chose a more abstract approach to investigate this problem by employing the REDS model, an energy-constrained spatial social network model first introduced by Antonioni et al.(2014). The REDS model comprises four components (Reach, Energy, Distance, and Synergy), and the generated topologies have key features of real social networks: high clustering, positive degree correlation, and the presence of community structure. We created REDS networks according to the six group sizes specified by Gamble et al. and ran a standard Hopfield network model on their topology to determine their capacity for global conflict resolution via local interactions. We report that networks with more than 150 nodes are no longer capable of spontaneously giving rise to global conflict resolution via local interactions alone. In addition, following related work by Froese et al. (2014), we consider how the emergence of large-scale group rituals could have helped to overcome this problem while otherwise keeping the original heterarchical network structure intact.

References

Antonioni, A., Bullock, S., & Tomassini, M. (2014). REDS: An energy-constrained spatial social network model. In: H. Sayama et al. (Eds.), ALIFE 14 (pp. 368-375). Cambridge, MA: MIT Press.

Froese, T., Gershenson, C., & Manzanilla, L. R. (2014). Can government be self-organized? A mathematical model of the collective social organization of ancient Teotihuacan, Central Mexico. PLoS ONE, 9(10), e109966. doi: 10.1371/journal.pone.0109966

Gamble, C., Gowlett, J., & Dunbar, R. (2014). Thinking Big: How the Evolution of Social Life Shaped the Human Mind. London: Thames & Hudson Ltd.

Turchin, P., Currie, T. E., Turner, E. A. L., & Gavrilets, S. (2013). War, space, and the evolution of Old World complex societies. Proceedings of the National Academy of Sciences of the USA, 110(41), 16384-16389.

Modelling and Training Unconventional in-Materio Computers using Bio-Inspired Techniques

Matthew Dale, Julian Miller, Susan Stepney and Martin Trefzer

Abstract:
As technology has matured the requirements of computing have evolved. Many state-of-the-art problems now focus on simulating and modelling physical phenomena, such as simulating neural networks, modelling emergent properties and implementing massive parallelism. The digital computing paradigm, however, is highly abstracted from what makes these systems interesting, which can lead to fragile designs and excessive computing requirements.

In our work, we propose, instead of forcing matter to conform to digital logic we can directly exploit information from complex physical interactions to solve modelling and prediction problems. We therefore argue, matter can be trained and perturbed to solve machine learning problems without heavily constraining the base substrate. To achieve this, we take an unconventional material, configure it through evolution to create an (unconventional) virtual machine, and then train that to perform computational tasks (unconventional computation).

By implementing a low-level abstraction we can make sense of all observable information whilst still utilising the full complexity of the substrate. In our (static) materials this is implemented using an adapted Reservoir Computing model [1]. This model allows us to train high-dimensional (open) systems without high-level abstraction.

At its centre, the ``reservoir'' (i.e. material), projects and separates embedded features within its input and stores them as addressable spatial-temporal states. These states are then extracted and combined (in the digital domain) to form a learned output using a trainable output filter [1].

The adapted reservoir model is adjustable through three important parameters; the microscopic material function, the macrostate projection and the output filter. Computation is shared across these parameters and heavily weighted towards the materials function and projection.

For the model to fit and for training to work, the material needs to form a suitable reservoir. In some cases, we argue a reservoir may only exist or emerge in a material under stimulation. This hypothesis therefore suggests a configurable material can be mapped to anywhere within the spectrum of all possible reservoirs; from poor to excellent.

Rather than manually searching for good reservoirs, applying evolutionary algorithms are suggested. Research from evolution-in-materio has demonstrated that matter can be configured via evolution to solve complex problems. Evolution is advantageous here for two reasons; i) the search is performed on a black-box, i.e. knowing the exact microstates that achieve a particular macrostate are somewhat redundant - similar to how a reservoir functions, ii) evolution is not restricted by domain knowledge, e.g. evolution can exploit

properties or “defects” unknown to the designer, which could lead to more efficient designs.

The concept of evolving unconventional materials and training them as reservoirs has been shown in [1]. In that work, randomly dispersed networks of carbon nanotubes (in polymers) form reservoirs trained on multiple temporal tasks. This first demonstration of the principle has provided competitive results to other methodologies and unconventional systems. It has also highlighted both the future potential and current challenges of the concept.

[1] Dale, M. et al. 2016. Evolving Carbon Nanotube Reservoir Computers. 2016 (Accepted). Proceedings of the 15th Conference on Unconventional Computation and Natural Computation (UCNC).

Impact of ALife Simulation of Darwin's and Lamarck's Theories of Evolution on Life and Society

Yuliya Betkher, Vitor Santos and Nuno Nabais

Abstract:
Until nowadays, the scientific community firmly rejected the Theory of Inheritance of Acquired Characteristics, a theory mostly associated with the name of Jean-Baptiste Lamarck (1774-1829). Though largely dismissed when applied to biological organisms, this theory found its place in a young discipline called Artificial Life. Based on two models of Darwinian and Lamarckian evolutionary theories using neural networks and genetic algorithms, this paper deals with the philosophical implications of Lamarckian inheritance at the level of mind and discusses possible consequences of the application of the Lamarckian inheritance framework in engineering and ethics in the nearest future. In these models, neural network is regarded as a learnable individual, and genetic algorithms are applied to the population of such individuals based on mechanisms of natural evolutionary processes and genetics.

Jean-Baptiste Lamarck (1744-1829) and Charles Darwin (1809-1882) both contemplated and developed ideas about how life on earth evolved to be the way it is now. In natural systems, Darwin's Theory of Evolution has been supported by evidence from a wide variety of scientific disciplines, and Lamarck's Theory of Inheritance of Acquired Characteristics has been proven wrong. Nevertheless, Lamarckian evolution has found its place and been proven effective within computer applications.

Since the Darwinian theory of evolution gained widespread acceptance in the late 1800s, scientists and philosophers have been looking for ways to relate traditional evolutionary theory to the way we live, interact with society, and think about our place in existence. With the emergence of artificial life as a discipline, the focus of the research extends to alternative evolutionary theories such as Lamarckian, since they are being widely applied in artificial environments. The questions of particular interest are how much of an influence Lamarckian evolution in ALife has on human behavior, and what are the philosophical implications of such evolution on issues that relate to ethics and morality.

Instead of presenting an automaton with single-layer neural networks like in AntFarm, we trained a multilayer neural network using backpropagation or the generalized delta rule. Training a network included the feedforward of the input training pattern, the back propagation of the associated error, and the adjustment of the weights.

The members of our focus group from the field of information systems concluded that this model can be used to demonstrate simplified evolutionary mechanisms of Lamarckian and Darwinian theories. The biologist confirmed that Lamarck was at least partially correct all along, and in some ways this evolution is already real (e.g. related to our instincts like fear of snakes or ability to breathe or to eat. Philosophers stated that if any of such systems meet the criteria of being considered alive, such evolution creates numerous philosophical questions, like whether the concept of free will disappears or not, or if Lamarckian inheritance of knowledge would do us any good. In static systems, this process would significantly impact the speed of the evolution, but in dynamic environments such as real world, Darwinian evolution and “slow” learning by trial and error seems to make perfect sense.

On the timescale of interactions in bio-hybrid systems

Rob Mills, Martina Szopek, Michael Bodi, Thomas Schmickl and Luís Correia

Abstract:
An emerging method within robo-ethology to study collective animal behaviours is to construct bio-hybrid societies: communities of robots that are immersed in an animal society (Halloy et al 2007). The intention is that robots can modulate the overall behaviour of the animals by injecting information; this should yield knowledge about influencing factors in collective dynamics. Within the ASSISIbf project (Zahadat et al 2014), we are developing bio-hybrid societies involving honeybees and arrays of distributed robots. Central to our work is establishing communication channels between these communities, including among multiple groups of animals that only interact via the robots. Even among conspecifics, natural systems in general exhibit substantial variability and nevertheless frequently appear resilient to such variability. One fundamental aspect of a population is its characteristic timescale, which may be modulated by local environmental conditions, individual characteristics, or population composition. However, the impact of differing characteristic timescales on successful collaboration in multi-group bio-hybrid systems is unclear.

Here we use simulation modelling to study a two-group bio-hybrid society, with the between-group interactions mediated by robotic devices. We consider groups of agents to exhibit two motion speeds, but are otherwise identical. By isolating a single aspect that differs between populations, we investigate the coordination ability as a function of characteristic time in a controlled condition.

Specifically, we simulate juvenile honeybees, which exhibit collective thermotaxis -- in groups, the ability to aggregate in environment regions of specific temperature. The bees act within an environment that is affected by by robots, which link the local bee density to the emitted temperature (see Mills et al, 2015).

Our preliminary results indicate that there is appreciable robustness in coordinated collective decision making in the face of varying motion speed: with less than a three-fold difference between populations, there is no significant difference in decision-making rates. Moreover, when comparing the response of a fast population interacting with populations of varying speed, the collective behaviour is not different until the difference is eight-fold.

We are currently investigating `leadership' -- does the faster population drive the decisions that create a gradient in the environment for the slow population to follow? Intriguingly, the coupling of populations operating at different timescales -- despite not differing in any other characteristics -- offers a balance of exploration and exploitation, which may be important in accommodating unstable or variable environments.

Acknowledgement. This work is supported by: EU-ICT project ASSISI no. 601074, and by centre grant (to BioISI, ref: UID/MULTI/ 04046/2013), from FCT/MCTES/PIDDAC, Portugal.

References

Halloy, J. et~al. (2007). Social integration of robots into groups of cockroaches to control self-organized choices. Science, 318(5853):1155–1158.

Mills, R. et al. (2015). Coordination of collective behaviours in spatially separated agents. In Procs. ECAL, pages 579–586.

Zahadat, P. et~al. (2014). Social adaptation of robots for modulating self-organization in animal societies. In Procs SASO, pages 55--60.

Complex systems approach to temporal soundscape partitioning in bird communities

Reiji Suzuki

Abstract

In forests, many male birds produce long vocalizations called songs to advertise their territory or attract females in a breeding season. Rather than vocalize at random, they may divide up soundscape in such a manner that they avoid overlap with the songs of other bird species or individuals (e.g., start to sing after other species finished singing) to communicate with neighbors efficiently. There have been empirical studies on the temporal partitioning or overlap avoidance of singing behaviors of songbirds with various time scales (Cody and Brown 1969, Masco et al. 2016).

Such acoustic interactions are interesting phenomena from the viewpoint of ALife or complex systems studies (Suzuki and Cody, Proc. of the 20th Symposium on Artificial Life and Robotics, pp. 11-15, 2015). This is because a temporal soundscape partitioning can be regarded as a self-organizing phenomenon emerging from interactions among neighboring individuals based on adaptive behavioral plasticity. Our purpose is to clarify the underlying dynamics and evolutionary significance of such acoustic interactions from both empirical and theoretical standpoints.

As an empirical approach, we are developing an easily-available and portable recording system (Suzuki, Hedley and Cody, Abstract Book of the 2015 Joint Meeting of the AOU/COS, 86, 2015), which we call HARKBird. It consists of a standard laptop PC with an open source robot audition system HARK (Honda Research Institute Japan Audition for Robots with Kyoto University) (Nakadai et al., Advanced Robotics, 24, 739-761, 2010) and a commercially available low-cost microphone array. It helps us with annotating recordings and grasping the soundscape around the microphone array by extracting the degree of arrival (DOA) of sound sources and its separated sound automatically. Our preliminary analyses, based on the annotation of singing behaviors in our research field in Japan, suggests that there might be the temporal overlap avoidance of songs among several different species. We also analyzing the existence of asymmetric information flows between species, implying the existence of inter-specific diversity in behavioral plasticity.

As a theoretical approach, to consider the evolutionary significance of such a diversity in behavioral plasticity, we have been constructing and analyzing computational models of the evolution of the niche overlap avoidance behaviors (Suzuki, Taylor and Cody, Artificial Life and Robotics, 17, 30-34, 2012; Suzuki and Arita, Journal of Theoretical Biology, 352, 51-59, 2014). In these models, several different species participate in a partitioning of their shared niches and evolve their behavioral plasticity to avoid an overlap of their niche use. The results showed that diversity in the behavioral plasticity can contribute to a more efficient establishment of niche partitioning. We are further extending this model to discuss the evolution of the intra-specific diversity in behavioral plasticity.

We present the current state of these research projects from the viewpoint of complex systems.

Acknowledgment: This work was supported in part by JSPS KAKENHI 15K00335, 16K00294 and 24220006.

Expanding the limits of bistability modelling: a Boolean-based continuous representation of the lac operon regulation dynamics

Marco Montalva Medel, Fabiola Lobos, Thomas Ledger and Eric Goles

Abstract:
Bistability is a defining characteristic of the lac operon in *Escherichia coli* because it is an inducible system, responsible for the metabolism of lactose in the absence of glucose, where the operon is either induced (ON) or uninduced (OFF) in a single cell, in response to specific extracellular lactose and/or glucose concentrations. As the basic components of its regulation network have been well characterized, it is an ideal candidate for global analysis and modelling. Although mathematic models of its functioning have been attempted repeatedly, the biologically bistable behaviour of the system when confronted with variable concentrations of the inhibitor glucose has not been accurately reproduced so far, describing only its behaviour separately at specific (low or high) sugar concentrations.

In [1], the authors proposed a Boolean model for the lac operon composed by 13 nodes; 10 represent the main mRNAs, proteins and sugars of the system, while the other 3 are binary parameters representing different concentration levels of extracellular glucose and lactose. By including stochasticity in the parameter selection and considering the absence of glucose, the model exhibits part of the qualitative behaviour as in the experiments performed in [2], where it is possible to observe a bistability region. In this work, we explore the ability of the model to reproduce the quantitative behaviour of the above experiments by transforming it into a continuous one, according to the technique presented in [3]. In particular, we are interested in observing if the bistability region is preserved. The results of simulations show a similarity with the experiments of [2] for extracellular glucose concentrations below 10 mu-M. Above that value, bistability tends to disappear. So, in an attempt to improve this situation and based on the biological literature, we propose a modification of two Boolean functions in the original discrete model. What is observed after this modification and regeneration of the ODE system with the transformation [3], is that the bistability region changes significantly with regard to the previous simulations, fitting better with the real data in all the extracellular glucose concentration range. Furthermore, using only the discrete model with the 2 improved functions, a new situation of bistability appears, unseen in the original model but present in the experiments of [2]; when concentration levels of both extracellular glucose and lactose are high.

[1] Veliz-Cuba, A., and Stigler, B. (2011). Boolean models can explain bistability in the lac operon. Journal of Computational Biology, 18(6), 783-794.
[2] Ozbudak, E. M., Thattai, M., Lim, H. N., Shraiman, B. I., and Van Oudenaarden, A. (2004). Multistability in the lactose utilization network of *Escherichia coli*. Nature, 427(6976), 737-740.
[3] Wittmann, D. M., Krumsiek, J., Saez-Rodriguez, J., Lauffenburger, D. A., Klamt, S., and Theis, F. J. (2009). Transforming Boolean models to continuous models: methodology and application to T-cell receptor signaling. BMC systems biology,3(1), 1.

Agency in Messy Chemistries: Information-Theoretic Measures vs. Strategies Case Study in a Reaction-Diffusion Model

Nathanael Aubert-Kato, Olaf Witkowski, Erik Hoel and Nicolas Bredeche

Abstract:

The spontaneous emergence of autonomous agents has long been a central question in the origins of life. Decades of research have attempted to reproduce this emergence within artificial systems. Among all candidate systems, a popular approach is artificial chemistry, which defines systems with chemical-like rules. Specifically, we arbitrarily choose to focus on a DNA implementation of such chemistries, using reaction-diffusion models.

Complex biological systems such as bacteria have been shown to exhibit decision-making capabilities [1,2], relying on a complex regulation network among macromolecules. On the other side of the spectrum, simple chemical reactions like combustion do not leave much room for decision. In between those two extremes, simple engineered chemical systems [3] can display interesting patterns in reaction-diffusion settings. By exploring these examples situated in the very transition to agential systems, one can hope to understand the nature and shape of the transition and identify a set of minimal conditions for it.

In this work, we measured agency in a given physical entity, through an information-theoretic model, based on the simple hypothesis that the higher level of agency displayed, the more complex dynamics it requires, and thus the more information it needs to encode. We use an evolutionary algorithm to efficiently explore the space of potential chemical reaction networks. Those systems compete in a spatial environment with energy sources that are replenished over time. We also rationally designed three possible strategies: a simple autocatalytic system, the same system with growth speed sensing triggering a conditional toxic species production (inspired by chemotaxis networks in bacteria), and a second-order autocatalyst.

None of those three strategies (simple autocatalyst, sensing system, second-order autocatalyst) would completely dominate, based on the amount of energy available and the spatial regularity of its distribution. However, the sensing system was dominant on more than 90% of the tested conditions. Based on our agency measures, we also confirmed that the systems encoding more decision-making scored higher.

Contrary to those designed strategies, evolved solutions tended toward extremely messy networks of chemicals. As a result, evolved systems tend to deplete energy sources, potentially triggering their own death. On the other hand, analysis of well performing strategies show that they are also producing intermediate elements that can be seen as secondary, less efficient energy sources. As such they are denying energy to their competitors.

Although our preliminary results do not show those strategies to trigger high agency scores or require higher levels of decision making, they present an interesting example of how, in

the origins of life, messy chemistries, that are known to emerge easily, could have been cleaned up through the pressure of agency.

References

[1] Macnab, R. M., and Koshland, D. E. The gradient-sensing mechanism in bacterial chemotaxis. PNAS, 1972

[2] Adami, C., Schossau, J. and Hintze, A. Evolution and stability of altruist strategies in microbial games. Phys. Rev. E, 2012

[3] Zaikin, A. N. and Zhabotinsky, A. M. Concentration wave propagation in two-dimensional liquid-phase self-oscillating system. Nature, 1970

Multiple action switching in embodied agents evolved for referential communication

Jorge Ivan Campos Bravo and Tom Froese

Abstract:
Action switching in embodied agents is not a trivial problem and it becomes harder to solve when the agents have to switch behaviors during a single trial on a task solving problem that requires that the actions must be performed in the right time to achieve a certain goal. Izquierdo and Buhrmann (2008) showed that we can evolve an agent to do two simple tasks using a single continuous-time recurrent neural network (Beer, 1995). The agent must know in which body is in and accomplish the task with the interaction with his environment. The interaction with the environment is crucial in the action selection process, we have to sense all the information that we can get from the environment before do something. If we want to cross the street we must first see both sides to know if we can cross over. Agmon and Beer (2014) proved that we can evolve agents that can switch between two behaviors during a single trial to solve a more complex problem. The agent must change the behavior according with his environment interaction and his internal states. The evolution of referential communication (Williams et al, 2008) in embodied agents showed that we can evolve agents with no dedicated communication channels that can pass crucial information to solve a task. The communication process emerges from a coordinated behavior between the agents. Can we make a model that solves the main problem of communication with coordinated behavior using only a single continuous-time recurrent neural network? The T-maze test used in animal cognition experiments let us a binary choice between two paths to follow. Blynel and Floreano (2003) evolved a CTRNN to solve the T-Maze test using reinforced learning. In the experiment the agent must locate and "remember" the location of the goal in a T shaped environment. The only sensor that has information about the location of the reward-zone is the floor sensor that can discriminate between a bright and a dark floor. In this case, the signal is fixed and can only be bright or dark. In the model that we propose we have the sender constrained in an area of a one dimensional environment and the receiver that can move freely on the environment. We have two targets and the sender must interact with the receiver and the receiver must go to the correct target in each trial. The sender is the only one that knows the position of the correct target in the environment. We will use the same structural copy of a CTRNN for both agents. This problem becomes harder and because the reference signal is not fixed but must co-evolve along with the rest of behavior the agent have to switch between the actions of sending and receiving depending the body they are in. Once they switch between the two roles, the receiver must switch again between receiving information and get to the correct target.

Emergent Homeostasis in a Synthetic Mutualism: modelling the interplay of abiotic and biotic interactions in an experimental proto-ecosystem

Alexandra Penn, Inman Harvey, Erik Hom and Claudio Avignone Rossa

Abstract:
Homeostasis is a core concept for both real and artificial life; here we use alife-influenced modelling techniques to analyse a specific biological scenario: A synthetic, obligate mutualism created between the yeast Saccharomyces cerevisiae and the alga Chlamydomonas reinhardtii (Hom and Murray 2014). The yeast produces CO2 to feed the alga, while the alga releases NH3 to feed the yeast in return. A crucial factor in the stability of this synthetic mutualism is the active maintenance of pH in a zone of co-viability in which both organisms can co-exist and in which their relative population sizes are stabilised at a lower level. In this seemingly homeostatic system, the interaction of both the mutualistic cross-feeding dynamics and the species effect on and tolerance to environmental pH is required to maintain a stable and persistent ecosystem.

Each mutualistic partner has opposite pH preferences and opposite directions of environmental (pH) forcing. Crucially, both organisms force pH in the direction of their own preference (and beyond it), resulting in an unstable equilibrium in the absence of the obligate mutualism. Thus, without mutualism, we would expect to see the system run away to extreme pH, resulting in extinction of one of the species. In conditions of obligate mutualism, the co-culture system becomes homeostatic with respect to pH: if either partner grows too rapidly, moving the pH out of the co-viability zone and thus reducing the growth of its mutualistic partner, its growth will be constrained by a negative feedback resulting from the reduction of an essential nutrient provided by the mutualism. The addition of these extra constraining feedbacks transforms the unstable equilibrium into a dynamically stable “homeostatic” state in which pH is maintained within a tolerable, but sub-optimal, range for both species, allowing them to stably coexist.

This simple system clearly shows a “synergistic homeostasis” arising without prior co-evolution of the two partners, which may be akin to rein control. Models of multi-species, rein control homeostasis have demonstrated a large range of dynamical behaviours can be possible. The existence of such dynamics and the overall structure of the system’s stability landscape depend strongly on the relative natures of forcing and preference functions over all species. In our system the mutualistic interaction between species and its connection to other environmental variables render the dynamics even more complex.
In this poster, we present the first results of simple models of the mechanism of homeostasis within the experimental system and their relationship to well-known models of rein control. We discuss crucial factors such as the persistence of pH as an environmental variable and the role of mutualism. We speculate on the potential consequences for the resilience and evolvability of such mutualisms, wherein extended persistence and co-evolution of species plus potential discontinuous change values of environmental and population variables provide a system-level context that may significantly alter the outcome of selective processes. We further discuss consequences for synthetic ecology and

implications for effective system design and engineering or manipulation of stable consortia, in both artificial life and real biological scenarios.

Complex modelling of bacterial interactions using an agent-based model

Eneas Aguirre-Von-Wobeser, Juan Toledo-Roy, Ana Leonor Rivera, Valeria Souza and Alejandro Frank

Abstract:
In natural communities, competition between similar species for limited resources can be strong (Tilman 2004, Proc Natl Acad Sci USA 101: 10854–10861). When different species compete for the same resources in a homogeneous environment, in the absence of complex interspecies interactions, an equilibrium establishes where at most the same number of species as limited resources coexist (Hardin 1960, Science 131: 1292-1297). This classical result, termed Competitive Exclusion Principle, is supported amply by experimental evidence. However, coexisting species are often observed in larger numbers than the limiting resources that can be identified, particularly in microbial communities, which is known as the Paradox of the Plankton (Hutchinson 1969, Am Nat 95:137-145).

Several mechanisms have been proposed to explain the large local biodiversity of microorganisms found in many environments (Roy & Chatopadhyay 2007, Ecological Complexity 4:26–33). A role of the production of antimicrobial compounds in the maintenance of biodiversity has been proposed (Czárán et al. 2002, Proc Natl Acad Sci USA 99:786-790). Such compounds, produced by many bacteria, hinder the growth, or even kill competing cells (e.g. Michel-Briand & Baysse 2002, Biochimie 84:499-510; Laskaris et al., 2010, Environ Microbiol 12:783-796). Antimicrobial compounds could promote the coexistence of bacterial strains due to the formation of non-transitive cycles, where the producer has an advantage over the sensitive ones, but is an inferior grower compared to resistant strains, which in turn grow slower than the sensitive ones (Riley et al. 2003, J Evol Biol 16:690–697).

Spatial structure is essential for coexistence based in these non-transitive cycles, since confrontations between pairs of strains take place locally in patches (Kerr et al. 2002 Nature 418:171-174). Thus, spatially explicit models have been used extensively to study the effects of antimicrobial substance production on microbial coexistence in naturally structured environments like soils (Vetsigian et al. 2011, Plos Biol 9:e1001184). Using cellular automata, coexistence of multiple bacterial strains is observed (Czárán et al. 2003, Proc R Soc Lond B 270:1373-1378; Zapién-Campos et al. 2015, Front Microbiol 6:489).

Cellular automata have also been used to describe bacteria under incompletely mixed water environments (Hulolt & Huisman 2004, Limnol Oceanogr 49:1424–1434). However, for low biomass water communities, huge grids with many empty cells would be needed for realistic simulations. Agent-based models, a related approach where the individual organisms are followed, might be more suitable for this kind of communities. Agent-based models have been used to study bacterial populations for diverse settings and research questions (Hellweger & Bucci 2009, Ecol Model 220:8-22).

Here, we used Agent-based modelling to study microbial competition under a constant input of discreet food particles, to test whether those particles could introduce enough

structure for coexistence, as we proposed before (Aguirre-von-Wobeser et al., 2015, Front Microbiol 6:490). We found that coexistence was promoted in this model, even in the absence of antagonistic activity. On the other hand, the effect of antagonism on coexistence was highly dependent on the density of food particles provided, allowing for maximum coexistence at intermediate input levels.

A set theoretic analysis shows different forms of closure in autopoietic theory, computational autopoiesis, and (M,R)-systems

Dobromir Dotov and Tom Froese

Abstract:

There has been an enduring stance in artificial life that a notion of circular entailment is required in order to appropriately capture the self-maintenance of living systems. The detailed character of this circular entailment can differ across approaches. The recursive operation of dynamical systems, the control feedback loops of cybernetics, the operational closure of autopoiesis, the top-down–bottom-up mutual constraint found in certain complex physical systems, and the closure to efficient cause of Rosenian complexity are all forms of circular entailment. In the latter case, a living system is understood as a collection of biological processes such as metabolism and repair whereby the system contains within itself the efficient causes of the making of these processes. Each process is the product of another process and these are contained in a closed set. In this sense a living system must exhibit closure to efficient cause.

How to determine the correspondence among these notions of circular cause and effect given that the different theoretical approaches have rarely been compared formally? A comparative approach is necessary in order to help consolidate the theory in artificial life. It has been proposed that set theory is both sufficiently abstract and rigorous to serve as framework for formalizing various domain-specific systems in nature such as particular social or biological systems as abstract cross-domain general systems (Mesarovic and Takahara, 1975). As a demonstration of what this could mean and how to achieve it, here we apply the suggested tools of set theory (Chemero and Turvey, 2008) in order to compare in a formal way autopoiesis, Randall Beer's GoL computational model of autopoiesis (Beer, 2014), Robert Rosen's complexity, and several other physical systems and their simulations.

The outcome of this analysis is that the computational models appear to possess operational closure but not closure to efficient cause unlike autopoiesis and complexity which possess both kinds of closure. This result is not surprising. Beer (2015, p.17) acknowledges that GoL is a model that reproduces certain properties of autopoiesis but it is not to be a complete instance of a simulated living system. This result should not be taken as diminishing the importance of simulation as a method of theoretical modeling, rather as a tool in determining the correspondence among different models and theories. An additional result is that at a theoretical level, operational closure is a more encompassing condition than closure to efficient causation. In conclusion, the field of artificial life would benefit from the existence of comparative work synthesizing the various conditions ("closures") necessary for living systems.

References

Beer, R. D. (2014). The cognitive domain of a glider in the game of life. Artificial Life, 20(812):183–206.

Beer, R. D. (2015). Characterizing autopoiesis in the game of life. Artificial Life, 21(1):1–19.

Chemero, A. and Turvey, M. T. (2008). Autonomy and hypersets. Bio Systems, 91(2):320–30.

Mesarovic, M. and Takahara, Y. (1975). General Systems Theory: Mathematical Foundations. Academic Press, New York, NY.

Synesthesia in Artificial Life

Eiko Matsuda and Takashi Ikegami

Abstract:
How can structures and patterns of pre-representational cognition evolve in primitive living systems? In the field of artificial life, we analyzed this question by simulating simple evolutionary robots. For example, we developed a robot that exhibits vicarious trialand-error (VTE) phenomena (2014), which is regarded as a deliberative decisionmaking process, e.g., searching, predicting, and evaluating outcomes. This process is slower than reflective action and can be understood as mediated by representation or pseudo-representational processes. In another evolutionary robot study, Morimoto and Ikegami (2004) showed how a robot's object categorization is formed by active touch, i.e., sensing by actively touching objects. Categorization by active touch exemplifies how a robot's motion structure can become differentiated due to the differences between object shapes. We assert that synesthesia can mediate mental representations of various kinds, e.g., sound and color. Studies on evolutionary robotics can provide evolutionary and ontogenetic prerequisites of any mental representation from dynamical behaviors.

In the field of psychological studies, synesthesia is defined as a sensation whereby a sensory stimulus evokes exceptional and incongruous experiences. For instance, reading graphemes induces color perception (Ward, 2013). Some researchers suggest that concurrent colors induced by graphemes can act as highlights for ease of remembering the grapheme (Asano and Yokosawa, 2013). Based on these previous findings, we hypothesized that synesthetic tendency – if it is weak – can generally be observed in children, helping them to understand and learn graphemes.

Matsuda and Okazaki quantified changes in synesthesia through development (Matsuda and Okazaki, 2016; Matsuda et al., 2013; Smilek et al., 2007; Simner and Holenstein, 2007). By conducting a paper-based questionnaire involving 213 children in Japanese elementary schools (9–12 years old; mean=11.0, S.D.=1.01), the results were analyzed based on the consistency levels in their answers. As a result, almost all the children obtained significantly higher scores than the random answers, suggesting that the participants had a modest level of synesthetic tendencies. Moreover, it was suggested that synesthetic tendencies are more observable in younger children.

Evolutionary robotics and human synesthetic studies can be linked in relation to subjective experiences. Ikegami and Zlatev (2007) maintained that experiences generally composed of several sensory modalities. The paper refers to a famous Japanese novel And Then as an example of describing subjective experience in terms of synesthesia (p.272): "Turning to the head of his bed (proprioceptive), he noticed a single camellia blossom that had fallen to the floor (visual). He was certain he had heard it drop during the night (hearing): the sound had resounded in his ears like a rubber ball bounced off the ceiling" (hearing). This novel shares similar properties with synesthesia in relation to the multimodality and arbitrariness of the mappings between sensory stimuli and concurrent sensations recalled from personal memories. We think that subjective experience is essentially composed of multimodal information and arbitral associations formed though personal memories. In the talk, we discuss new discoveries in recent synesthesia studies and how to model “subjective experience” with ALife This is a necessary step toward naturalizing subjective experiences with evolutionary robotics.

An Evolutionary Robotic Model of Explicit Agency Detection

Leticia Cruz and Tom Froese

Abstract:
Studying social cognition implies to deal with two different approaches. On the one hand, the individualism point of view mainly used by cognitive science, where social interaction is the result of individual cognition capacities. On the other hand, the interactionist perspective focused on that the resultant behavior of two or more individuals relies on collective dynamical interaction mechanisms. However, the interaction role has not been considered as an important factor in social cognition. Some of the difficulties are related to the identification of qualitative and quantitative essential characteristics of the overall processes (Lenay and Stewart, 2012). In order to have better analytical tools, Auvray et al. (2009) proposed a minimal cognition model that reduces of social cognition to the most basic elements. The aim of this experiment was to identify the underlying mechanisms due to the recognition of an intentional subject. The results showed that the behavior of the individuals encouraged the interactions with the other participant, as well as the discrimination of the objects due to individual's oscillatory movements. Additionally, there were developed works focusing on the discrimination from online interactions and recordings (Di Paolo et al., 2008) and dynamic stability (Froese and Di Paolo, 2011). In order to continue these efforts, we replicated the Auvray's psychological experiment using the Evolutionary Robotics methodology. We developed a synthetic model to investigate the interaction dynamics of explicit agency recognition between agents. The experiment demonstrates that there is an engagement between the agents in the interaction with each other in spite of the obstacles encountered in the environment. Our results were similar compared with the original experiment: the clicks between agents 66%, when meeting the shadow objects 28% and the static objects 5%. Regarding the source of stimulation: 69.7% due to the other agent, 17.12% for the shadow object and 12.7% in the case of the static object. We show that the explicit recognition of the other is not just based on individual capacities of the agents but on the dynamics of the joint perceptual activity itself. Accordingly, we confirm the crucial relevance of interaction as a key explanatory factor in order to have a deep understanding of social cognition. Additionally, we consider this experiment as a novel contribution to understanding in a more holistic perspective the explicit recognition of an intentional subject.

References

Auvray, M., Lenay, C., and Stewart, J. (2009). Perceptual interactions in a minimalist environment. New Ideas Psychol. 27, 79–97.

Di Paolo, E., Rohde, M., and Iizuka, H. (2008). Sensitivity to social contingency or stability of interaction? Modelling the dynamics of perceptual crossing. New Ideas Psychol. 26, 278–294.

Froese, T., and Di Paolo, E. (2011), "Toward minimally social behavior: social psychology meets evolutionary robotics," in Advances in Artificial Life: Proceedings of the 10th European Conference on Artificial Life, eds G.

Kampis, I. Karsai, and E. Szathmary (Berlin, Germany: Springer Verlag), 426–433.
Lenay, C. & Stewart, J. Minimalist approach to perceptual interactions. Front. Hum. Neurosci. 6, doi:10.3389/fnhum.2012.00098 (2012).

Can we incorporate sleep-like interruptions into evolutionary robotics?

Mario A. Zarco-López and Tom Froese

Abstract:
Traditional use of Hopfield networks can be divided into two main categories: (1) constraint satisfaction based on predefined a weight space, and (2) model induction based on a training set of patterns. Recently, Watson et al. (2011) have demonstrated that combining these two aspects, i.e. by inducing a model of the network's attractors by applying Hebbian learning after constraint satisfaction, can lead to self-optimization of network connectivity. A key element of their approach is a repeated randomized reset and relaxation of network state, which has been interpreted as similar to the function of sleep (Woodward, Froese, & Ikegami, 2015). This perspective might give rise to an alternative "wake-sleep" algorithm (Hinton, Dayan, Frey, & Neal, 1995). All of this research, however, has taken place with isolated artificial neural networks, which goes against decades of work on situated robotics (Cliff, 1991). We consider the challenges involved in extending this work on sleep-like self-optimization to the dynamical approach to cognition, in which behavior is seen as emerging from the interactions of brain, body and environment (Beer, 2000).

References

Beer, R. D. (2000). Dynamical approaches to cognitive science. Trends in Cognitive Sciences, 4(3), 91-99.

Cliff, D. (1991). Computational neuroethology: A provisional manifesto. In J.-A. Meyer & S. W. Wilson (Eds.), From Animals to Animats (pp. 29-39). MIT Press.

Hinton, G. E., Dayan, P., Frey, B. J., & Neal, R. M. (1995). The "wake-sleep" algorithm for unsupervised neural networks. Science, 268, 1158-1161.

Watson, R. A., Buckley, C. L., & Mills, R. (2011). Optimization in "self-modeling" complex adaptive systems. Complexity, 16(5), 17-26.

Woodward, A., Froese, T., & Ikegami, T. (2015). Neural coordination can be enhanced by occasional interruption of normal firing patterns: A self-optimizing spiking neural network model. Neural Networks, 62, 39-46.