Keynotes [blue room]

Keynote: Rob Dunn *The Past and Future of the Evolution of Intelligence in Nature*	18.07.2022 17:00 CEST
Keynote: Masatoshi Funabashi *Life as it will be -The Coevolution of Artificial and Biological life in Anthropocene*	19.07.2022 09:00 CEST
Keynote: Melanie E. Moses *Learning from COVID-19: The extraordinary success of the questionably alive*	19.07.2022 17:00 CEST
Keynote: Job Boekhoven *Chemically fueled droplets; towards the synthesis of life*	20.07.2022 09:00 CEST
Keynote: David O. Obura *Coral reefs, climate change and pathways into the future - a case study for future realities*	20.07.2022 17:00 CEST
Keynote: Dora Tang *Building life from scratch? Exploiting synthetic cellularity*	21.07.2022 09:00 CEST
Keynote: Susanne Still *Inference, prediction and thermodynamic efficiency*	21.07.2022 17:00 CEST
Keynote: Stuart Bartlett *Searching for Lyfe, Genesity, Complexity and Emergent Learning*	22.07.2022 09:00 CEST

Contributed Talks [blue room]

3. **Heterogeneity and Robustness in Social Learning** *Jonathan Lawry* Social learning is an important collective behaviour in many biological and artificial systems. We investigate a model of social learning which combines two distinct processes, one relating to how individuals adapt their beliefs as a result of interacting with their peers, and one relating to when they search for and how they learn directly from evidence. For each process we introduce conservative and open-minded behaviours and combine these to obtain four social learning behaviour types. A simple truth-seeking task is considered and a three-valued model of belief states is adopted. By means of difference equation models and agent-based simulations we then investigate the performance of the different learning behaviours. We show that certain heterogeneous mixtures of behaviours result in the most robust performance for a variety of learning rates and initial conditions, and that such mixtures are well suited for social learning in dynamic environments.	18.07.2022 10:20 CEST
92. **Bottom-up formation of number representation and top-down understanding of symbolic manipulation** *Yasuhiro Shimada, Wataru Noguchi, Hiroyuki Iizuka and Masahito Yamamoto* Several studies that deal with the acquisition of concepts in a bottom-up manner from experiences in the physical space exist, but there are few of them that deal with the bidirectional interaction between symbolic operations and experiences in the physical world. It was shown that a shared module neural network succeeded in generating a bottom-up spatial representation of the external world, without involving learning of the signals of the spatial structure. Furthermore, the module can understand the external map as a symbol based on its spatial representation, and top-down navigation can be performed	18.07.2022 10:40 CEST

using the map. In this study, we extended this model and proposed a simulation model that unifies the emergence of a number representation, learning of symbol manipulation on the representation, and top-down understanding of symbol manipulation onto the physical world. Our results show that the learning results of the symbol manipulation can be applied to the physical world prediction, and our proposed model succeeded in grounding symbol manipulation onto physical experiences.	
59. **Exploration and exploitation of the adjacent possible space for open-endedness** *Mikihiro Suda, Takumi Saito and Mizuki Oka* We use an agent-based model with the concept of adjacency possible space to analyze the interactions that contribute to the development of a more open-ended network. Specifically, we analyze the balance between exploration for newness and exploitation for access to existing things, and how the method of exploring possible adjacent spaces contributes to the growth of the network. The results show that in terms of open-ended evolution, the value of exploration is greater than exploitation and that the more random the search for possible adjacent spaces, the more likely new nodes will be accessed.	18.07.2022 11:00 CEST
103. **Simulations and the evolution of consciousness** *Joshua Bensemann, Padriac Amato Tahua O'Leary, Yang Chen, Ludmila Miranda-Dukoski and Michael Witbrock* We hypothesize that the emergence of consciousness in humans is directly related to the complexity, number of, and evolution of specialized cognitive systems. Here, we present our rationale and plan for an ongoing project to investigate the pathway to the emergence of consciousness via computer simulations of humans' evolutionary niche using artificialintelligence agents. Agents will contain subsets of the specialized cognitive systems and will complete tasks modeled after pressures encountered by early humans. We will observe whether the increase in cognitive complexity, measured by the number and complexity of the specialized cognitive systems, leads to an increase in task performance.	18.07.2022 11:15 CEST
76. **A Partial Integro-Differential Equation-Based Model of Adaptive Social Network Dynamics** *Hiroki Sayama*	18.07.2022 11:30 CEST

We formulated and analyzed a set of partial integro differential equations (PIDEs) that capture the dynamics of the adaptive network model of social fragmentation involving behavioral diversity of agents proposed in (Anonymous, 2020). Previous results showed that, if the agents' cultural tolerance levels were diversified, the social network could remain connected while maintaining cultural diversity. Here we converted the original agent-based model into a continuous equation-based one so we can gain more theoretical insight into the model dynamics (Anonymous, 2022). We restricted the node states to 1-D continuous values and assumed the network size was very large. As a result, we represented the whole system as a set of PIDEs about population density and connection density. The results of numerical integrations were consistent with the simulations of the original agent-based adaptive social network model. Specifically, when the variance of cultural tolerance d is large enough, the population with low d maintains the original clusters of cultures/ opinions, while the one with high d tends to come to the center and connect culturally distant groups.	
117. **Towards a Unified Framework for Technological and Biological Evolution** *Roger Tucker* It has long been observed that human cultural evolution is in some ways analogous to biological evolution, having reproduction with variation and a form of selection, but the fact that both technology and biology are physical brings them much closer than culture in general. Many have observed that they share universal traits that pervade their long-term trends, yet they seem so different. What is at the root of this? This paper considers a number of features that would seem essential to any evolutionary system which produces real artefacts – construction, search, selection and various aspects of structure and organisation – and explains briefly how each operate in technological and biological evolution. This provides a basic unified framework which can then be extended. Such a framework would help progress bio-inspired design, and suggest features to study on the way to meet the grand challenge of Open Ended Evolution.	18.07.2022 11:50 CEST
75. **Shake on It: The Role of Commitments and the Evolution of Coordination in Networks of Technology Firms** *Ndidi Bianca Ogbo, Theodor Cimpeanu, Alessandro Di Stefano and The Anh Han*	18.07.2022 12:10 CEST

Before embarking on a new collective venture, it is important to understand partners' preferences and intentions and how strongly they commit to a common goal. Arranging prior commitments of future actions has been shown to be an evolutionary viable strategy in the context of social dilemmas. Previous works have focused on simple well-mixed population settings, for ease of analysis. Here, starting from a baseline model of a coordination game with asymmetric benefits for technology adoption in the well-mixed setting, we examine the impact of different population structures, including square lattice and scale-free (SF) networks, capturing typical homogeneous and heterogeneous network structures, on the dynamics of decision-making in the context of coordinating technology adoption. We show that, similarly to previous well-mixed analyses, prior commitments enhance coordination and the overall population payoff in structured populations, especially when the cost of commitment is justified against the benefit of coordination, and when the technology market is highly competitive. When commitments are absent, slightly higher levels of coordination and population welfare are obtained in SF than lattice. In the presence of commitments and when the market is very competitive, the overall population welfare is similar in both lattice and heterogeneous networks; though it is slightly lower in SF when the market competition is low, while social welfare suffers in a monopolistic setting. Overall, we observe that commitments can improve coordination and population welfare in structured populations, but in its presence, the outcome of evolutionary dynamics is, interestingly, not sensitive to changes in the network structure.	
33. **The evolution of adaptive phenotypic plasticity stabilizes populations against environmental fluctuations** *Alexander Lalejini, Austin J. Ferguson, Nkrumah Grant and Charles Ofria* In this extended abstract, we summarize the findings of our recently published study, "Adaptive phenotypic plasticity stabilizes evolution in fluctuating environments". Environmental fluctuations are ubiquitous in natural systems, and populations have evolved a wide range of strategies to cope with environmental changes. The mechanisms that evolve profoundly influence subsequent evolution. One such mechanism is phenotypic plasticity, which is the capacity for a single genotype to produce alternate phenotypes depending on environmental conditions. We used populations of self-replicating computer programs (digital	18.07.2022 12:30 CEST

organisms) to investigate the evolutionary consequences of adaptive plasticity in a cyclically changing environment. Specifically, we examined the evolutionary histories of both adaptively plastic and non-plastic populations to ask: (1) Does adaptive plasticity promote or constrain evolutionary change? (2) Are plastic populations better able to evolve and then maintain novel traits? And (3), how does adaptive plasticity affect the potential for maladaptive alleles to accumulate in evolving genomes? We found that the evolution of adaptive plasticity reduced subsequent rates of evolutionary change in a cyclic environment. Non-plastic populations underwent more frequent selective sweeps and accumulated more genetic changes over time, as non-plastic populations relied on genetic variation from de novo mutations to continuously readapt to environmental changes. The evolution of adaptive phenotypic plasticity buffered populations against environmental fluctuations, whereas repeated selective sweeps in non-plastic populations drove the accumulation of deleterious mutations and the loss of secondary beneficial traits. As such, adaptively plastic populations were better able to retain novel traits than their non-plastic counterparts. In general, the evolution of adaptive phenotypic plasticity shifted evolutionary dynamics to be more similar to that of populations evolving in a static environment than to non-plastic populations evolving in an identical fluctuating environment.	
101. **Is Prediction Required? Using Evolutionary Robotics to Investigate How Systems Cope with Self-Caused Stimuli** *James Garner and Matthew Egbert* Living systems process sensory data to facilitate adaptive behaviour, but the same sensors can receive inputs both from purely external (environmental) sources, and as the result of internally driven activity. It is clear that these inputs are processed differently. The canonical explanation of this is that when the brain sends a signal that would result in motor activity, it uses a copy of that signal to predict the sensory consequences of the resulting motor activity. The predicted sensory input is then subtracted from the actual sensory input, resulting in the attenuation of the stimuli. To critically evaluate this idea, and investigate when non-predictive solutions may be viable, we implement a computational model of a simple embodied system with self-caused sensorimotor dynamics, and analyse how controllers successfully accomplish tasks in this model. We find that in these simple systems, solutions that regulate behaviour to control self-caused sensory inputs tend to emerge, rather than solutions which predict and filter out self-caused inputs - on the contrary, the proper functioning of these solutions depends on its presence.	18.07.2022 12:45 CEST

54. **Reliably Re-Acting to Partner's Actions with the Social Intrinsic Motivation of Transfer Empowerment** *Tessa van der Heiden, Herke van Hoof, Efstratios Gavves and Christoph Salge* We consider multi-agent reinforcement learning (MARL) for cooperative communication and coordination tasks. MARL agents can be brittle because they can overfit their training partners' policies. This overfitting can produce agents that adopt policies that act under the expectation that other agents will act in a certain way rather than react to their actions. Our objective is to bias the learning process towards finding reactive strategies towards other agents' behaviors. Our method, transfer empowerment, measures the potential influence between agents' actions. Results from three simulated cooperation scenarios support our hypothesis that transfer empowerment improves MARL performance. We discuss how transfer empowerment could be a useful principle to guide multiagent coordination by ensuring reactiveness to ones partner.	18.07.2022 14:00 CEST
61. **Toward automatic generation of diverse congestion control algorithms through co-evolution with simulation environments** *Teruto Endo, Hirotake Abe and Mizuki Oka* A definitive congestion control algorithm has yet to be developed. There are three reasons for this: First, the environment and usage of the Internet continue to evolve over time. Second, it is not clear what congestion control algorithms will be required as the environment evolves. Third, there is a limit to the number of the congestion control algorithms that can be developed by researchers. This paper proposes a method for automatically generating diverse congestion control algorithms and optimizing them in various environments by coevolving network simulations as environments and congestion control algorithms as agents. In experiments conducted using co-evolution, although the algorithms generated were not on par with conventional practical congestion control algorithms, the intent of the procedures in the algorithms was interpretable from a human perspective. Furthermore, our results verify that it is possible to automatically discover a suitable environment for the evolution of a congestion control algorithm.	18.07.2022 14:20 CEST
95. **The Information Complexity of Navigating with Momentum** *Bente Riegler, Daniel Polani and Volker Steuber*	18.07.2022 14:40 CEST

Many models of organism navigation concern themselves in essence just with the sequence of locations visited and how to manage it. However, larger and bulkier organisms have also to deal with managing momentum. We expect that this affects the cognitive management of movement. Here we propose a simple model for the information processing complexity of navigation when velocity and acceleration are considered, moving away from a kinematic perspective to a partially dynamic model, to separate the effects of location and momentum management. The work is discussed in the context of recent neurobiological research suggesting that biological agents plan around acceleration and deceleration phases, showing high neural activity during their body's velocity changes.	
64. **Cost-efficiency of institutional reward and punishment in cooperation dilemmas** *Manh Hong Duong Duong and The Anh Han* A central challenge in biological, computational and social sciences is to understand the evolution of cooperation within populations of self-regarding individuals and mechanisms that promote it. To this extent, various mechanisms have been revealed and studied using methods from evolutionary game theory, statistical physics and agent-based modelling and simulations. They include both endogenous and exogenous mechanisms such as kin and group selection, direct and indirect reciprocity, spatial networks, reward and punishment, and pre-commitments. Institutional incentives, positive (reward) and negative (punishment), are among of the most important ones. In institutional incentives, an external decision maker (e.g. institutions such as the United Nations and the European Union) who has a budget to interfere in the population in order to achieve a desirable outcome, for instance to ensure a desired level of cooperation. Providing incentives for promoting cooperation is costly and it is thus important to optimize the cost while ensuring a sufficient level of cooperation. This extended abstract summarizes a recent work that provides a rigorous analysis, supported by numerical simulations, for the problem of cost-efficiency of institutional reward and punishment in cooperation dilemmas for finite populations. The analysis takes into account various stochastic effects of evolutionary dynamics, that have been ignored in previous works, such as mutation and those resulting from behavioural update (such as the intensity of selection). The analysis provides new,	18.07.2022 15:00 CEST

fundamental insights into a cost-efficient design of institution-based solutions for promoting pro-social behaviours in social and artificial systems. Some open problems in this emerging research direction are also discussed.	
38. **Towards Adaptive Sensorimotor Autonomy: Developing a system that can adapt to its own emergent and dynamic needs** *Matthew Egbert* Egbert and Barandiaran (2014) present a model of sensorimotor autonomy (Di Paolo et al., 2017), demonstrating how, in certain architectures and contexts, a patterns of sensorimotor activity can reinforce the very mechanism that produces it. Subsequent investigation evaluated the adaptability of these autonomous sensorimotor 'habits', showing that they were robust to some perturbations, but not capable of adapting to changes in their own viability (Egbert, 2018). I am thus working on a new model intended to capture a more adaptive form of sensorimotor autonomy. The primary component of the model is a new dynamical construct called the VIability-Sensitive Sensorimotor Autonomy (VISSA). VISSA plays the role of a 'brain' or 'controller' in an agent, transforming sensorimotor state into 'motor' output and itself being transformed by the history of sensorimotor states that it experiences. It interacts with a dynamical environment through a body's motors and sensors and through these interactions, self-sustaining patterns of sensorimotor behaviour emerge. This abstract provides an overview of VISSA's architecture and the first experiments that we are performing to evaluate its adaptability.	18.07.2022 15:15 CEST
21. **Dirty Transmission Hypothesis: Increased Mutations During Horizontal Transmission Can Select for Increased Levels of Mutualism in Endosymbionts** *Claire Schregardus, Michael Wiser and Anya Vostinar* A mutualistic symbiosis occurs when organisms of different species cooperate closely for a net benefit over time. Mutualistic relationships are important for human health, food production, and ecosystem maintenance. However, they can evolve to parasitism or breakdown all together and the conditions that maintain and influence them are not completely understood. Vertical and horizontal transmission of mutualistic endosymbionts are two factors that can influence the evolution of mutualism. Using the artificial life system, Symbulation,	18.07.2022 15:30 CEST

we studied the effects of different rates of mutation during horizontal transmission on mutualistic symbiosis at different levels of vertical transmission. We propose and provide evidence for the “Dirty Transmission Hypothesis”, which states that higher rates of mutation during horizontal transmission can select for increased mutualismto avoid deleterious mutation accumulation.	
119. **Hereditary Stratigraphy: Genome Annotations to Enable Phylogenetic Inference over Distributed Populations** *Matthew Andres Moreno, Emily Dolson and Charles Ofria* Phylogenies provide direct accounts of the evolutionary trajectories behind evolved artifacts in genetic algorithm and artificial life systems. Phylogenetic analyses can also enable insight into evolutionary and ecological dynamics such as selection pressure and frequency dependent selection. Traditionally, digital evolution systems have recorded data for phylogenetic analyses through perfect tracking where each birth event is recorded in a centralized data structures. This approach, however, does not easily scale to distributed computing environments where evolutionary individuals may migrate between a large number of disjoint processing elements. To provide for phylogenetic analyses in these environments, we propose an approach to enable phylogenies to be inferred via heritable genetic annotations rather than directly tracked. We introduce a “hereditary stratigraphy” algorithm that enables efficient, accurate phylogenetic reconstruction with tunable, explicit trade-offs between annotation memory footprint and reconstruction accuracy. In particular, we demonstrate an approach that enables estimation of the most recent common ancestor between two individuals with fixed relative accuracy irrespective of lineage depth while only requiring logarithmic annotation space complexity with respect to lineage depth. This approach can estimate, for example, MRCA generation of two genomes within 10% relative error with 95% confidence up to a depth of a trillion generations with genome annotations smaller than a kilobyte. We also simulate inference over known lineages, recovering up to 85.70% of the information contained in the original tree using a 64-bit annotation.	18.07.2022 15:50 CEST
125. **Finding Chemical Organisations in Matter-Conserving AChems** *Jonathan Young and Simon Colton* Chemical Organizations Theory (COT) provides a way of understanding the evolution of collectively self-maintaining sets of molecular species. Adding conservation of matter to an Artificial	18.07.2022 16:10 CEST

Chemistry (AChem) can increase evolutionary activity, so it may be useful to understand the evolution of organisations under these conditions. This paper shows how, in a reaction network generated by a matter-conserving chemistry, every edge within an organisation must be a part of a cycle in the organisation's underlying directed graph. A consequence of this fact is used to alter an existing algorithm to more efficiently discover the complete set of organisations. This paper contributes useful theoretical tools that facilitate the analysis of chemical evolution in matter-conserving artificial or natural chemistries.	
12. **On the Trajectories of Planetary Civilizations: Asymptotic Burnout vs. Homeostatic Awakening** *Michael Wong and Stuart Bartlett* Previous studies show that city metrics having to do with growth, productivity, and overall energy consumption scale superlinearly, attributing this to the social nature of cities. Superlinear scaling results in crises called "singularities," where population and energy demand tend to infinity in a finite amount of time, which must be avoided by ever more frequent "resets" or innovations that postpone the system's collapse. Here, we place the emergence of cities and technological civilizations in the context of major evolutionary transitions. With this perspective, we hypothesize that once a planetary civilization transitions into a state that can be described as one virtually connected global city, it will face an "asymptotic burnout," an ultimate crisis where the singularity-interval timescale becomes smaller than the timescale of innovation. If a civilization develops the capability to understand its own trajectory, it will have a window of time to affect a fundamental change to prioritize long-term homeostasis and well-being over unyielding growth—a consciously induced trajectory change or "homeostatic awakening." We propose a new resolution to the Fermi paradox: civilizations either collapse from burnout or redirect themselves to prioritizing homeostasis, a state where cosmic expansion is no longer a goal, making them difficult to detect remotely.	18.07.2022 16:30 CEST
28. **Empathic Active Inference: Active Inference with Empathy Mechanism for Socially Behaved Artificial Agent** *Tadayuki Matsumura, Kanako Esaki and Hiroyuki Mizuno*	19.07.2022 10:20 CEST

This paper proposes a method for an artificial agent to behave socially by controlling it by active inference with an empathy mechanism. Active inference is a Bayesian hypothesis for understanding the mechanism of a biological agent's cognitive activities and is currently evaluated mainly for single-agent cases. We extended active inference to the case of an agent surrounded by other agents. These other agents are not only objects of recognition but also sources of social perceptions and actions. An agent controlled with the proposed method infers the others' expectations toward itself on the basis of an empathy mechanism and tries to act in response to the expectations. Although defining proper sociality for a given situation is difficult since it differs by situation, we define sociality as an agent behaving as others expect. Accordingly, the others surrounding the agent are teachers for the agent to learn proper sociality; thus, an agent controlled with the proposed method can learn proper sociality in a variety of situations in a unified manner. We evaluated the proposed method regarding the controlling of autonomous mobile robots (AMRs) and evaluated sociality from the trajectory of the AMRs. From the evaluation results, an agent controlled with the proposed method could behave more socially than an agent controlled by standard active inference. In two agents case, the agent controlled with the proposed method behaved in a social way that decreased travel distance of another by 13.7% and increased margin between the agents by 25.8%, even if it increased travel distance of the agent by 8.2%. They also indicate that an agent controlled with the proposed method behaves more socially when it is surrounded by altruistic others but less socially when surrounded by selfish others.	
35. **Emergence of Novelty in Evolutionary Algorithms** *David Herel, Dominika Zogatova, Matěj Kripner and Tomáš Mikolov* One of the main problems of evolutionary algorithms is the convergence of the population to local minima. In this paper, we explore techniques that can avoid this problem by encouraging a diverse behavior of the agents through a shared reward system. The rewards are randomly distributed in the environment, and the agents are only rewarded for collecting them first. This leads to an emergence of a novel behavior of the agents. We introduce our approach on the maze problem and compare it to the previously proposed solution, denoted as Novelty Search (Lehman and Stanley, 2011). We find that our solution leads to an improved performance while being significantly simpler. Building on that, we generalize the problem and apply our approach to a more advanced set of tasks, Atari Games, where we observe a similar performance	19.07.2022 10:40 CEST

quality with much less computational power needed.	
30. **Multi-Objective Evolutionary Game Theory: A case study in cancer therapy** *Lukas Bostelmann-Arp, Andreas Braun, Sanaz Mostaghim and Thomas Tueting* In this paper, we introduce an early concept of using multiobjective optimization to study various emerging strategies in evolutionary game theory and show its application in a case study. We aim to analyze the emergent behavior when changing the game's environment through optimization. The multi-objective approach allows looking at the results of each model evaluation from different points of view. For the realization, we suggest the use of a multi-agent model to compute the outcome of a game. Such a model allows modeling even complex interrelationships and can be used as input to multiobjective optimization algorithms. Finally, we demonstrate a use case by optimizing therapy plans for melanoma through the incorporation of medications into our multi-agent model of concurring cell populations in the tumor micro environment.	19.07.2022 11:00 CEST
52. **IPPS3D: A 3D Variant of the Primordial Particle System** *Martin Stefanec and Thomas Schmick* We demonstrate here that the morphogenetic Primordial Particle System, which was originally defined for two dimensions only, can also operate with minimal adaptations in a three-dimensional setting, producing similar life-like structures and dynamics.	19.07.2022 11:15 CEST
2. **Towards Computationally Efficient Evolutionary Robotics** *Kasper Stoy* A key challenge in evolutionary robotics is the computational cost of evolutionary runs. The high computational cost forces researchers to rely on power-hungry computer clusters and even with these researchers often are faced with long evaluation cycles that make development of evolutionary experiments a time consuming and tedious effort. In this paper we address this challenge on two fronts. We have developed an evolutionary robotic engine where all individuals are evaluated in parallel using a thread-based implementation on a graphical processing unit (GPU). This engine allows us to run an evolutionary robotics experiment in seconds on a modest laptop. The second avenue of exploration is that we have	19.07.2022 11:30 CEST

used this engine to study the role of initial robot poses in fitness evaluation. We find that if we co-evolve initial pose and controller competitively, we can reduce the evaluation period of individuals significantly. Combined the evolutionary robotics engine and the co-evolutionary approach are significant demonstrations of how to make evolutionary robotics more computationally efficient.	
90. **Centralized and Decentralized Control in Modular Robots and Their Effect on Morphology** *Mia-Katrin Kvalsund, Kyrre Glette and Frank Veenstra* In Evolutionary Robotics, evolutionary algorithms are used to co-optimize morphology and control. However, cooptimizing leads to different challenges: How do you optimize a controller for a body that often changes its number of inputs and outputs? Researchers must then make some choice between centralized or decentralized control. In this article, we study the effects of centralized and decentralized controllers on modular robot performance and morphologies. This is done by implementing one centralized and two decentralized continuous time recurrent neural network controllers, as well as a sine wave controller for a baseline. We found that a decentralized approach that was more independent of morphology size performed significantly better than the other approaches. It also worked well in a larger variety of morphology sizes. In addition, we highlighted the difficulties of implementing centralized control for a changing morphology, and saw that our centralized controller struggled more with early convergence than the other approaches. Our findings indicate that duplicated decentralized networks are beneficial when evolving both the morphology and control of modular robots. Overall, if these findings translate to other robot systems, our results and issues encountered can help future researchers make a choice of control method when cooptimizing morphology and control.	19.07.2022 11:50 CEST
22. **Testing the Efficiency of a Genome-Wide Association Study on a Computational Evolutionary Model** *Arend Hintze, Yasir Imam and Lars Rönnegård* Genome-wide association studies (GWAS) are a powerful tool to identify genes. They exploit the standing genetic variation and correlate phenotypic diversity to genetic markers close to or with genes of interest. However, it appears that	19.07.2022 12:10 CEST

their power is limited when it comes to complex phenotypes caused by highly epistatically interacting genes. To improve GWAS and to develop new methods, a computational model system could prove invaluable. In the computational model system presented here, the functionality of all genes in question can be identified using knockouts. This allows the comparison between the quantitative genetics results and the functional analysis. Here the goal is to perform a pilot study to investigate to which degree such a computational model can serve as a positive control for a GWAS. Surprisingly, even though the model used here is relatively simple and uses only a few genes, the GWAS struggles to identify all relevant genes. The advantages and limitations of this approach will be discussed to improve the model for future comparisons.	
11. **Voluntary safety pledges overcome over-regulation dilemma in AI development: an evolutionary game analysis** *The Anh Han, Francisco C. Santos, Luis Moniz Pereira and Lenaerts Tom* With the introduction of Artificial Intelligence (AI) and related technologies in our daily lives, fear and anxiety about their misuse, as well as the hidden biases in their creation, have led to a demand for regulation to address such issues. Yet, blindly regulating an innovation process that is not well understood may stifle this process and reduce benefits that society might gain from the generated technology, even under the best of intentions. Starting from a baseline game-theoretical model that captures the complex ecology of choices associated with a race for domain supremacy using AI technology, we show that socially unwanted outcomes may be produced when sanctioning is applied unconditionally to risk-taking, i.e., potentially unsafe behaviours. As an alternative to resolve the detrimental effect of over-regulation, we propose a voluntary commitment approach, wherein technologists have the freedom of choice between independently pursuing their course of actions or else establishing binding agreements to act safely, with sanctioning of those that do not abide to what they have pledged. Overall, our work reveals for the first time how voluntary commitments, with sanctions either by peers or by an institution, leads to socially beneficial outcomes in all scenarios that can be envisaged in the shortterm race towards domain supremacy through AI technology.	19.07.2022 12:30 CEST
42. **Simulations of Vesicular Distanglement**	19.07.2022 12:45 CEST

Peter Eggenberger Hotz, Federica Casiraghi, Johannes Josef Schneider, Mathias Sebastian Weyland, Dandolo Flumini, Martin Michael Hanczyc and Rudolf Marcel Füchslin As part of the European Horizon 2020 project ACDC, a chemical compiler is being developed that allows the selfassembly of artificial, three-dimensional, vesicular structures to be first simulated and then translated into reality. This work reports on simulations that shed light on an important aspect: How to disentangle inter-vesicular connections?	
10. **The benefits of credit assignment in noisy video game environments** *Jacob Schoemaker and Karine Miras* Both Evolutionary Algorithms (EAs) and Reinforcement Learning Algorithms (RLAs) have proven successful in policy optimisation tasks, however, there is scarce literature comparing their strengths and weaknesses. This makes it difficult to determine which group of algorithms is best suited for a task. This paper presents a comparison of two EAs and two RLAs in solving EvoMan - a video game playing benchmark. We test the algorithms both with and without noise introduction in the initialisation of multiple video game environments. We demonstrate that EAs reach a similar performance to RLAs in the static environments, but when noise is introduced the performance of EAs drops drastically while the performance of RLAs is much less affected.	19.07.2022 14:00 CEST
16. **Evolving Unbounded Neural Complexity in Pursuit-Evasion Games** *Thomas Willkens and Jordan Pollack* We study the conditions in which the unbounded growth of complexity – measured in terms of expressed genome size – can be observed in coevolving populations of neural agents involved in different classes of interactions. To reproduce the results of prior work on the dynamics of open-ended evolution, we introduce a simple pursuit-evasion scenario that allows for the development of increasingly intricate strategies. It is shown that for some configurations of our game, fitness-proportionate selection leads to stagnation while more sophisticated coevolutionary methods produce apparently unbounded complexity growth. Analysis of behavioral patterns sheds some light on the evolutionary pressures introduced by	19.07.2022 14:20 CEST

the model. Our findings replicate many features of previously reported work; however, we observe particular dynamics that differ in important respects, challenging their conclusions, creating new opportunities, and highlighting the need for further investigation of this domain.	
71. **Shape Change and Control of Pressure-based Soft Agents** *Federico Pigozzi* Softness is one of the greatest gifts of mother nature. Biological agents possess bodies that are mostly of soft tissues. Researchers have resorted to soft bodies to investigate Artificial Life (ALife)-related questions; similarly, a new era of soft-bodied robots has just begun. Nevertheless, because of their infinite degrees of freedom, soft bodies pose unique challenges in terms of simulation, control, and optimization. Here we propose a novel soft-bodied agents formalism, namely Pressure-based Soft Agents (PSAs): they are bodies of gas enveloped by a chain of springs and masses, with pressure pushing on the masses from inside the body. Pressure endows the agents with structure, while springs and masses simulate softness and allow the agents to assume a large gamut of shapes. Actuation takes place by changing the length of springs or modulating global pressure. We optimize the controller of PSAs for a locomotion task on hilly terrain and an escape task from a cage; the latter is particularly suitable for soft-bodied agents, as it requires the agent to contort itself to squeeze through a small aperture. Our results suggest that PSAs are indeed effective at those tasks and that controlling pressure is fundamental for shape-changing. Looking forward, we envision PSAs to play a role in the modeling of soft-bodied agents, including soft robots and biological cells.	19.07.2022 14:40 CEST
74. **The Last One Standing? - Recent Findings on the Feasibility of Indirect Reciprocity under Private Assessment** *Marcus Krellner and The Anh Han* Indirect reciprocity (IR) is an important mechanism for promoting cooperation among self-interested agents. Simplified, it means: “you help me, therefore somebody else will help you” (in contrast to direct reciprocity: “you help me; therefore I will help you”). IR can be achieved via reputation and norms. However, it was often argued that IR only works if reputations are public and does not do so under private assessment (PA). Yet, recent papers suggest that IR under PA	19.07.2022 15:00 CEST

is feasible, and that it has more variety and ways to improve, than have been considered before.	
79. **Lifeforms potentially useful for automated underwater monitoring systems** *Wiktoria Rajewicz, Thomas Schmickl and Ronald Thenius* Biohybrids combine artificial robotic elements with living organisms. These novel technologies allow for obtaining useful data on the environment by implementing organisms as ”living sensors”. Natural water resources are under serious ecological threat and there is a always a need for new, more efficient methods for aquatic monitoring. Project Robocoenosis introduces the use of biohybrid entities as low-cost and longterm environmental monitoring devices. This will be done by combining lifeforms with technical parts which will be powered with the use of MFCs. This concept will allow for a more well-rounded data collection and provide an insight into the water body with minimal human impact.	19.07.2022 15:15 CEST
46. **Physical Obstacles Constrain Behavioral Parameter Space of Successful Localization in Honey Bee Swarms** *Dieu My Nguyen, Michael Iuzzolino and Orit Peleg* Honey bees (Apis mellifera L.) localize the queen and aggregate into a swarm by forming a collective scenting network to directionally propagate volatile pheromone signals. Previous experiments show the robustness of this communication strategy in the presence of physical obstacles that partially block pheromone flow and the path to the queen. Specifically, there is a delay in the formation of the scenting network and aggregation compared to a simple environment without perturbations. To better understand the effect of obstacles beyond temporal dynamics, we use the experimental results as inspiration to explore how the behavioral parameter space of collective scenting responds to obstacle. We extend an agentbased model previously developed for a simple environment to account for the presence of physical obstacles. We study how individual agents with simple behavioral rules for scenting and following concentration gradients can give rise to collective localization and swarming. We show that the behavioral parameter space for successful localization exists, but is more constrained, as a result of the density spatial heterogeneity in the bees that the obstacles impose.	19.07.2022 15:30 CEST

51. **Perpetual Crossers without Sensory Delay: Revisiting the Perceptual Crossing Simulation Studies** *Eduardo J. Izquierdo, Gabriel J. Severino and Haily Merritt* We revisit the perceptual crossing simulation studies, which are aimed at challenging methodological individualism in the analysis of social cognition by studying multi-agent real-time interactions. To date, all of these simulation studies have reported that it is practically impossible to evolve artificially a robust behavioral strategy without introducing temporal delays into the simulation. Also, all of the studies report on a single strategy: a perpetually crossing agent pair. Here, we systematically report on the evolutionary success of neural circuits on the perceptual crossing task, with and without sensory delay. We also report on the variety of different strategies encountered in the ensemble of successful solutions.	19.07.2022 15:50 CEST
53. **Firefly-inspired vocabulary generator for communication in multi-agent systems** *Chantal Nguyen, Isabella Huang and Orit Peleg* Fireflies' dazzling light displays are courtship rituals: flying males announce their presence as suitable mates to the females on the ground. Their light signal is composed of a species-specific on/off light sequence repeated periodically. However, thousands of fireflies flashing in a swarm can create immense visual clutter that hinders the detection of potential mates. A partial solution to this visual clutter problem is to flash according to sequences that are more distinct and detectable than those of other individuals. Here, we investigate how distinguishable flash sequences can co-evolve by developing a method for simulating sequences that minimize their mutual similarity with each other while minimizing their energetic cost and predation risk. This simple set of rules produces flash sequences that are remarkably similar to those of real fireflies. In particular, we observe an emergent periodicity in the resulting sequences, despite the lack of any periodicity requirements on the sequences. In addition, we demonstrate a method of reconstructing the evolutionary pressures acting on sets of firefly species. We do so by carrying out simulations that follow known phylogenetic relationships of extant species alongside their characteristic flash patterns.	19.07.2022 16:10 CEST
86. **Generation of Complex Patterns using Coupled Generative Adversarial Networks**	19.07.2022 16:30 CEST

Hiroyuki Iizuka, Taiki Sasaki, Wataru Noguchi and Masahito Yamamoto This study reveals what kind of temporal and spatial patterns form when learning in an adversarial relationship between two individuals. The model was implemented by coupling generative adversarial networks, which are well-known in the field of machine learning. The obtained temporal patterns resulted in chaos with a positive Lyapunov exponent for time-series learning, whereas spatial pattern learning produced structured patterns with a higher fractal dimension, not just more complexity with a higher entropy.	
124. **Growing Isotropic Neural Cellular Automata** *Alexander Morsdvintsev, Ettore Randazzo and Craig Fouts* Modeling the ability of multicellular organisms to build and maintain their bodies through local interactions between individual cells (morphogenesis) is a long-standing challenge of developmental biology. Recently, the Neural Cellular Automata (NCA) model was proposed as a way to find local system rules that produce a desired global behaviour, such as growing and persisting a predefined pattern, by repeatedly applying the same rule over a grid starting from a single cell. In this work we argue that the original Growing NCA model has an important limitation: anisotropy of the learned update rule. This implies the presence of an external factor that orients the cells in a particular direction. In other words, “physical” rules of the underlying system are not invariant to rotation, thus prohibiting the existence of differently oriented instances of the target pattern on the same grid. We propose a modified Isotropic NCA model that does not have this limitation. We demonstrate that cell systems can be trained to grow accurate asymmetrical patterns through either of two methods: by breaking symmetries using structured seeds; or by introducing a rotation-reflection invariant training objective and relying on symmetry breaking caused by asynchronous cell updates.	20.07.2022 10:00 CEST
73. **Exploiting Intrinsic Multi-Agent Heterogeneity for Spatial Interference Reduction in an Idealised Foraging Task** *Christopher Bennett, Seth Bullock and Jonathan Lawry* Typically, collective behaviour research has tended to focus on behaviour arising in populations of homogeneous agents. However, humans, animals, robots and software agents typically	20.07.2022 10:20 CEST

exhibit various forms of heterogeneity. In natural systems, this heterogeneity has often been associated with improved performance. In this work, we ask whether spatial interference within a population of co-operating mobile agents can be managed effectively via conflict resolution mechanisms that exploit the population's intrinsic heterogeneity. An idealised model of foraging is presented in which a population of simulated ant-like agents is tasked with making as many journeys as possible back and forth along a route that includes tunnels that are wide enough for only one agent. Four conflict resolution schemes are used for determining which agent has priority when two or more meet within a tunnel. These schemes are tested in the context of heterogeneous populations of varying size. The findings demonstrate that a conflict resolution mechanism that exploits agent heterogeneity can achieve a significant reduction in the impact of spatial interference. However, whether or not a particular scheme is successful depends on how the heterogeneity that it exploits is implicated in the population-wide dynamics that underpin system-level performance.	
62. **Towards an FPGA Accelerator for Markov Brains** *Arend Hintze and Jory Schossau* The success of deep learning is to some degree based on our ability to train models quickly using GPU or TPU hardware accelerators. Markov Brains, which are also a form of neural networks, could benefit from such an acceleration as well. However, Markov Brains are optimized using genetic algorithms, which present an even higher demand on the acceleration hardware: Not only inputs to the network and its outputs need to be communicated but new network configurations have to be loaded and tested repeatedly in large numbers. FPGAs are a natural substrate to implement Markov Brains, who are already made from deterministic logic gates. Here a Markov Brain hardware accelerator is implemented and tested, showing that Markov Brains can be computed within a single clock cycle, the ultimate hardware acceleration. However, how current FPGA design and supporting development toolchains are limiting factors, and if there is a future size speed trade-off are explored here as well.	20.07.2022 10:40 CEST
113. **Self Recognition as Optimisation** *Timothy Atkinson and Nihat Engin Toklu*	20.07.2022 11:00 CEST

We tackle the concepts of ‘self-recognition’ and ‘selfawareness’ in a simulated setting. We propose an experiment where two simultaneous reinforcement learning environments are controlled by two agents. Although each agent is given the control of its own environment, both agents receive the visual input of the same environment. The success threshold depends on self-recognition by definition as the agent must answer: am I seeing a mirror, or am I seeing a camera? We show that this experiment can be posed as an optimisation problem, solvable via evolutionary computation.	
116. **Gradient Climbing Neural Cellular Automata** *Shuto Kuriyama, Wataru Noguchi, Hiroyuki Iizuka, Keisuke Suzuki and Masahito Yamamoto* Chemotaxis is a phenomenon whereby organisms like ameba direct their movements responding to their environmental gradients, often called gradient climbing. It is considered to be the origin of self-movement that characterizes life forms. In this work, we have simulated the gradient climbing behaviour on Neural Cellular Automata (NCA) that has recently been proposed as a model to simulate morphogenesis. NCA is a cellular automata model using deep networks for its learnable update rule and it generates a target cell pattern from a single cell through local interactions among cells. Our model, Gradient Climbing Neural Cellular Automata (GCNCA), has an additional feature that enables itself to move a generated pattern by responding to a gradient injected into its cell states.	20.07.2022 11:15 CEST
88. **Ethics of Artificial Life: The Moral Status of Life as It Could Be** *Olaf Witkowski and Eric Schwitzgebel* The field of Artificial Life studies the nature of the living state, by modeling and synthesizing living systems. Such systems, under certain conditions, may come to deserve moral consideration similar to that of non-human vertebrates or even human beings. Their rights might not be considerably reduced from the fact that they are non-human and evolve in a potentially radically different substrate, nor might they be reduced by the fact that they owe their existence to us. On the contrary, their creation may come with additional moral obligations to them, which may be similar to those of an owner to their pet or a parent to their child. For a field that aims to create artificial lifeforms with increasing levels of sophistication, it is crucial to consider the possible implications of	20.07.2022 11:30 CEST

our activities under an ethical perspective, and infer the moral obligations for which we should be prepared. If artificial life is “larger than life”, then the ethics of artificial beings should be “larger than human ethics”.	
29. **Q-learning for real time control of heterogeneous microagent collective** *Ana Rubio Denniss, Laia Freixas Mateu, Thomas E. Gorochowski and Sabine Hauert* The effective control of microscopic collectives has many promising applications, from environmental remediation to targeted drug delivery. A key challenge is understanding how to control these agents given their limited programmability, and in many cases heterogeneous dynamics. The ability to learn control strategies in real time could allow for the application of robotics solutions to drive the behaviour of microscopic collectives towards desired outcomes. Here, we demonstrate Q-learning on the closed-loop Dynamic Optical Micro-Environment (DOME) platform to control the motion of lightresponsive Volvox agents. The results show that Qlearning is efficient in autonomously learning how to reduce the speed of agents on an individual basis.	20.07.2022 11:50 CEST
25. **On the Entanglement between Evolvability and Fitness: an Experimental Study on Voxel-based Soft Robots** *Andrea Ferigo, Lisa Soros, Eric Medvet and Giovanni Iacca* The concept of evolvability, that is the capacity to produce heritable and adaptive phenotypic variation, is crucial in the current understanding of evolution. However, while its meaning is intuitive, there is no consensus on how to quantitatively measure it. As a consequence, it is hard to evaluate the interplay between evolvability and fitness and its dependency on key factors like the evolutionary algorithm (EA) or the representation of the individuals. Here, we propose to use MAPElites, a well-established Quality Diversity EA, as a support structure for measuring evolvability and for highlighting its interplay with fitness. We map the solutions generated during the evolutionary process to a MAP-Elites-like grid and then visualize their fitness and evolvability as maps. This procedures does not affect the EA execution and can hence be applied to any EA: it only requires to have two descriptors	20.07.2022 12:10 CEST

for the solutions that can be used to meaningfully characterize them. We apply this general methodology to the case of Voxel-based Soft Robots, a kind of modular robots with a body composed of uniform elements whose volume is individually varied by the robot brain. Namely, we optimize the robots for the task of locomotion using evolutionary computation. We consider four representations, two for the brain only and two for both body and brain of the VSR, and two EAs (MAP-Elites and a simple evolutionary strategy) and examine the evolvability and fitness maps. The experiments suggest that our methodology permits to discover interesting patterns in the maps: fitness maps appear to depend more on the representation of the solution, whereas evolvability maps appear to depend more on the EA. As an aside, we find that MAPElites is particularly effective in the simultaneous evolution of the body and the brain of Voxel-based Soft Robots.	
67. **Pseudo-attractors in Random Boolean Network Models and Single-Cell Data** *Marco Villani, Gianluca D'Addese, Stuart Alan Kauffman and Roberto Serra* In this extended abstract two novel concepts are defined in the study of Random Boolean Networks, i.e. those of “pseudoattractors” and “common sea”, and it is shown how their analogues can be measured in experimental data on gene expression in single cells.	20.07.2022 12:30 CEST
105. **A Modeling and Experimental Framework for Understanding Evolutionary and Ecological Roles of Acoustic Behavior Using a Generative Model** *Reiji Suzuki, Shinji Sumitani, Chihiro Ikeda and Takaya Arita* We propose a research framework for understanding the evolutionary and ecological roles of acoustic behavior by combining agent-based modeling and machine learning, particularly focusing on bird vocalizations, which is one of the major components creating natural soundscapes. We use a latent space of a generative model as a genotype space and regard a generated object as a corresponding phenotype in an evolutionary model, then further observe roles of the evolved phenotypes in a real ecological context. This paper introduces two independent trials to show the feasibility of the approach. We first introduce an agent-based model of syllables in Zebra Finch songs based on the coevolution of syllable structures and preferences. Then, we show	20.07.2022 12:45 CEST

artificially generated songs of conspecifics can affect the behavior of Japanese Bush Warbler in the wild.	
24. **On the Mutual Influence of Human and Artificial Life: an Experimental Investigation** *Stefano Furlan, Eric Medvet, Giorgia Nadizar and Federico Pigozzi* Our modern world is teeming with non-biological agents, whose growing complexity brings them so close to living beings that they can be cataloged as artificial creatures, i.e., a form of Artificial Life (ALife). Ranging from disembodied intelligent agents to robots of conspicuous dimensions, all these artifacts are united by the fact that they are designed, built, and possibly trained by humans taking inspiration from natural elements. Hence, humans play a fundamental role in relation to ALife, both as creators and as final users, which calls attention to the need of studying the mutual influence of human and artificial life. Here we attempt an experimental investigation of the reciprocal effects of the human-ALife interaction. To this extent, we design an artificial world populated by life-like creatures, and resort to open-ended evolution to foster the creatures adaptation. We allow bidirectional communication between the system and humans, who can observe the artificial world and voluntarily choose to perform positive or negative actions towards the creatures populating it; those actions may have a short- or long-term impact on the artificial creatures. Our experimental results show that the creatures are capable of evolving under the influence of humans, even though the impact of the interaction remains uncertain. In addition, we find that ALife gives rise to disparate feelings in humans who interact with it, who are not always aware of the importance of their conduct.	20.07.2022 14:00 CEST
27. **The Evolution of Fractal Protein Modules in Multicellular Development** *Harry Booth and Peter J. Bentley* Regional specification, or pattern formation, is the process by which developing cells in different regions are switched into different developmental pathways. We investigate this process through an ALife model of multicellular development using fractal proteins, where genes are expressed into proteins comprised of subsets of the Mandelbrot Set. The resulting network of gene and protein interactions can be designed by evolution to produce specific patterns, that in turn can be used	20.07.2022 14:20 CEST

to solve problems. Here fractal gene regulatory networks are incorporated into a multicellular model of development, and tested on the morphological problem of regional specification, using Map-Elites to explore the space of solutions. The results indicate the ability of this system to learn regularities in solutions and automatically create and use developmental modules, illustrating how an artificial system can replicate some of the fundamental processes of development.	
36. **Paths in a Network of Polydisperse Spherical Droplets** *Johannes Josef Schneider, Alessia Faggian, Silvia Holler, Federica Casiraghi, Jin Li, Lorena Cebolla Sanahuja, Hans-Georg Matuttis, Martin Michael Hanczyc, David Anthony Barrow, Mathias Sebastian Weyland, Dandolo Flumini, Peter Eggenberger Hotz and Rudolf Marcel Füchslin* We simulate the movement and agglomeration of oil droplets in water under constraints, like confinement, using a simplified stochastic-hydrodynamic model. In the analysis of the network created by the droplets in the agglomeration, we focus on the paths between pairs of droplets and compare the computational results for various system sizes.	20.07.2022 14:40 CEST
72. **Adversarial Takeover of Neural Cellular Automata** *Lorenzo Cavuoti, Francesco Sacco, Ettore Randazzo and Michael Levin* The biggest open problems in the life sciences concern the algorithms by which competent subunits (cells) could cooperate to form largescale structures with new, system-level properties. In synthetic bioengineering, multiple cells of diverse origin can be included in chimeric constructs. To facilitate progress in this field, we sought an understanding of multi-scale decision-making by diverse subunits beyond those observed in frozen accidents of biological phylogeny: abstract models of life-as-itcan-be. Neural Cellular Automata (NCA) are a very good inspiration for understanding current and possible living organisms: researchers managed to create NCA that are able to converge to any morphology. In order to simulate a more dynamic situation, we took the NCA model and generalized it to consider multiple NCA rules. We then used this generalized model to change the behavior of a NCA by	20.07.2022 15:00 CEST

injecting other types of cells (adversaries) and letting them take over the entire organism to solve a different task. Next we demonstrate that it is possible to stop aging in an existing NCA by injecting adversaries that follow a different rule. Finally, we quantify a distance between NCAs and develop a procedure that allows us to find adversaries close to the original cells.	
19. **Endosymbiosis or Bust: Influence of Ectosymbiosis on Evolution of Obligate Endosymbiosis** *Kiara Johnson, Piper Welch, Emily Dolson and Anya Vostinar* Endosymbiosis, symbiosis in which one symbiont lives inside another, is woven throughout the history of life and the story of its evolution. From the mitochondrion residing in almost every eukaryotic cell to the gut microbiome found in every human, endosymbiosis is a cornerstone of the biological processes that sustain life on Earth. While endosymbiosis is ubiquitous, many questions about its origins remain shrouded in mystery; one question in particular regards the general conditions and possible trajectories for its evolution. Modern science has hypothesized two possible pathways for the evolution of mutualistic endosymbiosis: one where an obligate antagonism is co-opted into an obligate mutualism (Co-Opted Antagonism Hypothesis), and one where a facultative mutualism evolves into an obligate mutualism (Black Queen Hypothesis). We investigated the viability of these pathways under different environmental conditions by expanding on the evolutionary agent-based system Symbulation. Specifically, we considered the impact of ectosymbiosis on de novo evolution of obligate mutualistic endosymbiosis. We found that introducing a facultative ectosymbiotic state allows endosymbiosis to evolve in a more diverse set of environmental conditions, while also decreasing the evolution of endosymbiosis in conditions where it can evolve independently.	20.07.2022 15:20 CEST
20. **Keep Your Frenemies Closer: Bacteriophage That Benefit Their Hosts Evolve to be More Temperate** *Alison Cameron, Seth Dorchen, Sarah Doore and Anya Vostinar* Bacteriophages, also known as phages, are viruses that infect bacteria. They are found everywhere in nature, playing vital roles in microbiomes and bacterial evolution due to the selective pressure that they place on their hosts. As obligate	20.07.2022 15:40 CEST

endosymbionts, phages depend on bacteria for successful reproduction, and either destroy their hosts through lysis or are maintained within the host through lysogeny. Lysis involves reproduction within the host cell and ultimately results in the disruption or bursting of the cell to release phage progeny. Alternatively, lysogeny is the process by which phage DNA is incorporated into the host DNA or maintained alongside the host chromosome, and thus the phage reproduces when their host reproduces. Recent work has demonstrated that phages can exist along the parasitism-mutualism spectrum, prompting questions of how phage would evolve one reproductive strategy over the other, and in which conditions. In this work, we present an agent-based model of bacteriophage/bacterial co-evolution that enables lysogenized phage to directly impact their host's fitness by using the software platform Symbulation. We demonstrate that a viral population with beneficial lysogenic phage can select against lytic strategies. This result has implications for bottom-up control of vital ecosystems.	
87. **Glaberish: Generalizing the Continuously-Valued Lenia Framework to Arbitrary Life-Like Cellular Automata** *Q. Tyrell Davis* Recent work with Lenia, a continuously-valued cellular automata framework, has yielded ~100s of compelling, bioreminescent and mobile patterns. Lenia can be viewed as a continuously-valued generalization of the Game of Life, a seminal cellular automaton developed by John Conway that exhibits complex and universal behavior based on simple birth and survival rules. Life's rules depend on previous cell states and on the sum of neighbors in a local neighborhood. Unlike Life, in Lenia updates are unconditional, i.e. they do not depend on cell state, only on the results of neighborhood convolutions. This limits Lenia to implementing Life-like CA with birth rules that are a subset of their survival rules. In the framework of Life-like rules, on the other hand, many interesting CA have non-overlapping rulsets. This work splits the Lenia growth update function into two components: genesis and persistence, conditioned on previous cell states and analogous to the B/S rules of Life-like CA. This addition recovers the ability to implement arbitrary Life-like CA and can make for more active CA dynamics. This work demonstrates the continuously-valued implementation of a common mobile puffer pattern in the Move (aka Morley, rules: B368/S245)	20.07.2022 16:00 CEST

CA, a rule set not natively implementable in Lenia. We also qualitatively and quantitatively compare the Hydrogeminium CA from the Lenia framework to a related CA implemented in the new framework sharing the same neighborhood kernel. The conditional CA is more dynamic and exhibits more structural localization than Hydrogeminium when initialized with a uniform random grid, but both readily support interesting mobile patterns.	
60. **DIAS: A Domain-Independent Alife-Based Problem-Solving System** *Babak Hodjat, Hormoz Shahrzad and Risto Miikkulainen* A domain-independent problem-solving system based on principles of Artificial Life is introduced. In this system, DIAS, the input and output dimensions of the domain are laid out in a spatial medium. A population of actors, each seeing only part of this medium, solves problems collectively in it. The process is independent of the domain and can be implemented through different kinds of actors. Through a set of experiments on various problem domains, DIAS is shown able to solve problems with different dimensionality and complexity, to require no hyperparameter tuning for new problems, and to exhibit lifelong learning, i.e. adapt rapidly to run-time changes in the problem domain, and do it better than a standard non-collective approach. DIAS therefore demonstrates a role for Alife in building scalable, general, and adaptive problem-solving systems.	20.07.2022 16:20 CEST
102. **Augmenting Evolution with Bio-Inspired “Super Explorers”** *Vincent Ragusa and Clifford Bohm* Natural evolving populations experience a constantly fluctuating selection strength, which also creates a fluctuating trade-off between exploration and exploitation. Range expansion, for example, creates semi-persistent spatiallydistributed differences in selection strength. During a range expansion, the subset of the population on the leading edge experiences reduced selection strength relative to the remainder of the population. The leading edge therefore experiences greater potential for exploration, while selection on the remainder of the population ensures that prior discoveries are not lost. Here we describe a method to augment selection algorithms inspired by the exploration-boosting properties of range expansion events. The key insight is that for	21.07.2022 14:00 CEST

productive exploration on deceptive landscapes, mutations must be able to accumulate and persist in some, but not all, lineages. We create artificially drifting lineages of “super explorers” and show that they can improve the performance of selection algorithms.	
106. **Evolution of Developmental Strategies in NK Fitness Landscapes** *Jacob Ashworth, Lyra Lee, Jackson Shen, Edward Kim, Zach Decker and Jason Yoder* Evolution and development are related processes although their relationship is still not well understood. Attempts to explore their relationship are challenged by scales of time and space, but also by the limitations of studies focused on specific constraints of model organisms. To help gain insight into these phenomena, we create an abstract, general model of a developmental process that guides an agent’s trajectory through a “tunably rugged” NK fitness landscape. The developmental process is represented by a genotype that is evolved and allows us to investigate periods of exploration and exploitation as they relate to periods of an agent’s lifetime and a given landscape’s difficulty. Results show that evolution selects for time-sensitive periods of exploration and exploitation, which vary with the difficulty of the landscapes being traversed. Because of the generality of the model, the implications of this work are wide-ranging and suggest that phenotypic diversity via random exploration present in both early and mid-life can help a developing organism to find superior phenotypes.	21.07.2022 14:20 CEST
112. **Two Theories of Responsiveness** *Jonathan Bowen* Organisms are responsive — they respond to stimuli. This is a unique mode of causation that we usually only ascribe to organisms. What does it amount to? In this talk, I propose two candidate theories of responsiveness. The first is a functional pathway theory according to which organisms that are responsive are organisms with a certain kind of physiologically realized functional architecture. The second is a vital-reorganizational theory, according to which responsiveness is a capacity of whole organisms to coordinate with pivotal outer objects. I will explain the two views and their underlying rationales. Finally, I will argue that adjudicating between these views could help to resolve a deeper, older debate between mechanistic and organicist theories of the	21.07.2022 14:40 CEST

organism. Therefore, we should find ways to test these theories of responsiveness.	
4. **Symbiosis in Digital Evolution: A Review and Future Directions** *Anya Vostinar, Katherine Skocelas, Alexander Lalejini and Luis Zaman* Symbiosis is a ubiquitous, vital biological dynamic (Paracerand Ahmadjian, 2000) that is difficult to experimentally study in DNA-based systems (Momeni et al., 2011). Since its inception, digital evolution has been used to study many types of symbiosis, and remains an area of active research in the field. Here, we summarize our recent review of symbiosis in digital evolution.	21.07.2022 15:00 CEST
91. **What does functional connectivity tell us about the behaviorally functional connectivity of a multifunctional neural circuit?** *Eduardo J. Izquierdo and Madhavun Candadai* What insights can statistical analysis of the time series recordings of neurons and brain regions during behavior give about the neural basis of behavior? With the increasing amount of whole-brain imaging data becoming available, the importance of addressing this unanswered theoretical challenge has become increasingly urgent. We propose a computational neuroethology approach to begin to address this challenge. We evolve dynamical recurrent neural networks to be capable of performing multiple tasks. We then analyze the neural activity using popular network neuroscience tools, specifically functional connectivity using Pearson's correlation, mutual information, and transfer entropy. We compare the results from these tools against a series of informational lesions, as a way to reveal their degree of approximation to the groundtruth. Our initial analysis reveals an overwhelming large gap between the insights gained from statistical inference of the functionality of the circuits based on neural activity and the actual functionality of the circuits as revealed by mechanistic interventions.	21.07.2022 15:20 CEST
94. **The Evolution of Genetic Robustness for Cellular Cooperation in Early Multicellular Organisms** *Katherine G. Skocelas, Austin J. Ferguson, Clifford Bohm, Katherine Perry, Rosemary Adaji and Charles Ofria* The major evolutionary transition to multicellularity shifted the unit of selection from individual cells to multicellular organisms. Constituent cells must regulate their growth and	21.07.2022 15:40 CEST

cooperate for the benefit of the whole organism, even when such behaviors would have been maladaptive were they free living. Mutations that stop cells from cooperating can lead to a variety of ailments, including physical deformities and cancer. Organisms therefore employ mechanisms to enforce cooperation, such as error correction, cellular policing, and genetic robustness. We built a simulation to study this last mechanism under a range of evolutionary conditions. Specifically, we asked: How does genetic robustness against cellular cheating evolve in multicellular organisms? We focused on early multicellular organisms (with only one cell type) where cells must control their growth to avoid overwriting each other. In our model, unrestrained cells will outcompete restrained cells within an organism, but restrained cells alone will result in faster reproduction for the organism. Ultimately, we demonstrate a clear selective pressure for genetic robustness in multicellular organisms, and show that this pressure increases with the total number of cells that make up the organism.	
98. **String: a programming language for the evolution of ribozymes in a new computational protocell model** *Mohiul Islam, Nawwaf Kharma and Peter Grogono* String is a new computer language designed specifically for the implementation of 'ribozymes', the active entities within a new (highly simplified) model of protocellular life. The purpose of the model (which is presented here, only in outline) is the study of the abstract nature of simple cellular life and its relationship to computation. This model contains passive and active entities; passive entities are data and active ones are executable data (or programs). All programs in our model are written or evolved in String. In this paper, we describe String and provide examples of both hand-written and evolved String programs belonging to different functional categories needed for cellular operation (e.g., mass transporter, information transporter, transformer, replicator and translator). Results from the evolutionary runs are presented and discussed.	21.07.2022 16:00 CEST
26. **Lineage Selection in Mixed Populations for Genetic Improvement** *Penelope Faulkner Rainford and Barry Porter* Emergent Software Systems take a large pool of potential building blocks, for a given system such as a web server, and	21.07.2022 16:20 CEST

learn at runtime how best to compose selected blocks from that pool in order to maximise some utility function in each set of deployment conditions that is encountered. To support this approach, at least some building blocks in the available pool must have implementation variants – alternatives which have the same functionality but achieve it using a different approach (such as different sorting algorithms or different cache eviction policies). We can automatically derive new building block variants for our pool of potential behaviour by using genetic improvement (GI), which has long proven effective for optimisation and repair of source code. When a novel deployment environment is detected, however, it is unclear which existing building block variant(s) should be used as starting points for new a GI process to tailor a new block for that environment; in this situation it would be necessary to try one GI process from every possible existing building block variant as a starting point, a process which could be extremely expensive. In this paper we present a mixed-population approach to examine whether GI can simultaneously offer both lineage selection and optimisation to find the ideal source code for a new building block variant tailored to a given environment. Using a lowest-common-ancestor approach to producing evolvable individuals, our results demonstrate strong evidence that combined lineage selection and optimisation is viable in multiple scenarios, offering far reduced compute time to locate a good individual for a novel environment.	
127. **Analogical comparison of circuits generating a multiply realizable walking behavior** *Kira Breithaupt and Abe Leite* An understanding of analogy and the multiple realizability of concepts, ideas, and experience is necessary to understand cognition and the generation of behavior even at the most abstract levels. One of the most fundamental questions one can ask about a pair of neural circuits is whether they are doing the same thing or different things. Our work addresses this question by applying a model of sequential narrative analogy, B-L analogical comparison, to neural circuits evolved to perform a simple locomotion task. Along the way, we develop a measure of the “experience” of a neural circuit performing a behavior we call its functional trace. We find (i) that B-L analogical comparison reports strong analogies between some, but not all, neural circuits that perform the walking behavior,	22.07.2022 14:00 CEST

(ii) that it finds stronger analogies between circuits of the same class (as reported in previous work on this problem space) than circuits of different classes, and (iii) that it reveals strong analogies between circuits of the previously-reported BS-switch and SW-switch classes, even though these classes are of different circuit sizes. We conclude that B-L analogical comparison is a powerful tool for understanding the multiple realizability of behavior.	
80. **Network Diversity Promotes Safety Adoption in Swift Artificial Intelligence Development** *Theodor Cimpeanu, Francisco C. Santos, Luís Moniz Pereira, Tom Lenaerts and The Anh Han* Regulating the development of advanced technology such as Artificial Intelligence (AI) has become a principal topic, given the potential threat they pose to humanity's long term future. First deploying such technology promises innumerable benefits, which might lead to the disregard of safety precautions or societal consequences in favour of speedy development, engendering a race narrative among firms and stakeholders due to value erosion. Building upon a previously proposed game-theoretical model describing an idealised technology race, we investigated how various structures of interaction among race participants can alter collective choices and requirements for regulatory actions. Our findings indicate that strong diversity among race participants, both in terms of connections and peer-influence, can reduce the conflicts which arise in purely homogeneous settings, thereby lessening the need for regulation.	22.07.2022 14:20 CEST
78. **Step Size is a Consequential Parameter in Continuous Cellular Automata** *Q. Tyrell Davis* Work in continuous cellular automata has generated compelling taxonomies of bioreminiscent patterns in recent years, laying the foundations for studying embodied intelligent agents in simulation and under consistent physics. A typical continuous cellular automaton update adds the results of an update function to previous cell states, proportional to a step size between 0 and 1. In other words, continuous cellular automata updates take the same form as a physical system described by a differential equation and simulated by Euler's method. Step size is largely ignored in optimization or evolution of continuous cellular automata, but this work demonstrates that step size is a	22.07.2022 14:40 CEST

consequential parameter. Not only does a step size that is too large lead to unstable patterns, but some patterns also become unstable with a step size that is too small, yielding cellular automata systems that support different patterns across different step size ranges, all else being equal. Finally, this work also shows that choice of step size can yield qualitatively different behaviors for a single pattern and ruleset differing only in step size.	
126. **Evolutionary stability of host-endosymbiont mutualism is reduced by multi-infection** *Emily Dolson, Anya Vostinar, Shakeal Hodge and Zhen Ren* Host-symbiont co-evolution is known to be an important process in producing the range of life on earth that we have today. A fair amount of research has been done on factors that influence the evolution of mutualism or antagonism between a single host and symbiont. However, in nature, there are nearly always many symbionts per host. Much less evolutionary theory currently exists to predict coevolutionary dynamics among hosts and multiple symbionts. Here, we conduct some preliminary research into how the presence of multiple symbionts inside the same host impacts the trajectory of evolution. We find that adding more symbionts reduces the evolutionary stability of mutualism.	22.07.2022 15:00 CEST