

ALIFE 2021

PROCEEDINGS OF THE ARTIFICIAL LIFE CONFERENCE 2021

Edited by
Jitka Čejková,
Silvia Holler,
Lisa Soros and
Olaf Witkowski



Preface

This volume contains the proceedings of the 2021 Conference on Artificial Life (ALIFE 2021) which was originally scheduled to be held in Prague (Czech Republic) 19 - 23 July 2021, but because of the covid-19 pandemic and its repercussions, is being held virtually only. (<https://2021.alife.org/>). The International Conference on the Synthesis and Simulation of Living Systems (ALIFE) and the European Conference on Artificial Life (ECAL) have been the major meetings of the artificial life (ALife) research community since 1987 and 1991, respectively. Currently, these scientific gatherings are supported by the International Society for Artificial Life (ISAL) - a democratic, international, professional society dedicated to promoting scientific research and education relating to artificial life, including sponsoring this conference annually, publishing scientific journals and proceedings, and maintaining web sites related to artificial life.

Prague hosted the ECAL conference in September 2001 and the witnesses say that the team of organizers then, led by Jozef Kelemen, prepared for the participants a great scientific gathering with several social activities. However, the witnesses also mentioned that the conference was affected by the September 11 attacks. This historical incident affected not only the ECAL conference in Prague, but everything across the globe. This year the global external circumstances affected the Prague ALIFE conference again and even in such a way that the situation did not allow a face-to-face conference in the heart of Europe at all and the conference had to be switched to the virtual format. The organising committee had to take into consideration the continued erratic development of the worldwide covid-19 pandemic and the accompanying restrictions on worldwide travel as well as the safety and health of the ALife community. It was not an easy decision, because the organizers had amazing plans for how to arrange not only a scientific program in Prague, but also the side events, that would include visiting of restaurants with Czech cuisine and drinking of good Czech beer, various guided tours related to artificial life themes and namely going to the theatre to watch the one hundred year old play *R.U.R.* (subtitled as "*Rossum's Universal Robots*"). In this play, which was premiered in the National Theatre in Prague in Czechoslovakia on 25 January 1921, the word "*robot*" was used for the first time, so all the robots celebrate the centenary of their name this year. On this occasion, the theme of ALIFE 2021 conference is "*Robots: The century past and the century ahead*", as discussed in the introductory paper with the same title by the conference chair Jitka Čejková.

Although the 2021 Conference on Artificial Life takes place solely online and requires attendees to focus on a screen for hours at a time, the organizing committee was working intensively to create a virtual conference that gives as much of a real conference atmosphere as possible. Besides 9 keynote talks, 27 hours of 6 special sessions, almost 40 hours of 11 workshops, 5 tutorials and 64 talks in parallel sessions, there are also a virtual art gallery, virtual pubs and virtual coffee rooms. The social program offers the documentary movie *Solutions* and a THEATRE project *Can a robot write a theatre play?* Further, we have announced a student essay competition this year and we have obtained almost thirty essays related to the artificial life, artificial intelligence, robots and/or *R.U.R.* The program offers also a dedicated session *1971-2021: Fifty Years with Autopoiesis*, in memory of Francisco Varela and Humberto Maturana, who passed away this year.

The ALife 2021 Program

We received a total of 158 submissions. All submissions were reviewed by typically three reviewers. Senior program committee members then performed a topic-wide meta-review to derive acceptance decisions. As a result, we accepted 58 full papers and 50 extended abstracts for publication.

The conference program this year included:

- Six special sessions:
 - Artificial Life and Society, organized by Alex Penn, Jesus Mario Siqueiros Garcia, Olaf Witkowski, Alan Dorin, Erik Hom, Imran Khan, and Andy Philippides
 - Artificial Perception: Machines with Lifelike Failings, organized by Lana Sinapayen, Eiji Watanabe, and Sofian Audry
 - Bio-inspired Approaches for Modular Robotics, organized by Giovanni Iacca, Eric Medvet, and Stefano Nichele
 - Complexity ALI[FIV]E: Socializing & Eco-integrating Robots with Living Organisms, organized by Thomas Schmickl, Donato Romano, Ronald Thenius, and Martin Grube
 - Hybrid Life IV: Approaches to Integrate Biological, Artificial and Cognitive Systems, organized by Manuel Baltieri, Keisuke Suzuki, Hiroyuki Iizuka, Olaf Witkowski, and Lana Sinapayen

- Illusions of Self: Beyond Human, Animal, and Robot, organized by Olaf Witkowski, Elizaveta Solomonova, Thomas Doctor, and Bill Duane
- Eleven satellite workshops:
 - ABMHub’21: 3rd International Workshop on Agent-Based Modelling for Human Behaviour, organized by Soo Ling Lim and Peter J. Bentley
 - A(rt)life’21: (Accidental) art from life-like systems, organized by Silvia Holler and Richard Löffler
 - COST Workshop on Chemobionics, organized by Jitka Čejková, Geoff Cooper, Erik Hughes, and Tan Phat Huyn
 - Developing Artificial Life Web Resources, organized by Emily Dolson
 - Emerging Researchers in Artificial Life, organized by Abe Leite, Kira Breithaupt, Austin Ferguson, Alex Lalejini, and Josheta Srinivasan
 - LIFELIKE 2021: Lifelike Computing Systems Workshop, organized by Anthony Stein, Sven Tomforde, Jean Botev, and Peter Lewis
 - OEE4: Open-Ended Evolution 4, organized by Mark Bedau, Norman Packard, Alastair Channon, and Tim Taylor
 - Robots for Good, organized by Olaf Witkowski, Alex Penn, Jesus Siqueiros, Imran Khan, Erik Hom, Alan Dorin, and Andy Philippides
 - SLACE 2021: The Fifth Workshop on Social Learning and Cultural Evolution, organized by James M. Borg, Simon Powers, Chris Marriott, Nathan Brooks, and Peter Andras
 - Synthetic Approaches to Biology and Artificial Intelligence: from R.U.R. to contemporary Artificial Life research, organized by Luisa Damiano, Yutetsu Kuruma, and Pasquale Stano
 - TEMC 2020: 2nd International Workshop on Theoretical and Experimental Material Computing, organized by Susan Stepney, Matt Dale, Simon O’Keefe, Angelika Sebald, and Martin Trefzer
- Five tutorials:
 - Behavioral and Cognitive Robotics, an adaptive perspective, organized by Stefano Nolfi
 - Cartesian Genetic Programming, organized by Julian F. Miller
 - Differentiable Self-Organisation, organized by Alexander Mordvintsev, Ettore Randazzo, and Eyvind Niklasson
 - Gene Regulatory Networks: Computational Models in Contexts of Morphogenesis and Evolution, organized by Anyela V Camargo and Jan T Kim
 - Open Science Project with Lenia, organized by Bert Chan and Will Cavendish

About the Editors

Jitka Čejková is an Associate Professor at the Laboratory of Chemical Robotics at the University of Chemistry and Technology in Prague, where she also studied chemical engineering and successfully defended her doctoral degree. Her primary interests include the investigation of organic droplets with life-like behaviour and recently she proposed to call such droplets “*liquid robots*”. On the 100th anniversary of *R.U.R.*, she edited the book *Robot 100*.

Silvia Holler is a Postdoctoral researcher at the University of Trento, where she completed her bachelor and master after a 6 months apprenticeship at the ETH Zurich. She completed her PhD in biotechnology at the University of Trento too. Her primary interest include chemotactic droplets and protocells, droplet based synthetic biology, DNA labelled droplet aggregation and chemical gardens.

Lisa Soros is a Postdoctoral Researcher at Cross Labs in Kyoto, Japan. She was previously a Research Associate in the Game Innovation Lab at New York University, an Assistant Professor of Computer Science at Champlain College and was more previously a Ph.D. student in the Evolutionary Complexity Research Group at the University of Central Florida. Her primary interests include open-ended evolution, virtual worlds, and generative systems writ broadly.

Olaf Witkowski is the director of research at Cross Labs, a research institute in machine intelligence, cognitive science, and artificial life, based in Kyoto, Japan. He co-founded ventures in science and technology on three continents, including YHouse in New York– a nonprofit transdisciplinary research institute focused on the origins of consciousness in the

universe – and the Center for the Study of Apparent Selves in Kathmandu – studying ancient philosophies and AI. He is also a lecturer at the University of Tokyo, a research scientist at the Tokyo Institute of Technology, and a regular visitor at the Institute for Advanced Study in Princeton, and is the Industrial Relations Chair of the board of directors of the International Society for Artificial Life, and he was a Program Chair for the ALIFE 2018 conference ‘Beyond AI’ in Tokyo.

Acknowledgements

Organising a virtual conference and publishing a proceedings requires a team effort. ALIFE 2021 would not have been possible without the help of many people. I (Jitka Čejková) am very happy to write this acknowledgement note on behalf of the Organising Committee of ALIFE 2021. I would like to start by calling special attention to co-organizers and co-editors of this proceedings: Silvia Holler, Lisa Soros and Olaf Witkowski. Together, they performed a massive amount of work on this proceedings, conference program, review process and many other things, even small details. I consider myself so lucky to work remotely with such hard-working individuals. Although everyone was on the other side of the world, each of them replied to all of my messages, which could seem to be unimportant for discussion for the others. However, these three friends always provided a useful feedback. Their continued support and all of the help they provided was invaluable. I never have to worry about anything being overlooked or the deadline being missed when I worked with them. Their enthusiasm, never-ending positivity and sense of humor made organising of this conference a pleasure.

Further I would like to thank to all conference co-organisers and the organisers of workshops, special sessions and tutorials. I am so grateful to have in the organising committee Richard Löffler and Bára Hudcová, who were responsible for the workshops and tutorials. I deeply appreciate the work of all members of the art jury and student essay competition jury, especially their chairs Juan Manuel Castro and (again) Olaf Witkowski.

We wish to thank all of the reviewers and meta-reviewers who contributed to the review process and without whom a successful conference would not be possible. We thank them for their time, hard work and dedication to this conference. We appreciate their support and giving the suggestions to both, authors and organisers. Without reviewers’ services the organisers could not maintain the high standards of artificial life conferences. And of course, we would like to thank all authors who submitted their papers and extended abstracts to this conference and thanks to them this high quality conference proceedings originated.

We wish to extend sincerest thanks to the following organisations and all who have directly or indirectly involved in making this conference a success. First of all the University of Chemistry and Technology in Prague, namely Daniela Šídllová and Jan Kříž for administrative and technical assistance. A sincere word of appreciation has to go to the graphic designers Tereza Tomáščíková and Jonáš Ledecký. We appreciate the support of Marek Rosa and his GoodAI. We are also grateful for the generous support of the International Society for Artificial Life (ISAL), namely its chair Charles Ofria and vice-chair Susan Stepney, for their kind advice and suggestions to the organisers and the willingness to help with anything anytime.

Senior Program Committee

Martyn Amos
Manuel Baltieri
Julyan Cartwright
Harold Fellermann
Takashi Ikegami
Jean-Baptiste Mouret
Stefano Nichele
Charles Ofria
Alexandra Penn
Donato Romano
Hiroki Sayama
Thomas Schmickl
Lana Sinapayen
Pasquale Stano
Susan Stepney
Olaf Witkowski

Program Committee

Dave Ackley
Eran Agmon
Takaya Arita
Jaume Bacardit
Jacob Beal
Luc Berthouze
Tim Blackwell
Markus Brede
Christopher Buckley
Silvio Capobianco
Alastair Channon
Luís Correia
Sylvain Cussat-Blanc
Thomas Hove Doctor
Richard Duro
Jan Feyereisl
Tom Froese
Carlos Gershenson
Kyrre Glette
Thomas Gorochowski
Heiko Hamann
Taichi Haruna
Salima Hassas
Simon Hickinbotham
Julien Hubert
Ioannis Ieropoulos
Klaus Jaffe
Genaro Juarez Martinez
George Kampis
Hiroki Kojima
Mathieu Lefort
Ling Lim Soo
Joseph Lizier
Odd Rune Lykkebø
Omer Markovitch
Atsushi Masumori
Eric Medvet
Dusan Misevic
Chrystopher L. Nehaniv
Mizuki Oka
Andrew Philippides
Andrea Roli
Guido Schillaci
Ben Shirt-Ediss
Elizaveta Solomonova
Russell Standish
Stephane Doncieux
Keisuke Suzuki
Taniguchi Tadahiro
Uwe Tangen
Guy Theraulaz

Andy Adamatzky
Miguel Aguilera
Nathanael Aubert-Kato
Banzhaf Wolfgang
Manuel Bedia
Guillaume Beslon
James M. Borg
Nicolas Bredeche
Larry Bull
Timoteo Carletti
Sung-Bae Cho
Ernesto Costa
Luisa Damiano
Emily Dolson
Penelope Faulkner Rainford
Alessandro Filisetti
Rudolf M. Fuchslin
Mario Giacobini
Ángel Goñi-Moreno
Laura Grabowski
Martin Hanczyc
Inman Harvey
Helmut Hauser
Arend Hintze
Barbora Hudcova
Hiroyuki Iizuka
Gorecki Jerzy
David Kadish
Imran Khan
Dragana Laketic
Juan Letelier
Trym Lindell
Huw Lloyd
George Magoulas
Chris Marriott
Simon McGregor
Tomas Mikolov
Xiaojuan Mo
Geoff Nitschke
Kai Olav Ellefsen
Simon Powers
Federico Rossi
Roberto Serra
Eric Silverman
Lisa Soros
Adam Stanton
Kasper Stoy
Yasuhiro Suzuki
Masanori Takano
Tim Taylor
Jim Torresen

Christoph Adami
Jean-Baptiste André
Joshua Auerbach
Stuart Bartlett
Peter Bentley
Martin Biehl
Amine Boumaza
David Breen
Madhavun Candadai
José M Cecilia
Insook Choi
Antoine Cully
Ezequiel Di Paolo
Alan Dorin
Jose A. Fernandez-Leon
Miguel A. Fortuna
Adam Gaier
Jean-Louis Giavitto
Erik Goodman
Nicholas Guttenberg
Kyle Harrington
Yasuhiro Hashimoto
J. Michael Herrmann
Thomas Hinze
Giovanni Iacca
Eduardo Izquierdo
Colin Johnson
Sara Kalvala
Hyunju Kim
Renaud Lambiotte
Hoo Lim Tiong
Taivo Lints
Herve Luga
Sheref Mansy
Georg Martius
Philip Mckinley
Marco Miraglia
Alberto Montebelli
Shin-Ichiro Nomura
Robert Pennock
Daniel Richards
Michael Schartner
Tomohiro Shirakawa
Jesús M. Siqueiros-García
Lee Spector
Martin Stefanic
Reiji Suzuki
Petr Svarny
Ivan Tanev
Christof Teuscher
Vito Trianni

Program Committee (continued)

Elio Tuci
Tomas Veloz
Michael Vogrin
Lance Williams
Masahito Yamamoto
Xiaoge Zhang

Gunnart Tufte
Marco Villani
Anya Vostinar
Michael Wiser
Xin-She Yang

Andrew Vardy
Nathaniel Virgo
Justin Werfel
Borys Wrobel
Jason Yoder

The ALIFE 2021 Organizing Committee:

Jitka Čejková (General Chair)
Silvia Holler (Program Committee Chair)
Lisa Soros (Proceedings Chair)
Richard Löffler (Workshops Chair)
Barbora Hudcová (Tutorials Chair)
Juan Manuel Castro (Art Chair)
Will Millership (Local Chair)
Olaf Witkowski (Student Essay Competition - Jury Chair)

Conference Program

Introduction

1

- 1 Robots: The century past and the century ahead, an Introduction to the 2021 ALIFE conference
Jitka Čejková

Short abstracts of keynote presentations

5

- 5 The autonomous Earth: How humans created a planetary civilisation that is beyond their control
James Dyke
- 7 Complexity begets complexity
Jessica Flack
- 9 Artificial Life at Scale? Lessons from Machine Learning
David Ha
- 11 Homage to R.U.R.: 100 Ways to Play a Robot
Jana Horáková
- 13 Experiments in Machine Behavior
Iyad Rahwan
- 15 Soft Robots: Increasing Robot Diversity with Soft Materials
Daniela Rus
- 17 Order from Order: How Life Emerged from a Convection-driven Submarine Spring
Mike Russell
- 19 Ageing in artificial and real life: can we code a cure?
Andrew Steele
- 21 Weird Tales: Early Visions of Machines That Can Reproduce and Evolve, and Their Relevance Today
Tim Taylor

Special session: ALife and society

23

- 23 ArchaeaBot: A Post Singularity and Post Climate Change Life-form
Anna Dumitriu and Alex May
- 25 Towards Guidelines for Mechatronic Ecosystem Monitoring and Management
Alan Dorin, Hazel Parry and James Cook
- 28 Listening to Ecosystems as Complex Adaptive Systems
Alice Eldridge
- 36 SARS-CoV-2 pandemic dynamics and infection tracing in Denmark
Morten W. N. Jørgensen, Niels Højby, Hans J. Ziock and Steen Rasmussen
- 39 How Artificial Life Researchers Can Help Address Complex Societal Challenges
Hiroki Sayama
- 42 Emergence of more contagious COVID-19 variants from the coevolution of viruses and policy interventions
Aymeric Vie
- 45 Creating Artificial Societies through Interaction Analysis: Translating Qualitative Observational Study into Agent-Based Modelling
Selin Zileli, Jiayu Wu, Cyriel Diels and Stephen Boyd Davis

Special Session: Artificial Perception: Machines with Lifelike Failings

51

- 51 Artificial Cognitive Map System based on Generative Deep Neural Networks
Hiroki Kojima and Takashi Ikegami
- 54 A Monocular Depth Estimator to Perceive Crater Illusions in Several Characteristics
Ryota Mima, Yuki Kubota and Masahiko Inami

- 57 How Artificial Life Can Advance Artificial Intelligence
Ali Tehrani-Saleh and Christoph Adami

60

Special session: Bio-inspired approaches for modular robotics

- 60 The Impact of Early-death on Phenotypically Plastic Robots that Evolve in Changing Environments
Karine Araujo, Jim Cuijpers, Bahadır Gülhan and A.E. Eiben
- 68 Evolving Modular Robots: Challenges and Opportunities
Andres Faina
- 72 The effect of selecting for different behavioral traits on the evolved gaits of modular robots
Babak Hosseinkhani Kargar, Karine Miras and A.E. Eiben
- 81 Decomposing the Prediction Problem; Autonomous Navigation by neo-RL
Per Roald Leikanger
- 89 Differentiable Programming of Reaction-Diffusion Patterns
Alexander Mordvintsev, Ettore Randazzo and Eyvind Niklasson
- 95 Evolution of morphology through sculpting in a voxel based robot
Kathryn Walker and Helmut Hauser

Special session: Complexity ALI[F|V]E: Socializing & Eco-integrating robots with living organisms

103

- 103 Toward Population-Level Biohybrid Systems: Bioinspiration and Behavior
Eric Aaron and John Long
- 106 Biomimetic robots promote the 3R Principle in animal testing
David Bierbach, Fritz Francisco, Juliane Lukas, Tim Landgraf, Moritz Maxeiner, Pawel Romanczuk, Lea Musiolek, Verena V. Hafner and Jens Krause
- 110 Underwater communication with artificial electric sense
Mohamed Boukens, Vincent Lebastard and Frédéric Boyer
- 113 Investigating the influence of probabilistic robot motion parameters on archerfish behavior in fish-robot interactions
Alexander Brown, Michael Brown and Brent Utter
- 116 The logic of biorobotics
Edoardo Datteri
- 118 WatchPlant: Networked Bio-hybrid Systems for Pollution Monitoring of Urban Areas
Heiko Hamann, Stjepan Bogdan, Antonio Diaz-Espejo, Laura Garcia-Carmona, Virginia Hernandez-Santana, Serge Kernbach, Andreas Kernbach, Alfredo Quijano-lopez, Babak Salamat and Mostafa Wahby
- 127 Bio-Hybrid Systems for Ecosystem Level Effects
Asya Ilgün, Kostadin Angelov, Martin Stefanec, Sarah Schönwetter-Fuchs, Valerin Stokanic, Jutta Vollmann, Daniel N. Hofstadler, Martin Kärcher, Heinrich Mellmann, Volha Taliaronak, Armands Kviestis, Vitalijs Komasilovs, Matthias A. Becher, Martina Szopek, David M. Dormagen, Rafael Barmak, Erol Bairaktarov, Matthieu Broisin, Ronald Thenius, Rob Mills, Stamatios C. Nicolis, Alexandre Campo, Aleksejs Zacepins, Sergey Petrov, Jean-Louis Deneubourg, Francesco Mondada, Tim Landgraf, Verena Vanessa Hafner and Thomas Schmickl
- 137 Acute Citalopram administration alters zebrafish social dynamics in a behavioral teleporting experiment
Mert Karakaya, Simone Macrì and Maurizio Porfiri
- 140 Can Robots Inform a Honeybee Colony's Foraging Decision-Making?
Dajana Lazic and Thomas Schmickl
- 144 Control of collective behaviours through artificial feedbacks
Stamatios C Nicolis, Mariano Calvo Martin, Alexandre Campo and Jean Louis Deneubourg
- 147 Controlling invasive species with biologically-inspired robots
Giovanni Polverino and Maurizio Porfiri

- 151 Toward artificial cells/living cells communication in hybrid ensembles
Giordano Rampioni, Yutetsu Kuruma, Livia Leoni, Luisa Damiano and Pasquale Stano
- 154 Any colour you like: using animal-robot interaction to unravel mechanisms promoting phenotypically heterogeneous fish aggregations
Donato Romano and Cesare Stefanini
- 160 Towards animal phenotype transfer into biomimetic robots: the LAMPETRA project
Cesare Stefanini and Donato Romano
- 163 Biohybrid Entities for Environmental Monitoring
Ronald Thenius, Wiktoria Rajewicz, Joshua Cherian Varughese, Sarah Schoenwetter-Fuchs, Farshad Arvin, Alexander Casson, Chao Wu, Barry Lennox, Alexandre Campo, Godfried Jansen van Vuuren, Cesare Stefanini, Donato Romano and Thomas Schmickl
- 173 Robots communicating with fish: Integration requires reciprocal interaction
Gerhard von der Emde and Martin Worm
- 176 A concept of full plant morphology modeling for robot-plant bio-hybrids
Mostafa Wahby, Julian Petzold and Heiko Hamann

Special Session: Hybrid life IV: Approaches to integrate biological, artificial and cognitive systems

179

- 179 Towards Autopoietic SB-AI
Luisa Damiano and Pasquale Stano
- 182 Social Search Evolves with the Emergence of Clustered Environments
Mahi Luthra and Peter M. Todd
- 191 Studying Embodied Cognition in the Android Alter
Norihiro Maruyama, Atsushi Masumori and Takashi Ikegami
- 194 An organismic inspired strategy for adaptive control
Alvaro Ovalle
- 197 Evaluation of the effect of mimicry on facial expression in Avatar-Mediated Communication
Mikihiro Suda and Mizuki Oka
- 206 A Design of a Virtual Agent that Facilitates a Spatial and Online Communication by Use of Social Particle Swarm Model
Meito Tsuruta, Reiji Suzuki and Takaya Arita

Illusions of Self: Beyond Human, Animal, and Robot

213

- 213 Can Being Aware of the Illusion of Self Augment an Agent's Affordances: Integrating Buddhist Philosophy, Cognitive Science, and Artificial Life
Thomas Doctor, Elizaveta Solomonova, Bill Duane and Olaf Witkowski
- 217 On the Scales of Selves: Information, Life, and Buddhist Philosophy
Carlos Gershenson
- 223 Monks, Labs, Cyborgs: the Plasticity of Personhood in Tibetan Buddhism
Ana Cristina Lopes
- 226 You, Robot. Empathy in a Hybrid World
Jesús Siqueiros

General Conference

229

- 229 A graph-theoretic approach to understanding emergent behavior in physical systems
Alyssa Adams
- 232 The Comparative Hybrid Approach to Investigate Cognition across Substrates
Sarah Albani, Acacia Ackles, Charles Ofria and Clifford Bohm
- 241 Searching for initial parameters in cell colony spatial pattern generation
Nicolás Araya, Guillermo Iglesias and Martín Gutiérrez

- 248 Emergence of structures from parasitic species in a spatially distributed molecular system
Nathanael Aubert-Kato, Guillaume Gines, Teruo Fujii and Yannick Rondelez
- 256 Towards open-ended evolutionary simulator for developing novel tumour drug delivery systems
Igor Balaz, Tara Petric and Namid Stillman
- 259 Efficient Spike Timing Dependent Plasticity rule for Complex-Valued Neurons
Alex Baranski and Tom Froese
- 268 Reaction kinetics exploration of a protocellular metabolism
Ditlev Hartmann Bornebusch, Hans-Joachim Ziock and Steen Rasmussen
- 271 Modeling behavioral experiments on uncertainty and cooperation with population-based reinforcement learning
Elias Fernández Domingos, Jelena Grujic, Juan Carlos Burguillo, Francisco C. Santos and Tom Lenaerts
- 274 Growing Opportunities to Grow: Achieving Open-Ended Multi-Agent Communication Learning
Marina Dubova
- 277 Random Networks with Quantum Boolean Functions
Mario Franco, Octavio Zapata, David A. Rosenblueth and Carlos Gershenson
- 280 A Probabilistic Game of Life on a Quantum Annealer
Thomas Gabor, Marian Lingsch Rosenfeld and Claudia Linnhoff-Popien
- 283 Goals for Self-Replicating Neural Networks
Thomas Gabor, Steffen Illium, Maximilian Zorn and Claudia Linnhoff-Popien
- 292 The Dynamical Landscape of Reservoir Computing with Elementary Cellular Automata
Eivind Glover
- 301 A life/dinner paradox: emergence of a proto-amygdala in response to virtual agents' fears on an artificial neural substrate
Kevin Godin-Dubois, Sylvain Cussat-Blanc and Yves Duthen
- 309 A Genome-Wide Evolutionary Simulation of the Transcription-Supercoiling Coupling
Théotime Grohens, Sam Meyer and Guillaume Beslon
- 317 Active Dynamical Prospexion: Modeling Mental Simulation as Particle Filtering for Sensorimotor Control during Pathfinding
Jeremy Gordon and John Chuang
- 326 Safer Reinforcement Learning through Transferable Instinct Networks
Djordje Grbic and Sebastian Risi
- 336 Generating Agent Based Models From Scratch With Genetic Programming
Rory Greig and Jordi Arranz
- 346 A regulation dilemma in Artificial Intelligence development
The Anh Han, Francisco C. Santos, Luis Moniz Pereira and Tom Lenaerts
- 349 An evolutionary game theory analysis of trust in repeated games and lessons for human-machine interactions
The Anh Han, Cedric Perret and Simon T. Powers
- 352 Physical reservoir computing in a soft swimming robot
Yuta Horii, Katsuma Inoue, Satoshi Nishikawa, Kohei Nakajima, Ryuma Niiyama and Yasuo Kuniyoshi
- 361 Computational Hierarchy of Elementary Cellular Automata
Barbora Hudcová and Tomáš Mikolov
- 369 Liquid Crystal Phase Assembly in Peptide-DNA Coacervates as a Mechanism for Primitive Emergence of Structural Complexity
Tony Z Jia and Tommaso P Fraccia
- 371 Quality Evolvability ES: Evolving Individuals With a Distribution of Well Performing and Diverse Offspring
Adam Katona, Daniel W. Franks and James Alfred Walker
- 380 Introducing asymptotics to the state-updating rule in Lenia
Takako Kawaguchi, Reiji Suzuki, Takaya Arita and Bert Chan

- 383 Reservoir computing with self-organizing neural oscillators
Sina Khajehabdollahi, Emmanouil Giannakakis, Jan Prosi and Anna Levina
- 386 The emergence of collective response to decisions in a group of physical agents
Yara Khaluf
- 394 Adaptation-By-Proxy: Contagion Effect of Social Buffering in an Artificial Society
Imran Khan and Lola Cañamero
- 404 Tracking data flow in digital brains exposes coincidental encryption
Douglas Kirkpatrick, Victoria Cao and Clifford Bohm
- 407 Using MAP-Elites to direct the evolution of desired neural characteristics
Douglas Kirkpatrick and Arend Hintze
- 416 Diversity control in evolution of movement
Maciej Komosinski and Konrad Miazga
- 424 Architecture of the Genotype-Phenotype Map and the Coevolution of Complexity
Bhaskar Kumawat and Luis Zaman
- 431 Tracking Multiple Fast Targets With Swarms: Interplay Between Social Interaction and Agent Memory
Hian Lee Kwa, Jabez Leong Kit and Roland Bouffanais
- 440 Hyperdescriptions of Quantum Dynamics - A Case Study for Avian Magnetoreception
Dragana Laketic
- 449 Generating reward structures on a parameterized distribution of dynamics tasks
Abe Leite and Eduardo Izquierdo
- 458 Imprecise Fusion Operators for Collective Learning
Zixuan Liu, Michael Crosscombe and Jonathan Lawry
- 466 Objective Sampling Strategies for Generalized Locomotion Behavior with Lexicase Selection
Jared Moore and Adam Stanton
- 474 Supervision and Evolution: Pretraining Neural Networks for Quadrupedal Locomotion
Jared Moore and Anthony Clark
- 482 Friendly rivalry solutions for direct reciprocity
Yohsuke Murase and Seung Ki Baek
- 485 Sensorimotor behavior under informational constraints: a robotic model of prey localization in the bat *Micronycteris microtis*
Thinh Nguyen, Dieter Vanderelst and Herbert Peremans
- 494 The Role of Speaker Prestige in Synthetic Language Evolution
Geoff Nitschke and Greg Furman
- 497 Asynchronicity in Neural Cellular Automata
Eyvind Niklasson, Alexander Mordvintsev and Ettore Randazzo
- 500 A Representation of Artificial Spin Ice for Evolutionary Search
Arthur Penty and Gunnar Tufte
- 509 Species in Morphogenesis: Introducing Symbiogenesis as an Additional Method for the Evolutionary Process of an Artwork
Tiago Barros Pontes E Silva and Marilia Lyra Bergamo
- 517 The dynamical regime and its importance for evolvability, task performance and generalization.
Jan Prosi, Sina Khajehabdollahi, Emmanouil Giannakakis, Georg Martius and Anna Levina
- 526 Connections between Noisy Fitness and Selection Strength
Vincent Ragusa and Clifford Bohm
- 534 Designing Considerate Swarms
Nishant Ramakuru and Namid Ram Stillman

- 543 Exploring collective intelligence in animal fission-fusion dynamics
Gabriel Ramos-Fernandez, Tania M. Palacios-Romo and Sandra E. Smith Aguilar
- 546 Recursively Fertile Self-replicating Neural Agents
Ettore Randazzo, Luca Versari and Alexander Mordvintsev
- 555 A Sustainable Ecosystem through Emergent Cooperation in Multi-Agent Reinforcement Learning
Fabian Ritz, Daniel Ratke, Thomy Phan, Lenz Belzner and Claudia Linnhoff-Popien
- 565 When a Robot Writes a Play: Automatically Generating a Theatre Play Script
Rudolf Rosa, Tomáš Musil, Ondrej Dusek, Dominik Jurko, Patrícia Schmidová, David Marecek, Ondřej Bojar, Tom Kocmi, Daniel Hrbek, David Košťák, Martina Kinská, Marie Nováková, Josef Doležal, Klára Vosecká, Tomáš Studeník and Petr Žabka
- 568 Evolution of Neural Complexity in Division of Labor Tasks
Ekaterina Sangati, Soheil Keshmiri and Federico Sangati
- 578 Exploration in Evolutionary Space by Hashtag Evolution on a Social Web Service
Hiroki Sato, Yasuhiro Hashimoto, Mizuki Oka and Takashi Ikegami
- 585 Learning to Penalize Other Learning Agents
Kyrill Schmid, Lenz Belzner and Claudia Linnhoff-Popien
- 594 Influence of the geometry on the agglomeration of a polydisperse binary system of spherical particles
Johannes Schneider, Alessia Faggian, Silvia Holler, Federica Casiraghi, Jin Li, Lorena Cebolla Sanahuja, Hans-Georg Matuttis, Martin Hanczyc, David Barrow, Mathias Weyland, Dandolo Flumini, Peter Eggenberger Hotz and Rudolf Füchslin
- 603 Major transitions in evolution and finite time singularities: Human wealth history
Paolo Sibani and Steen Rasmussen
- 606 What is a Parasite? Defining reaction properties in an open ended automata chemistry
Susan Stepney and Simon Hickinbotham
- 615 Co-evolution of Initial Configuration and Control in Evolutionary Robotics
Kasper Stoy
- 618 Growing 3D Artefacts and Functional Machines with Neural Cellular Automata
Shyam Sudhakaran, Djordje Grbic, Siyan Li, Adam Katona, Elias Najarro, Claire Glanois and Sebastian Risi
- 627 An Artificial Creature Approach to the Origin of Acoustic Communication
Reiji Suzuki, Ryohei Seki, Takahiro Banno, Kouki Kawai and Takaya Arita
- 630 Simulating short- and long-term evolutionary dynamics on rugged landscapes
Léonardo Trujillo, Paul Banse and Guillaume Beslon
- 639 Identification of Lifelike Characteristics of Human Crowds Through a Classification Task
Jamie Webster and Martyn Amos
- 649 Resurrecting FPGA Intrinsic Analog Evolvable Hardware
Derek Whitley, Jason Yoder and Nicklas Carpenter
- 657 Increased Complexity and Fitness of Artificial Cells that Reproduce Using Spatially Distributed Asynchronous Parallel Processes
Lance Williams
- 666 Incentive for Self-Protection in a Collective System: a Swarm Robotics Case Study
Payam Zahadat