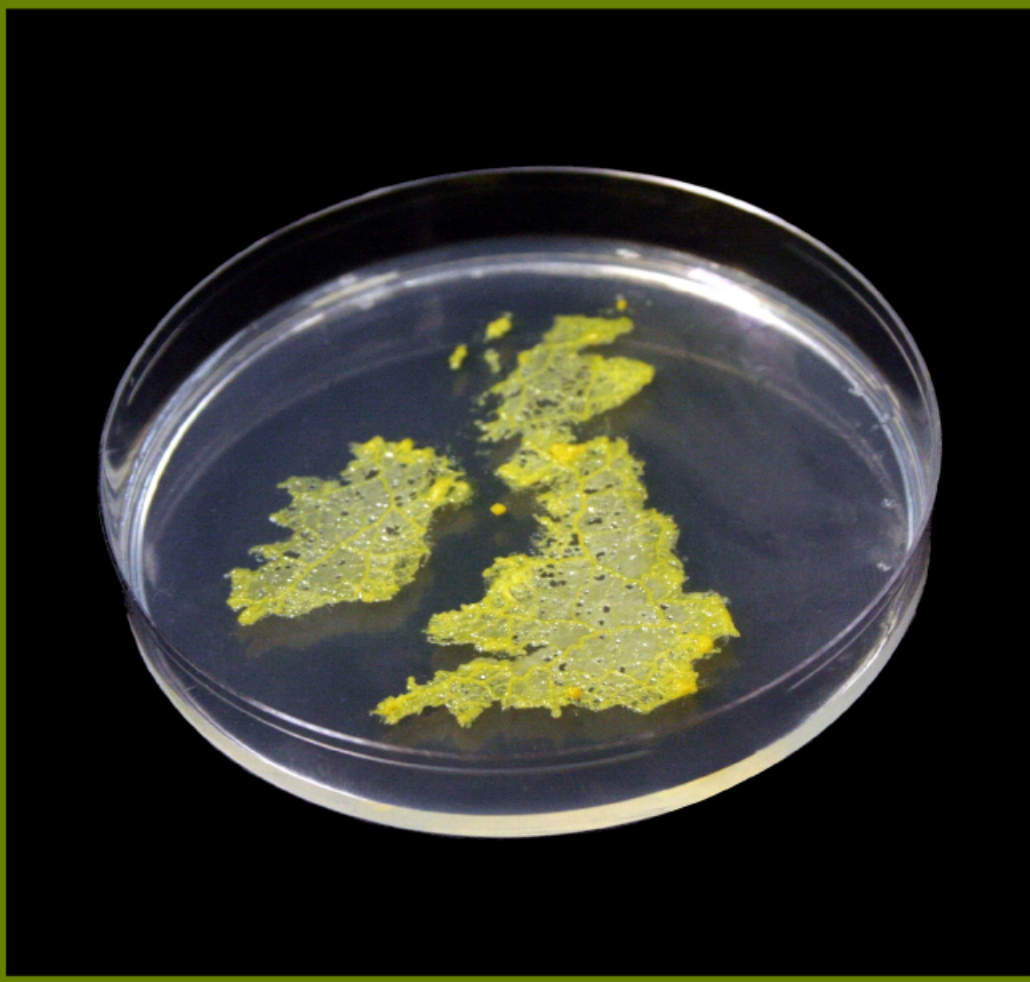
ARTIFICIAL LIFE XI



Proceedings of the Eleventh
International Conference on
the Simulation and Synthesis
of Living Systems

edited by
Seth Bullock, Jason Noble,
Richard Watson, and Mark A. Bedau

Artificial Life XI

Artificial Life XI

Proceedings of the Eleventh International Conference
on the Simulation and Synthesis of Living Systems

edited by Seth Bullock, Jason Noble, Richard Watson, and Mark A. Bedau

An ISAL Book

The MIT Press
Cambridge, Massachusetts
London, England

All rights reserved by the individual authors of the papers herein. No paper in this proceedings may be reproduced in any form by any electronic or mechanical means without permission in writing from the individual authors of the papers herein.

ISBN: 978-0-262-75017-2

Preface

The Eleventh International Conference on Artificial Life marks the twenty-first birthday of the conference series, which was founded in 1987 by Chris Langton at the Santa Fe Institute. As you might expect, over twenty-one years the community has grown, matured and stabilised around some key ideas, individuals and questions. However, while artificial life now, as then, continues to investigate the fundamental properties of living systems through simulating and synthesizing biological entities and processes in artificial media, there are signs that the field may be on the cusp of a second wave driven by new developments in molecular, cellular and systems biology, and renewed widespread interest in complex systems of many kinds.

The rise of synthetic biology (constructing artificial living cells, engineering with living biological materials, etc.) and systems biology, with its focus on biological organisations above the gene (e.g., proteomics, metabolomics, etc.), means that topics proper to artificial life are becoming key research areas across science and engineering. Additionally, the kinds of agent-based simulations and complex systems methodologies pioneered within artificial life are growing in importance within a large number of fields (ecology, economics, sociology, transport, etc.). This makes ALIFE XI a potential watershed event at which artificial life has the opportunity to engage with, and offer a stimulating home for, some of the largest and most interesting of modern research questions.

Over the last twenty-one years, the ALIFE conference series has, along with its European sister conference ECAL, played an important role as a meeting place for researchers from diverse disciplines. Biologists, physicists, chemists, computer scientists, engineers, economists, linguists, geographers, psychologists, mathematicians, anthropologists, philosophers, musicians and artists have come together to exchange ideas and inspiration. In doing so, many have found an informed audience for work that may have been considered peripheral to the interests of their home disciplines. Maintaining this diversity of ideas, tools, approaches and cultures is something that we feel is extremely valuable.

One measure of artificial life's success is that the community's research has had an influence on the mainstream work within adjacent disciplines. What was once somewhat marginal is increasingly central: witness the growth of interest in complexity, self-organisation, adaptation and simulation across a broad range of fields. Moreover, Alife has had a hand in the genesis of entirely new research communities in areas such as unconventional computing and self-* computing. If Alife is to remain healthy, there must be a continuing reason for researchers to keep coming back to the melting pot within which some of these ideas were incubated.

With this in mind, our aim was to make the meeting as open and attractive to researchers from as wide a range of disciplines as possible—our watchword was "inclusivity". In order to involve as many relevant kinds of academics as possible at ALIFE XI we have experimented with radical changes to the format and delivery of the conference. By allowing both full papers and abstracts to be submitted for presentation at the conference and inclusion in this proceedings, we hoped to engage not just with ALIFE's established core community, but also researchers from disciplines where conferences are not associated with published proceedings, e.g., many parts of biology.

For such conferences it is standard practice to submit abstracts only and for no lasting record of the conference to be published. We were also conscious that there are many Alife academics for whom a full conference paper may not look like a good return on the investment of time and effort required. For both of these groups of people, the opportunity to make a presentation based on a 500-word abstract may make the difference between attending the conference or not. The fact that ALIFE XI received roughly the same number of full paper submissions as ALIFE IX and X, but also received a similar number of abstracts on top of that is evidence that this has indeed been the case. Given this, we believe that the new format will maintain the character and quality of ALIFE whilst lowering the "barriers to entry" that may have existed in the past, opening it up to a more diverse and representative community of researchers.

ALIFE XI sees many firsts for the conference series. For the first time in its history, the conference visits Europe, being hosted in the United Kingdom by the University of Southampton at the nearby historic city of Winchester, known for its 11^{th}-century cathedral and 12^{th}-century castle. For the first time, the conference will be truly multi-track with around 180 talks taking place over three-and-a-half days. While it might not be ideal for delegates to have to choose between competing parallel sessions, we feel that allocating every accepted submission an oral presentation offers the best opportunity for each researcher to present their work clearly and effectively to the delegates that have a substantive interest in it. Also for the first time, the conference proceedings will be published by MIT Press as an open-access online volume containing all accepted papers and abstracts. Rather than receiving an expensive and heavy book at registration, conference delegates (and anyone else) will instead be able to freely access the entire conference proceedings online. In addition to obvious economic and environmental advantages, this arrangement should enable delegates to make informed decisions regarding which talks to attend at the conference, and should also increase the impact of conference papers outside the immediate community of delegates attending the conference.

We received a total of 275 submissions (145 full papers and 130 abstracts), each of which was reviewed by three referees. Of these, 95 full papers and 85 abstracts were selected for presentation at the conference and publication in this proceedings. At the time of writing we have registered over 250 delegates for the meeting itself. Our thanks to all those who submitted papers and abstracts to the conference.

We would like to take this opportunity to thank all who served on the programme committee for their assistance in shaping the direction that the field is taking and helping achieve a high level of quality across the accepted submissions:

Andrew Adamatzky
Fernando Almeida e Costa
Takaya Arita
Wolfgang Banzhaf
Lionel Barnett
Randall Beer
Josh Bongard
C. Titus Brown
Joanna Bryson
Chris Buckley
Larry Bull
Lola Ca namero
Angelo Cangelosi
Peter Cariani
John Cartlidge
Alastair Channon
Andy Clark
Dave Cliff
Bob Damper
Kerstin Dautenhahn
Manuel de Pinedo
Ezequiel Di Paolo
Marco Dorigo
Alan Dorin
Arantza Etxeberria
Chrisantha Fernando
Sevan G. Ficici
Dario Floreano
David Fogel
Daniel W. Franks
Nicholas Geard
Steve Grand
Patrick Grim
Jennifer Hallinan
Inman Harvey
Paulien Hogeweg
Owen Holland
Gregory Hornby
Phil Husbands
Auke Ijspeert
Frederic Kaplan
Jozef Kelemen
Jan Kim
Lex Kraaijeveld
Daniel Ladley

Tom Lenaerts
Kristian Lindgren
Hod Lipson
James Marshall
Barry McMullin
J. J. Merelo
Julian F. Miller
Melanie Mitchell
Chrystopher L. Nehaniv
Ulrich Nehmzow
Stefano Nolfi
Charles Ofria
Pierre-Yves Oudeyer
Alexandra Penn
Rolf Pfeifer
Andrew Philippides
Daniel Polani
Jordan Pollack
William Rand
Luis Rocha
Jonathan Rowe
Graeme Ruxton
Fabrice Saffre
Hiroki Sayama
Anil Seth
Eric Silverman
Kenny Smith
Andrew Smith
Susan Stepney
Tim Taylor
Charles Taylor
Rene te Boekhorst
Peter Todd
Elio Tuci
Richard Vaughan
Paul Vogt
James Watson
Barbara Webb
Michael Wheeler
Janet Wiles
Kai Willadsen
Hywel Williams
Peter Wills
Simon Worgan
Klaus-Peter Zauner

We would also like to acknowledge the valuable input of several additional reviewers:

Christos Ampatzis
Prasanna Balaprakash
Alexandre Campo
Anders L. Christensen
Rob Mills
Martin Nilsson Jacobi
Christopher Strelioff
Colin Tosh

It is extremely important to recognise the support offered to us by our sponsors: the School of Electronics and Computer Science at the University of Southampton, British Telecom, ProtoLife, Icosystem, EPSRC, the Southampton Life Sciences Interface Forum, the ESIGNET and SECSE projects, and the International Society for Artificial Life, as well as one anonymous donor. With their help we have been able to run a very affordable conference, and to offer significant financial assistance to over 30 delegates.

We were very lucky to secure the services of a truly excellent array of world-class keynote speakers: Andrew Ellington, Takashi Ikegami, Eva Jablonka, Stuart Kauffman, and Peter Schuster. Our thanks to them for taking the time and effort to contribute to the conference.

Andrew Ellington received his BS in Biochemistry from Michigan State University in 1981, and his PhD in Biochemistry and Molecular Biology from Harvard in 1988. As a graduate student he worked with Dr. Steve Benner on the evolutionary optimization of dehydrogenase isozymes. His post-doctoral work was with Dr. Jack Szostak at Massachusetts General Hospital, where his lab developed methods for the in vitro selection of functional nucleic acids and coined the term 'aptamer'. Dr. Ellington began his academic career as an assistant professor of Chemistry at Indiana University in 1992. In 1998 he moved to the University of Texas at Austin and is now the Fraser Professor of Biochemistry. Dr. Ellington's lab continues to develop functional nucleic acids for practical applications, including aptamer biosensors, allosteric ribozyme logic gates (aptazymes), and internalizing nucleic acids that can deliver siRNAs to cells. A next leap forward will hopefully be to develop synthetic genetic circuits that can perform amorphous computations. Ultimately, though, Dr. Ellington's first love remains origins of life research, which oddly melds with translational research initiatives in that it is the ultimate biotechnology challenge.

Takashi Ikegami is Associate Professor in the Department of General Systems Sciences, Graduate School of Arts and Sciences at the University of Tokyo. He is a long-standing member of the Artificial Life community, with work spanning a diverse array of concepts, such as chaotic

itinerancy, self-organisation, autopoiesis, and embodiment, applied to a range of behaviours including coevolution, learning, language, social behaviour and song, in systems of birds, robots, children, flies, cells, and even oil droplets. These interests are unified by a focus on understanding the fundamental behavioural dynamics of embedded, embodied, evolving and adaptive systems.

Eva Jablonka is a geneticist known especially for her work on epigenetic inheritance. Her research with Marion Lamb is in the vanguard of what has been described as an ongoing revolution within evolutionary biology. In their current book, they describe how the growing body of evidence for the evolutionary role of epigenetic processes is putting increasing pressure on the dominant neo-Darwinian paradigm. Jablonka is a professor at the Cohn Institute for the History of Philosophy of Science and Ideas at Tel Aviv University and was awarded the Landau Prize of Israel in 1981 and the Marcus prize in 1988.

Stuart Kauffman originally trained as a physician and is now a biologist and complex systems researcher. His primary work has been as a theoretical biologist studying the origin of life and molecular organization. His seminal models of autocatalytic sets, gene regulatory networks and fitness landscapes allowed him to develop an extremely influential account of the way in which self-organisation within biology can generate "order for free". He currently holds a chair spanning the departments of biological sciences and physics and astronomy at the University of Calgary where he is the director of the Institute for Biocomplexity and Informatics. A MacArthur Fellow and a Trotter Prize winner, his latest book *Reinventing the Sacred: A New View of Science, Reason, and Religion* was published this year.

Peter Schuster is a renowned biophysicist, known for his work with Manfred Eigen in developing the quasi-species model. His main research interests are bioinformatics and structure prediction of ribonucleic acids, the study of mechanisms of biological evolution by means of molecular models, the design of molecules for predefined purposes as well as the application of inverse methods in computational systems biology. He is full professor of theoretical chemistry at the University of Vienna. In 1992-1995 he was the founding director of the Institute of Molecular Biotechnology and head of its Department of Molecular Evolutionary Biology in Jena, Germany. He is member of the German Academy of Sciences Leopoldina, is the editor-in-chief of *Complexity* and is currently President of the Austrian Academy of Sciences. In 1995 Peter Schuster received the Phillips-Morris Award and in 1999 the Wilhelm-Exner Medal.

We would also like to recognise the invaluable assistance provided by the people who helped to make the conference happen: the postdocs, postgrads and MSc students in the SENSe group at ECS, Southampton, Denise Harvey, the group secretary, the ECS finance group, Joyce Lewis and Sarah Prendergast, for help with posters and other materials, C. Titus Brown for running the submissions website, MIT Press for agreeing to experiment with an entirely new model for delivering a conference proceedings, Hannah Lane and her team at the University of Winchester Conference Office who were outstanding in their support, efficiency and professionalism, and in particular, Nic Geard who has been central to the smooth running of the entire operation from start to finish.

By way of conclusion, it seems appropriate to remind the readers of this proceedings volume that, over the last two decades, some of the highly speculative ideas that were discussed at the field's inception have matured to the extent that whole new conferences and journals devoted to

them are being established: synthesising artificial cells, simulating massive biological networks, exploiting biological substrates for computation and control, and deploying bio-inspired engineering are all now cutting-edge practice. It is our intention that the ALIFE conference series continue to provide an opportunity for those working across these topics to get together and exchange ideas and results, showcasing the best current work in the field, highlighting new directions for investigation, and providing a platform for world-renowned keynote speakers. Our thanks to all who have attended and made this possible.

A note on the cover

We chose to promote the conference with an image that is in some sense itself an example of artificial life: a real organism artificially encouraged to adopt the shape of the host country (plus Ireland). The cover of this proceedings volume features a photograph of a single-cell creature, the slime mould *Physarum polycephalum*, that was grown over a period of between twelve and twenty-four hours in a petri dish. While we have tidied the image up a little, it is essentially undoctored. The slime mould was grown by Soichiro Tsuda, and photographed by Soichiro, Nic Geard and Seth Bullock. The initial idea was proposed by Richard Watson during a particularly creative lunch.

In order to achieve the shot, we used a piece of acetate with an appropriately shaped hole as a template, and grew the slime mould across this area. The network of microtubules that you can see forms spontaneously as the creature grows, and reflects the self-organised system of nutrient transport that the slime mould uses. Since *Physarum* does not enjoy acetate as a habitat, it is relatively easy to remove the template and leave behind the organism, which has adapted to the niche it was offered by creating a living map of the the United Kingdom (and Ireland).

The organising committee of Artificial Life XI,

Seth Bullock (Conference Chair)
Jason Noble (Program Chair)
Richard Watson (Proceedings Chair)
Mark Bedau

Southampton, June, 2008

Contents

Presented papers

Adaptive spam detection inspired by the immune system 1
Abi-Haidar and Rocha

Uncertainty and communication complexity in iterated cooperation games 9
Andras

Investigating patterns for the process-oriented modelling and simulation of space in complex systems 17
Andrews, Sampson, Bjørndalen, Stepney, Timmis, Warren and Welch

On preferred states of agents: how global structure is reflected in local structure 25
Anthony, Polani and Nehaniv

Information-theoretic aspects of control in a bio-hybrid robot device 33
Artmann, Tsuda and Zauner

Movement strategies for learning in visual recognition 41
Bermudez, Philippides and Seth

The emergence of specialization 49
Bersini

Autocatalytic replication of polymers revisited 56
Blundell

Behavior chaining: incremental behavioral integration for evolutionary robotics 64
Bongard

Evolving CSR strategies in virtual plant communities 72
Bornhofen and Lattaud

Building artificial personalities: expressive communication channels based on an interlingua for a human-robot dance 80
Bryden, Hogg, Popat and Wallis

Basic principles of adaptive learning through variation and selection 88
Burtsev

Design strategies for open-ended evolution 94
Cariani

On the ability of swarms to compute the 3-coloring of graphs 102
Cases, Hernandez, Graña and d'Anjou

The effects of periodic and continuous market environments on the performance of trading agents 110
Chaggar, Noble and Cliff

Measuring the robustness of a developmental system based on sequential growth rules 118
Cohen, Miodownik and Baum

"Soft" continuum robots: the interaction of continuous and discrete elements 126
Cowan and Walker

From single cell to simple creature morphology and metabolism 134
Cussat-Blanc, Luga and Duthen

A model chemical memory in an evolved animat 142
Dale

Protein folding with stochastic L-systems 150
Danks, Stepney and Caves

Unexpected evolutionary dynamics in a string based artificial chemistry 158
Decraene, Mitchell and McMullin

Predictive information and emergent cooperativity in a chain of mobile robots 166
Der, Güttler and Ay

Artificial-life ecosystems: what are they and what could they become? 173
Dorin, Korb and Grimm

Programmable architectures that are complex and self-organized: from morphogenesis to engineering 181
Doursat

Entropy production in an energy balance Daisyworld model 189
Dyke

Group formation and social evolution: a computational model 197
Geard and Bullock

A computational model of gene regulatory networks and its topological properties 204
Gonçalves and Costa

What makes the spatial prisoner's dilemma game sensitive to asynchronism? 212
Grilo and Correia

Being arranged in advance: quantum entanglement and biological feedback 220
Haruna

Misrepresentations 227
Harvey

NKα: non-uniform epistatic interations in an extended NK model 234
Hebbron, Bullock and Cliff

Why should you care? An arousal-based model of exploratory behavior for autonomous robot 242
Hiolle and Cañamero

The effects of payoff preferences on agent tolerance 249
Howley and O'Riordan

Analysis of a dynamical recurrent neural network evolved for two qualitatively different tasks: walking and chemotaxis 257
Izquierdo and Buhrmann

The evolution of evolvability in gene transcription networks 265
Izquierdo and Fernando

Energy, entropy and work in computational ecosystems: a thermodynamic account 274
Jacyno and Bullock

Evolving asynchronous cellular automata for density classification 282
Jeanson

Effects of signalling on the evolution of gene regulatory networks 289
Jenkins and Stekel

Evo-devo in silico: a model of a gene network regulating multicellular development in 3D space with artificial physics 297
Joachimczak and Wróbel

Evolving functional symmetry in a three dimensional model of an elongated organism 305
Jones, Jin, Sendhoff and Yao

Enrichment of interaction rules in a string-based artificial chemistry 313
Kelly, McMullin and O'Brien

Evolution and morphogenesis of differentiated multicellular organisms: autonomously generated diffusion gradients for positional information 321
Knabe, Schilstra and Nehaniv

Exploiting open-endedness to solve problems through the search for novelty 329
Lehman and Stanley

Adaptive multi-robot bucket brigade foraging 337
Lein and Vaughan

Tracking the evolution of chemical computing networks 343
Lenser, Matsumaru, Hinze and Dittrich

Simulated evolution of mass conserving reaction networks 351
Liekens, ten Eikelder, Steijaert and Hilbers

Distributed gradient optimization with embodied approximation 359
Litus and Vaughan

Emergence of glider-like structures in a modular robotic system 366
Lizier, Prokopenko, Tanev and Zomaya

The information dynamics of phase transitions in random Boolean networks 374
Lizier, Prokopenko and Zomaya

'Psychoanalysis' of a minimal agent 382
Manicka and Harvey

Conceptual structure in cellular automata: the density classification task 390
Marques-Pita and Rocha

The longevity of distinct cultures in an agent-based model of memetic drift 398
Matthews

Fitness transmission: a genealogic signature of adaptive evolution 404
Miconi

Anticipating future experience using grounded sensorimotor informational relationships 412
Mirza, Nehaniv, Dautenhahn and te Boekhorst

Common concepts in agent groups, symmetries, and conformity in a simple environment 420
Möller and Polani

KohonAnts: a self-organizing ant algorithm for clustering and pattern classification 428
Mora, Fernandes, Merelo, Ramos, Laredo and Rosa

Emergence of cooperation in N-player games on small world networks 436
O'Riordan, Cunningham and Sorensen

Optimal noise in spiking neural networks for the detection of chemicals by simulated agents 443
Oros, Steuber, Davey, Cañamero and Adams

Holey fitness landscapes and the maintenance of evolutionary diversity 450
Paperin, Sadedin, Green and Dorin

Conformist transmission and the evolution of cooperation 458
Peña

Hawks and doves in an artificial dynamically structured society 466
Pestelacci and Tomassini

Evolving morphological and behavioral diversity without predefined behavior primitives 474
Pichler and Cañamero

Complex systems models: engineering simulations 482
Polack, Hoverd, Sampson, Stepney and Timmis

Modelling stigmergic gene transfer 490
Polani, Prokopenko and Chadwick

The efficacy of group selection is increased by coexistence dynamics within groups 498
Powers, Penn and Watson

Mechanism as mind: what tensegrities and caterpillars can teach us about soft robotics 506
Rieffel, Trimmer and Lipson

"Embryo": an autonomic co-operative service management framework 513
Saffre and Shackleton

The limited utility of communication in simple organisms 521
Scheutz and Schermerhorn

Analysing honeybees' division of labour in broodcare by a multi-agent model 529
Schmickl and Crailsheim

Altruism amongst spatial predator-prey animats 537
Scogings and Hawick

Measuring emergence via nonlinear Granger causality 545
Seth

Modeling the neural basis of cognitive integration and consciousness 553
Shanahan and Connor

Evolving an agent-based model to probe behavioral rules in flocks of cowbirds 561
Smith

Evolutionary advantages of neuromodulated plasticity in dynamic, reward-based scenarios 569
Soltoggio, Bullinaria, Mattiussi, Dürr and Floreano

Can body language shape body image? 577
Steels and Spranger

Multiple functionalities of biochemical reaction networks 585
Steijaert, Liekens, ten Eikelder and Hilbers

An artificial chemistry-based model of economies 592
Straatman, White and Banzhaf

Homeodynamics in the game of life 600
Suzuki and Ikegami

How learning can guide evolution of communication 608
Suzuki and Arita

Self-assembly in physical autonomous robots: the evolutionary robotics approach 616
Tuci, Ampatzis, Trianni, Christensen and Dorigo

Evolution, development and environment toward adaptation through phenotypic plasticity and exploitation of external information 624
Tufte

Simulated trust: towards robust social learning 632
Vanderelst, Ahn and Barakova

A study of GasNet spatial embedding in a delayed-response task 640
Vargas, Di Paolo and Husbands

The connectivity of NK landscapes' basins: a network analysis 648
Verel, Ochoa and Tomassini

Adaptive growth processes: a model inspired by Pask's ear 656
Virgo and Harvey

The spatiality of swarms — quantitative analysis of dynamic interaction networks 662
von Mammen and Jacob

Optimal robot recharging strategies for time discounted labour 670
Wawerla and Vaughan

Hierarchical components and entity-based modelling in artificial life 678
Webster and Malcolm

Investigating emergence by coarse graining elementary cellular automata 686
Weeks, Polack and Stepney

Understanding robustness in random Boolean networks 694
Willadsen, Triesch and Wiles

Evolving referential communication in embodied dynamical agents 702
Williams, Beer and Gasser

Species selection of aging for the sake of diversity 710
Woodberry, Korb and Nicholson

Initial modelling of the alternative phenotypes hypothesis 717
Worgan and Mills

Passive and driven trends in the evolution of complexity 725
Yaeger, Griffith and Sporns

Fitness based identification of a robot structure 733
Zagal, Ruiz-del-Solar and Palacios

Presented abstracts

Topological properties of evolved robot brains 742
Adami, Chaumont, Edlund and Hintze

Evolutionary robotics and the morphological turn: an epistemological perspective 743
Almeida e Costa

Morphodynamics and perceptual worlds: conceptual approach and an experiment in evolutionary robotics 744
Almeida e Costa, Macinnes and Harvey

Smart plankton: a new generation of underwater wireless sensor network 745
Anguita, Brizzolara, Ghio and Parodi

Combinatorial optimization and self-disciplined computing by amoeba-based neurocomputer 746
Aono and Hara

Artificial mental life 747
Barandiaran and Di Paolo

Ruggedness and evolvability — an evolution's-eye view 748
Barnett

A functional account of minimal cellular life 749
Bedau

The arrow of complexity hypothesis 750
Bedau

Artificial life as cancer research: embodied agent modelling of blood vessel growth in tumours 751
Bentley, Bates and Gerhardt

Modelling spatial market dynamics with retail agents 752
Birkin and Heppenstall

Does coexistence solve the prebiotic information problem? 753
Branciamore, de Back and Gallori

How might group selection explain the major evolutionary transitions? 754
Bryden

Dynamical complexity of spatially embedded networks 755
Buckley, Barnett and Bullock

Learning drives the accumulation of adaptive complexity in simulated evolution 756
Burtsev, Anokhin and Bateson

Dynamically adapting parasite virulence to combat coevolutionary disengagement 757
Cartlidge

A measure for natural selection's contribution to the origins and maintenance of organismal complexity 758
Channon

An adaptive model of marine biogeochemistry in the Archaean 759
Clark and Williams

Phenotype-based evolution of complex food webs 760
de Back, Branciamore and Kampis

Life in time: the missing temporal dimension in autopoiesis 761
Di Paolo

Chemical organizations in living systems 762
Dittrich, Centler, Kaleta, Matsumaru and Speroni di Fenizio

Strategies for maintaining large robot communities 763
English, Gough, Johnson, Spanton, Sun, Crowder and Zauner

Abstract organization and material parts in ALife and synthetic biology 764
Etxeberria

Developing a methodology for social network sampling 765
Franks, James, Noble and Ruxton

Utility and experimental testability of the Gaia hypothesis 766
Free, McNeil, Mozley and Allen

CAT: a market design competition 767
Gerding, McBurney, Niu and Parsons

The gene-function relationship in the metabolism of yeast and digital organisms 768
Gerlee, Lundh, Zhang and Anderson

In silico evolution of chemotaxis 769
Goldstein and Soyer

Immune-inspired networked service delivery 770
Gowans, Marrow and Tateson

From market to non-market: an autonomous agent approach to central planning 771
Greenwood

How epigenetic evolution can guide genetic evolution 772
Groom, Mills and Watson

Chemical basis for minimal cognition 773
Hanczyc and Ikegami

Homeostasis via chaos: implementing the uniselector as a dynamical system 774
Harvey

Animatronic model of a human tongue 775
Hofe and Moore

Simulating active touch with a simple embodied agent 776
Iizuka and Ikegami

Adaptive fault tolerance in wireless sensor networks 777
Irons, Saffre and Cannings

Solving the division of labour problem using stigmergy and evolved heterogeneity 778
James, Noble and Watson

Nonconsumable resources facilitate complex evolution 779
Kampis, Gulyas and de Back

Intentional and causal urges: when to ascribe life or mind to artificial systems? 780
Keijzer

The effects of local information and trading opportunities in a network constrained economy 781
Ladley and Bullock

Towards mental life as it could be: a robot with imagination 782
Marques, Holland, Knight and Newcombe

Dimensions of adaptivity 783
McGann

An artificial chemistry towards the identification of the transition to life 784
Mendoza, Muethe, Gómez and Ewert-Sarmiento

Adaptive units of selection can evolve complexes that are provably unevolvable under fixed units of selection 785
Mills and Watson

Considering the reconfiguration process of subjective temporal order by using recurrent neural networks 786
Nakajima and Ikegami

Emergent intracellular network states and cell fate decision: a dynamically integrated study of the epidermal growth factor receptor network with an agent based model 787
Nene and Nagl

Is the organism really a machine? 788
Nicholson

Intelligent locomotion of eukaryotic cells 789
Nishimura and Sasai

What can artificial life offer ecology? 790
Noble, Clarke and Mills

Information-theoretic characterization of relative and fluctuating system–environment distinction 791
Nozawa and Kondo

Personalities in fish without genetic differences: a model 792
Oosten and Hemelrijk

What can artificial life offer the development of methodologies in the field of socio-ecological sustainability? 793
Penn

Mechanisms for the initiation of multicellularity in bacterial biofilms 794
Penn, Watson, Powers, Webb, Kraaijeveld, Conibear and Bigg

Quantifying creative symbiosis: a lexical analysis of the evolution of technology as reflected in patent records 795
Pepper, Francis, Bedau, Chalmers and Head

The group selection debate and ALife: weak altruism, strong altruism, and inclusive fitness 796
Powers and Watson

A strong local dependency of developmental bias orients adaptive evolution in a model evo-devo system 797
Psujek and Beer

Evolutionary robotics models in the interdisciplinary study of embodied time perception 798
Rohde and Di Paolo

Selective attention in artificial organisms 799
Ruini and Parisi

Organizational requirements for 'open-ended evolution' 800
Ruiz-Mirazo, Umerez and Moreno

Self-organizing heterogeneous swarms designed through evolutionary methods 801
Sayama

Redefining robustness 802
Silverman and Ikegami

Dancing robots: form, environment and context in human-robot interaction 803
Silverman, Ikegami, Ogai and Aucouturier

The virtual rocky shore — linking A-life with ecological and pedagogical research 804
Stafford, Davies and Williams

A minimal approach to modular assembly 805
Studer and Harvey

Evolution of complexity in RNA-like replicator systems 806
Takeuchi and Hogeweg

How to know without having been there? — Investigating communication channels in the nectar collecting system of a honeybee colony 807
Thenius, Schmickl and Crailsheim

Towards language acquisition in autonomous robots 808
Tikhanoff, Cangelosi, Tani and Metta

Complex consumer preferences from rudiments of visual processing 809
Tosh, Krause and Ruxton

Self-organising synchronisation in a robotic swarm 810
Trianni and Nolfi

Mammalian decisions 811
Trimmer, McNamara, Houston, Marshall, Paul, Bogacz and Mendl

Modelling the social coordination of behavior with public symbols 812
Türkmen and Zugic

Using the RNA sequence-to-structure map for functional evolution of ribozyme catalyzed artificial metabolisms 813
Ullrich, Flamm and Endler

Modelling resilience of agro-ecosystems: the co-evolution of regimes 814
van Apeldoorn, Kok, Sonneveld and Veldkamp

Diet learning and the evolution of cultural inheritance 815
van der Post, Ursem and Hogeweg

Reaction-diffusion spots as a model for autopoiesis 816
Virgo and Harvey

Can we rebuild a cell? Bryopsis — an experimental model! 817
Vladimirescu

Can individual selection favour significant higher-level selection? 818
Watson, Mills, Penn and Powers

Autopoiesis, enactivism, and the extended mind 819
Wheeler

Environmental regulation by higher level selection in a simulated network of microbial ecosystems 820
Williams and Lenton

Timing of critical periods in development 821
Winks and Berthouze

Time and space in neuronal networks: the effects of spatial organisation on network behaviour 822
Womble and Cohen

Canalization and environmental engineering 823
Yamauchi