The Program and Abstract Booklet of

EVOSLACE

Workshop on the emergence and evolution of social learning, communication, language and culture in natural and artificial agents

in ALIFE 2018

Place: Mirai-kan, Tokyo

Date: July 25th

Time: 10:30-19:00

Program

10:30-12:00 Session 1 (Opening, Evolinguistics and evolution of speech)

Opening
Emergent constructive approach to Evolinguistics: On intention sharing and hierarchy formation. *Takashi Hashimoto*
Evolution of Speech: What evolved, and how can A-life study it? *Bart de Boer*

13:30-15:00 Session 2 (Symbol emergence and cognitive models for robots)

Constructive approach towards symbol emergence systems with cognitive robotics and machine learning. *Tadahiro Taniguchi*
Integrated cognitive model for robots to learn concepts, actions, and language. *Takayuki Nagai*

15:30-17:00 Session 3 (Natural and artificial languages, poster session, closing)

Exploring the texture of new words in natural and artificial languages. *Ryoko Uno*
Poster session (12 posters)

17:30-19:00 Session 4 (Experimental and modeling approaches to cultural and biological evolution)

Experimental studies on the cumulative cultural evolution of technology, scientific knowledge, and arts. *Masanori Takezawa*
An integrated model of gene-culture coevolution of language mediated by phenotypic plasticity. *Takaya Arita*

Closing

Aim of the workshop

Language and communication emerges in humans through interaction with other agents in a physical, social and cultural environment. These interactions require a high level of sensory-motor intelligence (visual perception, body movement, navigation, object manipulation, auditory perception and articulatory control) but at the same time further enhance the capabilities and skills of the individual. All this appears to happen almost effortlessly in humans. How does this work? How does cooperation, communication and language emerge in natural and artificial systems. In particular, what are the biological, cognitive, social mechanisms and strategies that allow communication systems of human complexity to emerge and evolve. This workshop aims at answering these questions through an interdisciplinary approach.

In addition, the fields of social learning and cultural evolution aim at understanding how the exchange of knowledge within a group of individuals influences their performance. While cultural evolution focuses on how collective knowledge evolves over time within a population, social learning is concerned with the exchange of knowledge among individuals. Cultural evolution builds upon the mechanisms offered by social learning. This relationship is visible within the Alife community as social learning and cultural evolution are studied using similar methodologies, such as evolutionary robotics, evolutionary game theory, and evolutionary algorithms.

Furthermore, roles of constructive approaches are becoming more important in providing a framework to unify increasing knowledge about language and cultural evolution both in empirical studies such as communication in non-human animals, human evolution and language acquisition, and linguistic theories. We believe this can contribute to designing new co-creative ways of communication in modern societies such as SNS, IoT, and robots.

This workshop will mainly, but not exclusively, focus on grand challenges of social learning, cultural evolution, and language evolution research in Alife and Evolutionary Robotics, and other related interdisciplinary fields.

The name EVOSLACE is taken from the two different but closely related workshop proposals: Evolinguistics and SLACE. EVO is from MEXT/JSPS Grant-in-Aid for Scientific Research on Innovative Areas Evolinguistics: Integrative Studies of Language Evolution for Co-creative Communication, which is the silver partner of ALIFE 2018. SLACE is The Workshop on Social Learning and Cultural Evolution (SLACE). The second workshop was held in ECAL2017.

Invited talks

Session 1 (Evolinguistics and evolution of speech)

Emergent constructive approach to Evolinguistics: On intention sharing and hierarchy formation

Takashi Hashimoto

Japan Advanced Institute of Science and Technology, Japan

The idiosyncrasies of human linguistic communication are to use hierarchically organized symbol sequences in language and to share intentions in communication. The project "Evolinguistics" (http://evolinguistics.net/en/) aims at understanding the origins and evolution of language by focusing on these two characteristics and their integration in humans. We think that the integration of the two characteristics brought human communication co-creative. The emergent constructive approach plays a vital role in this project. This approach is to try to understand the origins and evolution of language by constructing and operating linguistic communication systems as emergent phenomena. With this approach, we model the emergence of linguistic communication based on empirical data obtained from animal, anthropological, and developmental studies related to language with linguistic theoretical bases. Further, we can afford insights on new experiments for empirical studies since this approach can be an abduction engine of complex and dynamic phenomena. In this talk, I will introduce two example studies taking the emergent constructive approach. One is an evolutionary simulation of recursive combination for analyzing the evolution of hierarchy formation ability and the other is an experiment of language evolution in a laboratory for the formation of symbolic communication systems for considering the process and neural basis of understanding the denotation and connotation of symbols.

Evolution of Speech: What evolved, and how can A-life study it?

Bart de Boer

Vrije Universiteit Brussel, Belgium

A-Life techniques have been used successfully not only for studying biological systems, but also for studying culturally evolving social systems, such as language and speech. This talk presents a sampling (based on my own research) of work investigating questions related to the evolution of speech, a subject that I will argue is difficult to study without A-Life techniques. It will focus on the evolution of anatomical and cognitive adaptations to using speech, and it will show how A-Life approaches, such as agent-based simulations, self-organizing systems and analysis of co-evolution can help address questions like: what evolved for speech, how did this evolve and in what order might these adaptations have evolved. It will highlight how different A-Life approaches can be brought to bear on these questions and what the advantages and disadvantages of the different approaches are.

Session 2 (Symbol emergence and cognitive models for robots)

Constructive approach towards symbol emergence systems with cognitive robotics and machine learning

Tadahiro Taniguchi

Ritsumeikan University, Japan

Symbol systems including language are changing over time while the meaning of symbols is grounded via human cognitive systems. To grasp the whole dynamics of symbol systems, we need to consider both cognitive and social dynamics of symbol systems. In this talk, I will talk about symbol emergence systems and symbol emergences in robotics (SER), which is a constructive approach towards symbol emergence systems. Relating to the SER, I will talk about machine learning model called SpCoSLAM which enables a robot to form spatial concepts and acquire lexical knowledge about places.

Integrated cognitive model for robots to learn concepts, actions, and language

Takayuki Nagai

The University of Electro-Communications

With the progress of robotics and machine learning technologies in recent years, robots are becoming possible to learn concepts and language. This talk introduces the important mechanisms behind the concept and language learning by robots in our research so far. In particular, it is emphasized that the integration of several learning modules is one of the important idea. Then, I will present current challenges and future directions of this research.

Session 3 (Natural and artificial languages)

Exploring the texture of new words in natural and artificial languages

Ryoko Uno

Tokyo University of Agriculture and Technology

While most of the linguistic and evolinguistic analysis sees language as a medium of communication, as Andy Clark points out in his book *Being There* (1987), the role of language as a tool to extend our minds or our cognitive abilities is equally important. In this talk, we focus on the human tendency to explore the "texture" of language that is connected to the mind extending function of language. We argue that this texture exploration leads to the creation of new words in natural language based on our previous research: The analysis of newly created verbs used in the Web and an experiment to investigate the mimetic descriptions of virtual objects. We also propose how to observe the emergence of an artificial language whose function is not limited to communicating ideas from an experimental semiotic point of view.

(Poster session)

Session 4 (Experimental and modeling approaches to cultural and biological evolution)

Experimental studies on the cumulative cultural evolution of technology, scientific knowledge, and arts

Masanori Takezawa

Hokkaido University, Japan

It has been argued that the unique feature of human culture is in that, through transmissions across generations, it can produce complex or sophisticated levels of knowledge that cannot be attained by a single individual in one's lifetime. Theories have been proposed to explain why only the human culture can cumulative evolve, and laboratory experiments have been growingly applied as a methodological tool for testing the theories of cumulative cultural evolution. In this talk, I present a series of laboratory experiments on the cumulative cultural evolution of technologies, scientific knowledge, and arts. The tasks employed in these experiments are much more complex than were used in most of the past experiments and help us identify principles underlying the cumulative cultural evolution. I make two arguments by presenting results from the six laboratory experiments. First, conceptualizing the cumulative cultural evolution as a search problem in multimodal fitness landscape is useful for understanding how and when cultures cumulatively evolve. Second, just like the language evolution, cultural artifacts gradually acquire specific structural features through the processes of transmission and reproduction across generations. I will discuss roles and advantages of laboratory experiments on the studies of cumulative cultural evolution.

An integrated model of gene-culture coevolution of language mediated by phenotypic plasticity

Takaya Arita

Nagoya University, Japan

Why do only humans have sophisticated language? This talk will present an agent-based model for investigating possible scenarios of genetic and cultural language evolution based on an integrated gene-culture coevolutionary framework. Based on the results of the evolutionary experiments, we will discuss the following problems: (1) how communicative ability can evolve directionally under positive frequency-dependent selection, and (2) how much of the directional effect there is between language and biological evolution.

Poster Abstracts

The Effects of Individual and Social Learning on Evolution of Co-creative Communication

Hiroto Yonenoh[1], Reiji Suzuki[1] and Takaya Arita[1]

[1] Graduate School of Informatics, Nagoya University

Effects of learning on evolution have been regarded as an important factor of the evolutionary process of complex and adaptive traits such as human linguistic abilities. For example, the Baldwin effect is known as a mechanism that enables the genetic acquisition of learned traits that are not easily acquired by the genetic evolution only.

Recently, social learning is receiving a lot of attention, because it is expected to play an important role in language evolution. In this context, our previous study showed that the interaction between individual learning and social learning facilitates the evolution of cognitive aspects of linguistic abilities composed of mutually interacting cognitive traits (i.e., positive relationships between the adaptivity and the degree of interactions among related traits), which are represented as a rugged fitness landscape (Higashi et al., *Proc. of EVOLANGXII*, pp. 165-167, 2018).

In this presentation, we further explore the biological and cultural evolution of co-creative communication in which both cognitive (e.g., hierarchical structures of language) and communicative (e.g., intention sharing) aspects of language abilities are combined. For this purpose, we extended the previous model by incorporating the benefit of communicative aspects of languages into fitness evaluation, assuming a synergetic relationship between cognitive and communicative benefits of languages, and additive benefits of different types of communication channels under the limited number of shared trait sets between communicating individuals.

Our preliminary results show that both individual learning and social learning can play roles of enhancing fitness increase on such a dynamic and complex fitness landscape arising from co-creative communications.

This work was supported in part by JSPS/MEXT KAKENHI: JP17H06383 in #4903.

Brain-body-environment-body-brain system of referential communication on a two dimensional agent based model

Jorge I. Campos[1], Tom Froese[2]
[1]Faculty of Higher Education Aragon, National Autonomous University of Mexico,
[2]Institute of Applied Mathematics and Systems Research National Autonomus University of Mexico.

Referential communication is a complex form of social interaction whereby agents manage to coordinate behavior with respect to features that are not immediately present during the interaction. The most common example of this kind of social interaction in nature is the bee waggle dance. We will extend the model of Campos and Froese (2017). Where two embodied agents (sender and receiver) interact in "hive" area within an environment for communicative purposes. The task is common for both agents, the receiver should move freely to a specific target in the environment, while the sender is the only one with immediate information about the location of the target, but constrained in the "hive" area.

The task implies that both agents negotiate their interactions to adopt the right role, disambiguating between movements than permits them change location in space and movements that form part of the communicative process; and make a behavioral switching between two actions: (1) Communicative behavior: The strategic movements developed during evolution that allows the pair of agents exchange of information about the location of the target. (2) Target seeking behavior: Once the exchange of information is complete the receiver should use their movements to go to the target.

We are going to use the interactive approach of referential communication presented on Campos and Froese (2017). Where their social interaction process should be better conceived of as a collective property of a brain-body-environment-body-brain system as a whole (Froese et. al. 2013) in contrast with the Shannon's theory of communication, because it cannot be assumed on an a priori basis that the agent that turned out to adopt the role of the receiver will not play a role in the successful realization of communication.

This time we will place the agents and the target in two dimensional space. What we expect to find is, similar to the waggle dance, a correlation between their behavior and the location of the target in the space as we found in our previous model, where the best solution involved a correlation between duration of contact and distance to be traveled. But now, with a two dimensional space the challenge increases. We want to know if there will be a two dimensional correlation with single features or behaviors for each dimension or one behavior that maps both dimensions.

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Searle, Goguen, and Algebraic Semiotics: Toward a General Theory of Social Institution

Tzu-Keng Fu[1]

[1] *College of General Studies, Yuan Ze University, Taiwan (R.O.C.)*

The core of this paper is to analyze the general theory of social institutions with the help of algebraic semiotics. First of all, we begin by considering John Searle's general theory of institutional reality, which is a special case of social reality, and examine the basic ideas underlying his theory. The advanced approach, as originally employed by Joseph Goguen and Rod Burstall's Institution Theory (algebraic semiotics), is introduced, after which Searle's general logical form of the imposition of status function at an abstract level is discussed. Secondly, we focus on a discussion of a statement that "language is a special and highly structural case of action". We elucidate this statement by explaining that "language is itself an institution" with Searle's general theory of institutional reality, and discuss that language is a highly structural case of action in a very specific sense. Thirdly, we argue that Goguen and Burstall's Institution Theory, which could supply one framework for Searle's general logical form of the imposition of status function, describes not only the preservation of basic properties of individual institutional facts but also the preservation of truth through institutions. Finally, we promote Searle's work on institutional reality to be related to the extended evolutionary synthesis by arguing that Searle's general logical form of the imposition of status function is necessary for the cultural niche construction.

Online Language Learning by Integrated Cognitive Architecture

Kazuki Miyazawa[1], Tatsuya Aoki[1], Takato Horii[1], Tomoaki Nakamura[1] and Takayuki Nagai[1]

[1] The University of Electro-Communications

In language learning in the real world, it is important to use not only speech but also multimodal information such as visual, auditory and tactile. How language grounds in multimodal information is a very interesting problem. Moreover, what role language plays in decision making process is also worth pursuing. From the viewpoint of constructive approach, the insights from analyzing how multimodal information facilitate language learning process and how the process of language learning affects decision making and vice versa may help to create better language learning agents. The purpose of this study is to propose an integrated cognitive architecture for robots that learn concept and language, and enables tasks to be execute by using learned language.

The proposed architecture consists of three modules: concepts formation using multimodal information, grammar learning, and decision making learning. In concepts formation, multimodal information including language are structured and conceptualized by categorizing using mMLDA (multilayer Multimodal Latent Dirichlet Allocation). In addition, planning in the concept space is made possible by modeling the time series information of the formed concept with BHMM (Bayesian Hidden Markov Model). A different BHMM is used to learn grammar. Especially, grammar and concepts are jointly learned. The data used to learn concepts and grammar are acquired in the process of interacting with the environment in which the agent tries to maximize the total reward using reinforcement learning paradigm. The data acquisition and language learning are carried out in an online manner.

We carried out several experiments using the agent with the proposed cognitive architecture to investigate the effect of integrating several modules in the process of online language learning. We show that the agent can perform a simple task that requires planning from language instructions.

The effect of autistic tendency on the formation of a new communication system

Akira Kojima[1], Masatomo Kurebayashi[1], Junya Morita[1]

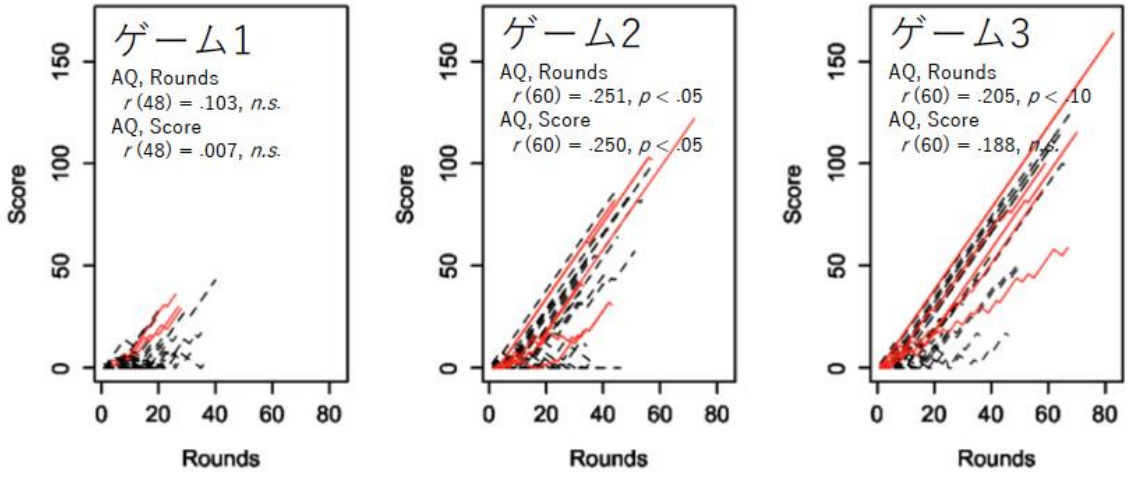
[1] Shizuoka University

What are the biological, cognitive, and social mechanisms leading to complications of communication in society? In this research, we focus on the autism spectrum (AS) as a personal characteristic related to this question. This characteristic may lead to difficulties in social life, but it is also suggested to have been involved in important innovation leading to the present age. Therefore, rather than considering the autism spectrum as an obstacle, we see it as an individual characteristic that plays a role in forming new communication in our society. In this research, we use a communication game that generates simple artificial languages as the experimental environment, and the associated autism spectrum index (AQ: Autism Spectrum Quotient) as a personal characteristic with data obtained from the games. Based on the obtained results, this research tries to clarify the mechanism of diversification of communication.

In the communication game used in this research, we examine how new communication is established in a situation where normal linguistic communication is restricted (Konno et. al., 2011). In the experiment, the grouped participants accessed the web server where the experimental environment was set up, and they were automatically paired with the other participants in the group. The experiment includes three games in which the participants paired with different partners.

As a result, associating the AQ with the game score, we found that the score obtained from the pairs in which the high-AQ participants included (the red lines in Figure 1) tended to exceed the score obtained from other pairs (the dotted black line in Figure 1). This result is not consistent with the known features of autism spectrum, which exhibit obstacles to communication. In addition, we analyzed the pair that got the highest scores in game 3 as a case study. We found that their behavior patterns led to formalization of the communication game.

As described above, in this research, autistic spectrum worked effectively in communication games. We considered that patterned thinking is deeply involved in how to advance communication games of people with autism spectrum tendency.



Proposal of perceptual system for **temporal learning**

Kunpei Kato[1], Ryosuke Tanaka[1], Shion Yamamoto[2], Kouhei Yamamoto[2] and Naoyuki Kubota[1]

[1] Graduate School of Systems Design Tokyo Metropolitan University
[2] Faculty of System design Tokyo Metropolitan University

In the 1980s, researches on cognitive science based on embodiment became popular, and now interdisciplinary research on cognitive development became to be done from various viewpoints, accompanied by further expansion to medical engineering collaboration. Research on communication is perfomed from a multifaceted point of view and research results on pragmatics have given various knowledge to research and development on human-robot communication including discussion on nonverbal communication. For example, the idea of Tomasello is influenced by Grice 's cooperative principle, conversational maxim and Dan Sperber and Deirdre Wilson's relevance theory, but these knowledges are gave important knowledge that robots are designed to communicate naturally with humans. The idea consider that human communication is fundamentally cooperative and individuals who were able to interact with each other with cooperative orientation, cooperative attention and cooperative motivation have become adaptive superiority in the process of evolution. Also, it believes that verbal communication has started to be used to follow nonverbal communication. In studies on cognitive developmental robotics and symbol emergence robotics, various methodologies related to embodiment based communication and cognitive development learning have been proposed both domestically and internationally. In research on symbol emergence robotics, researches on acquisition of object concepts and languages are being conducted from a multitude of multimodal information such as visual, auditory, tactile, and language. In human growth, it is important to develop in a way that cognitive ability, communication ability and physical exercise ability are mutually related.

For example, it is known that an infant at around 18 months becomes comprehensive grouping (concept acquisition) enabling categorization of items belonging to a plurality of categories, and a vocabulary explosion occurs at the same time .Bruner mentioned that brain's representation is a means to know something, it is classified into three types of behavioral representation (movement), visual representation (visual) and symbolic representation (language). He state that is represent the exercise world, the visual world, and the linguistic world. Tomasello suggests the importance of joint attention, shared experience, common cultural knowledge as the ability to build a common conceptual foundation of human beings. However, he says that the skill of imitation, simulation, symbolization is required. Behavior learning in cognitive development can be roughly classified into social learning mediated by others and self-learning conducted by trial and error. Furthermore, social learning includes unidirectional learning by imitating others and interactive learning based on teaching. In this research, we aim to clarify the constructive theory of interdependent temporal learning process of body exercise ability and communication ability in cognitive development. Therefore, we develop clustering (symbolization) of perceptual information using prediction based perceptual system and development of learning system (inter-symbolic correlation learning) to perform temporal transition learning between clusters.

A framework for emergence and evolution of acoustic communication among virtual creatures that physically make sounds

Yoshiyuki Omomo[1], Ryohei Seki[1], Naoaki Chiba[2], Reiji Suzuki[1] and Takaya Arita[1]

[1] Graduate School of Informatics, Nagoya University
[2] Graduate School of Information Science, Nagoya University

Constructive and evolutionary approaches have significantly contributed to discuss the emergence and evolution of acoustic communication including human languages, because "spoken languages do not leave fossils" and thus it is difficult to directly observe those processes from past materials. However, it is still unclear about the origin of communicative interactions including the emergence of communication channels themselves from scratch. We believe that frameworks for evolving virtual creatures can contribute to the discussion of such an evolutionary novelty of communicative traits. We have discussed interactions among ecological, evolutionary and developmental (eco-evo-devo) processes using several frameworks of virtual creatures, showing the emergence and diversity of novel morphological, behavioral and niche-constructing traits (Arita et al., *Artificial Life and Robotics*, 21(2): 141-148, 2016; Ito et al., *Artificial Life*, 22 (2): 226-240, 2016; Joachimczak et al., *Artificial Life*, 22 (3): 271-298, 2016; Chiba et al., *Proc. of ECAL 2017*, pp. 96-97, 2017).

In this presentation, we propose a framework for emergence and evolution of acoustic communication in the population of virtual creatures that can make sounds in a 3D physically simulated environment. Specifically, there are multiple individuals of virtual creatures of which body is composed of several rectangular blocks connected with hinges. They can make sounds, of which amplitude is proportional to the magnitude of collision forces, when their bodies collide with each other or with obstacles, and these sounds can be perceived by their auditory sensors. The genotype of each individual is represented as a directed graph, which is a simplified version of Sims's Blockies model (Sims, *Proc. of the SIGGRAPH94*, pp. 15-22). This graph represents the developmental process of the physical phenotype, yielding both physical structures of bodies (e.g., the number and sizes of blocks, hinges between blocks) and the neural network inside each block that connects inputs from its sensors (e.g., visual, auditory, contact, hinge angle, the information from other blocks) to outputs (e.g., the torque applied to the hinge connected with another block).

We conducted preliminary experiments for evolving virtual creatures that make louder sounds more times with several conditions. When we assumed that collisions between creatures' own blocks only emit sounds, "castanet-like" creatures, which make sounds by hitting their own blocks with each other, emerged. When we assumed that collisions between a block and the ground only emit sounds, we also observed "drumstick-like" creatures, which strikes its own body parts to the ground efficiently to make sounds like a drum roll, emerged. It should be noted that both creatures created their own rhythm of sounds. We expect that such diversity in acoustic behaviors can be exploited for communicative interactions when we assume tasks that require cooperative or coordinative behaviors among creatures.

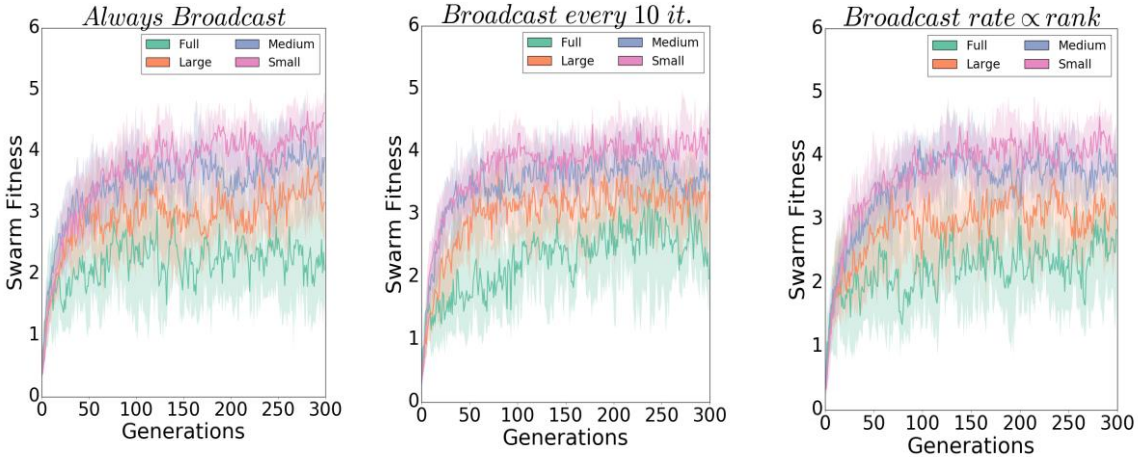
This work was supported in part by JSPS/MEXT KAKENHI: JP18K11467, JP17H06383 in #4903.

Influence of Mating Mechanisms in Distributed Evolution for Collective Robotics

Iñaki Fernández Pérez[1] *and Stéphane Sanchez*[1]

[1] *IRIT - University of Toulouse, France*

Distributed Embodied Evolution [1] is a compelling family of approaches to learning swarm robot behavior online that exploits the intrinsic parallelism of robot swarms: each robot in the swarm runs a separate instance of an evolutionary algorithm *onboard*, including an internal population, and robots locally exchange genomes when meeting, which is known as the *mating* operator or migration policy. Since the internal populations in different robots do not contain the same individuals, these approaches have been shown to naturally maintain diversity [2], which can improve search, especially in deceptive problems. Here, using a vanilla dEE algorithm (mEDEA with task-driven selection pressure), we evaluate the influence on the fitness of the evolved behaviors of 12 different mating operators, in terms of distance (short, medium, large, and full distance-based broadcast), and in terms of frequency (constantly broadcast every time step, every 10 time steps, or at a rate proportionate to the genome's rank in the local population). We perform a set of experiments running 20 independent runs for each one of the 12 algorithmic variants during 300 generations on a well-known swarm robotics task, item collection, and we measure the swarm fitness (average number of collected items over the robots in the swarm). Figure 1, 2 and 3 show the average swarm fitness over the swarm during evolution for each mating mechanism. The best results are obtained with the short mating range: this is explained by the fact that larger ranges tend to make homogeneous the local populations of different robots, thus reducing diversity in the evolving swarm, which leads to premature convergence. Regarding when mating is performed, there is no significant difference between always broadcasting and broadcasting every 10 timesteps: since the number of genome exchanges remains the same between these variants (not shown here), this may indicate that a mating rate of 1/10 still remains high enough not to limit genome propagation over the swarm. Finally, rank-based mating rate yields similar results to always broadcasting: since the local selection operator is elitist, low-fitness genomes are always discarded, and the performance reaches similar values, either during mating in the rank-based variant, or during local selection.



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[2] Fernández Pérez, I., Boumaza, A., Charpillet, F.: Maintaining Diversity in Robot Swarms with Distributed Embodied Evolution. To appear at ANTS 2018.

Emergence of Online Echo Chambers

Kazutoshi Sasahara[1,2]

[1] *Department of Complex Systems Science, Nagoya University*
[2] *JST PREST*

Social media provide nearly infinite possibilities for accessing information and networking with others. However, when it comes to political conversations in particular, people become more narrow-minded and cluster with like-minded individuals, forming ideologically segregated online environments known as “echo chambers.” However, the exact mechanisms by which echo chambers arise are still unclear. We study the emergence of online echo chambers using a simple opinion dynamics model with social sharing. Results show that the dissolution of social ties (e.g. “unfriending” or “unfollowing”) and confirmation bias both play a pivotal role in opinion polarization and network segregation. Furthermore, different following methods can affect different key characteristics of the network, such as the development of closed triads, which are responsible for repeated exposure (“echoes”), and the presence of users with large followings (“influencers”). Although these results suggest that the echo chambers are somewhat inevitable features of online social media, they also provide insights into possible mitigation strategies−constantly adjusting triadic closure and unfriending.

Analyzing Behavioral Complexity of Social Bots and Bot Clusters

Masaki Sugimori[1] *and Kazutoshi Sasahara*[1,2]

[1] *Graduate School of Informatics, Nagoya University*
[2] *JST, PRESTO*

Nowadays social media has become more involved in our lives with a significant effect in the real world. With the advent of social media, social bots —computer programs that automatically post news— have become popular, and some of these have been intentionally used to disseminate fake news. As a result, social bots influence user communications on social media, causing various problems in the real world, such as controlling and polarizing the opinion of users. Here, we study the activity of social bots and bot clusters regarding online communications in a social media ecosystem. In particular, we quantify the activities of Japanese bot accounts in comparison with English bot accounts. Furthermore, we analyze bot clusters that may cause more serious problems than a single bot. The results show that the behavioral features related to social interactions are important to detect social bots and that these features enable us to construct bot detection models that are language-independent. We also confirmed that it is possible to detect bot clusters. The results provide insights into the evolution of communication in a world of social bots.

Building hierarchical structure: Its functional model and evolutionary simulation

Genta Toya[1], *Rie Asano*[2] *and Takashi Hashimoto*[1]

[1] *School of Knowledge Science, Japan Advanced Institute of Science and Technology*
[2] *Department of Systematic Musicology, University of Cologne*

In goal-directed behavior, human beings can generate plural hierarchically structured actions using recursive combination. Recursive combination is frequently observed in human behavior such as language, music, mind-reading, technology. Humans can use plural hierarchical structures, namely, different orders of assembling, to produce one product (Greenfield, 1991). According to archaeological evidence, recursive combination appeared in the age of Acheulean at the latest (Moore, 2010). Recursive combination in object manipulation is assumed to be a precursor of recursive combination in syntax (Fujita, 2009, 2016).

Our previous studies showed that the adaptive significance of recursive combination in object manipulation is to quickly find ways to make complex products and to produce diverse products such as stone tools (Toya and Hashimoto, 2015) in a highly competitive environment for resources (Toya and Hashimoto, 2017). In the current research, we study the evolutionary expansion and adaptability of recursive combination using evolutionary simulation. The objective of this study is to demonstrate the conditions and possible evolutionary processes in which recursive combination could have extended to other domains from action control. We designed a functional model for building hierarchical structure from three cognitive functions suggested by brain functions: sequential chunking by the fronto-parietal network (Boeckx, 2017), temporal maintenance of representation by part of Broca's area (Fitch & Friederici, 2012), and rule learning as well as action and cognitive/executive control (Dominey et al., 2009). Sequential chunking is particularly important for generating a sequence of sequences, namely, hierarchical structure. In our simulation, agents constructing and performing action sequence by building hierarchical structures to obtain fitness value is modeled with a reinforcement learning and evolve through a genetic algorithm. We set the fitness function in which making action sequences as diversified as possible in several cognitive domains. These domains have multiple searching spaces with causal relationships. For example, an action sequence often accomplishes an object assembling. In an object space, an agent may be able to find a making method of a tool. For another example, an action sequence often accomplishes generating a phonetic sequence. In phonetic space, an agent may be able to find a method to express its internal state or an external state. In this model, all of the domains are integrated and influenced each other under action sequences.

Understanding ecoacoustic interactions among songbirds as complex systems using robot audition techniques

Reiji Suzuki[1], Shinji Sumitani[1], Shiho Matsubayashi[2], Takaya Arita[1], Kazuhiro Nakadai[3, 4] and Hiroshi G. Okuno[5]

[1]Graduate School of Informatics, Nagoya University, Nagoya, Japan
[2]Center for Open Innovation Research and Education Graduate School of Engineering, Osaka University, Osaka, Japan
[3]Department of Systems and Control Engineering, School of Engineering, Tokyo Institute of Technology, Tokyo, Japan
[4]Honda Research Institute Japan Co., Ltd., Saitama, Japan
[5]Graduate School of Fundamental Science and Engineering, Waseda University, Tokyo, Japan

We are interested in understanding emergent dynamics in acoustic communication among songbirds as complex systems composed of multiple individuals interacting with each other using acoustic signals that have various complexity and structures. The spatial information is an important ecological property of acoustic events in natural systems, including human spoken language, because it can strongly affect their semantics, functions, or roles. To obtain fine-scaled spatial or ecoacoustic data of bird songs in a real field, we are developing a portable system for bird song localization called HARKBird, which automatically extract sound sources and their direction of arrival (DOA), using a laptop PC with an open source software for robot audition HARK combined with a commercially available microphone array (Suzuki et al., *Journal of Robotics and Mechatronics*, 27(1), 213-223, 2017).

In this presentation, we introduce two case studies to clarify acoustic interactions among wild songbirds from the viewpoint of complex systems and constructive approaches using HARKBird. We show that the observed spatio-temporal patterns of songs of great reed warblers in a reed marsh showed significant temporal overlap avoidance between neighbors, and an asymmetric relationship between their song timings using transfer entropy analysis (Suzuki et al., *Ecology and Evolution*, 8(1), 812-825, 2018). We also constructed some situations in which a conspecific individual intruded into a territory of an individual of Japanese bush-warbler (*Horornis diphone*), and recorded his vocalization and spatial movement, by extending HARKBird (Suzuki et al., *Journal of Ecoacoustics*, 2: #EYAJ46, 2018). We observed that this individual tended to sing type-H (advertising) songs less frequently and move actively during which conspecific songs were replayed from a loudspeaker, and sing a type-L (threatening) song after a large movement with a high probability, which was also clarified by using transfer entropy.

These two cases clearly show that the spatial information is strongly related with their dynamics of acoustic interactions, implying that such fine-scaled ecological properties should be considered to understand emergence and evolution of communications in natural systems.

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Organizers

Reiji Suzuki (Nagoya University, Japan) :
Michael Spranger (Sony Computer Science Laboratories Inc., Japan)
Julien Hubert (TITech, Japan)
James Borg (Keele University, UK)
Hiroto Yonenoh (Nagoya University, Japan)
Jacqueline Heinerman (Vrije Universiteit Amsterdam, Netherland)
Chris Marriott (University of Washington, USA)
Peter Andras (Keele University, *UK*)
Kazutoshi Sasahara (Nagoya University, Japan)
Takaya Arita (Nagoya University, Japan)
Takashi Hashimoto (Japan Advanced Institute of Science and Technology, Japan)
Takayuki Nagai (The University of Electro-Communications, Japan)
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Contact

- Reiji Suzuki (Nagoya University): reiji@nagoya-u.jp