博士学位論文審査要旨

２０２０年7月１３日

論文題目： Optimizations of Morphology, Behaviour and Evolution in Multi-Agent Systems for Predator-Prey Pursuit Problem
(捕食者 - 被食者追跡問題を用いたマルチ・エージェント・システムにおける行動，形態および進化の最適化に関する研究)

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要　　旨：

The objective of our research is to investigate two relatively orthogonal ways of improving the overall performance of MAS: (i) minimizing the time needed by MAS to solve a given problem by evolutionary optimizing (coevolving) both the morphology and behaviour of agents, and (ii) minimizing the runtime needed by evolutionary framework – genetic programming to successfully accomplish such a coevolution. The application domain is the well-known, but difficult to solve predator-prey pursuit problem (PPPP) comprising a team of predator agents that needs to capture a prey by surrounding it in a simulated 2D world.
The results obtained from the evolution of the team of simple predator agents suggest that an asymmetric morphology (i.e., an angular offset of the line-of-sight sensor) coevolved with an intricate "driving" behaviour of predator agents, results in a most efficient behaviour of the agents. The results confirm that even the complex problems, such as PPPP, could be solved by the team of extremely simple predator agents if their morphology and behaviour are developed by means of simulated evolution.

This thesis researches the optimizations of morphology, behaviour, and evolution in multi-agent systems for predator-prey pursuit problem.

よって、本論文は、博士（工学）（同志社大学）の学位を授与するにふさわしいものであると認められる。

総合試験結果の要旨

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要　　旨：

The presenter of the dissertation is aspiring for a Doctoral Degree in Information and Computer Science. The research has been presented in two full papers in *Information* in 2019, Vol. 10 (2), and *Computational intelligence and Neuroscience* in 2019, Vol.2019, paper #1538757 and four peer-refereed conferences including in GECCO in 2018 (two papers), AIMSA in 2018 (best paper award), and SICE in 2019. The dissertation has been orally defended on July 11, 2020, from 13:00 to 15:10.

The following meeting of the committee of investigators and judges of the dissertation has concluded that the defender has demonstrated sufficient academic abilities. The dissertation has been written and presented orally in English.

よって、総合試験の結果は合格であると認める。

博 士 学 位 論 文 要 旨

論 文 題 目： Optimizations of Morphology, Behaviour and Evolution in Multi-Agent Systems for Predator-Prey Pursuit Problem
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氏 名： GEORGIEV MILEN SVETOSLAVOV

要 旨：

Multi-agent systems (MAS) are widely applied for problem solving, software engineering, and the simulation of (human, robotic, etc.) societies. Compared to a monolith system, owing to their complex, non-linear nature, MAS can often provide efficient solutions to complex problems. However, the main challenge of applying MAS is that due to the enormous semantic gap between the properties of (i) entities (agents) and (ii) the system as a whole, it is difficult to obtain an optimal solution to the problem analytically.

The objective of our research is to investigate two relatively orthogonal ways of improving the overall performance of MAS: (i) minimizing the time needed by MAS to solve a given problem by evolutionary optimizing (coevolving) both the morphology and behaviour of agents, and (ii) minimizing the runtime needed by evolutionary framework – genetic programming – to successfully accomplish such a coevolution. As an evolutionary framework we adopted the in-house XML-based genetic programming (XGP), which offers a flexible, human-readable, and cross-application compatible XML representation of the genotype of evolved agents.

The application domain is the well-known, but difficult to solve predator-prey pursuit problem (PPPP) comprising a team of predator agents, that needs to capture a prey by surrounding it in a simulated two-dimensional world. We considered two instances of PPPP featuring predator agents with different abilities. The first instance, inspired by the opportunity to challenge the relevance of the "average" (rather than the individual) abilities of agents, comprises relatively complex, reactive predator agents with continuous sensory (morphological) and moving abilities. The second instance - comprising absolutely simple reactive predator agents (that do not even compute in their decision making) with rather primitive, discrete sensory and moving capabilities (a single line-of-sight sensor and two thrusters in a differential drive configuration, respectively) - is motivated by our intention to model the recently emerged nano- and micro robots and their potential applications in biomedicine.

The experimental results obtained from the evolution of the team of complex predator agents in PPPP indicate that, indeed, MAS with lower values of the average (mean) sensory- and moving capabilities of agents could have a superior performance compared to that of MAS with higher average values. This finding is consistent with the concept of the "end of average" arguing that the combination of individual qualities of entities in complex system matters more than the average value of these qualities. From another standpoint, the results could be seen as a verification of the survival value of the diversity of qualities of entities in complex systems, such as MAS.

The results obtained from the evolution of the team of simple predator agents suggest that an asymmetric morphology (i.e., an angular offset of the line-of-sight sensor) coevolved with an intricate "driving" behaviour of predator agents, results in a most efficient behaviour of the agents. The results confirm that even the complex problems, such as PPPP, could be solved by the team of extremely simple predator agents if their morphology and behaviour are developed by means of simulated evolution. On the other hand, the experimental results also indicate that efficiency of this evolution depends on the size of the evolved population of agents. Counterintuitively, the smaller sizes of populations - due to lower genotypic redundancy and favourable cache-related effects during the simulation - result in faster overall runtime of evolution.

Presented research could be viewed as a step towards the development of MAS that are capable of solving complex problems efficiently, having a lower evolutionary overhead.