要　　　旨 ：

　The objective of this research is to investigate the emergent successful escaping behavior, evolved automatically via genetic programming (GP), of a team of prey (caribou) agents in the Wolf-caribou Predator-prey Pursuit Problem (WCP). The proposed instance of WCP is a multi-agent system, in which a team of inferior prey (caribou) agents is required – thanks to their cooperation -- to escape from a single superior predator (wolf) agent in an unbounded 2D world.

　The achieved results could be summarized from the following standpoints: (1) Evolutionary psychology – verifying the survival value of the empathy and compassion exhibited by caribou agents. Moreover, the results also prove that self-consciousness improves the survival chances of the caribou; (2) Philosophy – investigating the importance of the critical mass (the number is more than the sum of its parts") of the caribou's behavior; (3) System Architecture - investigating the solution to the dilemma between the reactiveness and pro-activeness of the behavioral architectures of caribou agents.

　This thesis researches the emergent successful escaping behaviour of a team of caribou agents in the Wolf-caribou 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。

<p style="text-align:center">総合試験結果の要旨</p>

<p style="text-align:right">２０１９年１月２２日</p>

論 文 題 目： Evolving Social Behavior of Caribou Agents in Wolf-caribou
Predator-prey Pursuit Problem
(狼とカリブー捕食者捕食問題におけるカリブーエージェントの社会的
行為の進化に関する研究)

学位申請者: 黄　芳葳（Fang Wei Huang）

審 査 委 員：
　主　査：　同志社大学大学院理工学研究科　教授　Ivan TANEV
　副　査：　同志社大学大学院理工学研究科　教授　三木　光範
　副　査：　同志社大学大学院理工学研究科　教授　下原　勝憲

要　　　旨：

The presenter of the dissertation is aspiring for a Doctoral Degree in Information and Computer Science. It has been presented in IEEJ Transactions on Electronics, Information and Systems Journal, Vol. 138, No.5, and SICE Journal of Control, Measurement, and System Integration, Vol.11, No.3, etc. The dissertation has been orally defended on January 19, 2019, from 16:00 to 17:40.

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。

論 文 題 目 :　Evolving Social Behavior of Caribou Agents in Wolf-caribou Predator-prey Pursuit Problem　（狼とカリブー捕食者捕食問題におけるカリブーエージェントの社会的行為の進化に関する研究）

氏　　　　名 :　黄　芳葳　（Fang Wei Huang）

要　　　旨 :

　　The objective of our research is to investigate the emergent successful escaping behavior, evolved automatically via genetic programming (GP), of a team of prey (caribou) agents in Wolf-caribou Predator-prey Pursuit Problem (WCP). WCP is originally defined and investigated by Tian, Tanev, and Shimohara and can be viewed as a reversed instance of the well-studied predator prey pursuit problem. The proposed instance of WCP is a multi-agent system, in which a team of inferior prey (caribou) agents is required to escape from a single superior predator (wolf) in an unlimited two-dimensional simulated world.

　　Moreover, we are interested in verifying whether some socio-psychological aspects, introduced in the behavior of caribou agents would result in (i) an improved efficiency of both of the evolution of their escaping behavior and (ii) the effectiveness of this behavior. Our research could be summarized in the following five points:

(1) Firstly, we investigated the survival value of the empathy exhibited by the caribou agents. The empathy is introduced as the following information, available to each caribou agent: (i) which peer caribou is chased by the wolf, (ii) whether the chased peer caribou is exhausted (and, therefore, needs a help).

(2) We conducted research on the survival value of the number （ "critical mass" ） of the caribou agents that allow a transitions from quantity into quality of their escaping behavior.

(3) We researched on the effect of consciousness of the caribou agents on the effectiveness of their escaping behavior. The consciousness is implemented in our work as an ability of caribou agents to understand whether they are currently being chased by the wolf.

(4) We investigated the dilemma between the reactiveness and pro-activeness in the behavior of the caribou agents.

(5) Finally, we researched the effect of morphological and behavioral fuzziness of the caribou agents on the efficiency of evolution of the escaping behavior of caribou agents and the effectiveness and robustness such a behavior.

　　In our research for the evolution of the behavior of caribou agents we used the in-house XML-based genetic programming framework (XGP).

　　The experimental results verified that the empathy improves both the efficiency of evolution of escape behavior and the effectiveness of such behavior. In the experiments we consider a team of eight caribou agents. We employed the empathic caribou agent and obtain the experimental results with the caribou group size equal to 1, 2, 4, 8 and 10. The experimental result shows that the quantity (number of caribou agents) yields a

corresponding quality (i.e., a successful escaping behavior) in that both the efficiency of evolution and the behavioral effectiveness improved with the increasing of the size of the team of caribou agents; however when the caribou group size is too high (i.e., the population density of caribou is too high), both the efficiency of evolution and the behavioral effectiveness somehow deteriorate. Also, we found the most important perception is the superposition of the consciousness and self-consciousness of the caribou. The experimental result demonstrated that only consciousness and only self-conscious alone are contributing to the better survival of the caribou agents. However, when the consciousness and self-conscious are combined together, both the efficiency of evolution and the effectiveness of the behavior of caribou agents improves significantly, suggesting a super-additive effect of these two features.

The results of the investigation of the dilemma between pro-activeness and reactiveness in the behavior of caribou agents indicate that neither a pure reactiveness nor deep pro-activeness can improve the efficiency of evolution and the effectiveness of the escaping behavior of caribou. Rather, a trade-off of these two extreme behavioral features results in best-performing team of caribou agents.

Finally, the experimental results on the incorporation of the fuzziness of the sensory- and moving abilities of caribou agents demonstrate that this fuzziness indeed facilitates a better efficiency of evolution and an improved robustness to a realistically simulated perception noise.

In our future work we are planning to i) investigate the effect of dithering on the efficiency of the escaping behavior of caribou agents in the proposed WCP, ii) improve the fuzzy model of caribou agents, and iii) employ co-evolution to evolve the behavior of both the wolf agent and the caribou agents.