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学 位 論 文 内 容 の 要 旨

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Environmental Variability and Adaptative Evolution: Insights from Neural-Network-based Artificial Agents and Virus Dynamics
(環境変動と適応進化：ニューラルネットワークを用いた人工エージェントとウイルス動態に基づく知見)

An organism' s ability to reproduce across generations determines its evolutionary success. This is called "fitness", a quantitative measure of reproductive success. Genotype (or phenotype) and the environment the organism lives in shape its traits and functions that affect its fitness. To illustrate how genetic and phenotypic differences affect fitness changes, evolutionary biology often employs the concept of a fitness landscape. In this metaphor, every possible genotype (or phenotype) corresponds to a point in a multidimensional space, and each point is assigned a fitness value. Plotting these values creates a landscape with peaks and valleys like a mountain, where higher peaks represent genotype (or phenotype) with greater fitness. In such a landscape, a population composed of multiple organisms can evolve (seen as 'walks') and adapt (seen as 'climbs') toward higher positions on the fitness surface.

Numerous theoretical and empirical studies have characterized fitness landscapes in specific environments and identified their optima, exploring how the peak can be reached through evolutionary dynamics. However, less attention has been paid to how different environment reshapes the optimal genotypic (or phenotypic) state of a focal organism. In addition, when one or more environmental shifts occur during adaptive evolution, the location of the optimum changes. As a result, the population experiences a decrease in fitness and is forced to alter its adaptive trajectory, leading to a non-linear evolutionary path.

This thesis aims to investigate how does different environment shape distinct evolutionary consequences for populations. Another critical objective is to examine how population endure fitness declines due to environmental shift and how difficult it is for the population to keep track of the moving optimum in a changing world.

This paper consists of three chapters. Chapter 1 aims to improve algorithms designed to capture the global convergence of a given search space. Here, fitness is treated as the objective function, framing biological evolution as an optimization problem. Environmental changes, including shifts in fitness peaks, degrade algorithm performance (or fitness). This study successfully enhanced population diversity using methods inspired by evolutionary processes, focusing on crossover, mutation, and selection. Maintaining this diversity demonstrated the ability to dynamically adapt to environmental changes.

Chapter 2 focused on viral phenotypes, examining which phenotypes are evolutionarily advantageous in response to environmental changes, specifically the frequency of contact with host organisms. Because viruses cannot replicate without a host organism, host population dynamics affect viral evolution. This study demonstrated that in high-dense contact environments, a type of virus with high viral production rate but low replication accuracy is optimal, and infections with short duration are evolutionarily advantageous. In contrast, in low-dense contact environments, a type with low viral production but high accuracy becomes advantageous, suggesting infections with long duration can be selected.

Chapter 3 examined whether behavior changes during the COVID-19 pandemic—such as isolation—by humans protecting themselves from infection may have driven viral evolution. Analysis of previously published clinical data revealed that as the virus evolved from the pre-alpha variant to the delta variant, the infection period shortened, while the peak viral load increased and appeared earlier. This suggests that selective pressure for enhanced transmissibility altered the shape of the viral load dynamics, indicating that the evolution of the novel variant may have been influenced by clinical symptoms such as asymptomatic rate and human behavior.