NATIONAL RESEARCH UNIVERSITY
HIGHER SCHOOL OF ECONOMICS

Faculty of Computer Science
Bachelor's Programme "Data Science and Business Analytics"

Software Team Project Report on the Topic:

Computer analysis of the biological model of adaptive dynamics

(interim, the first stage)

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Moscow 2024

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1 Annotation

In various scientific fields, mathematical modeling is widely used as a research methodology. This approach is used in this study to study the Dickman-Low population dynamics model. In particular, the study focuses on the case of two species, when there are two different organisms in a community. Among the various strategies for the coexistence of a population of two species, this study specifically examines heteromyopia, which refers to intraspecific competition occurring at a greater distance than interspecific rivalry.

The purpose of the study is to study the behavior of the second spatial moment. For this purpose, a predefined set of parameters and settings was used during the research.

Using the proposed implementation of the numerical method, the surfaces of the second spatial moment were generated for three different regions: R1, R2 and R3. The implementation of the numerical method used to calculate the second spatial moments for the spaces R1, R2 and R3, and the construction of the surface of the second spatial moments is proposed.

The obtained surfaces of the second spatial experiments for the spaces R1, R2 and R3 are the main results of this study. We considered the situation when the magnitude of the second spatial moment depends on the interindividual distance of the pair, and the spatial variation of the size of the core of intraspecific competition. The size of the core of interspecific competition has changed.

Аннотация

В различных научных областях математическое моделирование широко используется в качестве методологии исследования. Этот подход используется в данном исследовании для изучения модели динамики популяции Дикмана-Лоу. В частности, исследование сосредоточено на случае двух видов, когда в сообществе есть два различных организма. Среди различных стратегий сосуществования популяции двух видов в этом исследовании конкретно рассматривается гетеромиопия, которая относится к внутривидовой конкуренции, происходящей на большем расстоянии, чем межвидовое соперничество.

Целью исследования является изучение поведения второго пространственного момента. Для этой цели в ходе исследований использовался заранее определенный набор параметров и настроек.

Используя предложенную реализацию численного метода, поверхности второго пространственного момента были сгенерированы для трех разных областей: R1, R2 и R3. Предложена реализация численного метода,используемого для расчета вторых пространственных моментовдля пространств R1, R2 и R3,ипостроеныповерхностивторыхпространственныхмоментов.

Полученныеповерхностивторыхпространственныхмоментовдля пространств R1, R2 и R3 являются основными результатами данного исследования. Рассматривалась ситуация, когда величина второго пространственного момента зависит от межиндивидуального расстояния пары, и пространственный момент вариации размера ядра внутривидовой конкуренции. Размер ядра межвидовой конкуренциинеизменился.

2 Keywords

Coexistence of species - The condition of the system is such that there exists a non-zero quantity of a given species within the system.

Dynamic model - An illustrative model that portrays the sequential and evolving processes within dynamics, emphasizing the temporal dimension.

Mean-field theory - A theoretical proposition positing that the interaction among species takes place in correlation with their respective density of distribution across a given territory.

IBM (individual-based model) - An ecological model that considers and incorporates the intricate processes associated with each individual member within the community.

n-th order moment - A mathematical function that articulates the mean density n of species in relation to their separation distance from one another.

Closure of spatial moments - A representation of a particular instance through the summation of moments of lesser orders; specifically referring to moments at lower orders.

Competition-colonization trade-off (CCTO) - A mechanism of coexistence characterized by the dominance of one species over another within a given ecological context.

Heteromyopia (HM) - A coexistence mechanism that operates under the assumption that competition between different species takes place over shorter distances compared to the competition within the same species occurring at longer distances.

3 Introduction

All of the processes in the actual sciences may be explained using mathematics. This allows us to analyze and articulate the establishing facts of natural laws using mathematical techniques. The most common, salient characteristics of different scientific systems are emphasized through the use of mathematical models. When doing tests would be expensive or impracticable, models might be used instead. There are several steps that must be taken in order to build the mathematical model. First, it is necessary to state a few key queries and searches to be conducted. Secondly, information on the goal of study must be found. The primary objective of the modeling must then be stated, along with the key aspects of the issue. Extraction of the fundamentals of dealing with models is the last phase. Once the mathematical model is put together, it must be investigated using counting and analytical techniques. All of the answers to the queries listed in the first stage will be found in this investigation. It is necessary to compare the outcomes with comparable data from the study topic in order to ascertain whether the model is operating correctly. Another characteristic of mathematical models is their capacity to forecast brand-new object facts.

As computer technology has advanced, computer simulation has been used in research more and more. The primary benefit of using computer models is the ability to obtain both quantitative and qualitative findings from the model as it stands. The process of identifying novel features in complex systems requires qualitative investigation. Researchers can use quantitative analysis to characterize the value of variables that now exist or forecast the value of variables that will exist in the future.

A significant component of biological mathematics is the simulation of biological systems. This approach is sometimes the only means to conduct experiments and provides the possibility to analyze processes in complicated systems.

Our research is to investigate and utilize Lotki-Volterr and Lou-Diegmann models. The dynamic IBM was created by Ulf Diegmann and Richard Lou to depict changes in the system's dimensional organization over time. The dimensional moments approach served as the foundation for the model. Furthermore, this model incorporates species connections within a single system. The interaction between a predator and victim is described by the Lotki-Volterr model. The percentage of two species in a system is hypothesized in the model.

Our research is based on a thesis by Victor Zelenkov that investigates a spatial moments model for three different kinds of creatures. The project began with a review of relevant literature, particularly the papers "Spatial Segregation and the Coexistence of Species" by D. Velasquez and "Mechanisms of coexistence of stationary biological communities in spaces of different dimensions" by A.S. Savostyanov. In addition, a presentation based on the collected data was prepared and delivered.

In order to finish our investigation, we have a plan. We first made the decision to research the models we would be using. Next, we discovered instances of biological systems in which these models can be used. Studying how to make these models better in order to obtain more precise research results is the second phase. We discovered during the second step of studding that the Poisson process's necessary events occasionally needed a lengthy time to run in order to attain the model's balance. Our project's next step will therefore involve researching the best ways to shorten the time it takes to reach a plateau and whether there are any opportunities to do so. Building a simulation based on the provided models is the last stage.

We made the decision to divide up the work while doing the study. Nikita Kozlovtsev has to research the models and identify scenarios in which they might be used. Andrei Vasilkov has to investigate ways to make the models better by including more research on plateauing. Pavel Gnilomedov must learn how to write simulation code, combine the code of earlier researchers, and figure out how to make the code better. Egor Kukushkin needs to research the various dimensions (R1, R2, and R3) in which to visualize the model.

4 Review and comparative analysis of sources, theoretical part

A mathematical framework for explaining the complex dynamics found in biological communities is the Law-Dieckmann model. Its main goal is to disentangle the intricate web of relationships between species, which includes things like competition and predation. This model was developed to investigate the conditions that support biodiversity in ecosystems and assess the effects of various factors on the stability and organization of communities.

The Law-Dieckmann model is based on differential equations, which illustrate the variations in species populations over time. The concept of "spatial structure," which allows for the consideration of both the numerical abundance and the spatial distribution of each species, is a remarkable feature of this model.

Equations for individual species that describe their growth and interactions with other species through mechanisms like resource competition, predation, and parasitism are essential parts of the Law-Dieckmann model. It is also essential to include parameters that represent biological features, competitive ability, mortality rates, and reproductive capability. Moreover, the model takes individual mobility and spatial structure into account, which makes it possible to simulate migration dynamics, distribution dynamics, and the emergence of geographically varied populations.

Examining important ecological questions is one of the Law-Dieckmann model's practical uses. These include the investigation of mechanisms maintaining biodiversity, the analysis of ecosystem resilience, the forecasting of the effects of outside impacts on natural communities, and the development of biodiversity management methods. This model is a useful tool for ecological modeling because it promotes a deep understanding of complex interactions within ecosystems.

Simultaneously, the theoretical framework of adaptive dynamics emerges in evolutionary biology with the goal of modeling the complex interaction between natural selection and adaptation. This method explores how organismal features change throughout evolutionary periods, examining how they evolve in response to changes in the environment and interactions between species. Adaptive dynamics is the only field that focuses on small-scale mutations and how they affect individual fitness, explaining the long-term evolutionary paths of populations.

Adaptive dynamics is based on a number of fundamental principles that shed light on the complex dynamics of evolution. These ideas provide a framework for comprehending the adaptive responses seen in populations in addition to throwing light on the mechanisms driving species evolution. Let us examine each of the principles:

1. Invasive Fitness Analysis: This idea entails a careful analysis of the conditions that permit the successful introduction of mutant methods into a population. The goal is to comprehend the circumstances that give rise to a change in the evolutionary steady state. Through analyzing the fitness of these mutant methods, scientists hope to identify the conditions that lead to their effective integration and consequent influence on the evolutionary history of the population.

2. Pairwise Comparisons of Strategies: The adaptive dynamics framework assesses an individual's fitness based on the various tactics they use to interact with their surroundings and with one another. This entails a thorough examination of the outcomes of different tactics, which helps determine the direction of natural selection. Through evaluating the comparative effectiveness of various tactics, scientists can obtain significant understanding of the selection dynamics influencing population dynamics.

3. Evolutionarily Stable Strategies (ESS): The idea behind this notion is to search for strategies that, once they become established in a population, are too fit to be replaced by any other mutant strategy. Examining evolutionarily stable tactics helps us comprehend the mechanisms underlying the long-term stability and persistence of particular features within a population.

4. Adaptive Pathways: The study of adaptive dynamics entails breaking down the series of minute evolutionary modifications that populations go through in reaction to changes in their internal dynamics or environment. Researchers can decipher the gradual changes that take place within a population over time by examining adaptive pathways, which provides important insights into the adaptive processes that drive evolutionary trajectories.

5. Theoretical Study of Cospeculation: This concept explores the theoretical underpinnings of species' coevolutionary connections. It focuses on comprehending the mutual evolutionary changes that occur between interacting species, including hosts and parasites or predators and prey. By employing models based on adaptive dynamics, scholars have a theoretical structure for examining and understanding the complex dynamics of coevolutionary processes in ecological systems. Essentially, adaptive dynamics offers a broad range of instruments to disentangle the intricate workings of evolutionary processes by providing theoretical frameworks through which to examine the interactions between coevolution, stability, and strategies in a variety of biological systems.

A wealth of evolutionary research topics can be explored with the help of adaptive dynamics, including the origins of new species, the evolution of cooperative behaviors, and the complex evolution of sexual selection and reproductive tactics. This multidisciplinary method offers deep insights into the underlying principles guiding the course of evolution and adaptation by fusing theoretical biology with mathematical modeling in a seamless manner.

A fundamental component of evolutionary processes, biological adaptation describes how organisms pick up characteristics that increase their odds of surviving and procreating in certain settings. Under the direction of natural selection, this crucial process helps organisms overcome obstacles presented by a variety of environmental conditions, including variations in the climate, the availability of food, and the presence of rivals and predators. Three basic domains are used to exhibit adaptations: morphological, physiological, and behavioral.

1. Morphological Adaptations: These include changes to an organism's bodily parts or structural makeup. For example, the flattened beak of platypuses makes it easier for them to catch food in aquatic conditions, and chameleons' ability to blend in with their surroundings helps them avoid potential predators.

2. Physiological Adaptations: These adaptations entail changes to an organism's internal operations. Physiological flexibility is exemplified by the ability of some fish species to flourish in both freshwater and saltwater habitats. Furthermore, the unique systems that allow bears to hibernate in the winter represent another aspect of physiological adaptation.

3. Behavioral Adaptations: Changes in an organism's response to its environment fall under this category. Examples include the migratory habits of birds, which are deliberately carried out to evade harsh winter circumstances, and the development of particular food-seeking techniques by some species to enable them to survive in difficult environments. Essentially, the rich tapestry of evolutionary processes is revealed by the interaction between adaptive dynamics and the study of biological adaptation. Through the application of mathematical models and theoretical ideas, scientists are able to obtain a comprehensive knowledge of how organisms adapt and change in response to the constantly changing conditions in which they live. This process eventually shapes the wide variety of living forms that can be found in the natural world.

Rather, adaptations are the result of the complex process of natural selection rather than a conscious reaction to an organism's requirements. This process results in the slow evolution of populations to better fit their surroundings through the preservation and accumulation of random genetic changes that provide advantages in a particular environment.

Being able to change in response to changes in the environment makes biological adaptation a dynamic phenomena. Climate variations, changes to the landscape, and the influx of new species are a few examples of these environmental changes. Understanding the complex interactions between organisms and their environments and the subtle interactions across evolutionary processes is based on an understanding of biological adaptation.

The Ulf Dickman Self-Structuring Community Model offers a unique viewpoint for investigating the dynamics of biological communities and ecosystems. It has been designed to clarify the complicated mechanisms that, in the absence of outside interference, lead to the construction of stable, complex structures in nature. With a focus on self-organization and community adaptability, this model is a development and extension of the ideas found in species interaction models such as the Law-Dieckmann model.

The Ulf Dickman model is based on the fundamental premise that species relationships and community structure are dynamic and always adapting. Species in a community are able to change how they interact with the environment and with each other as well as with other species when they are subject to external and internal influences. Because of its dynamic adaptability, the ecosystem maintains a state of balance, underscoring the continual nature of community adaptations to external circumstances. The Ulf Dickman model, in its essence, highlights the ecosystems' intrinsic flexibility and responsiveness and offers a prism through which to see the dynamic and always changing character of biological communities.

The concept of self-structuring communities comprises several key components, each contributing to our comprehension of the dynamic and adaptive nature of biological communities. One critical element is Systems of Self-Organization. This element examines how interactions among organisms naturally lead to the formation of organized structures without external influence. These self-organizing mechanisms encompass the creation of symbiotic relationships, the establishment of trophic levels, and the emergence of spatial patterns within the community. The focus is on revealing how communities' innate ability to self-organize and produce ordered patterns via the complex interactions of their constituent species.

2. Adaptation and Evolution: The idea that animals have the capacity to adapt their genetic and behavioral traits in response to evolutionary stresses is incorporated into the model. Because of its adaptability, a species' place in the community may change, illustrating the fluidity of evolutionary processes. The model reflects the flexibility with which species features can change over time, affecting their interactions and responsibilities within the larger community environment, by taking adaptation and evolution into consideration.

3. Population Dynamics: The model's primary focus is on how interactions between species affect changes in species abundance over time. These interactions include abiotic influences as well as competition, cooperation, and predation. The model aims to represent the complex web of relationships that shapes the makeup and structure of the community by simulating and comprehending the dynamic fluctuations in population sizes.

4. Spatial Structure: This component investigates how spatial factors affect the dynamics and structure of communities by looking at the spatial distribution of species and the movement of individuals. Through the incorporation of spatial considerations, the model provides insights into

how community dynamics are shaped by the intricate interplay between the physical arrangement of species and their ecological interactions.

5. Resilience and Vulnerability: The model explores the examination of variables that affect a community's capacity to preserve its composition and operations across time. This includes analyzing internal and external processes as well as how disturbances and environmental changes may impact the community's resilience or vulnerability. Through the examination of these aspects, the model advances knowledge on the resilience and flexibility of communities when confronted with diverse obstacles.

Basically, the self-structuring communities model is a framework that integrates all of these elements to give a full representation of the complex dynamics, flexibility, and resilience that are present in biological communities. The self-structuring communities model developed by Ulf Dickman is a very useful tool that offers a solid way to explore the complexities and dynamic dynamics that are present in ecosystems. Through the use of this model, researchers can obtain a deeper understanding of the complex interactions of various species and their ties with the environment. The ultimate objective is to improve our understanding of how these complex relationships lead to the development of complex and robust biological communities.

In this context, using multispecies simulation emerges as a sophisticated computational technique, offering ecologists and biologists a valuable tool for studying the intricate relationships and dynamics among different species in ecosystems. By employing computer models, researchers can explore the complex biological and ecological processes within multispecies communities. This approach allows for the examination of detailed phenomena such as resource competition, predation dynamics, symbiotic interactions, migration patterns, and the evolutionary changes that are integrated into these complex ecological networks.

Multispecies simulations are useful in many domains, such as resource management, agroecology, conservation efforts, and studies of climate change. Researchers are able to model and examine the complex dance of life inside ecosystems by using the lens of these simulations, which allows for a more nuanced understanding of the underlying mechanisms that determine the stability, adaptation, and resilience of biological communities.

Ulf Dickman's self-structuring communities model and multispecies simulations work together to provide a comprehensive and innovative method for deciphering the intricate workings of ecosystems. It not only deepens our understanding of the complex processes that exist within biological communities, but it also provides researchers with invaluable resources to tackle urgent problems in a variety of scientific fields. Key Components of Multispecies Simulation: 1. Population Dynamics Modeling: This aspect involves developing mathematical models that capture the complexities of species development, reproduction, and extinction. These models provide a dynamic depiction of how populations react to shifting environmental conditions and interact with one another because they are made to reflect the complex interactions that occur between species and their surroundings.

2. Species Interactions Exploration: Examining the manner in which various species affect one another, this component delves into the complex web of ecological connections. This includes researching the dynamics of predation, resource rivalry, mutualistic partnerships, and other ecological relationships. The objective is to disentangle the intricate web of interaction between species in a particular environment.

3. Ecosystem Process Analysis: By examining the complex interactions between biotic processes like photosynthesis and decomposition and abiotic elements like soil type and climate, multispecies simulation broadens its scope. By revealing the significant impact of both living and non-living elements on the overall dynamics of ecosystems, this holistic approach seeks to provide a thorough grasp of the interdependencies among these complex biological systems.

4. Spatial Dynamics Modeling: This part allows the study of spatial dynamics in ecosystems by simulating the movements and distributions of species over space. Researchers can study the establishment of species distribution patterns, isolation processes, and the dynamics of metapopulation formation by modeling the spatial features. This spatial lens helps us comprehend how different species interact and make their home in a particular landscape more thoroughly.

5. Evolutionary Change Consideration: The aspect of evolutionary changes among species—partic in reaction to environmental shifts—is incorporated into a lot of multispecies simulations. This involves simulating processes like genetic drift, natural selection, and mutations. Researchers can learn more about how species change and adapt throughout time by mimicking evolutionary processes. This helps to maintain the overall sustainability and resilience of biological populations in the face of shifting environmental conditions.

Essentially, multispecies simulation's diverse nature offers an extensive toolkit for academics to investigate the complex dynamics of ecosystems. This method expands on our knowledge of the various and interrelated mechanisms influencing the biodiversity and sustainability of natural systems by combining mathematical models with ecological insights.

Advantages of Employing Multispecies Simulations: 1. Predictive Precision: Researchers may foresee and forecast changes within ecosystems with the help of multispecies simulations, which provide essential insights into the potential effects of various scenarios on the natural world. This ability to forecast includes situations like changing land usage, invasive species introduction, and climate change. Scientists can evaluate possible outcomes and take a proactive approach to ecosystem management and conservation by simulating these scenarios.

2. Decision Support Framework: Multispecies simulations play an important function as a reliable decision support system. These simulations generate scientific data that forms the foundation for informed decision-making regarding biodiversity and natural resource management. Conservationists and policymakers can utilize the outcomes of multispecies simulations to develop strategies that enhance ecological balance, optimize resource use, and support conservation efforts.

3. In-Depth Process Understanding: Multispecies simulations can also deepen our comprehension of the intricate relationships and processes within ecosystems. By modeling the dynamics and ecological interactions of various species, researchers gain insights into the fundamental mechanisms governing population dynamics, biodiversity, and ecosystem functionality. This enhanced understanding enables targeted and well-informed interventions for sustainable ecological management.

4. Scenario Exploration and Risk Assessment: Multispecies simulations are flexible enough to investigate different situations and carry out risk analyses. Researchers can model possible modifications to habitats, animal interactions, and environmental conditions, enabling a thorough assessment of the dangers involved. With the help of this proactive approach, potential ecological concerns can be identified and adaptive measures to effectively reduce or manage them can be developed.

5. Conservation Planning and Resource Allocation: Because they offer a dynamic platform for evaluating the effects of various conservation measures, multispecies simulations are essential to the design of conservation efforts. This entails assessing protected area efficacy, comprehending habitat interconnectedness, and allocating resources for conservation initiatives as efficiently as possible. These simulations aid in the creation of focused and effective conservation strategies that take into account the intricate dynamics of various ecosystems. To sum up, the advantages of multispecies simulations go much beyond their ability to anticipate. In addition to promoting a thorough understanding of ecological processes and facilitating strategic planning for the conservation and sustainable management of our natural environment, they are essential instruments for decision support.

Constraints and Challenges of Multispecies Computer Analysis: 1. Complexity and Uncertainty: A thorough grasp of ecological processes and the availability of reliable data are prerequisites for the success of multispecies simulations. Because ecosystems are complex systems, there are inherent complications to consider, and the dependability of simulation findings can be greatly impacted by uncertainties in input data. The difficulty is in dealing with these intricacies and improving models to increase their precision, so offering a stronger basis for ecological insights.

2. Computational Resource Demands: Completing intricate multispecies simulations requires a significant amount of processing power. Advanced computational capabilities are needed for the complex interactions between various species and the simulation of various environmental circumstances. This is a drawback, especially for academics and organizations with limited access to high-performance computer resources. To overcome this obstacle, one must look for creative ways to optimize simulations without sacrificing their accuracy.

Multispecies Simulation in Adaptive Dynamics: In the field of adaptive dynamics, multispecies simulations use computer technology to simulate and examine the complex processes of evolution and adaptation in biological systems. With this advanced method, scientists can investigate the profound effects of morphological, physiological, behavioral, and genetic alterations on an organism's capacity for survival and reproduction in a variety of environmental settings. Developing computer simulations using adaptive dynamics is primarily aimed at deciphering the complexity of evolutionary processes. These simulations are effective instruments that facilitate the investigation of complex processes including coevolution, species specialization, and the dynamic emergence of new species. Researchers can simulate and investigate the adaptive methods that organisms use in response to changing environmental dynamics by utilizing computer analysis. This creates a virtual laboratory.

In adaptive dynamics, multispecies simulations have great potential, but it's important to understand the accompanying drawbacks. Improving the applicability and dependability of these simulations requires not only optimizing computational resources but also addressing the intricacies and uncertainties. Researchers work to overcome these obstacles as computer skills and technology develop, opening the door to more precise and perceptive studies of the adaptive dynamics of biological systems.

Key Elements and Aims in Computational Evolutionary Modeling: 1. Evolutionary Processes Modeling: By use of computer analysis, scientists are able to model and illustrate the complex trajectory of evolutionary processes. These simulations offer a dynamic depiction of how natural selection and tiny genetic mutations lead to changes in an organism's adaptive features. Furthermore, the background of population dynamics is examined in relation to these modifications, providing insight into the complex network of relationships that mold a species' evolutionary course.

2. Adaptive Landscapes Exploration: Adaptive landscapes are multidimensional environments that are easier to explore thanks to the computational modeling technique. The elevation of each point in these spaces indicates the fitness of an organism with a particular set of features, and each axis in these spaces represents a unique trait or parameter. Through navigating these

environments, scientists can learn more about the intricate interactions between features and how these affect an organism's ability to adapt within a population that is evolving.

3. Stability and Branching Analysis: A potent method for examining population stability and examining the circumstances of branching is computational modeling. Population divergence is a component of branching events, and it may result in the formation of new species. By use of these simulations, scientists can examine the variables that lead to population stability and the boundaries where branching takes place, so advancing our comprehension of evolutionary dynamics.

Comprehensive Objectives of Computational Evolutionary Modeling: The main goal of computational evolutionary modeling is to give scientists a dynamic, virtual lab in which to dissect the complex principles behind evolutionary processes. By concentrating on particular elements and goals, these models seek to:

1. Uncover Mechanisms of Evolution: Researchers can discover the fundamental mechanisms that underlie evolution by using computational models. This covers the investigation of genetic mutations, the forces of natural selection, and the consequent adaptations that mold an organism's characteristics through multiple generations.

2. Visualize Adaptive Landscapes: The modeling approach provides a thorough grasp of the interactions between many features and how they affect an organism's fitness, making it easier to visualize adaptive landscapes. This helps determine the best combinations of traits for both survival and successful reproduction.

3. Study Population Dynamics: Through the use of computational simulations, population dynamics can be studied, shedding light on how modifications to adaptive qualities affect species interactions, abundance, and distribution within changing populations.

4. Analyze Stability and Branching: The models are useful for examining population stability and identifying the circumstances that give rise to branching occurrences. Understanding the variables causing population divergence and the possible creation of new species depends on this realization. Computational evolutionary modeling is, at its core, a fundamental tool for improving our comprehension of the complex mechanisms guiding the evolution of life on Earth. Through the integration of theoretical understanding and computational capabilities, scientists can explore the intricacies of evolutionary dynamics, leading to pioneering findings and an enhanced understanding of the variety and versatility of living beings.

Diverse Applications and Instances:

1. Co-evolutionary Dynamics Modeling: Researchers explore the complex dance of co-evolution by using computational models to study interactions between various species pairings,

including hosts and parasites, plants and pollinators, and predators and prey. The dynamic changes in evolutionary tactics and adaptations that take place as various species interact with one another in a reciprocal evolutionary process are better understood thanks to these simulations.

2. Behavioral Evolution Studies: Researchers use computational models as a lens through which to see how behavior evolves. These models allow researchers to investigate how natural selection drives the evolution of behavioral adaptations, including mating habits, migration patterns, and altruistic conduct. Researchers can learn more about the intricate interactions between genetics, environment, and behavioral traits that shape evolutionary paths by mimicking these activities.

3. Conservation Strategy Development: In the field of conservation, adaptive dynamics models are useful instruments for creating strategies for managing biodiversity. The development of conservation and rehabilitation plans for threatened and endangered species is aided by these models. Researchers can evaluate the efficacy of alternative management strategies by modeling different conservation scenarios, which helps to ensure the long-term preservation of biodiversity.

Challenges and Constraints in Computational Evolutionary Modeling:

1. Model Complexity and Realism: The correctness of biological assumptions and data availability are critical to the effectiveness of computer models. The difficulty is in faithfully representing the complexities inherent in evolutionary processes while encapsulating the complexities of real-world biological systems within models. For simulation results to be legitimate, a balance between model complexity and realism must be struck.

2. Computational Cost in Large Systems: Computational demands arise from the comprehensive modeling of adaptive processes in large-scale complex systems. The modeling becomes more computationally intensive the larger and more complicated the system. In order to manage the computing costs associated with simulating complex and large-scale evolutionary dynamics, this challenge must be addressed by investigating novel computational methodologies, optimizing algorithms, and utilizing technological improvements.

5 Description of the computational experiment

The course work will present a comparison of two teams dealing with numerical methods and stochastic simulations. The teams will analyze the effectiveness and accuracy of the methods used in numerical calculations and modeling of random processes. Let's consider the specific applications of numerical methods and stochastic simulations.

As mentioned earlier, this study aims to identify the advantages and disadvantages of each method, identify areas of their application and determine the most effective approach in various scenarios. The results obtained will help determine the optimal strategies for using numerical methods and stochastic simulations to achieve the required goals and solve specific problems.

We study a group of plants from species n located within a specific area A. We define a density function for the i-th species, where X_i represents the collection of positions of individuals at time a, and $\delta(x)$ denotes the Dirac delta function : $p_i(x) = \sum_{x' \in X_t^i} \delta\left(x - x'\right)$

The spatial pattern, or functional density vector $p_i(x)$ for each species i, should represent the state of the system at time a. Let $p(x) = (p_1(x), ..., p_n(x))$. The average density of species i within the area A corresponds to the first moment : $N_i(\boldsymbol{p}) = \frac{1}{A} \int p_i(x)dx$

The density of species pairs i and j at a distance ξ within the area A corresponds to the second moment : $C_{ij}(\xi, p) = \frac{1}{A} \int p_i(x) \times [p_j(x + \xi) - \delta_{ij} \times \delta(\xi)]\, dx$

6 Results of simulations and numerical method

6.1 Results of simulations

Graph of the mechanism of coexistence of two species

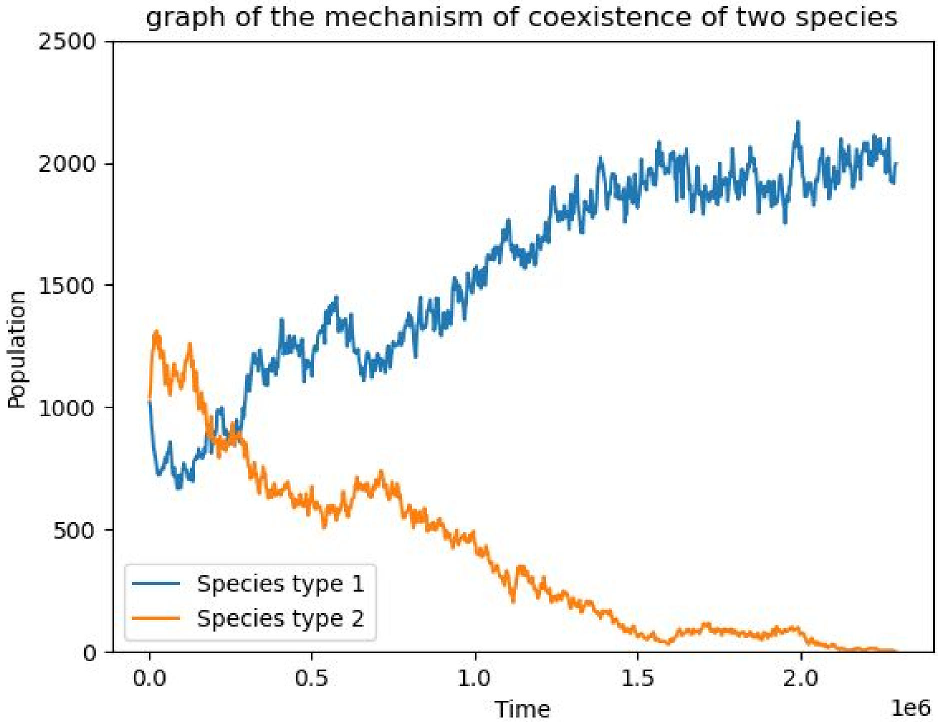


Figure 6.1: Graph of the mechanism of coexistence of two species

Further, the parameters from this article were taken as basic parameters that do not participate in coexistence mechanisms [3].

Below are some examples of how the numbers of species can behave during coexistence and when one of the species dominates

The case of extinction of a prey species, which occurs at $\sigma_{in^w} = 0.01 \sigma_{ex^w} = 0.16, \sigma_{2^m} = 0.01, d_{12} = 4.00E - 04$

Simulations were carried out for a one-dimensional and two-dimensional two-species model in two scenarios, Heteromyopia and CCTO. They were carried out in the space of parameters $\sigma_{in^w}, \sigma_{ex^w}$

6.2 graph of the mechanism of coexistence of two species particular case

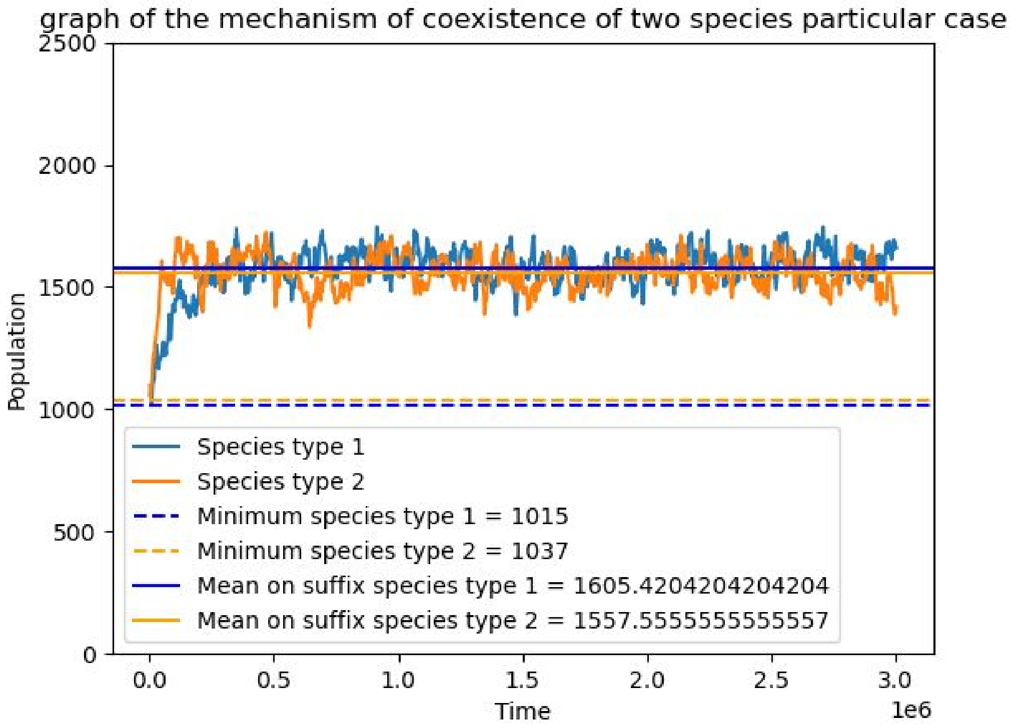


Figure 6.2: graph of the mechanism of coexistence of two species particular case

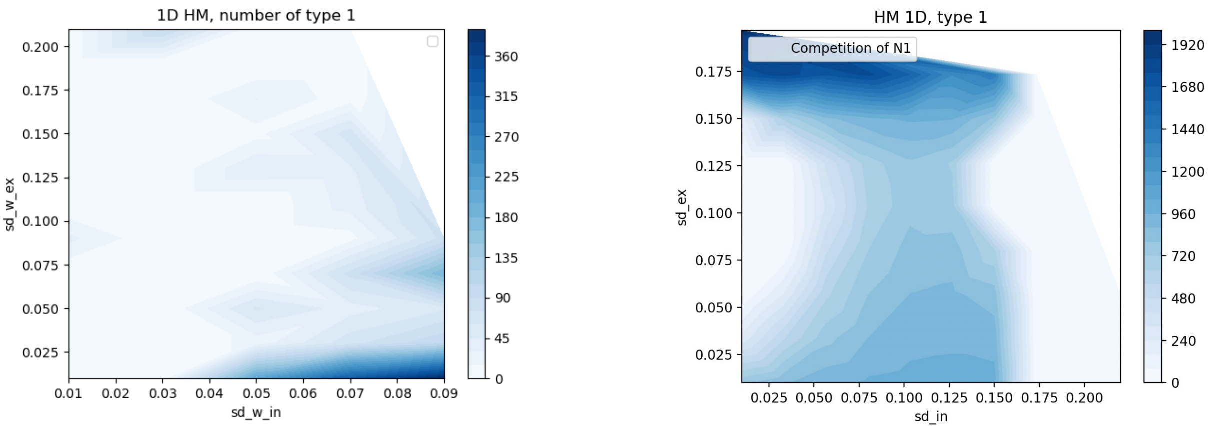
A striking example of coexistence, which is realized at $\sigma_{in^w} = 0.16$, $\sigma_{ex^w} = 0.01$, $\sigma_{2^m} = 0.01$, $d_{12} = 7.00E - 04$.

6.3 Heteromyopia

6.3.1 How Heteromyopia Works

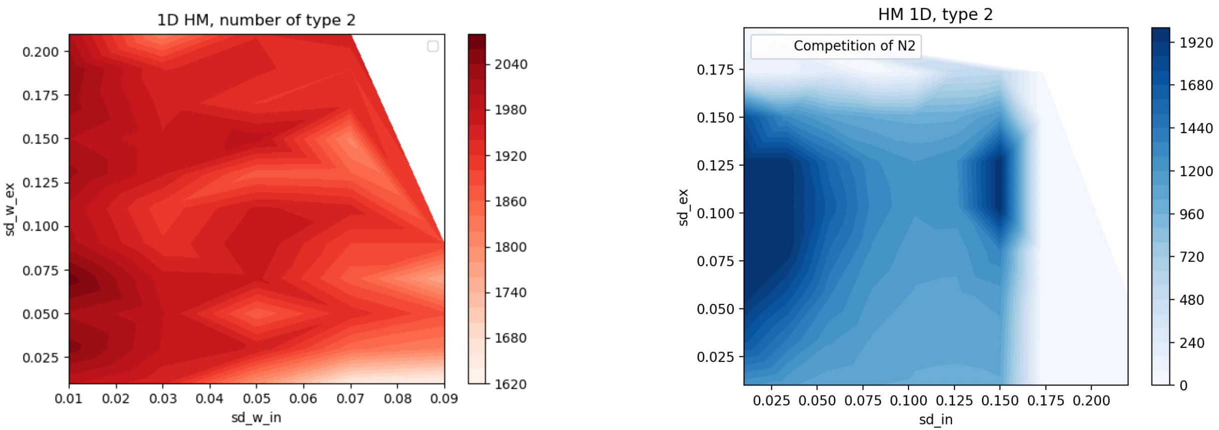
The link between intra- and inter-species competition is related to the heteromyopia process. The mechanism assumes that species will coexist if the distance between interspecies competition and intra-species competition is less.

The example of heteromyopia in one dimension According to one theory of the heteromyopia mechanism scenario, coexistence happens when the radius of the intraspecific competition core is less than the radius of the interspecific competition core. The parameters used to mimic this process were obtained from the paper, and two species were started: the first with 100 individuals and the second with 200. $\sigma_{2^m} = 0.06$ and $d_{12} = 0.001$ were fixed.



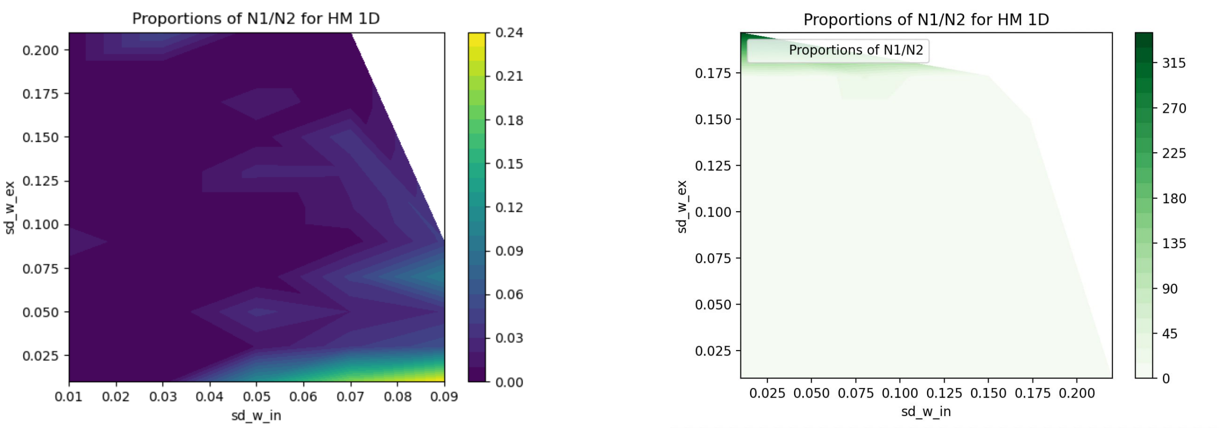
(a) Simulation (b) Numerical method

Figure 6.3: Comparison of numbers of species of type 1 for HM 1D



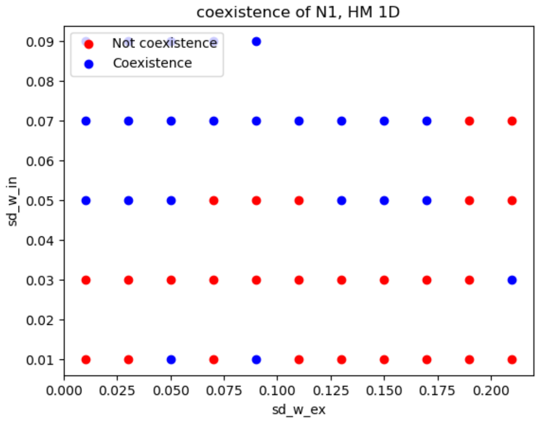
(a) Simulation (b) Numerical method

Figure 6.4: Comparison of numbers of species of type 2 for HM 1D

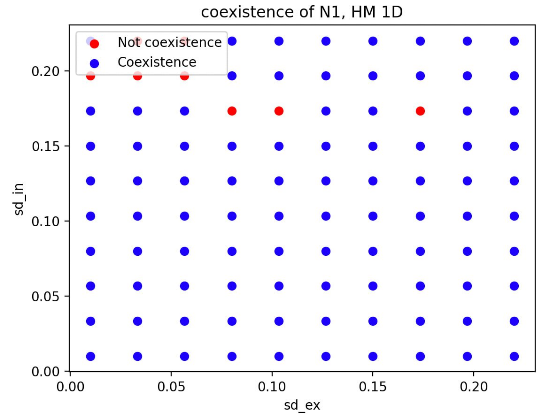


(a) Simulation (b) Numerical method

Figure 6.5: Proportions of N1/N2 for HM 1D

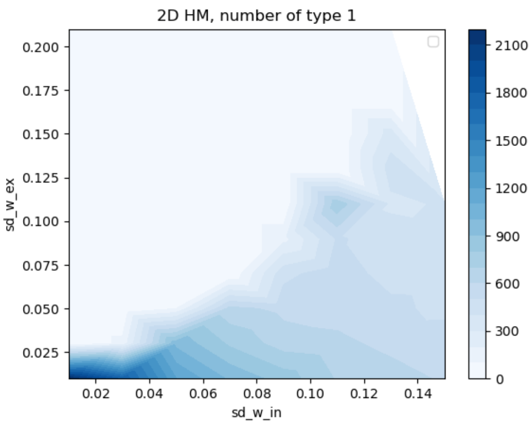


(a) Simulation

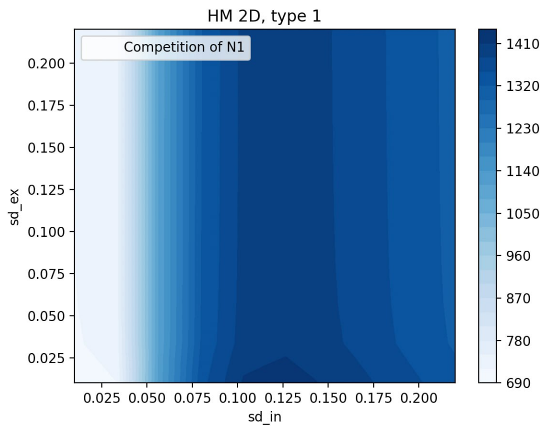


(b) Numerical method

Figure 6.6: Comparison of coexistence of N1 for HM 1D

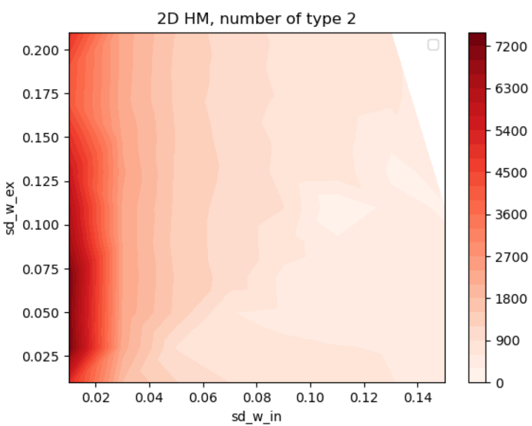


(a) Simulation

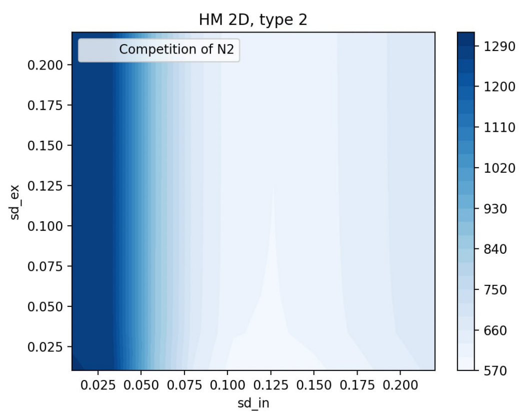


(b) Numerical method

Figure 6.7: Comparison of numbers of species of type 1 for HM 2D

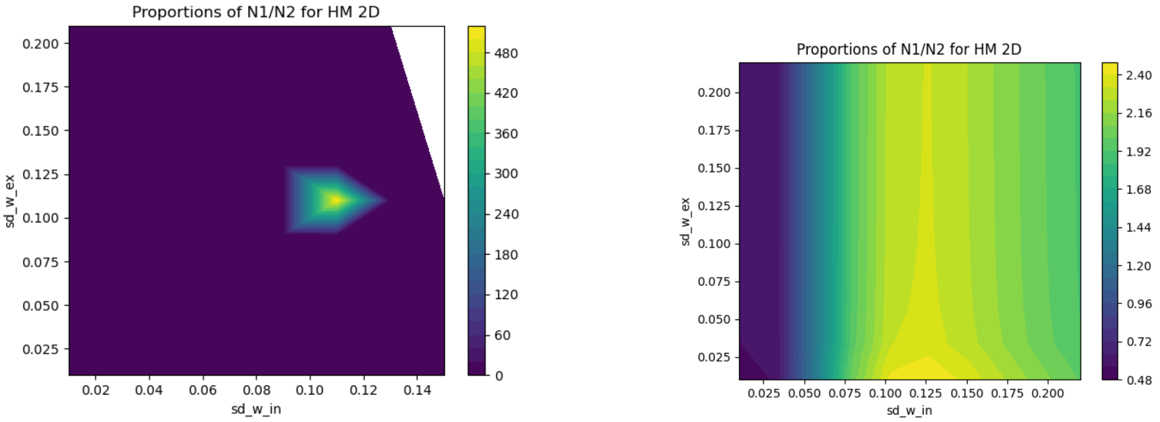


(a) Simulation



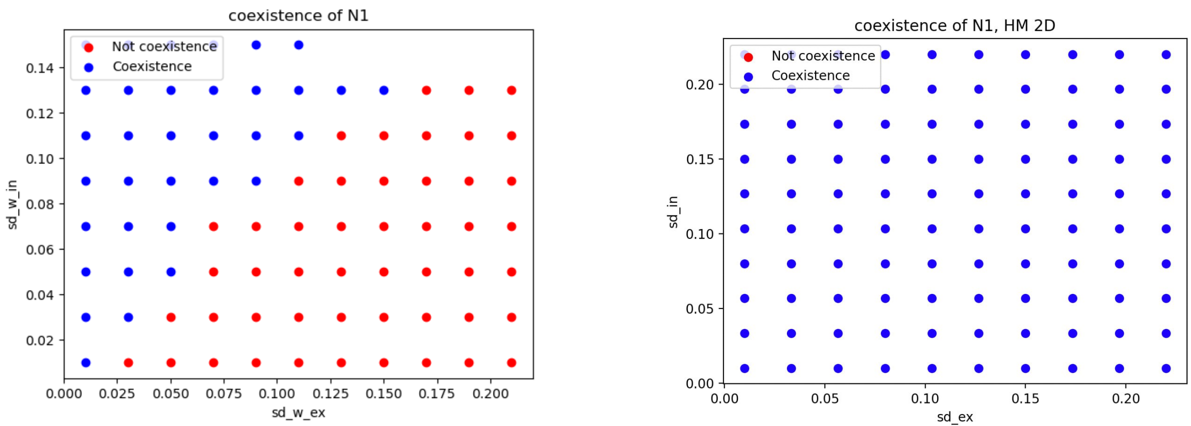
(b) Numerical method

Figure 6.8: Comparison of numbers of species of type 2 for HM 2D



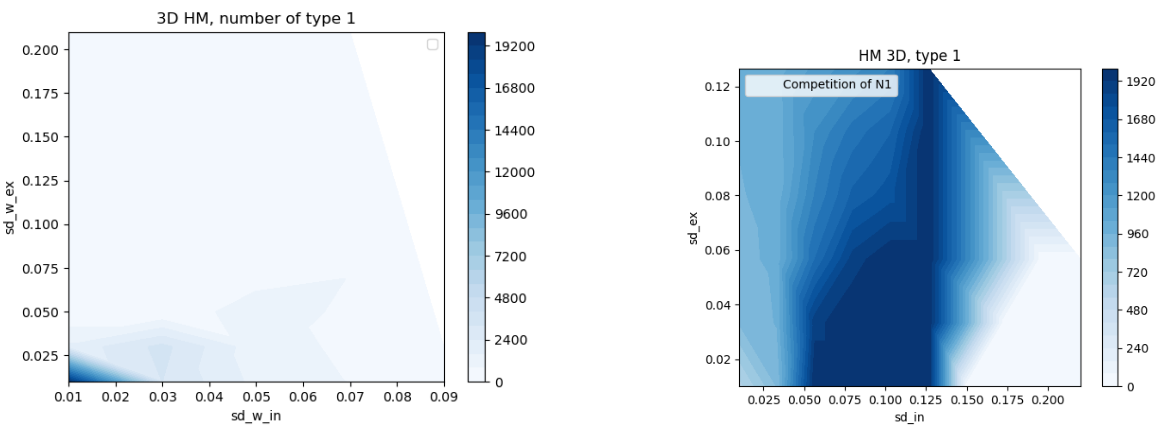
(a) Simulation (b) Numerical method

Figure 6.9: Proportions of N1/N2 for HM 2D



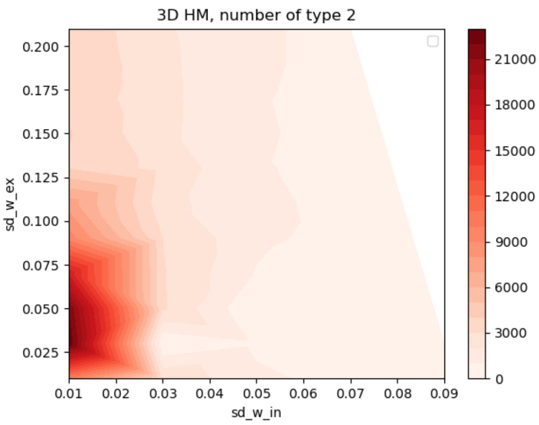
(a) Simulation (b) Numerical method

Figure 6.10: Comparison of coexistence of N1 for HM 2D

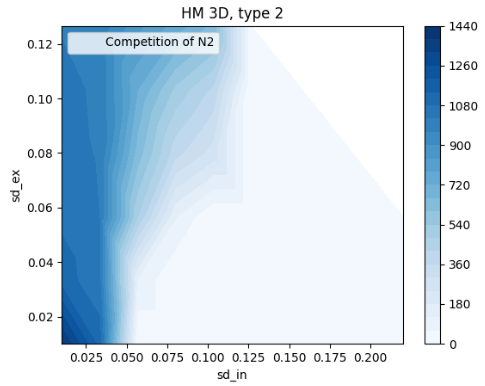


(a) Simulation (b) Numerical method

Figure 6.11: Comparison of numbers of species of type 1 for HM 3D

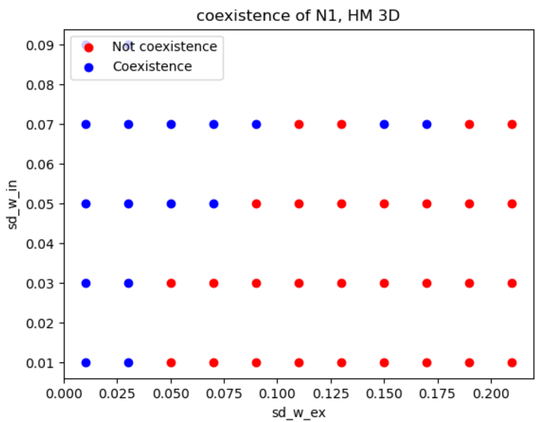


(a) Simulation

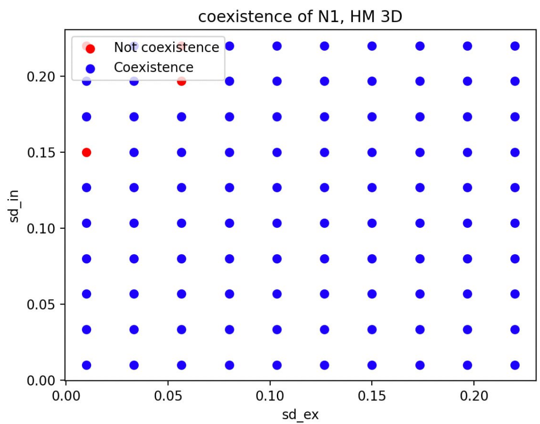


(b) Numerical method

Figure 6.12: Comparison of numbers of species of type 2 for HM 3D



(a) Simulation

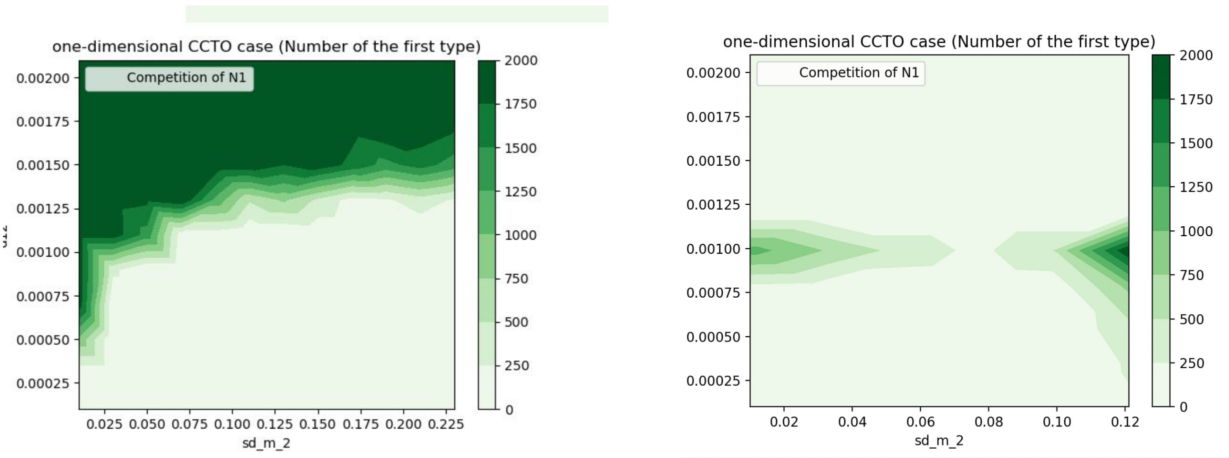


(b) Numerical method

Figure 6.13: Comparison of coexistence of N1 for HM 3D

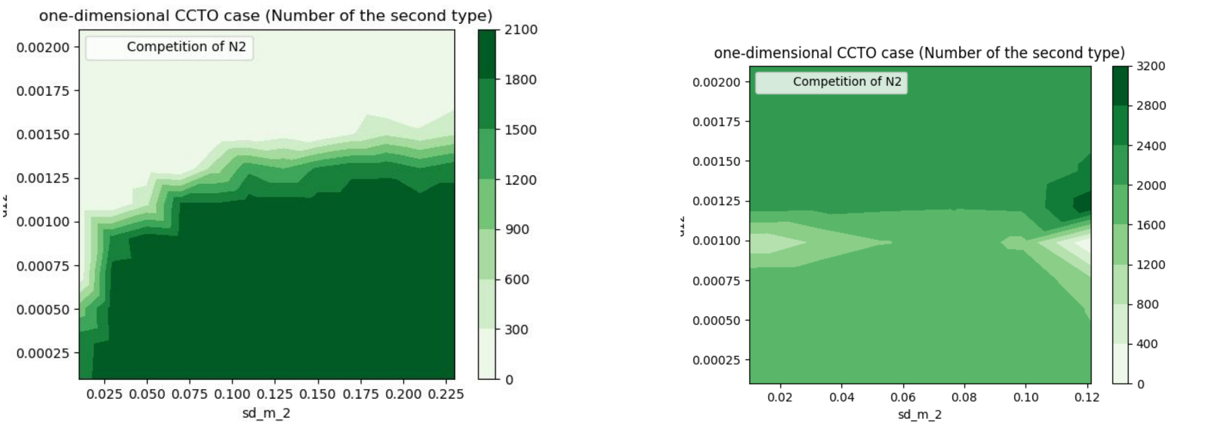
6.4 CCTO

The "predator-prey" situation, in which one species strikes and the other manages to flee, is referred to by the CCTO mechanism. This mechanism in the model is caused by d_{12} and σ_{2m}, where d_{12} is a predator and σ_{2m} is a victim. It is expected that the predator and prey species will coexist if the parameters are set appropriately.



(a) Simulation (b) Numerical method

Figure 6.14: Comparison of 1D CCTO of number of species of type 1



(a) Simulation (b) Numerical method

Figure 6.15: Comparison of 1D CCTO of number of species of type 2

7 Conclusion

Comparing numerical techniques with equivalent simulations was the focus of this effort. Numerous comparisons carried out by our team using numerical methods verified the convergence simulations. The numerical approach, however, does not converge to the simulation for some input values; for instance, it yields a negative result for the first spatial instant. Potential areas of investigation might involve streamlining simulation performance and expediting value computation for a three-view model, which proved to be significantly more complex to deal with than a two-view model.

8 Possibilities for more research

We think one of the most exciting tasks is automating computer simulations. To find out if the graph for the first instant has steadied, you currently need to look at the graph and assess the oscillations visually.

As a result, we have a "stopping problem," which means that we don't know if we can stop the simulations without first viewing the graph. You may think about creating an algorithm that would enable me to figure out on my own when the value of the first minute reaches a plateau. The simulation time will be much decreased as a result of this approach, and averaged values may be obtained at the output by counting them several times by analogy using the numerical technique. Despite the task's seeming simplicity, it is not easy to complete since it calls for the use of a significant mathematical equipment in addition to programming abilities.

It can also can be seen that on some charts there is a small white triangle on the left. we made the assumption that this happened due to broken data that was received at the input of the numerical method and simulation, so others can try to prevent this and somehow improved this library and reduce the number of that kind of data.

9 References

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[7] GitHub repository : https://github.com/zimble111/bio_model_adaptive_dynamics