Coupling multiscale models of complex biological systems: Application to evolutionary ecology

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A complex system is a set of heterogeneous interacting entities , which adopts a dynamic behavior and evolves over time. In a complex system, such as groups of individuals, knowing the properties and behavior of isolated individual is not sufficient to predict the behavior of the group. It is therefore essential to fully describe the system, to integrate simultaneously several models at different scales of resolution [Weinan and Jianfeng, 2011].

A major challenge in modeling multi-scale systems is the coupling of different models that describe the same phenomenon at different scales [Dada and Mendes, 2011].

In practice, we consider an hermaphrodite[1] marine population that evolve in time and space as a complex dynamic system. We aim for modeling and analysis of this population by the integration of various complementary approaches (mathematical and computational models), with the aim of unifying ecological and biological theories, mainly DEB theory and the sex-ratio theory.

We chose these two theories because they are able to describe the process of search, retrieval and use of the energy by an organization to maximize its chances of survival and reproduce effectively. [Cadet et al., 2004]

- The theory of a dynamic energy budget (DEB theory) presents the mechanisms that describe the uptake and use of energy for maintenance, development, growth and reproduction and consequences throughout life cycle of an organism. This "unifying" theory is the biological equivalent of theoretical physics and encompassing other theories as well founded Bertalanffy growth [Bertalanffy, 1951] and Kleiber's law [Kleiber, 1932], [Kooijman, 2010]
- The sex-ratio theory studies the allocation of resources to reproduction of males versus females to understand the sex ratio of populations particularly hermaphrodites (capable of producing male and female gametes) [Charnov, 1982] [Kebir, 2010].

It would be interesting to see how these theories and their arising mathematical models are connected. This could be done in two ways:

- Link in the context of a broader theory including these two aspects in different scales.
- Verify that the two models implemented in a multi-agent and multi-scale system, are connected.

We aim to propose a framework for integrating these models for the design and simulation of complex systems, to validate the consistency and coherence of the different components (models and computational codes).

[1] An organism capable of producing male and female gametes.

The goal is to propose a multi-scale approach, where at least two models, one at a microscopic level (individual level with DEB theory) and the other at macroscopic level (population with sex-ratio theory), defined at different space and time scales, will be coupled.

On a practical level, we have to define the sex allocation model for hermaphrodite marine individual in the context of DEB theory and integrate the sex-ratio theory to define the interaction between individual of the same population.

We would like to answer these questions

- What is the relationship between sex ratio and allocation of energy.
- Find optimal age/size of sexual inversion for Sequential hermaphrodite[2].
- Find evolutionarily stable strategy (ESS) for diocy[3] vs sequential hermaphrodite.

It would be interesting to combine these two theories and models involved, to explain the behavior of an individual hermaphrodite and parameters that affect the sex ratio of the entire group. This approach would thus provide the answers needed to understand complex systems in their entirety. More generally, we aim to "interoperate" various complementary approaches.

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[2]Sex change / Sequential Hermaphroditism: An organism that has only one sexual organ i.e. an organism that functions as one sex and then switches to the other sex.

[3]Gonochoristic (dioecious): An organism with two separate sexes.