



Morpheus: User-friendly modeling of multicellular systems

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Understanding how cells form tissues is not only central to developmental biology, but is also crucial to elucidate tissue and organ function and their dysfunction in disease. Increasing appreciation of this is causing a shift in systems biology to scale up to higher levels of biological organization and, in particular, to integrate molecular with cellular and multicellular systems. This requires novel computational tools that facilitate the construction, simulation and integration of multiscale multicellular models in reproducible and reusable ways. A major challenge in this field is to provide flexibility while maintaining usability and support an effective workflow in the collaboration and model sharing between modelers and biologists.

Morpheus is a user-friendly application for the modeling, simulation and integration of cell-based models, ordinary differential equations and reaction-diffusion systems that allows rapid and flexible development of complex multiscale models without programming [1]. It separates modeling from implementation by using a declarative domain-specific markup language for multicellular modeling. This language allows users to describe their complex models in familiar biological terms and mathematical expression using common infix notation and symbolic identifiers, similar to SBML. Morpheus automates multiscale model integration by appropriately mapping data between spatial models as well as scheduling numerical updates according to the dependencies between symbolic identifiers. The graphical user interface streamlines the modeling workflow by providing tools for model construction, simulation and model exploration as well as archiving and batch processing.

Due to its modular design, Morpheus facilitates the simulation of a range of disparate modeling formalisms, combining algebraic or differential equations, cell-based models and reaction-diffusion systems. To date, it has been applied to the study of collective motion in bacteria, cell fate decisions and pattern formation in the pancreas as well as vascular morphogenesis. The ease of use of this modeling and simulation environment has also proven to be useful in education, for mathematicians and physicists as well as biologists.

[1] J. Starruß, W. de Back, L. Brusch, A. Deutsch, Morpheus: a user-friendly modeling environment for multiscale and multicellular systems biology, *Bioinformatics*, 10.1093/bioinformatics/btt772, 2014.