15-400 Project Proposal
Self-Assembly Modeling and Simulation

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Project Web Page: https://yygwww.github.io

Project Description:
Professor: Russell Schwartz, Computational Biology Department
Graduate student: Marcus Thomas, Jonathan Laurent
Tentative title: Self-Assembly Modeling and Simulation

Summary:
Biochemical self-assembly is a poorly understood phenomenon where biomolecular monomers form stable structures without external assistance. Self-assembly systems are ubiquitous in many biological activities and understanding the process and properties of them is crucial in many biochemical applications. One commonly discussed example of such, is virus protein shells. Understanding virus capsid self-assembly is crucial to understanding of viral life cycles and developing treatments for viral illnesses.
However, since the self-assembly processes happen at small-scale biomolecular level, traditional physical experiments that rely on observation of molecular population are not able to reveal the process. Computational modeling and simulation have been proven to have the potential to provide more insights. This project aims to propose a new modeling and simulation method with special focus on the ability to provide assembly pathway information.

Project Goals
Objective: A new modeling and simulation method that provides more pathway information.
75%: A new modeling and simulation method, but no particular strength in their reliability with respect to physical experiment results, or in pathway information retrieval
100%: A new modeling and simulation method, and a feasible way to retrieve pathway information
125%: A new modeling and simulation method, and a feasible way to validate the model with physical experiment results, and to retrieve pathway information

Milestones:
1st Technical Milestone for 15-300: Better understanding of existing literature in self-assembly modeling and simulation, evaluate feasibility of formal modeling approach, setup software for simulation

Bi-weekly Milestones for 15-400:

February 1st, , define/start to get physical experimental data that serves as simulation metrics

February 15th, try self-assembly modeling in Kappa language

March 1st, try modeling add-ons to the local rules simulation (Professor Schwartz's thesis)

March 22nd, try modeling add-ons to gillespie simulation

(The above three milestones will be mingled together)

April 5th, implement resulting modeling and simulation algorithm on Matlab, etc., or as an add-on to existing simulator

April 19th, test implementation with actual data, optimize simulation efficiency if possible

May 3nd, prepare for poster/presentation at Meeting of Mind

Literature Search:

To do: more study/search in simulation methods, especially Gillespie and its variations; more on self-assembly systems, especially on modeling

Biochemical Simulation and modeling:

[1] Daniel T. Gillespie, Stochastic Simulation of Chemical Kinetics. Annual Review of Physical Chemistry, 2007

Self-Assembly:

[1] R Schwartz, PW Shor, PE Prevelige Jr, B Berger, Local rules simulation of the kinetics of virus capsid self-assembly. Biophysical journal, 1998

[2] Tiequan Zhang, Russell Schwartz, Simulation Study of the Contribution of Oligomer/Oligomer Binding to Capsid Assembly Kinetics, Biophysical Journal, 2006,

(Formal methods on) pathway analysis:

[1] Vincent Danos, Jrme Feret, Walter Fontana, Russell Harmer, Jonathan Hayman, Jean Krivine, Christopher D. Thompson-Walsh, and Glynn Winskel. Graphs, rewriting and pathway reconstruction for rule-based models. In Leibniz International Proceedings in Informatics, LIPIcs, 2012

[2] Vincent Danos, Jrme Feret, Walter Fontana, and Jean Krivine. Abstract interpretation of cellular signalling networks. In the 9th International Conference on Verification, Model Checking and Abstract Interpretation - VMCAI, May 2008.

[3] Jonathan Laurent, Jean Yang, and Walter Fontana. Counterfactual resimulation for causal analysis of rule-based models. In Intl. Joint Conference on Artificial Intelligence (IJCAI), 2018

Resources Needed:

MATLAB (√)

Mathematica(√)

Simulator presented in Professor Schwartz's thesis (X) → Professor Schwartz

Kappa Simulator (X) → https://kappalanguage.org