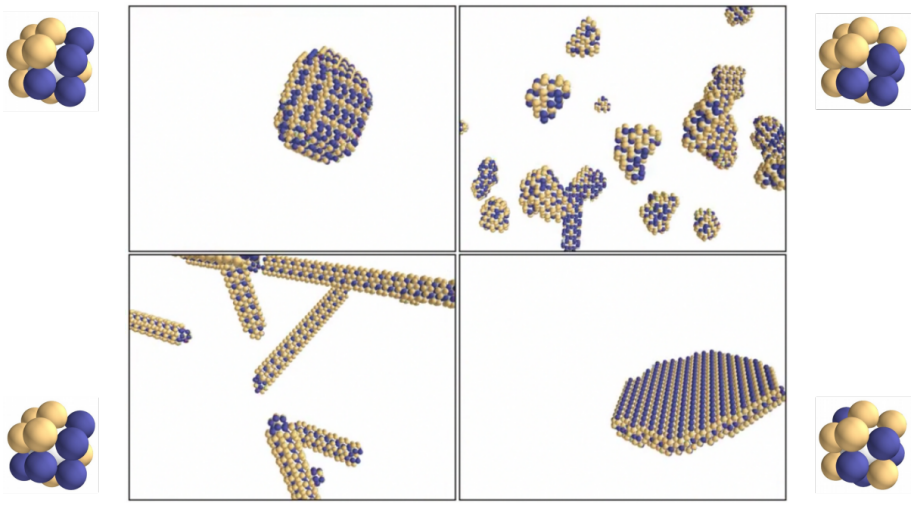
Frustrated self-assembly with multiple particle types

(theoretical & numerical internship, possibly leading to a thesis)

Self-organization is key to the function of living cells – but sometimes goes wrong! In Alzheimer's and many other diseases, normally soluble proteins thus clump up into pathological fiber-like aggregates. While biologists typically explain this on the grounds of detailed molecular interactions, we have started proving that such fibers are actually expected from very general physical principles. We thus show that **geometrical frustration builds up when mismatched objects self-assemble, and leads to non-trivial aggregate morphologies, including fibers**.

While we have shown that collections of identical particles form aggregates of various dimensionalities, realistic biological examples often involve multiple proteins. We will thus investigate how collections of several types of different particles typically interact and interfere. Our study will first consist in developing multi-geometries variants of the lattice-based numerical model presented in the illustration. We will then ask whether species with different geometries tend to phase separate, or conversely whether the mutiplicity of interactions they offer eases geometrical frustration and favors co-assembly. We will also wonder how this combinatorics affects the dimensionality of the aggregates, and whether we can identify generic features of the particles that distinguish between the two scenarios. We will then conduct off-lattice simulations to assess the robustness of these scenarios. Finally, we will attempt to construct a mean-field theory describing the co-assembly of a large variety of particles ($\geqslant 10$ or so) thus revealing the interplay between frustration and combinatorial freedom in self-assembly.

Beyond protein aggregation, this project opens investigations into a new class of "disordered" systems where the disorder is carried by each identical particle, as opposed to sprinkled throughout the system. This will help define the much-debated notion of frustration in dilute systems. This project will be conducted in collaboration with Pierre Ronceray (Turing Center for Living Systems, Marseille), who will co-direct a possible PhD project.



In our simulations, complex lattice particles with geometrically incompatible orientational preferences (in the corners: sites with identical colors attract) give rise to aggregates of different dimensionalities.

Expected skills:
A taste for statistical mechanics and numerical simulations connected to analytical aspects.

Location:
PMMH at ESPCI & Sorbonne U. and/or LPTMS at U. Paris-Saclay (Orsay)

Contact:
martin.lenz@espci.fr or martin.lenz@u-psud.fr
http://lptms.u-psud.fr/membres/mlenz/