1. Assembly of Mesoscale Components

Traditional pick-and-place assembly processes are intrinsically serial in nature and work well for macroscopic components.

**Mesoscale components**

- Off-the-shelf functional mesoscale components are now readily available in sizes from 100 μm (LEDs) down to 100 nm (magnetic beads).
- However, pick-and-place based assembly
  - gets difficult because of increased surface effects
  - becomes impractical for a large number of components

**Our approach and goal**

- Explore a new paradigm for micro-assembly
- Self-assembly based on bio-inspired molecules
- Heterogeneous and parallel assembly
- Demonstrate a proof-of-concept

2. Bio-inspired Self-Assembly

Bio-molecules have the innate ability to recognize and bind to certain other molecules. The recognition is typically driven by supramolecular forces between complementary molecules.

"Smart-glue": Examples of bio-inspired bonds

- Two complementary single strands of DNA which can hybridize
- Molecules with Hydrogen bonding like ureido-pyrimidinone (UPy) group
- Protein-ligand bonds like biotin and streptavidin

Assembling mesoscale components using molecules

- Use complementary patches of engineered molecules inspired by nature to separately pattern the component and a particular site on the substrate
- The assembly process is intrinsically parallel as each component searches for its target site
- Specificity from molecular recognition allows us to assemble different components on the same substrate simultaneously

3. Part Trajectories in Self-Assembling Systems

The prospects of self-assembly allows a new possibility: the substrate can be patterned randomly. At the same time, it introduces a new question: what is the optimum path for parts on such a substrate?

**Sequential and random exploration**

- For a single part, sequential exploration is more efficient
- For multiple parts, generally random walkers improve their collective efficiency
- However that of sequential exploration is expected to be highly dependent on initial conditions. Furthermore, collisions arising from crowding are expected to introduce randomness

4. Parallel Manipulation of a Large Number of Components

To understand the optimum conditions for parallel self-assembly over a random substrate, we shall explore the collective dynamics of an ensemble of mesoscale parts subject to deterministic and stochastic forces.

**Langevin equation of motion**

\[
m \frac{d^2 \vec{X}_0}{dt^2} = -\gamma \frac{d\vec{X}_0}{dt} + \vec{F}^{st} + \vec{F}^{det} + \vec{F}^{SA}
\]

- Ensemble of heterogeneous parts with mass \( m \) and drag coefficient \( \gamma \)
- \( \vec{F}^{st} \) describes deterministic forces arising from actuating potentials
- \( \vec{F}^{st} \) describes stochastic forces arising from agitation potentials
- \( \vec{F}^{SA} \) are self-assembling forces arising from localized potential wells
- parts from different classes \( \alpha \) see potential wells at different locations

**Considerations and approaches**

- Mechanical collisions and hydrodynamic interactions are important
- Parametric studies using numerical simulator
- Experimental feedback control of statistical parameters of the ensemble

5. Towards triggered manipulation of flowing micro-parts

To enhance self-assembly in a fluidic medium, the function of micro-fluidic channels can be extended by incorporating actuator arrays which can be autonomously triggered by in-situ part detectors.

**Real-time in-situ detection with integrated optical waveguide**

- An optical waveguide can be patterned monolithically with a microfluidic channel in a fused silica glass substrate
- A He-Ne laser is injected into the fluidic device using the patterned waveguide. The result is a localized light source placed along the middle of the fluidic channel

- As a component passes in front of the waveguide, the transmitted light falling on the photo-detector is attenuated due to partial masking by an opaque flowing component

**Actuator arrays**

- The real-time detection signals can be used to dynamically trigger programmed events in the fluidic system
- In the future, these signals shall be coupled to an array of patterned electrodes to create an actuator array based on:
  - localized heating for inducing local diffusion
  - localized electric field traps for inducing local attraction