Numerical Analysis of Morphological Influence on Self-Assembly Robots

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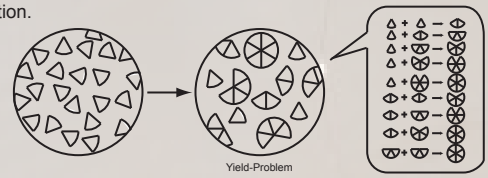
Self-Assembly

Self-Assembly is a term used to describe processes in which a disordered system of pre-existing components spontaneously forms an organized structure or pattern as a consequence of specific, local interactions among the components themselves, without external direction.



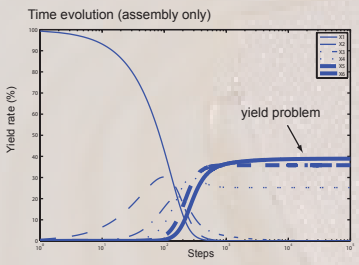
The kinetic rate model

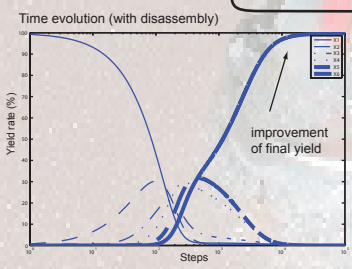
The kinetic rate model,known from chemical reactions, allows us to model the stochastic time evolution of our system with a large amount of models. The transition of the state vector **x** = (x1,...,x6), in which xk denotes the number of clusters consisting of k modules, obeys the following difference equation if x is large enough:

$$\mathbf{x}(t+1) = \mathbf{x}(t) + \mathbf{F}(\mathbf{x}(t))$$

F is a transition function expressed as the sum of the products of (i) the collision probability, the bonding probability and the stochiometric number and (ii) the sum of the products of the disassembly probability and the stochiometric number.

F(x) = ∑ (stochiometric number) * (bonding prob.) * (collision prob.)
+ ∑(stochiometric number)*(disassembly prob.)



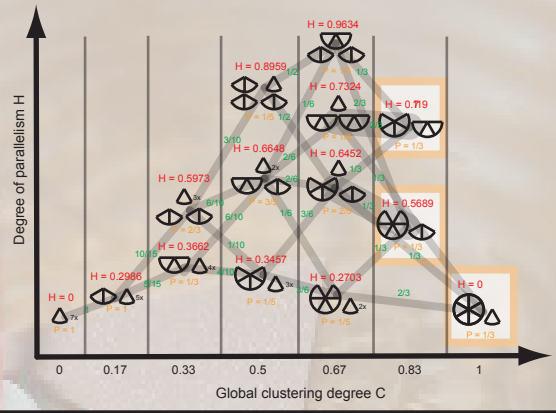


Degree of Parallelism - DOP

The degree of parallelism (DOP) H is a function of the local clustering degree (ci) and is used to quantify the aggregation paths:

$$H = - \sum ci \ln ci$$

The figure on the left shows the aggregation pathways for a system with 7 units. The probability that the system will reach a state with a complete cluster of 6 units plus a single unit is merely 1/3. The final states with a X4 + X3 and X5 + X2 cluster each have the same probability (Xk is defined as a cluster with k units).
The higher the DOP-value of a particular state is, the less probable it is for the system to converge into a complete final state. By setting the bonding probability relative to the size of the cluster we can make the system aggregate along a path that has intermediate states with a low *H*.



Time evolution

Our model starts out with 100 units. Each time step represents one colision of clusters. Two units can bond together on collision, forming a single new cluster composed of the sum of previous units.
The time evolution shown on the left does not include disassembly. In the figure on the right we see the time evolution of a system that also incorporates disassembly. Whereas the yield of complete clusters (full circles) saturates below 40% in the case of assembly only, in the disassembly case we reach a yield rate of over 99%.

Conclusion

The yield rate problem is a fundamental problem in stochastic modular robotics. We propose two approaches to address this.
- **Disassembly:** As suggested by comparing the time evolution of the system with and without disassembly we introduce diassembly. Especially for the clusters X4 and X5 since they can lock the system into a final state with incomplete clusters. Disassembling these clusters effectively puts the system in a state with lower DOP-value.
- **Assembly:** By rincreasing the bonding probability for larger clusters we can force the system to aggregate along a less parallel pathway already from the onset of reactions.

In conclusion we propose that the morpology of the clusters should be considered as a control mechanism for stochastic self-assembly robot systems.

References

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2.) K. Hosokawa, I. Shimoyama, and H. Miura, Dynamics of self-assembling systems, Analogy with chemical kinetics, Artificial Life 1 (1994), no. 4, 413–427.

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