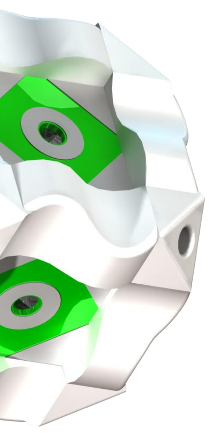
A Robotic Module for Stochastic Fluidic Assembly of 3D Self-Reconfiguring Structures

Cornell Creative Machines Lab

Jonas Neubert, Advisor: Hod Lipson
Creative Machines Lab

Programmable Matter: Thousands of small building blocks autonomously assemble into any shape requested by the user. Structures self-repair and decompose into their building blocks when no longer needed. We are trying to build a small robotic module to be the building block for this.

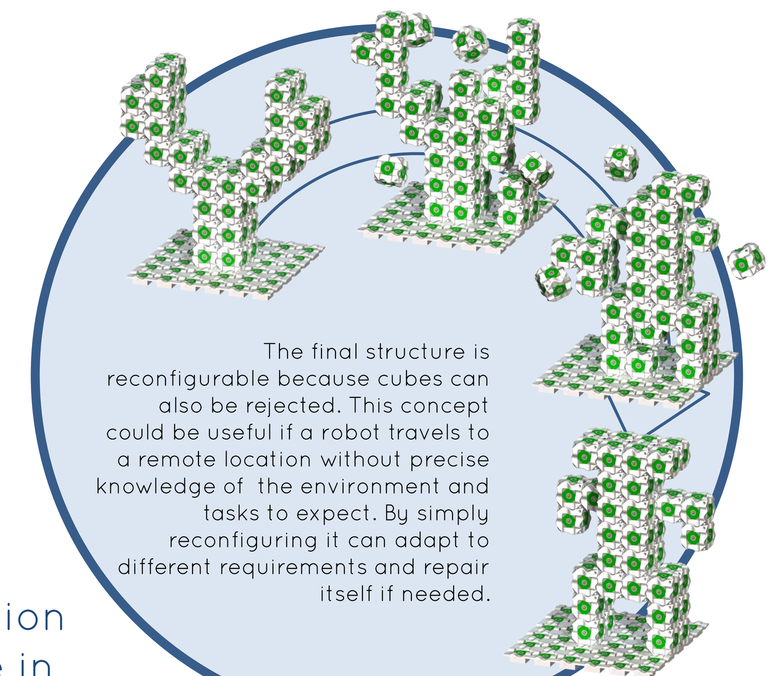
This system relies on the stochastic behavior of turbulent flow for assembly and disassembly operations. Thermorheological liquids are used to implement flow routing for control of the assembly process. This is the first use of thermorheological valves in three dimensions. We also introduce a novel reversible "self-soldering" connection mechanism for the robotic modules.



Each module consists of an 3D-printed skeleton, 12 conventional circuit boards, one flexible circuit board and 6 fluidic valves.

Step 4: Repeat until done

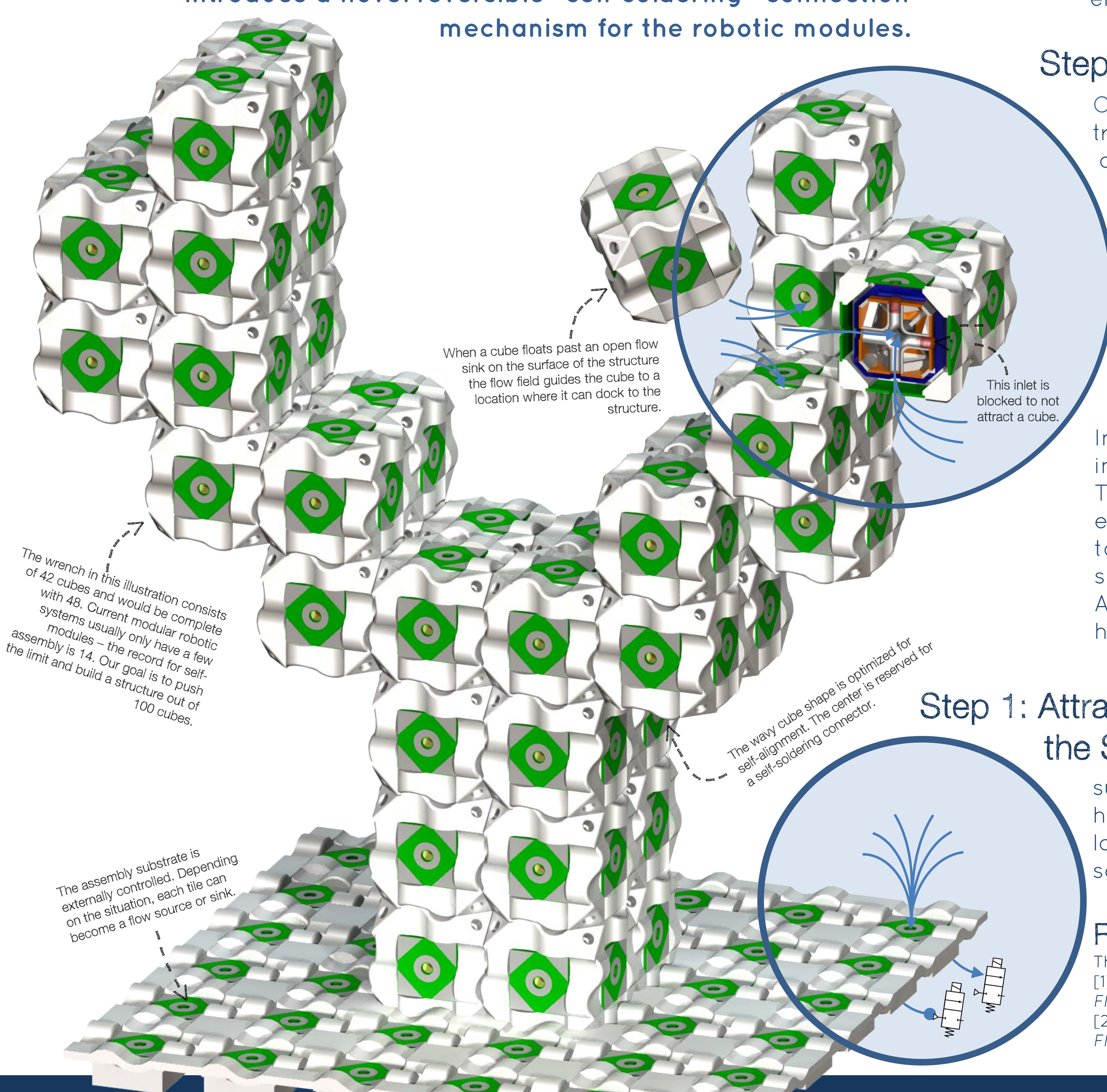
Every cube added to the structure effectively becomes part of the assembly substrate to which further cubes can be attracted. Because the time until a cube arrives cannot be predicted, assembly strategies are not straightforward. In the case of an error or broken cube, the attachment process can be reversed to reject a cube. Re-configuration is possible in the same way.



The final structure is reconfigurable because cubes can also be rejected. This concept could be useful if a robot travels to a remote location without precise knowledge of the environment and tasks to expect. By simply reconfiguring it can adapt to different requirements and repair itself if needed.

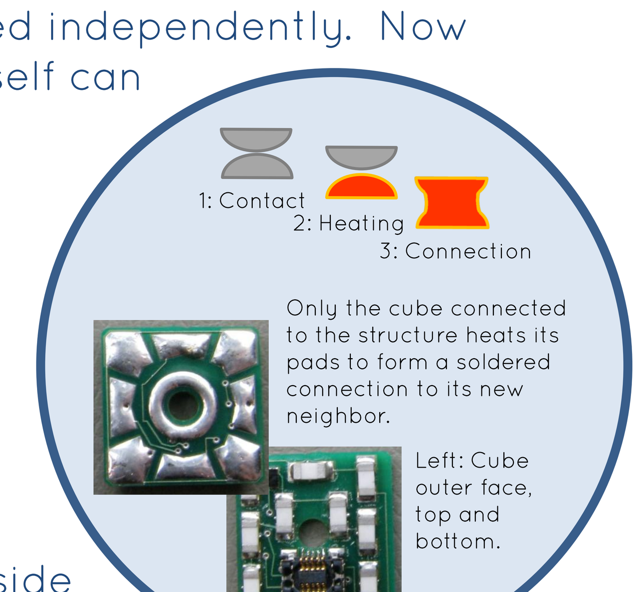
Step 3: Directing flow through the cube

Once power and information can be transmitted to the cube, it turns into an active participant in the assembly process. Based on information from the base it directs fluid flow through its internal channels. We developed small valves (more at the bottom of the poster) so that each face of the cube can be switched open or closed independently. Now each cube itself can create sinks and attract more cubes.



Step 2: Forming an electrical and mechanical connection

Initially, the newly added cube is held in place by the water flow through it. To make it part of the structure, an electrical and mechanical bond needs to be established. This is achieved by soldering the cube onto the substrate. A low melting point alloy is used and heated by running current through resistors on the underside of the cube's face. After heating and cooling, this forms a stable connection to the cube that holds the structure together and is used to transfer power and signals to the cube.



Only the cube connected to the structure heats its pads to form a soldered connection to its new neighbor.

Left: Cube outer face, top and bottom.

Step 1: Attracting the Seed

For the assembly process to begin, a first cube – the seed– is attracted to the substrate. We can control where this happens because every possible location is a flow sink controlled by a solenoid valve in the tank base. The entire tank is stirred, but there is enough flow through one or more sinks to attract cubes that randomly pass by. Because inside every cube there are channels connecting all faces, the water will keep flowing after the cube is in place.

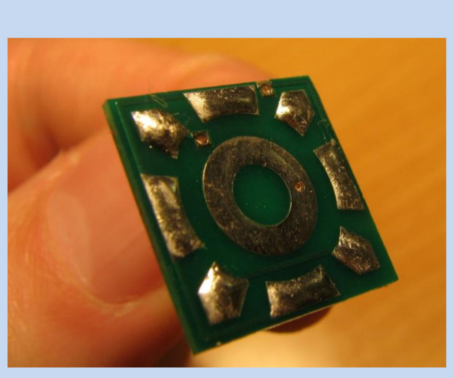
References & Acknowledgements

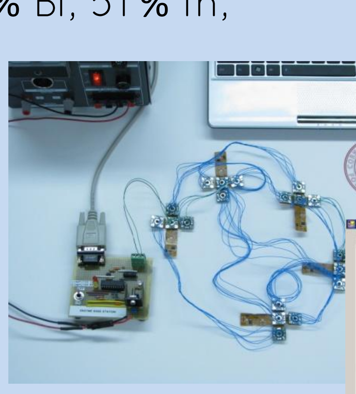
This work was funded by DARPA grant W911NF-08-1-0140 (Programmable Matter) and NSF EFRI grant #0735953.

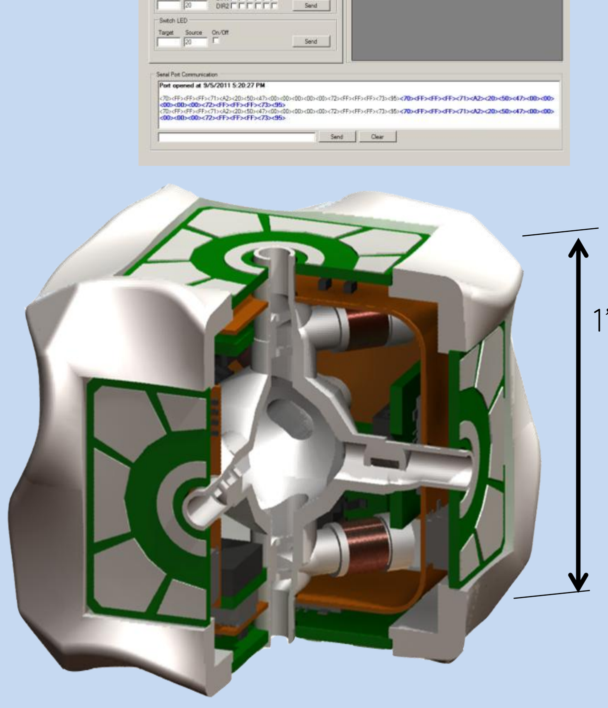
[1] Neubert, J., Cantwell, A., Constantin, S., Kalontarov, M., Erickson, D., Lipson, H. (2010) *"A Robotic Module for Stochastic Fluidic Assembly of 3D Self-Reconfiguring Structures"*, Int. Conf. on Robotics and Automation, Anchorage AK, May 2010.
[2] Tolley M. T., Kalontarov M., Neubert J., Erickson D., Lipson H. (2010) *"Stochastic Modular Robotic Systems: A Study of Fluidic Assembly Strategies"*,IEEE Transactions on Robotics, Vol. 26, pp. 518-530..

Cube docking

A stochastic assembly system requires a method of docking cubes that is **controllable, reversible and fits into a 1" by 1" cube six times**. We developed as connector with no moving parts that provides a mechanical and electrical connection. An alloy with a melting temperature of 60°C (32.5% Bi, 51 % In, 16.5 % Sn) is deposited onto the tin pads of a printed circuit board (PCB). On the opposite site of the PCB a resistor is mounted under each pad. Applying current to this resistor network on one cube melts the alloy and two modules placed adjacent to each other forms a connection.







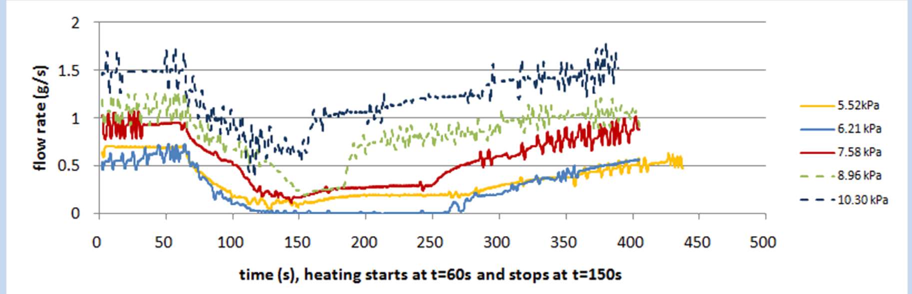
top: connector circuit board
left: Test of communication system in mesh topology
bottom: PC GUI for sending and receiving commands to the assembly substrate

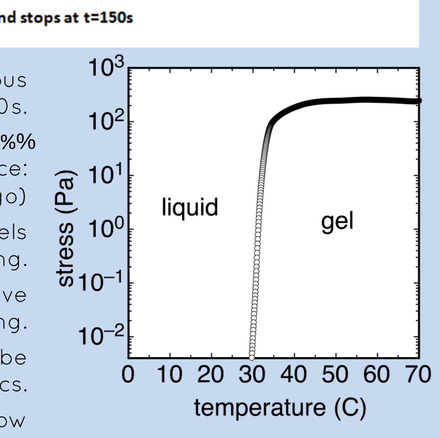
Module Communication

The **brain of the cube** is an Atmega48 microcontroller mounted on a flexible circuit board wrapped around the cube, sandwiched between the outward facing connector board and the valve control board. Modules are **unpowered while floating** but become active as soon as they connect to the structure. Communication between all connected cubes is over a **single wire communication bus** but using a serial protocol and the USART interface of the microcontroller. Additionally, the assembly substrate is connected to the serial port of a PC from where the communication can be observed and messages sent.

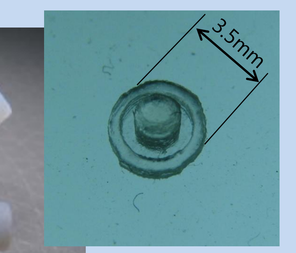
Thermorheological Valves

Each cube accommodates six miniature valves. Their functionality relies on using a fluid with **thermorheological properties** in the assembly tank. That means the fluid turns into a gel when heated but has low viscosity at room temperature. We found that mixing 20% Pluronic® F127, 10% Pluronic® F68 and 70% water results in such properties. This effect is used to **selectively heat channels thereby blocking flow through them.**





top: Pluronic water flow rate for various applied pressures. Heating betw. t=60s, 150s.
right: Stress/temperature curve for 20%% Pluronic F127, 10% P. F127 aqueous mix. (Source: Eric Brown, Univ Chicago)
below top left: Module interior, flow channels and valve housing.
below top right: 3D-printed cap of valve housing.
below bottom right: Fully assembled cube interior with valves and all electronics.
below bottom left: Schematic cut-away of flow channels and valves (magnets, coils in orange).



Miniature Solenoid Valves

The miniature solenoid valve is an alternative to the thermorheological valve allowing for **larger pressures and flow rates**. The valve is constructed from a DIY miniature airplane motor's coil, a small Neodymium magnet, and a 3D-printed housing and flow channel. Power is only required for switching and an H-bridge circuit makes the valve double-acting with only one coil.