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Two Electromechanical Self-Assembling Systems

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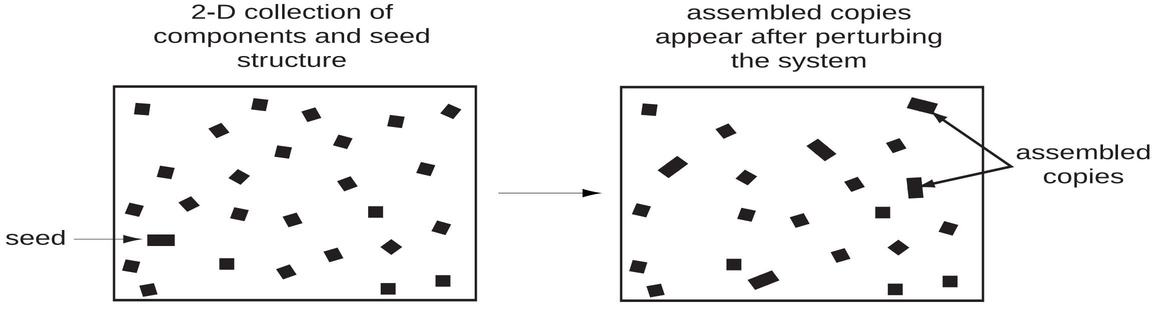
Self-assembling systems are of great interest in nanotechnology. Although the design of such systems can differ widely at nano and macro scales, certain design principles are invariant. Because of these similarities, investigating designs at multiple scales can generate insight and the cross-fertilization of ideas.

Some of the earliest mechanical models of self-assembling systems were proposed by Penrose, Jacobson, and others in the 1950s, and some of these models were successfully implemented. Here we present the designs for two simple electromechanical self-assembling systems that can be constructed out of plastic, batteries and electromagnets. Our systems are designed through analogy to chemistry: electromagnetic forces model molecular bonding and complementary physical shapes model molecular structure. Physical implementation of these models require resources beyond what was available to the authors.

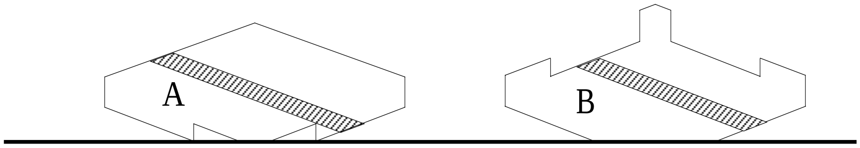
It is clear that systems able to reproduce or assemble themselves are of great interest to nanotechnologists (Merkle, 1994). However, designing an artificial self-assembling system is non-trivial. The earliest studies of self-assembling machines were inspired by the work of John von Neumann on abstract self-replicating automata. In the late 1950s, mechanical devices were designed that exhibited self-assembly from a pool of components, for example: "bricks" (Penrose and Penrose, 1957), model railroad cars (Jacobson, 1958), and floating electromagnets (Morowitz, 1959). In addition to being clever, these designs could be tested and demonstrated through physical models -- making them compelling and amenable to direct investigation.

Designing a self-assembling structure is akin to engineering an artificial catalyst, where a specific event becomes likely only in the presence of specific components. This problemappears simple but is deceptive: it is not very difficult to engineer the self-assembly process where a parent structure attracts the necessary components, assembles them, then detaches from the offspring structure. The difficulty lies in ensuring robustness. One must prevent the possibility of blocked active sites, cancerous growths, crystal-growth formations, and other deleterious side effects that may occur when components are randomlyinteracting.

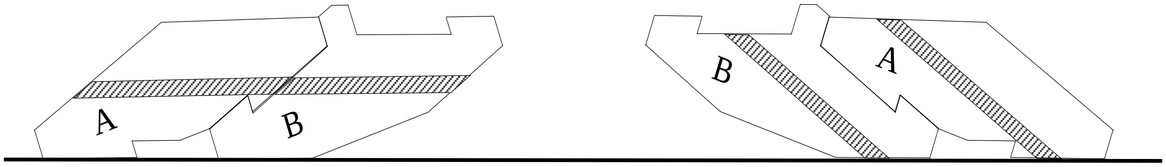
In the design of the self-assembling system presented below, we adhere to the requirements set forth by Penrose (Penrose, 1958). That is, a structure is self-assembling if it causes the formation of two or more new structures which are identical to the original "seed" structure. Furthermore, replicants must be assembled by combining simpler components present in the environment. Another way of expressing this notion is shown in the figure below. Assume we have a two-dimensional environment in which components are mobile (e.g., coins placed in between two parallel plates of glass). If we populate the environment with numerous components, add energy to it (e.g., by shaking), and wait, we expect that the initial and final configurations of the system to be similar -- randomly placed components. However, if we place a self-assembling seed structure into the initial environment, then add energy, we would expect to see multiple seed copies appear over time, with a corresponding decrease in the number of free components.



First Model of Penrose (1957)

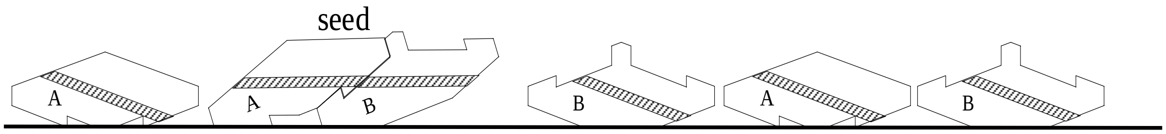


components A and B in "neutral" position

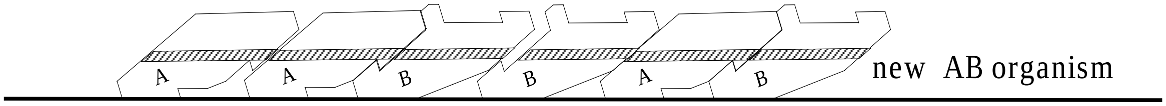


an AB organism

a BA organism

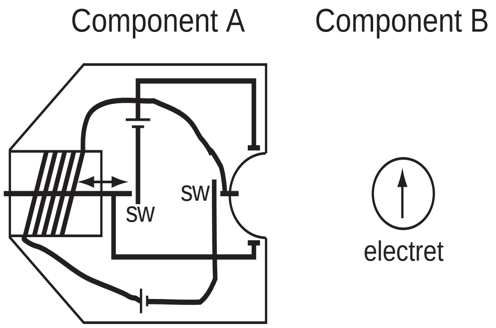


initial state



after shaking

Model of Morowitz (1959)



2 batteries
2 mechanical switches

We present two simple electromechanical models of self-assembly: the first model is a two-component structure comprised of distinct components, and the second structure is comprised of two identical components. These designs were inspired by Morowitz's model (Morowitz, 1959), with the goal of making them simpler with active components. The main difference is that there are no mechanical linkages on our components: whereas the Morowitz model relies on two sliding parts to operate two switches, our components use a static design consisting solely of circuits. Another difference is that all components of our structures are active, whereas the Morowitz model used one active and one passive component. Our components do not have explicit switches -- circuits are switched on and off via the bonds that form between components. Also, our designs require one battery rather than two.

The electromechanical models presented here represent one medium in which self-assembling machines can be studied. The future of designing such models for nanotechnology will likely benefit from work in many disciplines, ranging from biochemistry to physics to artificial life. Because designing self-assembling systems is non-trivial, automating the design process may hold great benefit (Lohn and Reggia, 1997). Furthermore, automated approaches may create self-assembling systems that embody principles human designers would never think of.

References

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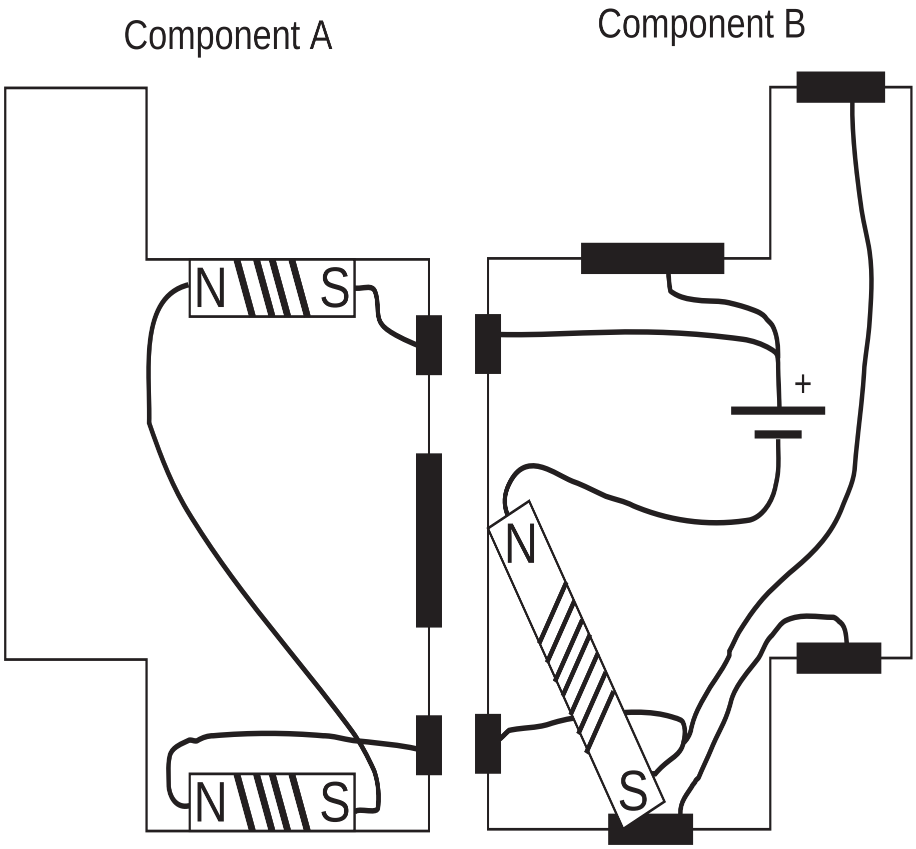
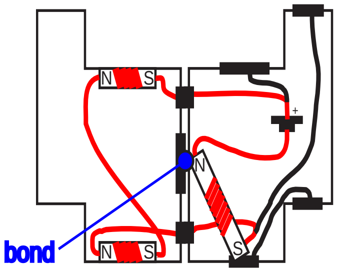
Model 1 - Two Distinct Components

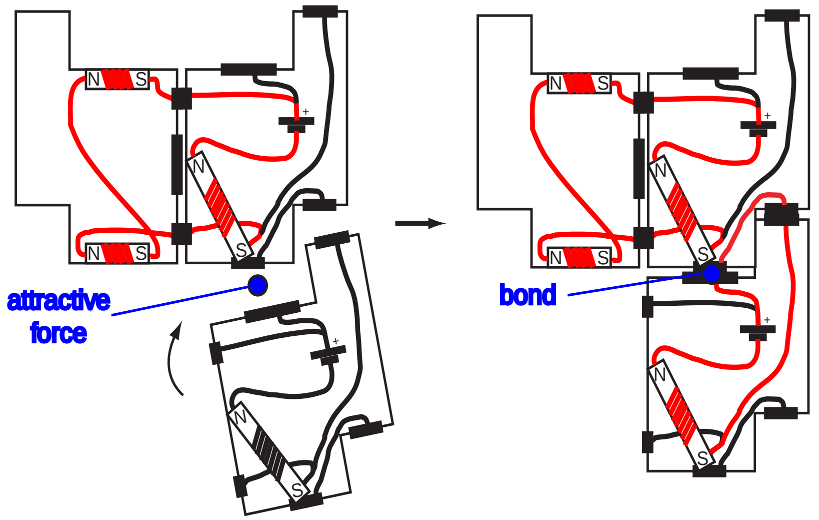


Self-Assembly Steps

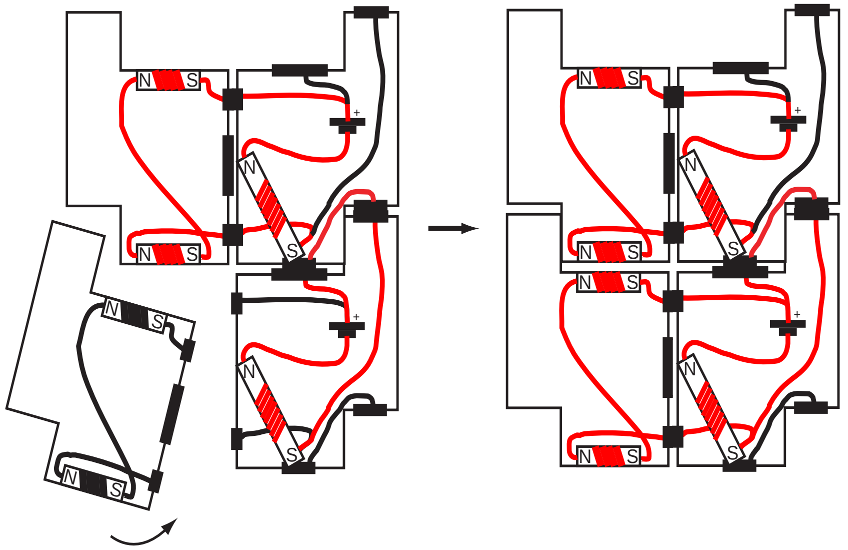
Seed forms via random collision or by artificial introduction. Circuit 1 is energized forming a **bond** between components A and B.



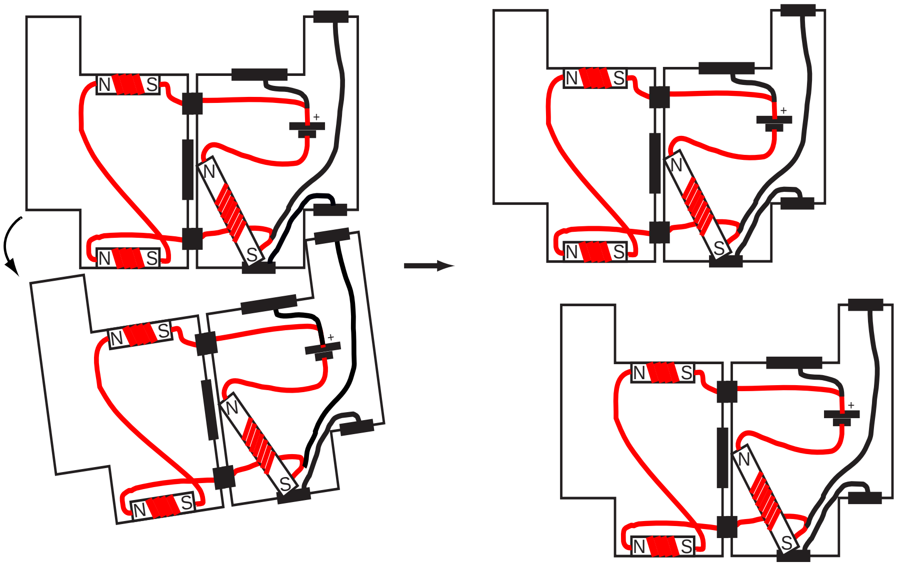
When immersed in a sea of individual components, only component B is biased towards attaching to the AB complex. An attractive force and complementary shapes encourages B to attach.



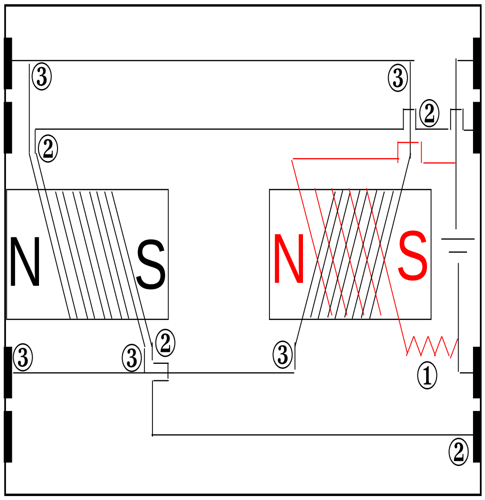
Likewise, the AB-B complex encourages component A to attach as shown



Once attached, the lower AB complex is energized, and a repellant force pushes the offspring complex away



Model 2 - Single Component

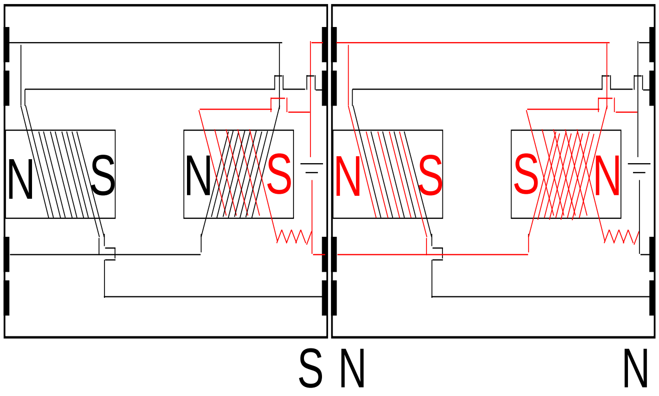


① A resistor limited current always flows through a circuit that energizes the right electromagnet and generates a relatively weak south terminal at the right side of the element. This south pole is the external pole in the single element.

② One open circuit energizes the left electomagnet and produces a northpole at the left side of the element.

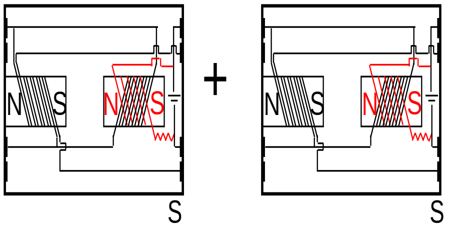
③ A second open circuit redundantly energizes the left electromagnet, strengthening the north pole at the left side of the element. The circuit also energizes the right electromagnet in an opposing winding to the #1 circuit, thus flipping the polarity of that magnet and producing a north pole at right side of the element (see the "seed" below).

Seed



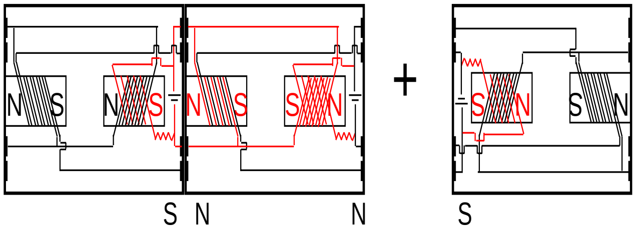
Self-Assembly Steps

The seed is formed by forcing two elments (each with only one exposed south terminal) together.



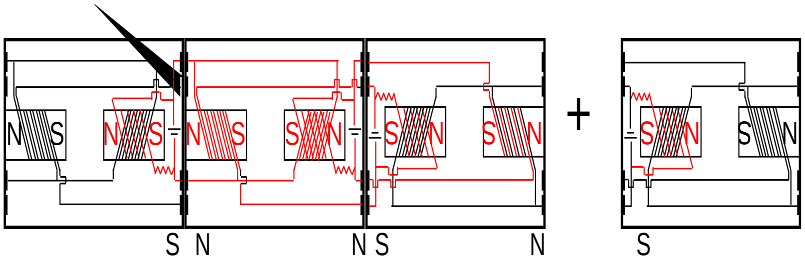
Forming the seed closes contacts that flip the polarity of the rightmost electromagnet and energizes the second electromagnet in the same (left) element, locking the two "seed" elements.

The south terminal of a single element is attracted to the newly energized north "seed" terminal



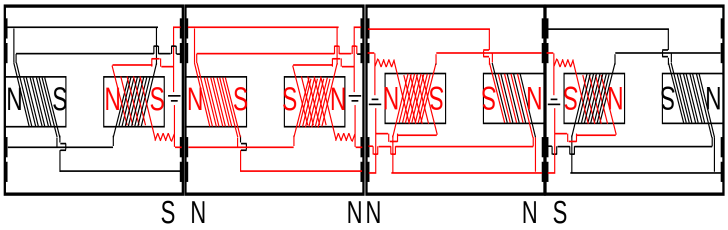
The new 3-some closes circuits that strengthen the existing charges and energize the leftmost electromagnet, exposing a north terminal.

As in the previous step, a single element is attracted to the exposed north terminal



The attachment of the 4th element closes a circuit that flips the sign of the middle-left electromagnet (parallel to the original seed formation) causing the arrangement to be unstable.

The two north terminals in the center of the 4-some repel each other.



The final result is a new 2-element seed in addition to the first 2-element seed

Over time the single elements with an exposed south terminal are transformed into 2-element "seeds" with a north terminal exposed