roBlocks: Understanding Emergent Complexity from the Bottom Up

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Many children learn particularly effectively by designing and building things. It is far easier to understand a complicated assembly if one has put it together than by trying to reverse-engineer it. With this in mind, we have seen a great variety of construction kits made available to children, providing the opportunity to build spaceships, log cabins, molecular models, cardboard polyhedra and the like. More recently, we have seen computation added to these kits, with a small computer or a link to a PC enabling children to add action and behaviors to their constructions. When we look around us, however, we see complex systems of all varieties, from biological systems to computer networks. These complex systems can be difficult to think about because they emerge from many local interactions between their component elements and have no centralized control. These systems cannot be modeled with current construction toys. roBlocks is a modular robotic construction kit that encourages children to design and build their own complex physical systems.

Figure 1: A little robot that operates based on the values of two connected sensor blocks

Significant contributions have been made in attempts to support the construction of emergent behavior on the computer screen. Early cellular automata programs such as implementations of Conway's *Game of Life* **[Gardner 1970]** became important catalysts to new ideas about how complexity can emerge in the natural environment **[Wolfram 2002]**. Even though most cellular automata programs are extremely simplified abstractions, the patterns and actions that arise from a small rule set have provoked thought experiments for many years. More recently, Resnick's group has created programs that encourage children to create their own on-screen worlds and seed them with a number of rule-following agents **[Resnick 1994] [Wilensky 2001]**. While on-screen simulations can be valuable models for thinking about the world, physically embodied construction kits present a dramatically improved educational opportunity. While screen simulations are inherently abstract, real-world models are situated in the same environment as the user, and can be physically perturbed. It isn't clear that ideas and behaviors exhibited by on-screen icons are easily mapped to the real world, but no mapping is required in an embodied kit. The discrete nature of digital representations often seems so oversimplified as to be completely unrelated to the messy, imprecise, analog world around us. The messy real world around us, in fact, is what gives rise to true complexity.

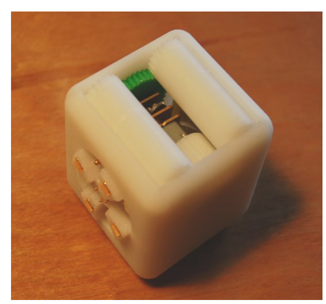

Figure 2: Motor and gear train inside of a tread block

In *Sciences of the Artificial*, Simon begins describes the complex trajectory of an ant moving around on a beach – he hypothesizes that the "apparent complexity of its behavior over time is largely a reflection of the complexity of the environment in which it finds itself **[Simon 1969]**." More recent research into embodiment draws on the phenomenological tradition to contend that intelligence is closely tied to perception with the senses **[Dourish 2004]** and even that being situated in a real environment is critical to intelligence **[Brooks 1991]**. In contrast to screen-based models of the world, roBlocks encourages children to design and build agents that operate in the real world rather than a screen based simulation. A small robot responding to environmental conditions in a child's bedroom is much more evocative than a collection of on-screen icons.

roBlocks are 40mm plastic cubes that snap together with magnetic connectors **[Schweikardt and Gross 2006]**. Children as young as nine snap together the magnetized plastic cubes and create constructions that drive around on a tabletop, reacting to light and sound. Each roBlock is different. *Sensor* blocks, including specific blocks for sensing light, sound, touch, motion and (infrared) distance, take in data from the environment and pass it on to connected blocks. Multicolored *operator* blocks apply functions to that data including sum, maximum, minimum, inverse and threshold. *Actuator* blocks translate the data passed to them into various types of action. A tread block contains a small motor and drives around on a tabletop according to its data value. Other actuator blocks have rotating faces, bright LEDs and piezoelectric speakers. The fourth block category, *utility* blocks, includes a block containing a small lithium-ion battery that must be included in each construction, a Zigbee wireless block, and passive data-connection blocks that are added so the physical form of a construction is less constrained by its programmatic layout.

In a roBlocks construction, each block possesses a single dynamic one-byte *value*, which determines how it operates. Sensor blocks calculate this value from environmental input. A light sensor block, for example, has a value of about 5 in a dark room, and a value of over 200 outside on a sunny day. A touch sensor has a resting value of zero but jumps to 255 when it detects contact. Actuator blocks, on the other, hand, actuate according to their value, which they derive from data passed to them by their neighbors. A *Rotation* block with a value of zero does not move, but the same block with a value of 127 would rotate at half speed.

roBlocks pass their values to their connected neighbors. Sensors acted as sources and actuators as sinks, and constructions formed an implicit directed graph that may have cycles. The blocks operate asynchronously, transferring data with no centralized clock. Each block's value is determined by the number of steps from each data source in a weighted average. With two sensor blocks at either end of a chain of blocks, for example, a gradient of block values is created, with blocks closer to a high sensor reading exhibiting higher values. This weighted averaging scheme allows users to create densely packed 3D data structures from a set of blocks and predict the value at any given point.

Each roBlock body is made of two identical three-face halves that screw together enclosing the electronics inside. The bodies are made on our 3D printer and are built with different colors of plastic depending on the type of block. Each face of the blocks is identical, and the hermaphroditic connectors allow each block to be connected to any other block at any of the four possible orientations. Embedded magnets on each connector provide both physical and electrical connectivity between blocks. On the back of each connector, the magnets are attached with conductive epoxy to the circuit boards shown in Figure 3. Each roBlock has identical electronics: an Atmel AVR microcontroller, programming header, H-bridge motor controller, shift register, and power circuitry.

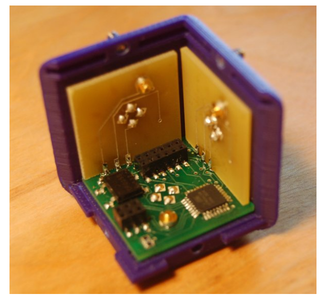

Figure 3: Inside a roBlock

The simple example robot shown in Figure 1 is built with five roBlocks: two sensor blocks (*Light* and *Knob*), a *Maximum* operator block, an LED actuator block and a power block. The network and data flow diagram of this robot is shaped like a “Y”, with the two sensor inputs merged at the operator block and the data passed to the actuator. Any two sensors could be used here – due to the *Maximum* block, the function of the actuator will correspond to the highest of the two sensor values. Since we've chosen a *Knob* as one of our sensors, its data value can be set manually by the user. With this combination, we've created a sort of *Threshold* robot, in which the value of the light sensor is taken into account only if it becomes greater than the value of the *Knob* sensor. Braitenberg **[Braitenberg 1984]** describes how a simple threshold device can be a key element in creating lifelike, emergent behaviors.

The mobile robot shown in Figure 4 is also built with only five blocks: two *Light* sensor blocks, two *Tread* actuator blocks and a power block. Each actuator is connected most directly to one of the sensors, so will respond more powerfully whenever the sensor is activated more powerfully. With two *Tread* blocks, we have created a differential drive robot that turns away from a stimulus, appearing to exhibit the intention of avoiding light. Children as young as six are able to make the transition from ascribing intent to a robot to understanding how it's instructions could exhibit an intentional-appearing behavior **[Mioduser, Levy and Talis 2002].**

Figure 4: A mobile robot that steers away from light sources

The learning potential of modular robotic toys like roBlocks is less direct and explicit than the potential afforded by technologies like robotic tutors. While students could be evaluated on their understanding of material specific to the kit's domain (robotics, in this case), this is not the main point of our work. We intend roBlocks to be an epistemological tool – an artifact which helps young users examine the ways in which they think about the world. We identify four preliminary themes that are components of emergent complexity and can be examined through the analysis of user activities.

1. Recognition of the appearance of intentional behavior arising from non-intentional elements.
2. Understanding parallel systems.
3. The ability to switch levels of abstraction when thinking about a complex problem.
4. Using modularity and hierarchy to break down complex problems.

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Submission Note:

We would prefer to be included in the poster/demonstration session. We will bring a set of roBlocks to the RSS workshop -- assembling them in person provides users with an enhanced idea of their affordances in comparison with a lecture presentation.