Arduino at Work: the *Hylozoic Soil* control system

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1 **Two views** of *Hylozoic Soil*, installed at the Montreal Museum of Fine Art, 2007

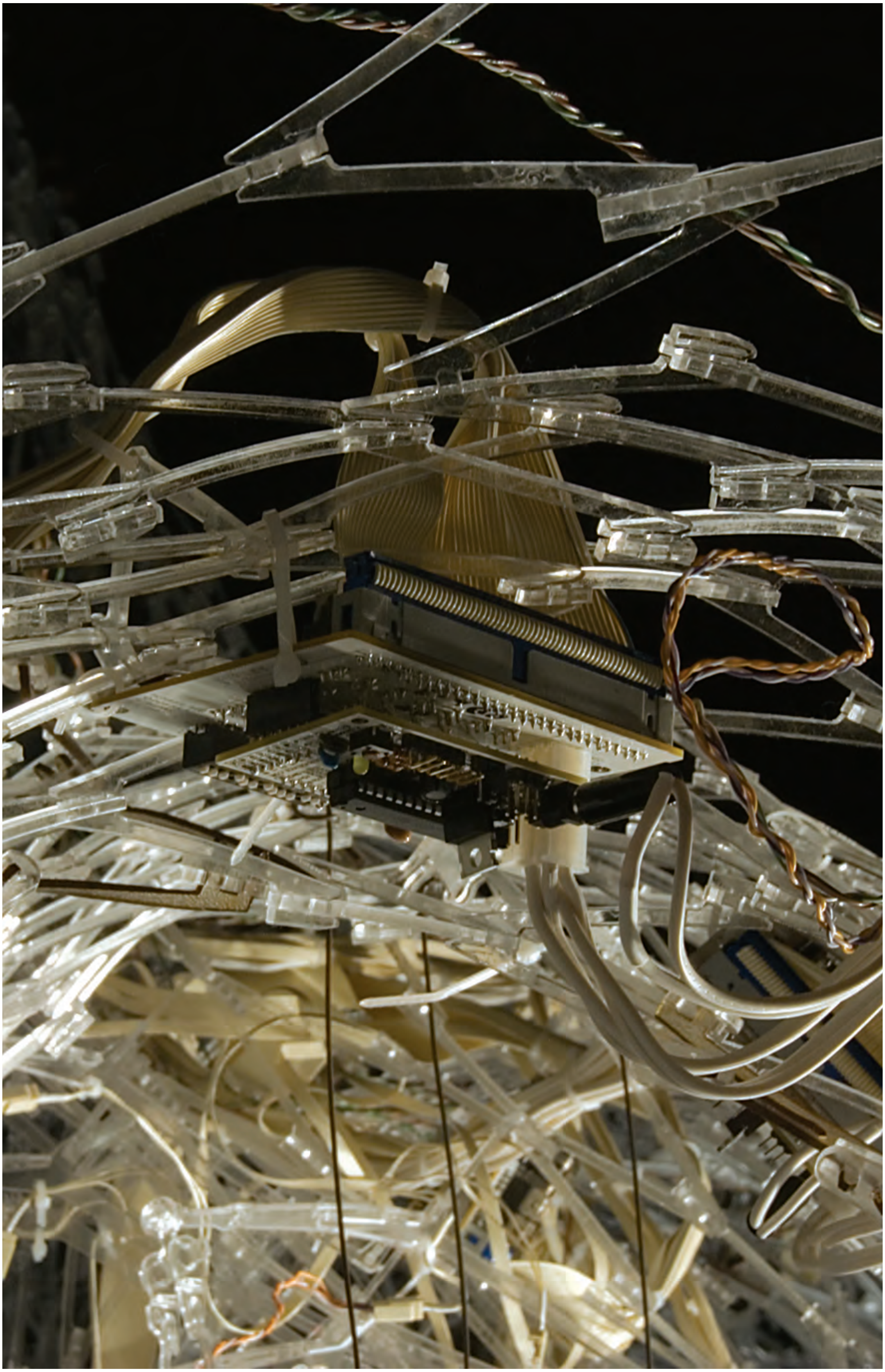
Arduino is an open-source physical computing platform that was created to make tools for software-controlled interactivity accessible to non-specialists. The Arduino microcontroller board can read sensors, make simple decisions, and control devices. This palm-sized computing platform is the product of an open-source community project that began with a small group of hardware developers giving workshops and that now numbers many tens of thousands of international users that co-operate in developing specialized applications.

Hylozoic Soil, an interactive environment exhibited in 2007 at the Montreal Museum of Fine Arts, is an example of Arduino at work. The distributed nature of *Hylozoic Soil* and the group behaviour which emerges is strongly related to the open-source Arduino project. Occupants move within the *Hylozoic Soil* structure as they would through a dense thicket within a forest. Microprocessor-controlled sensors embedded within the environment signal the presence of occupants, and motion ripples through the system in response. Dozens of microprocessors, each controlling a series of sensors and actuators, create emergent reactions akin to the composite motion of a crowd. Visitors move freely amidst hundreds of kinetic devices within this environment, tracked by many dozens of sensors organized in 'neighbourhoods' that exchange signals in chains of reflexive responses. The installation is designed as a flexible, accretive kit of interlinking parts organized by basic geometries and connection systems. Variations are created by numerous individuals assembling the work. The result is a turbulent chorus of motion.

The first developers of Arduino—Massimo Banzi, David Cuartielles, Tom Igoe, Gianluca Martino, David Mellis, and Nicholas Zambetti—ran workshops that demonstrated assembly of the devices and gave copies of the board away to stimulate development. A community of developers and users now provides co-operative support, and the programming environment and documentation is written with the neophyte in mind. The Arduino community has to date created myriad documents describing how to extend and interface Arduino with different systems, including

- MaxStream's inexpensive and compact XBee RF wireless transceivers

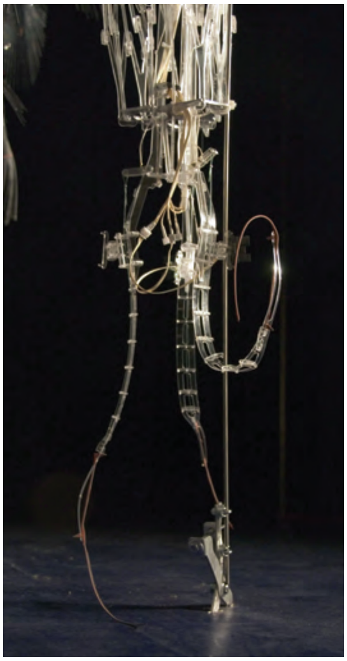
facing page
2 **Close-up view** of the Printed Circuit Boards used in *Hylozoic Soil*. The Bare-Bones *Arduino* board is mounted to a custom 'daughter' board.



- Bluetooth-enabled mobile phones, with the Arduino BT extended board
- LCD displays
- Cycling 74's Max/MSP/Jitter graphical scripting environment

The following description focuses on the control system that was developed for active functions within the *Hylozoic Soil* project. The micro-controller used in our Arduino platform is an Atmel ATmega168, a tiny computer-on-a-chip that contains specialized hardware to process digital signals, read analog inputs, and communicate over a serial connection. User-designed software is created in a high-level language and programmed into the microcontroller by connecting the Arduino board to a computer's USB port.

The version of the Arduino hardware used for *Hylozoic Soil* is the Bare-Bones Board, Revision C, developed by Paul Badger (www.moderndevice.com). This inexpensive implementation of the platform has a small forty by sixty millimeter footprint, and is provided fully assembled or in kit form. It includes power regulation, timing, and external components for digital inputs and outputs that can control a range of interactive devices. A custom 'daughter board' (or 'shield') was developed to provide three key additional elements to extend the function of the main board: a high-current output stage, configuration switches, and a communication interface. Twelve high-current output channels permit digital control of devices at currents of up to one amp per circuit at voltages up to fifty volts. Twelve switches are read by the software during initialization of the boards and can be used for functions such as configuring individual board addresses and specifying software modes to control individual board behavior. The communication interface converts serial communication signals from the Arduino and supports distribution at high speed to a network of boards using the RS485 standard. The daughter board also provides a sixty-pin ribbon cable interface for connecting actuators and sensing devices, and a two-channel power connector to distribute high currents to actuators as well as a lower current 'electronics' supply.



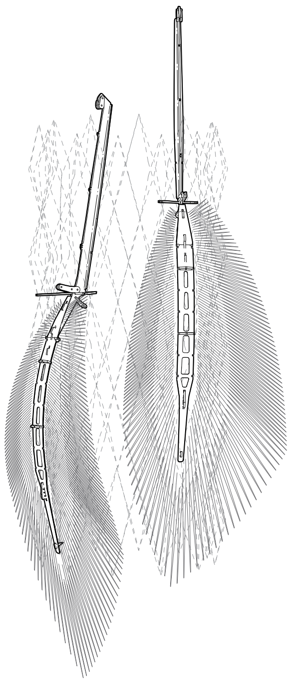
3 **'Kissing' pore** in detail installation view showing actuators driven by muscle wire

The *Hylozoic Soil* sculpture includes three kinds of actuator elements: 'breathing' and 'kissing' pore mechanisms actuated by shape-memory alloy 'muscle' wires; 'whisker' elements driven by small direct-current motors; and miniature LED lights. The structural core of *Hylozoic Soil* is a flexible meshwork assembled from small acrylic chevron-shaped tiles that clip together in tetrahedral forms. These units are arrayed into a resilient, self-bracing diagonally organized space-truss. Curving and expanding this trusswork creates a flexible grid-shell topology. Columnar elements extend out from this membrane, reaching upward and downward to create tapering suspension and mounting points. Fitted into this flexible structure are hundreds of small mechanisms that function in ways akin to pores and hair follicles in the skin of an organism.

facing page
4 **An upward view** of the *Hylozoic Soil* canopy mesh showing a partial network of interconnected microprocessors

'Breathing' pores are composed of thin sheets shaped into outward-branching serrated membranes, each containing flexible acrylic tongue stiffeners fitted with monofilament tendons. The tendons pull along the surface

of each tongue, producing upward curling motions that sweep through the surrounding air. 'Kissing' pores are a cousin of this mechanism. These use a similar mechanical structure fitted with a fleshy latex membrane and offer cupping, pulling motions. A 'swallowing' pore occurs in a triangular layout that creates a dense series of openings running throughout the meshwork. These openings contain pivoting arms in triangular arrays that push out radially against the surrounding mesh, producing expanding and contracting movements. LED lights are fitted within the lower surfaces of these elements, configured to pulse in synchronization with swallowing motions. 'Whisker' wound-wire pendants are arranged in dense colonies within this environment, supported by acrylic outriggers with rotating bearings and driven by small DC motors. Tensile mounts for the whiskers encourage cascades of rippling, spinning motion that amplify swelling waves of motion within the mesh structure.



5 **3-D model** of the 'breathing' pores

Each device is designed to operate at five volts and is interchangeable in the control harness, allowing flexibility in the spatial distribution throughout the meshwork. Under software control, the output drive channels switch current from the high-current five-volt supply to each of the individual actuator elements using a transistor switch. The SMA-actuated pores are driven by ten-inch lengths of 300-micron-diameter Flexinol wire (www.dynalloy.com) that contract when an electrical current runs through them. Mechanical leverage amplifies the half-inch contraction that occurs in each wire and translates this into a curling motion. Whisker elements are composed of flexible wound wire strings extending from the shaft of a small three-pole motor. Yellow LED lights are combined with 150-ohm current-limiting resistors to form a visual actuator configured for the five-volt power supply.

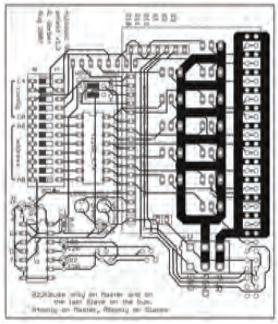
Each daughter board accommodates up to three analog sensors.[1] Sharp infrared proximity sensors with varying detection ranges provide feedback that allows the sculpture to respond to occupant motion. Powered by the five-volt electronics supply, the sensors emit an infrared signal and receive reflected signals from nearby objects, registering the distance of the reflecting surface and feeding that information back to an input on the Arduino board.

The daughter board also contains a communication layer which translates the raw serial data from the Arduino to the RS485 communication standard, and contains jacks to connect the boards to a 'full-duplex, differential multi-drop' bus. RS485 being a differential standard, information is transferred on pairs of wires that carry differing voltages. Bit values are detected by measuring the difference in voltage on the paired wires. This scheme, along with the use of twisted-pair cabling, makes the system less prone to noise-induced communication errors. A full-duplex implementation uses two pairs of wires: one pair for incoming information and the other for outgoing data, allowing for simultaneous communication in both directions along the bus. Each board constitutes one 'drop' of the multi-drop system, and communicates with the others via a single board which assumes the role of 'bus controller'. The Maxim MAX3466 transceiver chip used in the daughter board allows up to 128 such boards to communicate. Since

1 **The Arduino** can accommodate more, up to eight depending on the version, but the *Hylozoic Soil* system sacrifices some in favour of additional digital outputs for device control.

there is the potential for multiple devices to 'drive' the shared bus lines, bus conflicts can occur which result in garbled information at best, and can pose a serious threat to the hardware. The MAX3466 chip includes a pin which allows the microcontroller to effectively 'turn off' the driver circuitry, and this pin is controlled by one of the Arduino's digital outputs.

In addition to the bus transceivers, the daughter board also contains additional hardware which permits simultaneous batch programming of all the devices connected to the bus. Normally, a device is programmed by connecting it to a computer's USB port, then resetting it before running a software tool on the computer to download code to the Arduino. When the Arduino is reset, special code called a 'bootloader' executes for a few seconds, listening for incoming information on the serial port. By setting a switch on the bus controller board to program mode, any board connected to the bus will see messages sent by the computer to the bus controller. If they are all reset just prior to downloading new code from the computer, the bus controller will act as a proxy for all of them in the exchange of information required to download the program, and every board will receive the new code. The bus controller switch is then reset to normal mode and it resumes control of the bus.



6 **A schematic** of the custom 'daughter' board designed for *Hylozoic Soil*

The Arduino system combined with the bus architecture described above provides an inexpensive environment for experimentation with distributed intelligence and emergent behaviour in a physical environment. For example, each local board in *Hylozoic Soil* has several layers of response to a presence within the mesh. As a local reflexive response, any board which registers a change in its sensor status immediately activates a reflex device, reinforcing the connection between the actions of the visitor and the sculpture. Reflex responses are followed up by slightly delayed and more orchestrated chains of local reactions, all by devices connected to the triggered board. Additionally, the board informs the rest of the mesh, via the bus controller, that it has detected a visitor. Boards are programmed in software to respond to messages from their spatial neighbours, setting up larger but more muted chains of reaction. A third layer of behavioural control is orchestrated by the bus controller: Since it relays all messages it is aware of the general level of activity within the mesh. It can therefore exercise some control over system-wide behaviour by asking the mesh to set up a general low-level behaviour if things are too quiet, or conversely to quiet down if activity is excessive.

Hylozoic Soil is a project within a body of work that has been gradually moving from individual figures composed of complex hybrid organisms towards immersive architectural environments that behave like highly mobile crowds of interlinked individuals acting in chorus. Recent generations of this work have employed active sensing and actuator mechanisms in pursuit of reflexive, kinetic architectural environments. *Hylozoic Soil* builds upon previous generations by developing a decentralized structure where much of the system is distributed and extensible, based on localized intelligence. The distributed nature of *Hylozoic Soil* and the group behaviour which emerges has much common ground with the Arduino project.

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