A Scalable Platform for Intrinsic Hardware and *in materio* Evolution

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Abstract

An evolvable motherboard is an intrinsic evolution platform that allows the detailed probing of internal signals of circuits that have been evolved. Several designs for an evolvable motherboard have already been demonstrated to work sucessfully as a platform for the evolution of electronic circuits. This paper proposes a new platform that is suitable for intrinsic evolution using a wider variety of media. The platform presents a more modular design, making it suitable for use in evolving more complex physcial primitives whilst affording the possiblity of performing evolution in parallel for simpler problems. The construction of the device is discussed and examples of potential experiments in silicon, liquid crystal and other media are described.

1 Introduction

Natural evolution has created and utilised an extremely sophisticated technology, that of protein chemistry. Recently researchers have become able to implement a process of artificial evolution to build electronic circuits using such devices as Field Programmable Gate Arrays (FPGAs) [6][7], Field Programmable Transistor Arrays (FPTAs) [5] and Field Programmable Analog Arrays (FPAAs) [2], this is known as intrinsic evolution. However, it is not clear that intrinsic evolution is most suited to the medium of conventional circuit design. Much research in the field of Evolvable Hardware has been dominated by a transistor-centred view of hardware. However we should guard against the temptations of such a world when we are using bio-inspired algorithms to design things. Evolutionary algorithms are abstract formalisations of natural processes. In a sense they have been removed from their natural context and transplanted into the artificial world of the computer. Transistors were developed to help realise a top-down view of system design where components are stable, predictable, with almost mathematical properties. Natural evolution works with messy, unstable, complex, chemical systems. We have already argued that such systems with their rich array of embedded and exploitable physics are pre-eminently suitable for natural evolution [4]. We argue here that artificial evolution of hardware might work much better if we can create ways of exploiting the rich resident physics of materials or complex systems. To some extent researchers in Evolvable Hardware are in a uniquely favourable position to do this. This is because we are already applying artificial evolution to exploit real physical systems.

Thompson carried out experiments in silicon on an FPGA [6][7] and found that unconstrained intrinsic evolution appeared to be able to utilize the basic physics of the silicon substrate. However, FPGAs are designed to implement digital circuits. It is not at all clear that such a physical environment is best suited to artificial intrinsic evolution. To some extent FPGAs were used simply because they allowed unconstrained intrinsic evolution not because they are particularly suited to it. This suggest that it would be very fruitful to search for other platforms to conduct artificial evolution. One obvious suggestion is to try to *enrich* the physics in the silicon. This might be accomplished by a sufficient level of ionising radiation. Silicon devices are built to human design with extremely stringent doping requirements. In this paper we discuss the design of an intrinsic evolution platform that should allow us to explore what we feel to be an important question:

What kinds of physical systems are most easily exploited by an artificial intrinsic evolutionary process?

It may be possible for artificial evolution to construct complex information processing systems using components that are not thought of as being capable of such. Such systems may have many advantageous properties over conventional technology. We refer to this kind of intrinsic evolution as *in materio*. The intrinsic evolutionary platform needs to be generic, scalable, flexible and have minimal interference in the internal workings of the evolved system. This paper presents a possible way of working with these systems using a new version of an existing platform. In section 2 a brief overview of the previous platforms on which this new work is based is given. Sections 3, 4 and 5 give technical details of the system and its related components. The types of experiments to be attempted are described in section 6.

2 The Evolvable Motherboard

The evolvable motherboard (EM), developed by Paul Layzell, is a research tool for performing intrinsic hardware evolution [3].There have been two previous designs for the motherboard, this new design is an adaptation of previous designs and is more suitable for the types of experiments we expect to perform.

The evolvable motherboard is a large switch matrix that can be programmed from a PC. External components can be connected to the output nodes and the wiring between them can be modified by closing switches in the cross point array.

These boards are convenient to work with as they allow for ease of access when trying to probe a circuit. The evolved designs can also be transfered to a simulator as the internal architecture is know.

Previous work with EM has been limited to evovling electronic circuits. This paper demonstrates the board may not be limited to circuits but to many types of electronically configurable media.

2.1 Paul Layzell's Evolvable Motherboard [3]

This design uses a triangular matrix of twelve cross switch arrays. Each device contains 8 by 16 switches. The triangular architecture allows for any external node to be connected to any other external node.

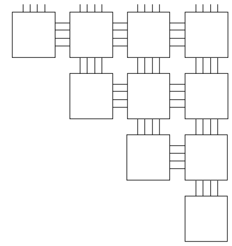

Figure 1- Triangular Switch Matrix

This motherboard has been used to successfully evolve amplifiers, inverters and oscillators. Each of these circuits was then investigated fully.

2.2 Jamie Crook's Evolvable Motherboard [1]

The key difference in this design is the rectangular architecture. The decision to restrict the search space in this way comes from analysis of the types of circuit that were intended to be worked with. The design of the board is simple, with four cross switch arrays. The boards include a PIC microcontroller for assistance in programming the arrays and a signal generator. The behaviour of the signal generator can also be modified to provide various basic shapes of wave.

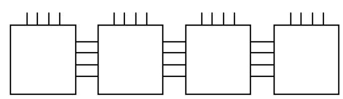

Figure 2 - Rectangular Switch Matrix

3 A More Modular Design

Rather than using a single board, our design separates each switch matrix onto its own standalone board. The boards then stack together to form a complete motherboard. The design allows for each stack in the motherboard to consist of between 1 and 16 boards. Stacks can also be linked together, with no limit on the number of stacks.

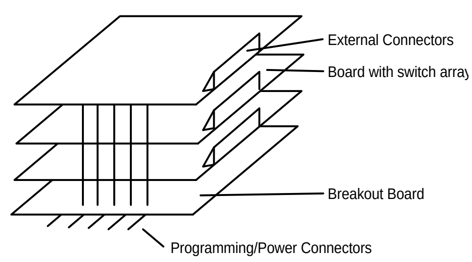

Figure 3 - Evolvable Motherboard Stack

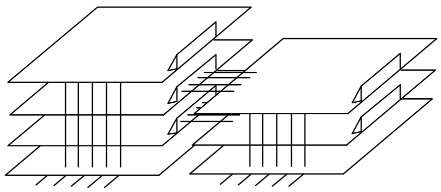

Figure 4 - Two EM stacks, forming a partial triangular switch matrix

This design has a number of advantages over previous designs. Each board is cheap to produce, with a small physical size and few components. The PCB routing has been simplified using this approach. If other designs were extended in a similar way, they would also need to use additional boards Experiments can use up to 16 boards. You could use it to evolve on large system, evaluating multiple individuals simultaneously for checking performance for robustness. The ability to test the fitness of several individuals simultaneously will be of benefit for the types of experiments that we intend to perform. The same design will be tested on variatons of the same device - either to improve robustness, or to intentionally drive evolution toward using the differences in physical properties of external components. An evolvatron (described in section 5) configured similar to the one descibed is able to perform all the measurments needed for fitness evaluation simultaneously.

The board is easy to tap into, which is useful for debugging purposes, as well as providing the ability to insert extra circuitry into the EM without any redesign.

Each of the boards connects to a bus. The bus contains the ‘horizontal’ connections between the matrix switches, power, address, programming lines and several currently redundant lines.

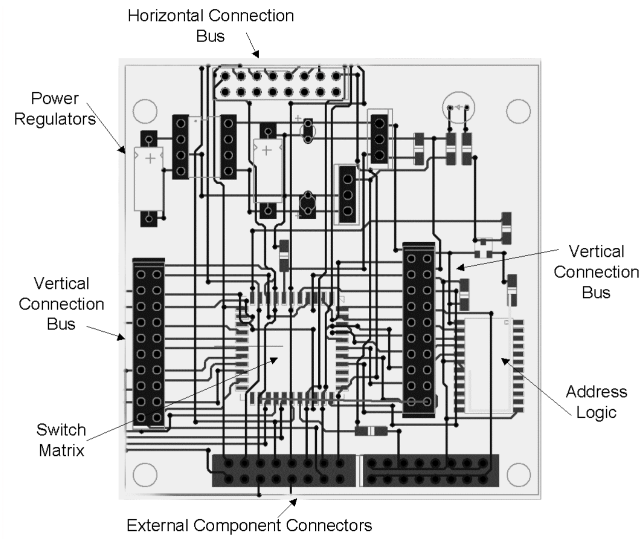

Figure 5 - Schematic of Evolvable Motherboard

The boards can be used in either a rectangular , triangular or any other shape that is suitable. In order to conserve space, examples in this paper will be shown with a rectangular architecture.

A breakout board is used to link the motherboard to the host computer and power supplies. These boards can be inserted anywhere on the bus, and multiple boards can be used to help with debugging. The breakout board also has LEDs to provide visual feedback.

3.1 The Switch Matrix

The connection matrix is made from Mitel/Zarlink Semiconductors MT8816 crosspoint switches[8]. The device contains a 8 x 16 array of crosspoint switches, and contains the necessary decoder and latch circuits.

A cross point switch is a programable switch that connects two wires (a horizontal and a vertical line) together.

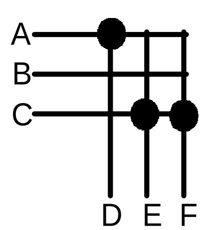

Figure 6 - Example Cross Switch Array

For example, this diagram shows a section (3 x 3) of a crosspoint array, the black dots represent a closed junction. In this instance, A is connected to D, and F is connected to both E and C. In the evolvable motherboards, DEF either connect to a vertical bus or to external components. ABC connect to a horizontal bus.

These arrays are intended for use in video and audio routing, and are therefore suitable for use in high frequency analog circuits.

The device is readily available in low quantities [9] and low cost.

3.2 Power

Each board in the stack contains its own power regulators and inverters used to provide power and reference voltages. Although this adds to the cost, it also helps ensure the modularity of the system.

Keeping the power supplies as separate as possible may also help remove undesired interactions between the boards.

3.3 Addressing

The boards in the EM stack are individually addressable with a 4 bit address, accommodating up to 16 boards in a complete motherboard. Everyboard has its own address decoder with a hard wired address. Depending on the number of boards used, stacks may need to use independent address busses.

3.4 Expansion

The design allows for intermediate boards to be inserted anywhere in the stack. A four wire redundant bus runs through the stack, which could be used to provide more expansion capabilities. It would be possible for example, to build a breakout board that does not pass through the address lines, and to split the stack into two pieces. Each section could then be addressed separately, increasing the size of the motherboard.

3.5 Physical Construction

Each board is a double sided PCB measuring 65mm by 65mm. Long pin dual inline connectors are used to join the boards together. The breakout board is of the same dimensions as the other boards, and other than indicator LEDs is passive.

4 Software

The host PC is responsible for configuring the devices as well as running the evolutionary algorithm and the test and measurement processes.

The crosspoint switches are programmed by addressing a board, resetting the device and then selecting the switches to be enabled. This is done by addressing the switch and raising the data line on the device.

Software is also responsible for ensuring that the circuit is valid before downloading it to the motherboard. Certain switch configurations would cause the power supply connections to be short circuited

5 The Evolvatron

The Evolvatron[6] consists of a host PC containing cards suitable for test and measurement. Each PC is capable of 16 channels of analogue output , 16 channels of analogue input, 2 channels of high speed analog input and 64 channels of isolated digital I/O.

In the current configuration, the evolvable motherboard stack is configured using the digital I/O interface, it is expected that future variants of this EM will be programmed directly from the ISA bus of the PC.

The computers used are industrial specification, which despite the increase in cost have advantages over typical office PCs. They have a high degree of shielding, which helps ensure that sampling and waveform generation is less likely to suffer from noise issues. The IPC platform also has a large number of PCI and ISA expansion slots available, 16 in total, and provides the potential for greater expansion than a standard office PC.

In our configurations evolvatrons are linked using a gigabit ethernet. Experiments can be performed in parallel using the machines separately, or other machines can be used to provide meaurement or signal generation facilities, and be controlled in real time from a central PC.

6 Planned Experiments

The majority of the planned research using this platform will be looking at how to exploit physical characterstics of certain materials using evolution. In this respect, when coupled with a suitable medium this evolved motherboard becomes a Field Programmable Matter Array[4]. In the next sections we discuss the experiments that will be performed.

Electronic Components

The first experiments will attempt to replicate previous work [1][2][6] in order to validate the new set up. We will attempt to evolve resistor networks, amplifiers, inverters, oscillators and tone discriminators.

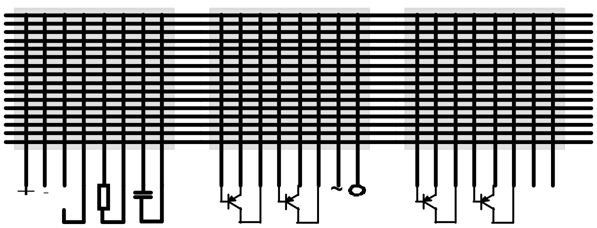

Figure 7 - Electronic Components connected to an EM

Electronic components are connected to the motherboard as shown in the diagram (fig. 7). The cross switches then define the wiring between the components.

An incident signal can be injected into any of the external connections and an osciloscope attached to another point. The evolutionary search will be responsible for linking the signal and measurement probe to the appropriate part of the circuit, so this does not need to be specified.

The next logical step is to try to enrich the physics of the components used, and see if evolution can exploit this to gain some advantage. One method may be to irradiate the electronic components connected to the EM. Ionising radiation will upset the silicon doping in an existing transistor device. Submitting transistors or even FPGAs to known amounts of radiation damage and then evolving them to perform some useful computation may reveal a correlation between damage and evolvability. By comparing the behaviour of a circuit made from regular components and one from 'enriched' components, it will be possibly to alter the fitness evaluation to move the search towards a more exploitative solution. Using a fixed genetic representation we will compare the number of generations required to construct simple circuits for components with known amounts of damage. A number of runs will be performed in each component/damage configuration to eliminate ambient and environmental variations. We expect an intermediate level of damage to confer advantages for intrinsic evolution.

6.1 Liquid Crystal

A Liquid Crystal Display (LCD has a number of virtues that make it an obvious candidate for intrinsic evolution. It is already widely available in a form that they can be addressed by digital voltages. In its simplest form an LCD is a sandwich of crossed polarising filters, transparent electrodes and liquid crystal. The glass immediately surrounding the liquid crystal is scratched in a regular fashion. The liquid crystal molecules align themselves with local surface of the glass. Essentially the application of a local electric field causes the liquid crystal molecules to untwist. This means that the incident light will be blocked by the crossed polaroid filters and hence a dark spot will be visible at the electrode position. An evolutionary algorithm could be used with the LCD to evolve local molecular twists so that one local group of liquid crystal molecules caused a change in the behaviour of another. Liquid crystals now come in an amazing number of forms. It seems likely that at least one form will have exploitable properties. The semi-liquid nature of liquid crystal is a very attractive feature as it implies that the material is semi-ordered and can relax back to its quiescent state. This is an important requirement of all artificially evolvable systems [4].

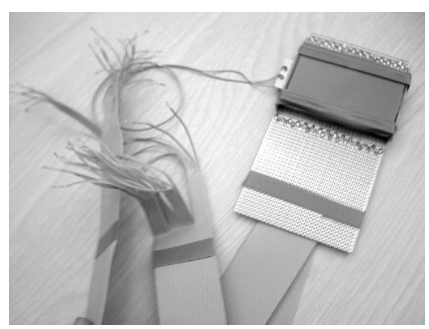

Figure 8 - Prototype LCD programmable matter array

Experiments have already been conducted that show that liquid crystal may be a suitable medium in which to evolve some form of electronic circuit. A signal generator and an oscilloscope were attached to two different connections on the LCD. Applying voltages to other connections on the LCD caused the wave amplitude and shape to be modified. Again, evolution will need to work out how to route the signal and measurement to the appropriate points.

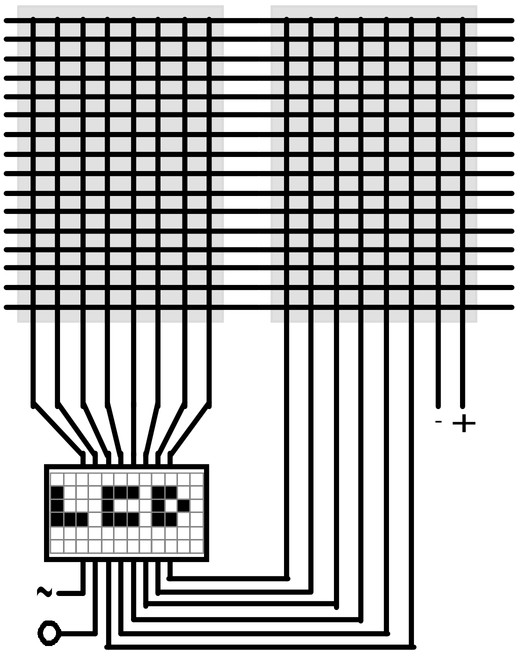

Figure 9 - LCD connected to an EM

An LCD can be connected to the EM's external connections as shown below. The LCD that has been experimented with has several hundred connections, so only a selection will be able to be connected to the EM. In the experiment described above multiple connections were joined together, it would be possible to use the EM to access every single connection. However this would take a large number of boards and stacks in order to get fully connectivity.

6.2 Field Programmable Matter Array

In its broadest sense, the Field Programmable Matter Array (FPMA) is a physical device whose configuration is determined by discrete set of signals (voltages, fields). The idea is that a computer can supply the configuration data (which may be transformed into another physical data format). A candidate medium for evolution are devices containing electronically controlled conducting organic polymers. Several such polymers have been identified as potential candidates, and designs for suitable packaging and interfaces are being designed.

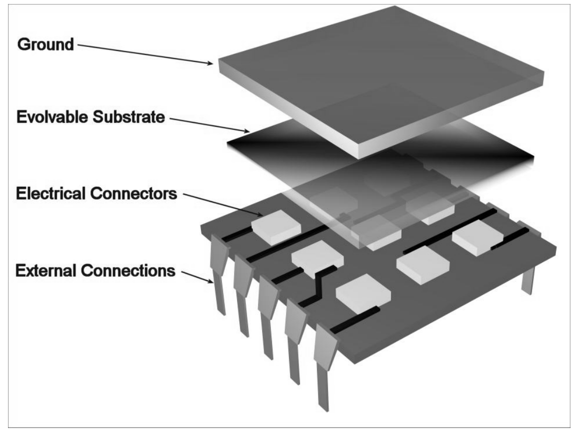

Figure 10 - The diagram shows a conceptual view of the FPMA device

Such a device would be linked to the evolvable motherboard in a similar way to the LCD display. The evolutionary process would also be very similar. We also intend to examine the field effects in Langmuir-Blodgett films and electrochromic layers (where reversible chemical changes can be induced) [4].

Conclusions

We have discussed the idea that systems are more intrinsically evolvable when there is a rich embedded physics in the computational substrate. We have described a scalable and flexible design for evolvable motherboard that should allow us to investigate this. Components can be removed and replaced with completely different devices without the need to modification to the system. We have outlined the way the evolvable motherboard will be used in a number of experiments involving the evolution of circuits in physical media. Using this apparatus we hope to show that intrinsic evolution can utilize novel physical effects to construct new kinds of useful computational devices.

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