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Design of Self Repairing Digital System Inspired by Endocrine Cellular Communication

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Abstract: In this study, researchers proposed a system inspired by endocrine cellular communication which simplifies the rerouting process in two ways by lowering the hardware overhead along with the increasing size of the circuit and by reducing the hardware unutilized for fault recovery while maintaining good fault coverage. The proposed system is composed of a structural layer and a gene control layer. The structural layer consists of novel modules and their interconnections.

Key words: Spare (stem) cell, Differentiation Unit (DU), Index Changing Unit (ICU), MUXTREE cell, self healing digital system, embryonic

INTRODUCTION

Reliability has always been an issue with electronic systems ever since the first electronic systems were designed. Different from biological systems, electronic systems are so fragile that even a single problem can render the entire system useless. Therefore, devising fault tolerant systems that can deal with such delicate problems has been a considerable challenge. During the early stages of the development of fault tolerant systems, Dual Modular Redundancy (DMR) and Triple Modular Redundancy (TMR) Methods were introduced. These techniques ran the same modules in parallel and thus a faulty module could be distinguished by comparing outputs of the same modules and voting for the majority one (with TMR) or by using an additional device (with DMR).

However, these methods have several problems. The size of the module is so huge that a large part of the circuit must be replaced even if a small part in the module is malfunctioning. Furthermore, redundancy has to be running all the time and it can only cover the fault once. In the last 10 years, these conventional methods have proven to be rather inefficient and scientists have consequently turned to biology to find inspiration for a more suitable self-repairing circuit that can resolve the mentioned problems and faults with fault tolerant systems.

Literature survey and problem formulation

A new methodology for designing field programmable gate arrays with self-repair and self-replicating properties: Embryonic is discussed by Mange *et al.* (1998). But this process is remarkable for its complexity and its precision and also faults are rare and in the majority of cases, successfully detected only.

Fault tolerance using dynamic reconfiguration on the poetic tissue is proposed by Barker *et al.* (2007). Fault tolerance is a crucial operational aspect of biological systems and the self-repair capabilities of complex organisms far exceeds that of even the most advanced electronic devices. Both fault tolerant components and redundant components tend to increase cost. This can be a purely economic cost or can include other measures such as weight. Manned spaceships, for example have so many redundant and fault tolerant components that their weight is increased dramatically over unmanned systems which don’t require the same level of safety.

Robust configurable system design with built in self healing explained by Gericota *et al.* (2007). The new generations of SRAM-based FPGA (Field Programmable Gate Array) devices, built on nanometer technology are the preferred choice for the implementation of reconfigurable computing platforms. However, their vulnerability to hard and soft errors is a major weakness to robust system given by Mitra *et al.* (2005) design based on FPGAs. It maximize robustness-improve the intended function of the product by developing and increasing insensitivity to noise factors which tend to degrade performance and develop or change product formulas and process settings to achieve desired performance at the more cost.

On-line self-healing of circuits implemented on reconfigurable FPGAs proposed by Gokhale *et al.* (2004). To boost logic density and reduce per unit power consumption SRAM-based FPGAs manufacturers

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adopted nanometric technologies. Despite soft errors do not physically damage chips, values stored in memory cells may be modified, causing incorrect data to be transmitted or an improper instruction to be retrieved by a processor. After large periods of operation, defects related to small manufacturing imperfections, not detected by production tests, may become exposed due to for example, electromigration phenomena, emerging as permanent faults.

Dependable adaptive computing systems the stanford CRC roar project presented by Mitra *et al*. (1998). It describe architectures and concurrent error detection, fault-location and recovery techniques for designing reconfigurable systems with high availability, data integrity and protection from temporary, permanent and common-mode failures. These systems can also be used for unmanned remote applications. Disadvantage is temporary failures can be caused due to intermittent or transient failures. For temporary failures in the configuration bits of a reconfigurable system, a reload of the contents from a safe storage is sufficient.

The online partial reconfiguration feature of FPGAs can be used to read back and modify the data in configuration memory cells of FPGAs without stopping the system operation. Design of basic cell to construct embryonic arrays is proposed by Ortega-Sanchez and Tyrrell (1998). Embryonic systems are cellular arrays with reconfiguration characteristics similar to those found in biological cellular organisms is explained by Ortega and Tyrrell (1997). Implementation in silicon is not economic and the changes in function of the logic block affect the function of other blocks.

An endocrinologic inspired hardware implementation of a multicellular system explained by Greensted and Tyrrell (2004). Within higher animals there operates an inter-cell communication system that is responsible for regulating the physiological balance of its host. The Inter-Node Communication System of the architecture is based on endocrinology discussed by Brook and Marshall (2001), a set of hormone mediated biological processes that allows cells to communicate. It is this communication system that allows faults within cells to be masked, system layout to be reconfigured and failed cells to be physically removed and replaced online. But it has no automatic rerouting and cell replacement highly complex.

Architecture for self healing digital systems is explained by Lala and Kumar (2003). The use of very deep submicron technology makes VLSI-Based Digital Systems more susceptible to transient or soft errors and thus compromises their reliability. This study proposes an architecture inspired by the human immune system that allows tolerance of such errors discussed by Bradley and Tyrrell (2000). In this approach, if a functional cell in an array is found to be faulty the row containing the faulty cell is replaced by a row of spare cells. All the spare cells in the new row are reconfigured to function as the cells in the replaced row. The disadvantage is row elimination also forces the non-faulty functional cells in the replaced row to move to the spare row and transfer their functions to the spare cells thus, using up more spare cells than necessary and also it has less functional fault recovery.

A novel bio-inspired fault tolerant cellular system presented by Samie *et al*. (2011). It proposes a novel model that uses the characteristics and behavior of unicellular organisms such as those of bacteria and bacterial communities to construct highly reliable electronic systems with online fault repair properties. But rerouting process are highly complex and if the same architecture, that commercial FPGAs use was adopted for prokaryotic arrays then it would also suffer from large silicon overhead and with no fault recovery mechanism.

Prokaryotic Bio-Inspired Model for Embryonics is presented by Samie *et al*. (2009). A key feature of this model is that system reliability can be increased with a minimal amount of hardware overhead. It also offers a bioinspired compression/decompression technique that exploits the intimate relationship between different genes. Distributed DNA, highly dynamic and flexible routing resources and optimized self-repair characteristics (using block and cell elimination) are some of the other advantages of the proposed model. Disadvantages are large genome redundancy consumes large amount of silicon, inefficient cell, functionality vs. area, storing increased amount of redundant information increases the probability of hardware fault and information mutation in the memory cells, inefficient self-repair, row and column elimination kills an unnecessary large number of healthy cells in response to the occurrence of a single fault and demanding routing resources especially for long distance communication.

In spite of the multiple advantages of self-repairing systems, several problems remain as major obstacles for practical use. Because the two essential procedures of self-repair, cell replacement and the rerouting process are highly complex, these systems are difficult to implement. The system must assign the proper module to replace a faulty one and the substitute module must be connected to neighboring modules in the same way that the faulty module was previously connected. Therefore, such methods of self-repair involve both additional hardware for rerouting after the replacement of faulty cell (module) and inefficient arrangement of functioning modules as well as spare (stem) modules.

As the circuit size increases, the size of the spare modules and additional modules beside the functional modules exponentially increases. Furthermore, if there is no available spare module, existing self-repairing circuits must dispose off the entire group of modules, even if some of them are still functioning. Both the MUXTREE and Lala Self-Repairing Systems present the basic methods for arranging modules during expansion but these methods do not provide a complete solution that can resolve the problem with good fault coverage.

Proposed method overcome this drawbacks, It simplifies the self-repairing mechanism and helps the circuit to maximize the efficiency. The size of the hardware can grow in proportion to the number of functional modules and ensuring good fault coverage. It provides good scalability. WC's can be recovered up to four times and maintain the function and connections through single step embedding of the encoded data.

MATERIALS AND METHODS

Self-repairable digital system: In order to separate the roles of hardware structure and control, researchers propose a functional layer and a gene control layer, the functional layer consists of an artificial endocrine cell (module) and the artificial endocrine routing architecture between cells. The artificial endocrine cell has a basic structure, genome (encoded data) and fault detection unit.

The structure of each cell is identical and modules are classified as working, stem (spare) or isolated cells. The only difference between the cells is the genome in the cell. Every Working Cell (WC) has four neighboring SCs and the WC can be replaced by any available SC among them in the event of fault occurrence. In the gene control layer, the Index Changing Unit (ICU) takes charge of one WC and its four neighboring SCs in the functional layer. It chooses the proper candidate SC for the faulty WC without collision.

The Differentiation Unit (DU) differentiates (reprograms) the SC when the ICU chooses the SC as an alternative to the faulty WC. WCs in the proposed system can be expanded to any direction as far as every WC has four neighboring SCs. Because the SC can be used for four nearby WCs by exact control without collision. A WC can be recovered up to four times even though the number of SCs is similar to the number of WCs.

Each identical structure of a cell in the proposed system can be differentiated by expressing various genetic codes as in embryonic. However, the cell replacement and rerouting process of the proposed system, the primary process of self repairing are completely different from other self-repairing methods. In particular, the primary difference between existing approaches and the approach is the reduction of steps for self-repairing. A rerouting process after cell replacement is not needed as the replacement of the WC with the SC sets the system to reroute itself. Two kinds of fault coverage are considered.

First, simultaneous fault coverage is the maximum number of faults that occur at the same time and can be recovered in the system. The three systems except the MUXTREE System, self healing and self-repair system can recover simultaneous faults as long as the number of faults does not exceed that of the spare cells. Because the MUXTREE System does not refer to simultaneous faults, its coverage is considered as one. Second, Functional Fault Coverage (FFC) is the maximum number of faults that can be tolerated for one functional cell. One functional cell in the proposed system can be recovered four times and that in the MUXTREE System can be recovered as many times as the number of columns of SC.

On the other hand, the functional cell in the self-healing system and the TMR System can tolerate only one since such systems cannot use another spare cell and redundancy after it is recovered once. For the rerouting that controls every wire that is connected to neighboring cells, the hardware overhead for the rerouting in a cell is considered the same as that for the spare cell (Fig. 1):

$$\text{Overhead}(\%) = \frac{\text{No. of spare cell} + \text{No. of hardware for rerouting}}{\text{No. of working cells}} \times 100 \quad (1)$$

Fault coverage enhancement using extra spare cells: There are already several available devices that can replace a faulty module by embedding the same encoded data of the faulty module into the stem module but none of them can maintain the function and connections through single step embedding of the encoded data into

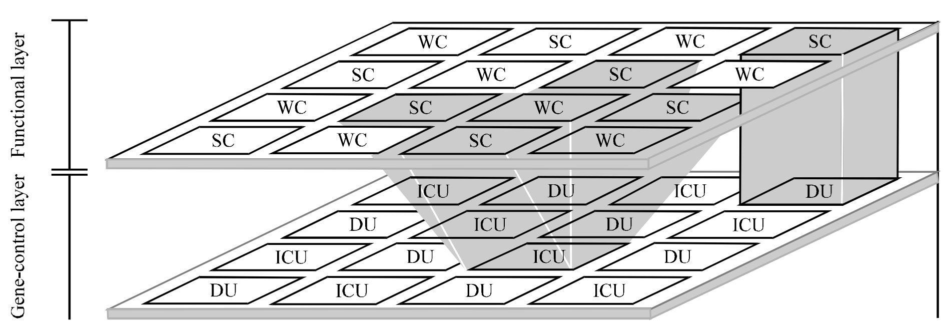

Fig. 1: Proposed self-repairing digital system

the spare module as proposed in this study. The fault signal is generated in the structural layer and then reaches the gene control layer which determines the spare (stem) module in the structural layer that will take the faulty module instead. The main role of the gene control layer is to assign the correct spare (stem) module to replace the faulty one.

The input is given to the working cell then it given to fault detection unit if there is any faults occur then the connection between that cell is disconnected through the fault detection unit and the corresponding spare is taken from the spare module so the connection is introduced between neighboring and spare cell then it is received in output through working cell. researchers use external spare cells are connected in parallel for supporting the working cells. It is suitable for large functional circuits. These are more efficient and working speed is increase (Fig. 2).

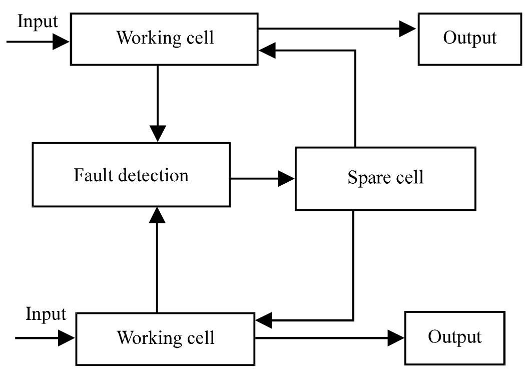

Fig. 2: Fault coverage enhancement using extra spare cells

RESULTS AND DISCUSSION

A new self-repairing digital system providing good scalability and fault coverage was proposed. It consists of a functional layer and a gene control layer. The functional layer performs the function and the gene control layer controls the functional layer so that proper assignment of SC for the replacement of a faulty cell is carried out. New architectures for the routing and the cell in the functional layer were developed and well organized such that rerouting between neighboring cells after the replacement of a faulty cell would be done by only replacing the faulty cell with an SC.

In the new architecture, the cells could be arranged in a flexible manner such that the WC could be expanded to any four directions and could also be arranged densely such that SC could be replaced by any of four neighboring WCs for fault recovery without collision. As a result, all these make the system efficient. The proposed system was compared with other major self-repair approaches and it was found that the proposed system has good fault coverage, low overhead and no unutilized resources for fault recovery. The function of the target system is represented in the functional layer of the proposed system framework and this target system is to be operated as fault tolerant or self-repairing:

- Inputs are A, B, C, Ini and Clk. Here A, B, C used to perform full adder operation to indicate fault present or not, Ini and Clk input '1' in all cases. F = 0 which means no fault in the working cell. As a result working cell 00010 is taken as default, no other changes (Fig. 3)

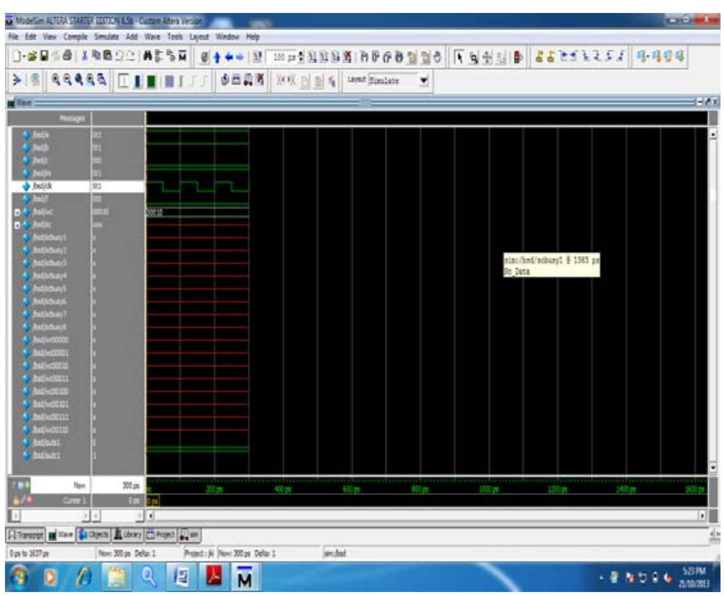

Fig. 3: Output for non faulty condition. Signal and thier values are: A = 1; B = 1; C = 0; Ini = 1; Clk = 1; F = 0

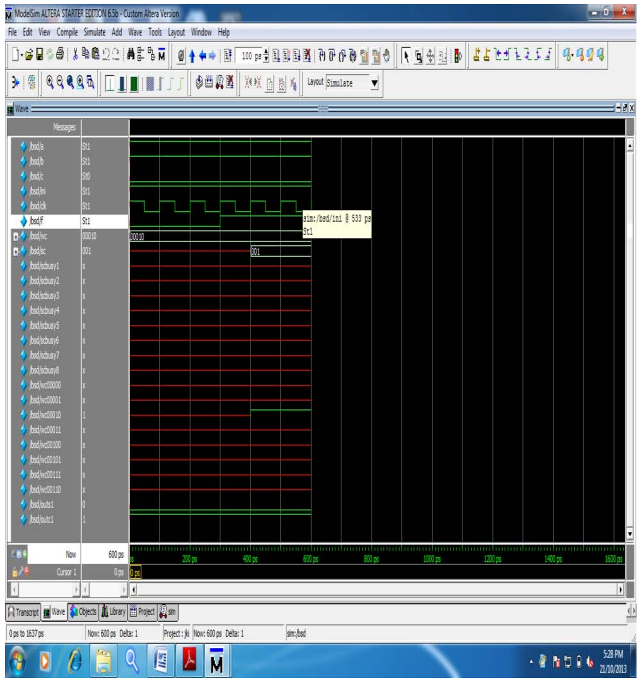

Fig. 4: Output for faulty contidion. Signal and thier values are: A = 1; B = 1; C = 0; Ini = 1; Clk = 1; F = 1

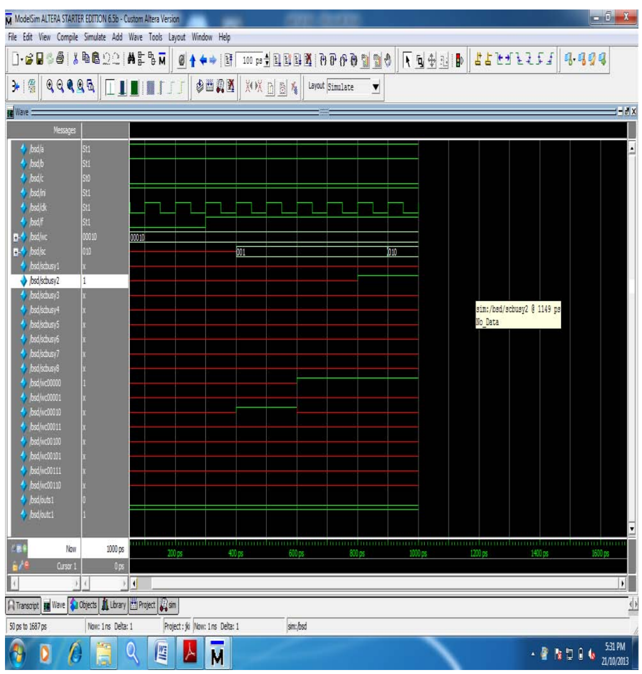

Fig. 5: Output for faulty condition with any of 4 stem cells. Signal and thier values are: A = 1; B = 1; C = 0; Ini = 1; Clk = 1; SC = 010

- A, B, C, Ini, Clk inputs same as above. F = 1 which means fault is present in the working cell in this case Working Cell (WC) 00010 replaced by Spare Cell (SC) 001 (Fig. 4)
- Inputs are same. F = 1, in this faulty condition researchers can replace working cell with any of the four stemcell here, workingcell 00010 replaced with stem cell 010 (Fig. 5)

CONCLUSION

In each module of the system, the encoded data, called the genome, contains information about the function and the connection. Therefore, a faulty module can be replaced and the whole system's functions and connections are maintained by simply assigning the same encoded data to a spare (stem) module. In existing systems, a huge amount of hardware such as a dynamic routing system, is required for such an operation.

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