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FAULT TOLERANT BIO INSPIRED SELF REPAIRING DIGITAL SYSTEM

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ABSTRACT

Self-repairing digital systems have recently appeared as the most hopeful substitute for fault-tolerant systems. This idea get up from the biological functioning of endocrine cells. The motivation we obtained from the biological endocrine system lies in the effectual and flexible communication mechanism between endocrine cells. In the endocrine system, the data between endocrine cells is exchanged via the hormones, and this forms a complex communication grid. The proposed system architecture is consists of a structural layer and a gene-control layer. In the structural layer, the circuit is alienated into modules. Encoded data in each module are composed of both functional and connection data. Therefore, the function and networks of the whole system are retained by simply communicating the same encoded data to the spare (stem) module, while the wiring architecture connects correctly after the encoded data are properly allocated to the spare module. The main role of the gene-control layer is to allot the right spare (stem) module to switch the faulty one. The system propose new architecture for developing working cell and fault detection. The modified architecture offers more fault coverage compared to the existing system. The proposed system has been implemented in Spartan 6 and simulated using Isim simulator in Xilinx software

Keywords: bio-inspired engineering, endocrine cellular, gene control layer, index control unit.

INTRODUCTION

Fault tolerance has been a critical feature for reliable space borne electronic systems that run under hostile cosmic environments. Researchers are continuously looking for efficient ways to design more reliable fault tolerant electronic systems. The basic principle in fault tolerant system design is redundancy. We propose a fault-tolerant approach to reliable microprocessor design. The complexity of VLSI-based digital systems has been increasing continuously. As the level of complexity increases, systems become more susceptible to faults especially transient faults. Since it is almost impossible to detect such faults, the reliability of VLSI systems can be increased only by built-in fault tolerant mechanisms to recover from such faults. High-quality verification and testing is a vital step in the design of a successful microprocessor product. Designers must verify the correctness of large complex systems and ensure that manufactured parts work reliably in varied (and occasionally adverse) operating conditions. If successful, users will trust that when the processor is put to a task it will render correct results. If unsuccessful, the design can falter, often resulting in serious repercussions ranging from bad press, to financial damage, to loss of life. There have been a number of high-profile examples of faulty microprocessor designs. Self-repairing digital systems have recently emerged as the most promising alternative for fault-tolerant systems. However, such systems are still impractical in many cases, particularly due to the complex rerouting process that follows cell replacement. They lose efficiency when the circuit size increases, due to the extra hardware in addition to the functional circuit and the unutilization of normal operating hardware for fault recovery.

Objective

Objective of the project is to propose a system with self repairing capability inspired by endocrine cellular communication, which simplifies the rerouting process in two ways: 1) by lowering the hardware overhead along with the increasing size of the circuit and 2) by reducing the hardware unutilized for fault recovery while maintaining good fault-coverage

Organization of the Paper

This paper is organized as follows. In section 2, we discuss endocrine cellular communication. Section 3 extends the idea of proposed self repairing digital systems. Simulation results are provided in section 4.Conclusion provided in the section 6.

ENDOCRINE CELLULAR COMMUNICATION

Among the various methods of cell to cell communication in our body, endocrine cellular communication is particularly noteworthy. Basically, a cell releases an endocrine hormone from the endocrine cell signaling, and hormone circulates in the blood vessel until it binds to the target cell [1]. Although blood contains various hormones, only the receptor on the target cell receives the selected hormone. The special method of endocrine cell communication that inspired this project is based on a specific endocrine cell that secretes a hormone that if it accepts another hormone from another cell of the endocrine system. The hormone of the anterior pituitary gland stimulates endocrine cell in peripheral endocrine gland to secrete hormone gland device. When operating an endocrine cell dies by apoptosis, endocrine special cellular communication keeps the transfer of the hormone by differentiating a SC in a cell having the same part of the genome than the dead cell .Thus, in addition to its own operation, the genome of the endocrine cell has

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information about the connections between the cells. The inspiration we got from the biological endocrine system is the efficient and flexible communication mechanism between endocrine cells. Inspired by this characteristic of the endocrine system, the proposed system was developed. In the proposed system, clear links between a work module and spare modules are considered, so that the work module can be redirected and connected to a replacement module when the module is working bombs and replaced by the replacement module.

PROPOSED SELF REPAIRING DIGITAL SYSTEM

By adopting a similar mechanism in an electronic circuit, we designed a system with a new coding strategy in each module and also a new wiring architecture that can maintain function and connections by replacing the defective module with a spare (stem) module without any additional redirection process.

Architecture of Proposed System

The architecture of the proposed system is composed of a structural layer and a control gene layer .In order to separate the roles of structure and control equipment, we offer a functional layer and a control gene layer, as shown in Figure 1. The functional layer consists of artificial endocrine cell (module) .The artificial endocrine cell has a basic structure, the genome (encoded data), and the fault detection unit. The structure of each cell is identical and the modules are classified as working, stem (alternative), or isolated cells. The only difference between the cells is the cell genome. Each work cell (WC) has four neighbors SC and WC can be replaced by any SC them available in case of fault occurrence. In the command-layer gene, the unit of the index change (ICU) takes charge of a working cell and its four neighboring centers in the functional layer. It choose the SC suitable candidate for the defective WC without collision. The differentiating unit (DU) differentiates (reset) of the SC when the ICU chooses the SC as an alternative to the faulty WC. WC in the proposed system can be extended to all directions since all WC has four neighboring centers. Because the SC can be used for WC close by precise control without collision. A WC can be recovered up to four times, even if the number of SC is similar to the number of WC.

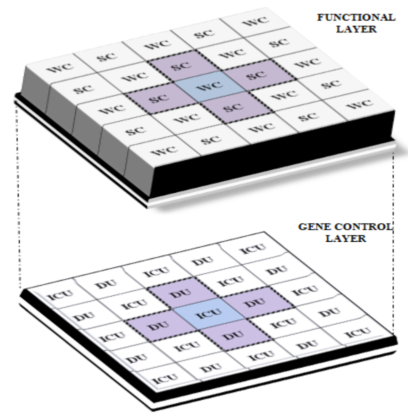

Figure-1. Proposed self-repairing digital system. Overall architecture and related cells between the functional layer and the control layer. WC: working cell. SC: stem cell. ICU: index changing unit. DU: differentiation unit.

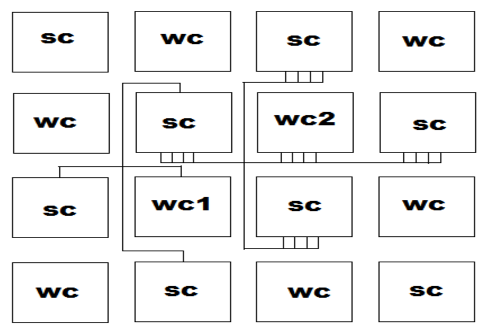

Figure-2. Artificial endocrine routing architecture.

Functional Layer

The proposed system simplifies the self-repairing mechanism and also it gives enough efficiency when number of hardware increases. While adding spare modules it ensuring good fault-coverage. Self-repairing system composed of structural layer and gene control layer. Structural layer consist of both working cell (WC), spare cell (SC) and their interconnection. Gene control layer consist of Index Changing Unit (ICU), Differentiation Unit (DU). It determines the proper spare module in the structural layer to replace the faulty module without collision. This self-repairing mechanism is operated in parallel. So, even several faults occur in different modules at same time, the system can recover them. Here the functional layer consists of four working cell that performs the following operations

- Addition
- Subtraction
- Multiplication
- Shifting

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Figure-3 shows self-repairing ALU without any fault. Consider it can perform 4 different operations like addition, subtraction, multiplication and shifting. The WC and SC arranged as in Figure-3.

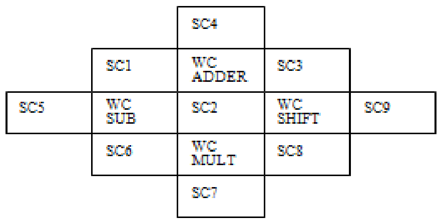

Figure-3. Self repairing ALU without any fault.

Gene Control Layer

The gene-control layer is functionally positioned in parallel with the functional layer and it consists of two units. The Index Changing Unit (ICU) which takes in charge of a WC and its four neighbouring SCs and the Differentiation Unit (DU) which is assigned for every SC. In case of permanent fault, the fault signal is sent to the ICU. When the ICU receives the fault signal, it checks for the spare cell in anti-clockwise direction, starting from the left. In order to control the cell replacement, index bits are used which are changed corresponding to the available spare cell and indicates to the DU, that the spare cell is ready to replace the function of the faulty cell. Index bits comprise of three types of bits: state bit, differentiation bit and direction bits as shown in Table-1. Three types of index bits in each SC of the gene-control layer change during the runtime by taking the fault signal from the functional layer: the state bit, the direction bits, and the differentiation bit. Their initial values are “0.” The state bit shows whether or not the cell is available as a spare cell, the direction bits determine which direction of the WC from the spare cell is to be substituted, and the differentiation bit differentiates the spare cell from the WC. On the basis of index bits, cellular differentiation of the functional layer is precisely controlled.

Table-1. Index bits for stem cell.

STATE BIT	STEM CELL	0
STATE BIT	WORKING CELL	1
DIRECTION BIT	LEFT	00
DIRECTION BIT	DOWN	01
DIRECTION BIT	RIGHT	10
DIRECTION BIT	UP	11
DIFFERENTIATION BIT	NO CHANGE	0
DIFFERENTIATION BIT	DIFFERENTIATE THE STEM CELL	1

Fault Coverage

We consider a Full adder is a working cell. The full adder is a 16 bit ripple carry adder. Arithmetic operations like addition, subtraction, multiplication, division are basic operations to be implemented in digital computers using basic gates like AND, OR, NOR, NAND etc. Of all the arithmetic operations if we can implement addition then it is easy to perform multiplication (by repeated addition), subtraction (by negating one operand) or division (repeated subtraction).These are the four working cells developed. The input is given to working cell as well as stem cells. The fault is detected by comparing the outputs from working cell and stem cells. The comparison is carried out by using five comparators in such a way that the output from working cell and left stem cell has been compared and the output from left and down SC and output from down and right SC and the output from right and up SC and finally up SC and working cell. The fault bit position can be located by xoring the wrong and correct outputs. It can be recovered by xoring the wrong output.

E.g.: If our WC got damaged. Hence it gives wrong output and the left SC act as current WC and gives the output.

WC ---- 0 1 0 1

SC ---- 1 1 0 1

SC is giving correct output. On xoring both outputs we get 1 0 0 0. If the result of xoring is zero then no error is detected. If the result is not zero then error can be located by looking the 1 position. In this example 3rd bit (MSB) indicates error. In order to recover it xoring the WC output with 1 0 0 0.
i.e. 1 0 0 0 $\oplus$ 0 1 0 1 = 1 1 0 1 which is the correct output.

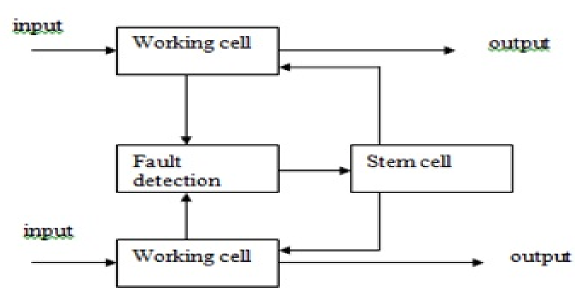

Figure-4. Fault coverage using stem cells.

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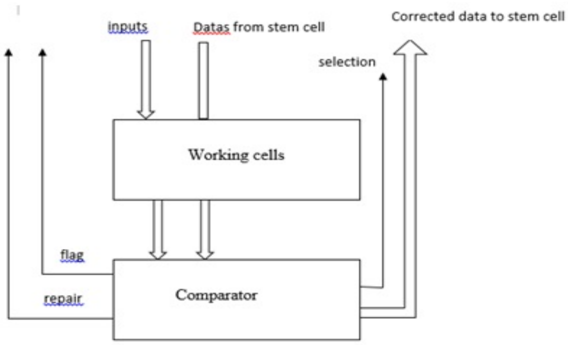

Figure-5. Fault detection and correction unit.

The Figure-5 shows the modified fault detection and correction unit. The above method speed up the fault detection and can be completed in single clock cycle. If we go for bit wise comparison it takes clock cycle that depends on number of output bits. So in between there is a chance for any other stem cells got damaged. For 16 bit output, it requires 16 clock cycle. This helps to complete within one cycle and speed up the process.

If WC fault occurred can be replaced by one of the four available SC neighbors. Consider SC1, SC2, SC3 and SC4 are placed to the left, down, right and top side of WC, respectively. When WC gets reproached, replaced by SC1 (SC left). If SC1 is busy with another WC, the faulty WC is replaced by SC2. It is an anti-clockwise operation. The WC has some coded data, which is available in the four neighboring countries SC. For this reason WC can be replaced by any neighboring SC available for normal fault-free operation. WC may be replaced up to four times, even if the number of SC is similar to four times the number of WC. Permanent fault corrupting the genome or its basic structure. Thus, it can recover by selecting appropriate alternative and isolates defective cell. Take the case of selecting addition operation. If there is no defect in the WC adder, the system continues it operates without using SC as in Figure 3. But when the adder 4 WC suffer the temporary fault, it will try to overcome the fault detection and correction unit and maintain its condition. Sometimes it is impossible to correct the defect, due to permanent fault in the genome. Thus, the WC get replaced by stem cells and also isolated from the defective cell. Gene control layer to generate corresponding signals according to the state of the functional layer. The following figures 6 to 9 show various stages of the fault recovery in ALU.

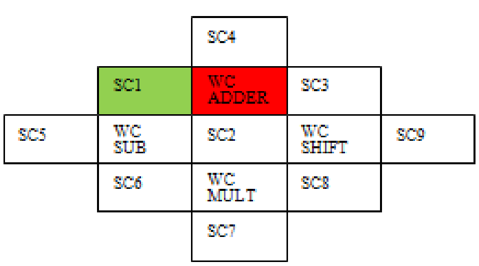

Figure-6. Fault recovery by left and down stem cells.

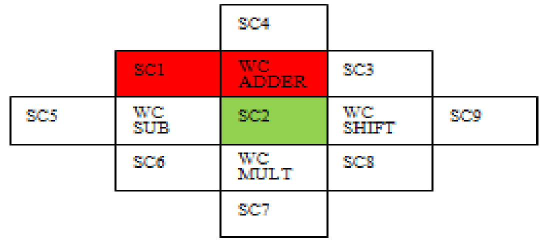

Figure-7. Fault recovery by left and down stem cells.

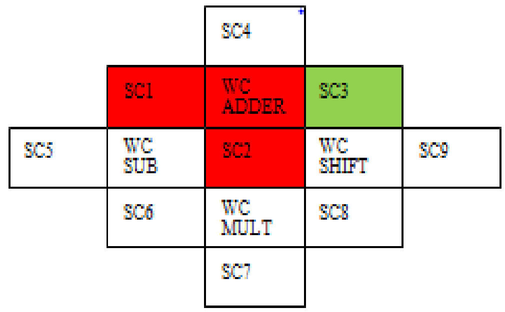

Figure-8. Fault recovery by right stem cell.

If 4 SC and working cell WC ADDER become default, the module adder operation stops its operation by isolated SC as in Figure-9. Thus the unit adder is lacking the normal operation and becomes fault.

Simultaneous Fault Coverage

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, can recover simultaneous faults as long as the number of faults does not exceed that of the spare cells [12].

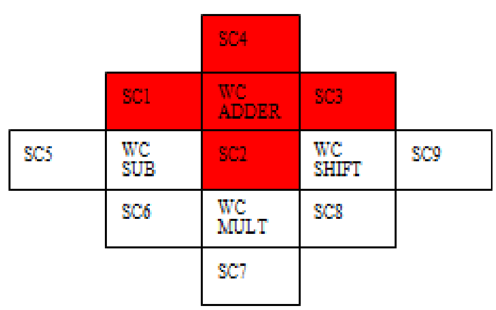

Figure-9. Permanent fault in all stem cell and adder working cell.

Functional Fault Coverage

Functional fault coverage 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

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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[13],[12].

Fault coverage of the existing system can be improved by find the root cause. In case of ripple carry adder the input is given to the adder circuit. If an error occurred in the initial stage is detected, then it is easy to improve the circuit fault coverage. The error occurring in the input section can be identified using MUX method. In ripple carry adder the carry output of one full adder is given as input to the next full adder. If any connection mistake occurred, we get wrong output. Such error occurrence can be corrected by using MUX method. In MUX method, we are placing MUX in between every full adder. All possible inputs are giving to the MUX. According to the change in the selection bits of several MUX connected between the full adder, we get correct output. The time we get correct output the changing of the selection bits is stopped. Hence the fault coverage of the working cells can be improved. As a result, the fault coverage of the entire ALU unit can also be improved.

SIMULATION RESULTS

The proposed system is embedded in a digital platform with Xilinx Spartan 6 FPGA for the application of an ALU. The proposed system has been implemented using Verilog Language using software Xilinx ISE Figure 10.shows simulation result of adder section without any fault.

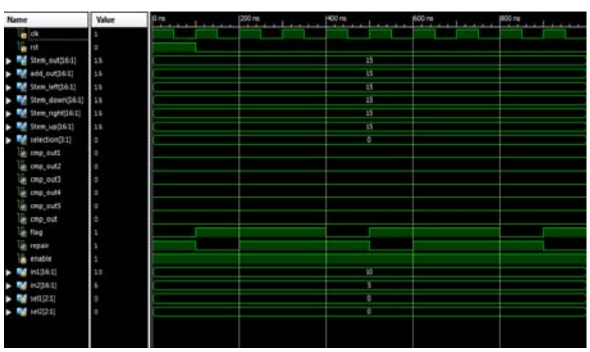

Figure-10. Simulation result of adder without fault.

Figure-11.shows simulation result of fault recovery of adder circuit after injecting errors to adder working cell and two stem cells like left and down. Hence the working cell got replaced by right stem cell and gives the output and act as current working cell.

Figure-11. Simulation result of system after fault recovery.

Figure-12 shows simulation result without fault recovery since we inject errors to all working cell and stem cells. Hence the system stops working and need to be replaced with other circuit

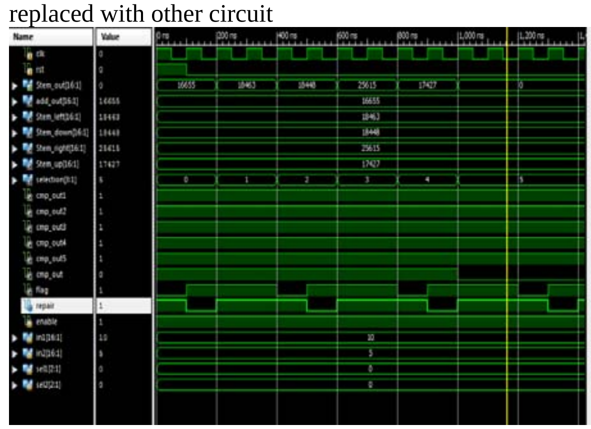

Figure-2. Simulation result of system with no fault recovery.

Figure-13.shows simulation result of the entire ALU unit that consists of adder, subtractor, multiplier and shifter. The system can be verified by injecting different error condition to various working cell and stem cells. Output of ALU displayed on the LEDs

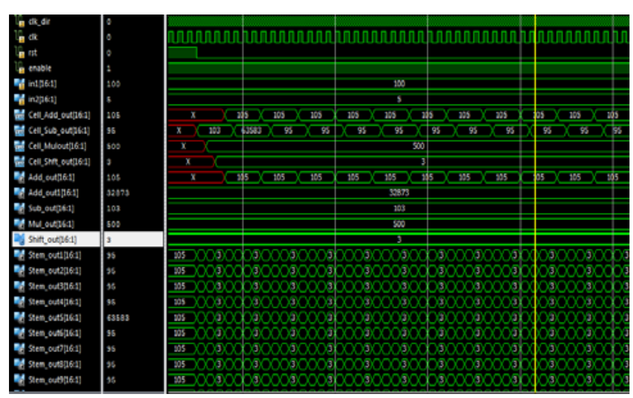

Figure-13. Simulation result of the entire ALU unit.

EXPERIMENTAL SETUP

In permanent fault, normal operation is maintained using cells replacement. Figure-6 and Figure-9 shows the altered states of cells by the fault recovery after a fault is injected into cells. Here repairs of the system of permanent failure in a counterclockwise sequence. However, if the fault is generated TS after Faulty RS is replaced by TS, the whole system stops working because there is no SC left for repair. The speed of the clock used for the recovery is much faster. Thus, the ALU can operate normally after fault generation. Through various events, the proposed system is verified.

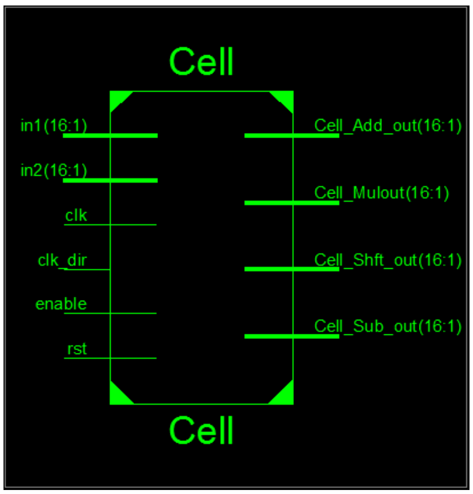

Figure-14. Self repairing ALU.

CONCLUSIONS

The digital self-repairing system provides good scalability and fault coverage. New architecture for fault detection provides less memory usage and having a good default coverage. And also the new MUX method of implementation of working cell offers improved fault coverage. Even the system is increased, the coverage of the cam unit ALU defects be improved. In addition, due to the new architecture, the cells may be arranged in densely and flexibly, so the WC could be extended to all four directions. Precise control in the gene-control layer provides default recovery without collision. Consequently, all these create the efficient system compared to other existing approaches. For further improvement of the proposed self-repair system, there are still several issues awaiting new studies. The main objective of developing a fault tolerant or self repair system is to deal with defects that may occur in the target system. Other faults that might occur in additional equipment are not considered. Therefore, secondary faults that may occur in the additional functional material should be considered as well in the examination of the cost and frequency. This means that the fight against possible defects in the additional functional equipment also remains a subject for further study.

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