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Survey on FPGA Architecture and Recent Applications

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***Abstract*— Field Programmable Gate Array or FPGA is introduced in the year 1985 and it is getting popular day by day due to its properties like design to reuse and flexibility. As compared to microprocessor, FPGA have high performance and configurability. When compared with application specific integrated circuit (ASIC), FPGA reduces development time, non-recurrent engineering (NRE) costs. The unique property which differ it from ASIC is its reconfiguration. The recent trends in FPGA architecture are in the direction which reduces the gap between the ASIC and FPGA. This paper will discuss on the classification of FPGA based on their routing architecture and the recent trends in the field of Physics, computation, defense, space research, etc., which are focusing on betterment of the existing technology.**

Keywords*— *Field Programmable Gate Array, Application specific integrated circuit, Non-recurrent engineering cost

I. INTRODUCTION

Modern FPGA are able to cover extremely wide range of application and due to this it can be called as entirely programmable system on chip (SoC).If performance of FPGA as a computational platform is consider then FPGA exceeds the conventional processors in following performance vectors: input/output bandwidth, computation and memory bandwidth. FPGA have advantages over the ASIC.FPGA's are reprogrammable whereas the ASIC is not. Due to this reconfiguration property FPGA's are suitable for prototyping which helps to eliminate the possible error and makes the design error free. This reduce the development time of the product and time to market will get reduced. Second, the time required for FPGA to reconfigure or reprogram in only few minutes whereas ASIC requires lot of resources in terms of money and time to get the first device. We can update the changes in the design at the last moment where as in ASIC it is not possible. However there are some disadvantages associated with the FPGA, due to its flexible nature makes them larger and slower as compared to its counterpart.

Normally FPGA have: (I) Programming logic block which is there for implementing the logic function. (II) Routing Interconnect for establishing the connection between the programming logic blocks and (III) Input output block which is ultimately used for to have an interaction between the internal architecture of FPGA and the outside peripherals.

Various programming technologies have been used for the reconfiguration architecture. Each technology have its own advantage and disadvantage. First is SRAM based programming technology where the static memory cell are used in the CLB's to store the configuration information in form of bits. This technology is very successful in the commercial and academic FPGA's because of the standard CMOS technology is used in it. Disadvantage of this technology is its static cell. The number of transistor required for single cell are six which makes this technology costly as compared to the other technologies available. Similarly static RAM are volatile in nature so we need to reprogram the device every time the power is removed from the system. Second technology is the flash based programming technology which is the alternative of the SRAM technology where we use flash or the EEPROM as the basic bit storing element [14]. Here the advantage is it is nonvolatile in nature whereas these FPGA's cannot be reconfigured or reprogrammed infinite number of times. Therefore the main property of the reconfiguration is lost in this technology. Third technology is the anti-fuse technology where the basic bit storing element is the fuse. Here the advantage over the other two technologies is that the area required is less. But again the technology is the again nonstandard CMOS and these FPGA's cannot be reconfigured number of times [1, 4].

So each technology have advantages and disadvantages but FPGA's with the SRAM based programming technology are very successful in commercial and academic sector due to the CMOS technology and reprogrammable properties.

II. FPGA ARCHITECTURE

The flexibility of the FPGA is due to its basic component and this component is called as configuration logic block (CLB). CLB's provides the basic logic and storage capability. The configuration logic block are spread all over the FPGA structure along with some blocks. Now the question is what is their inside CLB? The CLB can have single basic logic element (BLE) or the cluster of BLE. Lookup table (LUT) and flip-flop are the basic elements of BLE. If the LUT have k input then number of bits that can be configured are 2^k. Let us take the example of 4 input LUT. So according to the above explanation it have 16 configuration bits. The output of this LUT is connected to the D flip-flop [2]. The flip-flop is optional. The multiplexer selects which configuration bit is need to be given to the input of flip-flop depending on the input. This example can be easily understand by the Fig. 1.

But the modern FPGA usually contains up to 10 BLE's in a cluster. Although the above discussion only contains the basic blocks, but in modern FPGA contains the heterogeneous mixture of the blocks like along with some basic block the hardwire blocks are also available on the FPGA like ARM Cortex A9 hard IP is available on the Arria 10 FPGA by Altera.

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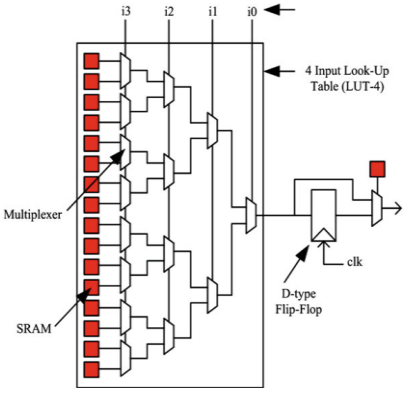

Fig. 1. Basic Logic Element (BLE)

Since FPGA is capable of implementing almost all digital circuit so its routings interconnect need to be flexible so that they can implement the circuits with more efficient way and resources will be utilized in the optimized way which will eventually reduce the consumption of the power. But there are some connections which will be connected through the long interconnect wire and therefore we need to take the care while designing routing interconnect for the FPGA architecture. Arrangement of the routing is also crucial which ultimately decides the efficiency of the FPGA. Depending on the global routing architecture the FPGA architecture are classified as hierarchical architecture and island-style architecture [1, 2].

A. Island-style Routing Architecture

Island style architecture is the traditional FPGA architecture. Commercially this architecture get lot of success along with the academic. This architecture is called island architecture because of the arrangement of the CLB's is as shown in the Fig. 2. From the diagram it is clear that CLB's are looking like they are placed in the sea of routing interconnect. The IO blocks are on the outer side of the FPGA. The routing network are prefabricated and arranged horizontally and vertically throughout the FPGA. Totally, routing interconnect comprises of 80% to 90% of the architecture whereas the CLB's occupies 10% to 20% of total area. The routing interconnect which are laid on FPGA horizontal and vertical are connected to each other through switch box (SB). So the interconnect are connected through switch box and switch box are connected to Logic blocks or the CLB's [1, 15]. This provides the sufficient flexibility to the architecture and the adaptability of the FPGA has been achieved. Example for island-style architecture is Altera's Stratix II architecture.

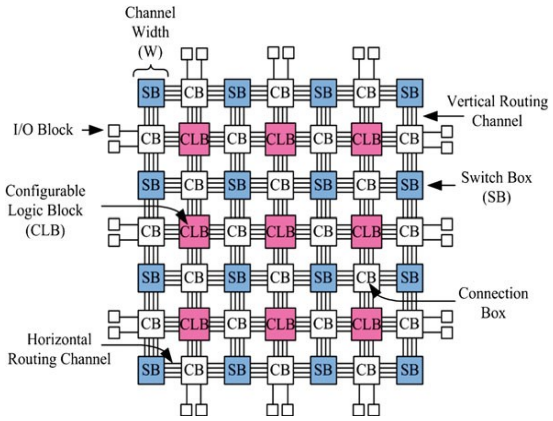

Fig. 2. Island-style Routing Architecture

B. Hierarchical Routing Architecture

In hierarchal routing the locality has been exploit by dividing the FPGA logic block into separate groups and clusters. The clusters are repeated throughout the architecture. Connections between the logic blocks within same cluster are established by wire segments to the lower level of hierarchy. Traversal is required when the signal has to move from one cluster to the other cluster. The bandwidth varies as we move up in the hierarchal level. Multi-level hierarchical like two level of hierarchy and tree based one are also available in this group of architecture. [1] Example for hierarchical architecture is Altera's Apex devices. Both the routing architecture have some advantages and disadvantages over each other but mostly we will find island style routing architecture in commercial and academic FPGA. Example for hierarchical routing architecture is shown in Fig. 3.

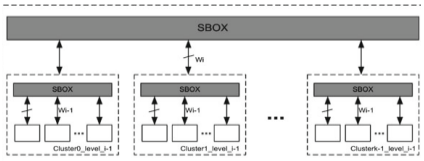

Fig. 3. Hierarchical Routing Architecture

III. APPLICATION

FPGA is suitable for very diverse application like audio and video processing, cryptography, signal processing, image processing, random number generation and various algorithm implementation. It is expected that it will be used in various sector like oil and gas, finance and many more. Since 1985 lot of changes in the architecture and due to this architectural changes its area of coverage has been increased in terms of application. The improvements are done so that to reduce the gaps between the FPGA and ASIC. In this section, several FPGA applications are covered so that to get idea how vastly the FPGA is used for various purpose.

A. Cloud Servers

Generally the IOT devices have limited memory size, processing power and bandwidth. The interface is offered by the developers through framework and tools. Using the in the cloud enable to run all artificial intelligence and big data algorithms on the same platform. FPGA is used in Elastic Compute Cloud (EC2) cloud environment which is offered by some web service companies. In healthcare and finance FPGA is used to push over the gene sequencing anomalies. The latest FPAG have almost 2.4 million logic elements which have 6500 DSP engines and strong board CPU. For FPGA as a cloud server they need to use in the ring topology with speed up to 400GB/sec. This is used to in commercial FPGA to distribute the workload as shown in Fig. 4. [8]

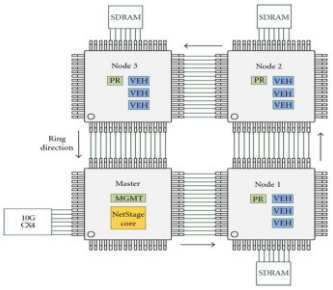

Fig. 4. Multi-FPGA network in ring topology

B. *Artificial Intelligence*

In artificial intelligence the deep neural network requires high performance, more power proficient, large computation and less time. High end devices are power-up by deep neural network.as we know that the deep network can have many number of hidden layer. Hidden layer will be more for getting the precise output. Let us take the example of the P-Neuro which is power efficient accelerator. It is built on Serial input and multiple data architecture FPGA has been used to implement the P-Neuro and it is found that it is faster by a factor of 2, 3 and 5 more efficient in terms of energy when compared with the embedded GPU even though the FPGA is running on the frequency of 100 MHz whereas the other competitors where running above 500 MHz From the table it is clear that FPGA is energy efficient that it's counterpart except Application specific integrated circuit or the ASIC [6]. Comparison is shown in the TABLE I.

C. *Space Technology*

When the JSWT or the James Webb Space Telescope is compared with the Hubble Telescope views 100 times larger. Near Infrared Spectrograph which is have more than two and half lakh micro-shuttles is the important element of the JSWT telescope. Because of the micro-shuttle it is possible to observe distant galaxies in the space. The micro-electro mechanical system devices are present in the micro shuttle which shutters its light exposure. FPGA is used in the JWST and due to the flexibility of the FPGA the designers are able to adjust the sensor interface and the changing image processing requirement [6].

D. *Defense Systems*

FPGA's are used in the defense system due to its ability of high speed data processing. FPGA also provides high performance and integration along with high safety. Due to the anti-tamper technology it actually reduces the risk. Defense graded FPGA have high endurance to the heavy load of work. FPGA are also used in the electronics warfare system where the important driver for improvements are ECCM [11]. Another application is the tactical data communication system where there is a need to re configure the transmission of data with the help of SDR (Software defined Radio).Here FPGA's are act like the natural enabler for the Software defined Radio.

E. *Renewable Energy Systems*

For solar charge system the panel need to face sunlight all the time so that sunlight should fall perpendicular on the silicon or the solar panel. Therefore the feedback from the sensor is given back to FPGA and the controller on the FPGA takes the action accordingly and rotate the solar panel. FPGA are also used in the system where the strong EM wave is used to break down lime scale deposit which prevents the pipe from oxidation. Toxic gas detection is also possible by using the sensor based FPGA system. Along with some wireless module we can send the data about the surrounding to the central or the monitoring system

F. *Translation*

Microsoft's FPGA system which is based on the Altera FPGA can translate the Wikipedia article in less than 1/10th of the second. This articles can hold around 3 billion words. They uses the FPGA accelerate servers. FPGA is already used by Microsoft in search engines for improvement in the search qualities [7].

G. *Derivative Pricing*

There are lot of algorithms were used for finding the probabilities for certain event. Consider the example of the Monte Carlo Simulation. Usually Monte Carlo have large number of randomized trial to infer the probability distribution of certain event like derivative pricing. With interest rate derivative, Monte Carlo can be used to price large range of financial derivative. [6] In this process the time period is very long. So such large computation can be easily handled by the FPGA. To optimize and increase the speed we can use some concepts of parallel computing

H. *Particle Physics*

The famous experiment named Compact Muon Solenoid or CMS is a general purpose particle detector which is built on the Large Hadron Collider at CERN in France. The goal of the experiment is to investigate the search of Higgs boson and the extra dimension. This experiment leads to the discovery of the new particle which is highly unstable and breaks into the smaller particles which are stable in the environment. This particles is the by-product collision of the beam. Detection of this new particles is done by pattern recognition. Large number of calculation are need to perform for the pattern recognition [6]. This calculations are handled by the FPGA so that they we get the results fast since the new particles are highly unstable.

IV. CONCLUSION

FPGA has been introduced to the world in the 1985 but now it has become one of the major player in the electronics industry. They are very suitable for the prototyping ultimately reduces the non-recurrent or NRE cost for the product. In some aspects FPGA is better than its counterpart ASIC. This paper covered the brief architectural classification of FPGA on the basis of the routing interconnect along with some recent application. It is possible that we come across many FPGA applications without knowledge and it is expected that it will grow with faster rate in coming future.

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