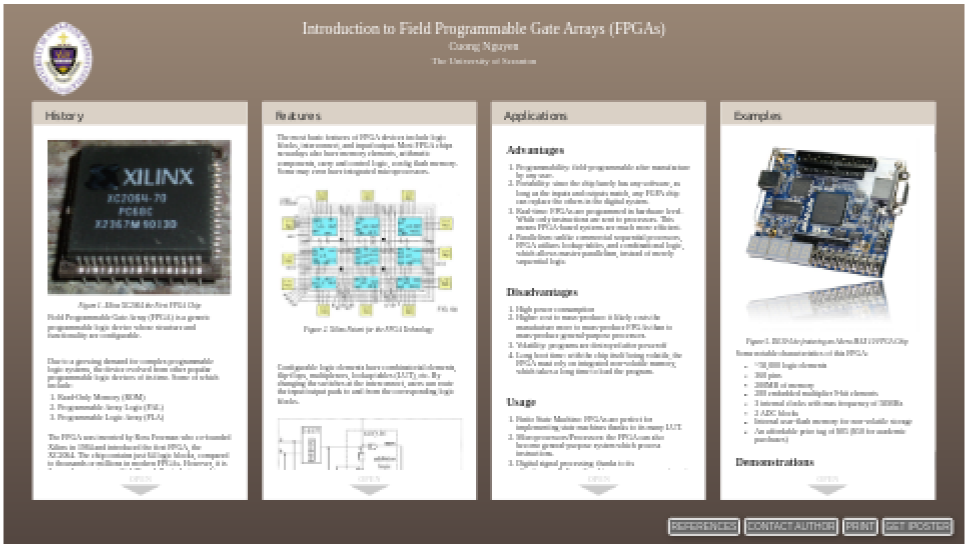
Introduction to Field Programmable Gate Arrays (FPGAs)



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HISTORY

Figure 1. Xilinx XC2064 the First FPGA Chip

Field Programmable Gate Array (FPGA) is a generic programmable logic device whose structure and functionality are configurable.

Due to a growing demand for complex programmable logic systems, the device evolved from other popular programmable logic devices of its time. Some of which include:

1. Read-Only Memory (ROM)
2. Programmable Array Logic (PAL)
3. Programmable Logic Array (PLA)

The FPGA was invented by Ross Freeman who co-founded Xilinx in 1984 and introduced the first FPGA, the XC2064. The chip contains just 64 logic blocks, compared to thousands or millions in modern FPGAs. However, it is the predecessor to a multi-billion-dollar industry, and to one of the most influential technological advancements. Thanks to its importance, the XC2064 is one of the 33 chips presented in the IEEE Chip Hall of Fame.

FEATURES

The most basic features of FPGA devices include logic blocks, interconnect, and input/output. Most FPGA chips nowadays also have memory elements, arithmetic components, carry and control logic, config flash memory. Some may even have integrated microprocessors.

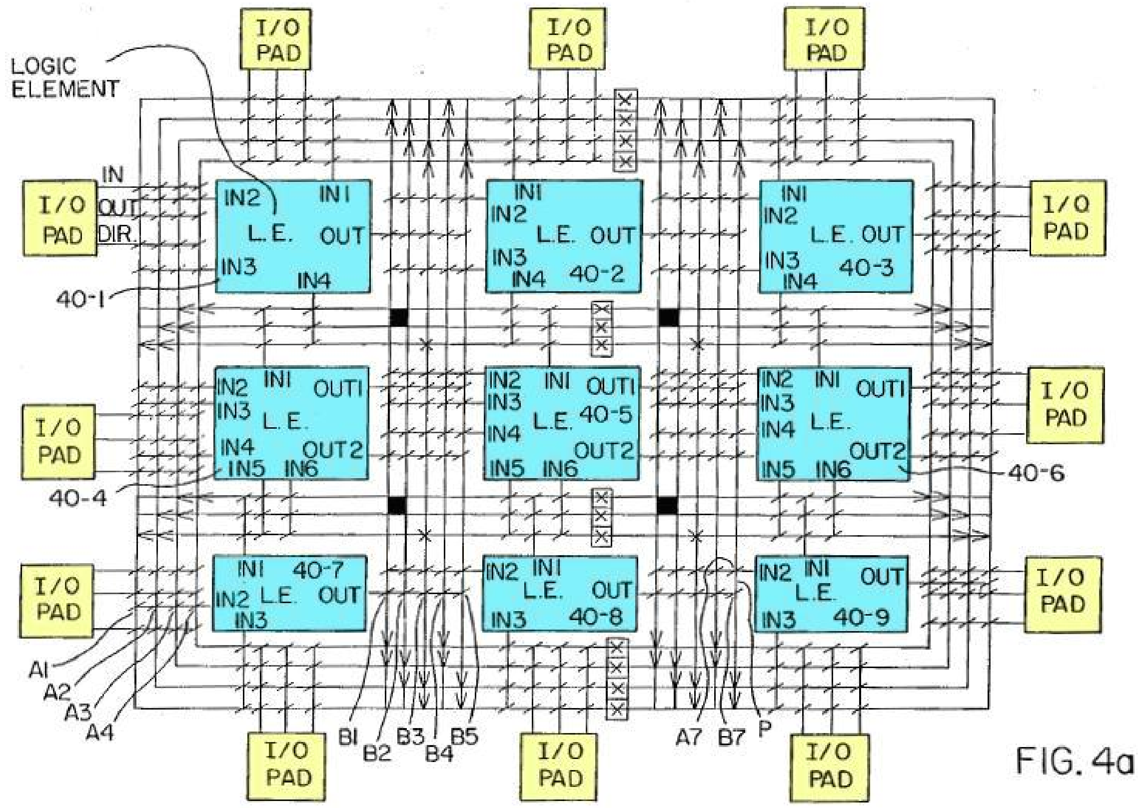

Figure 2. Xilinx Patent for the FPGA Technology

Configurable logic elements have combinatorial elements, flip-flops, multiplexers, lookup tables (LUT), etc. By changing the switches at the interconnect, users can route the input/output pads to and from the corresponding logic blocks.

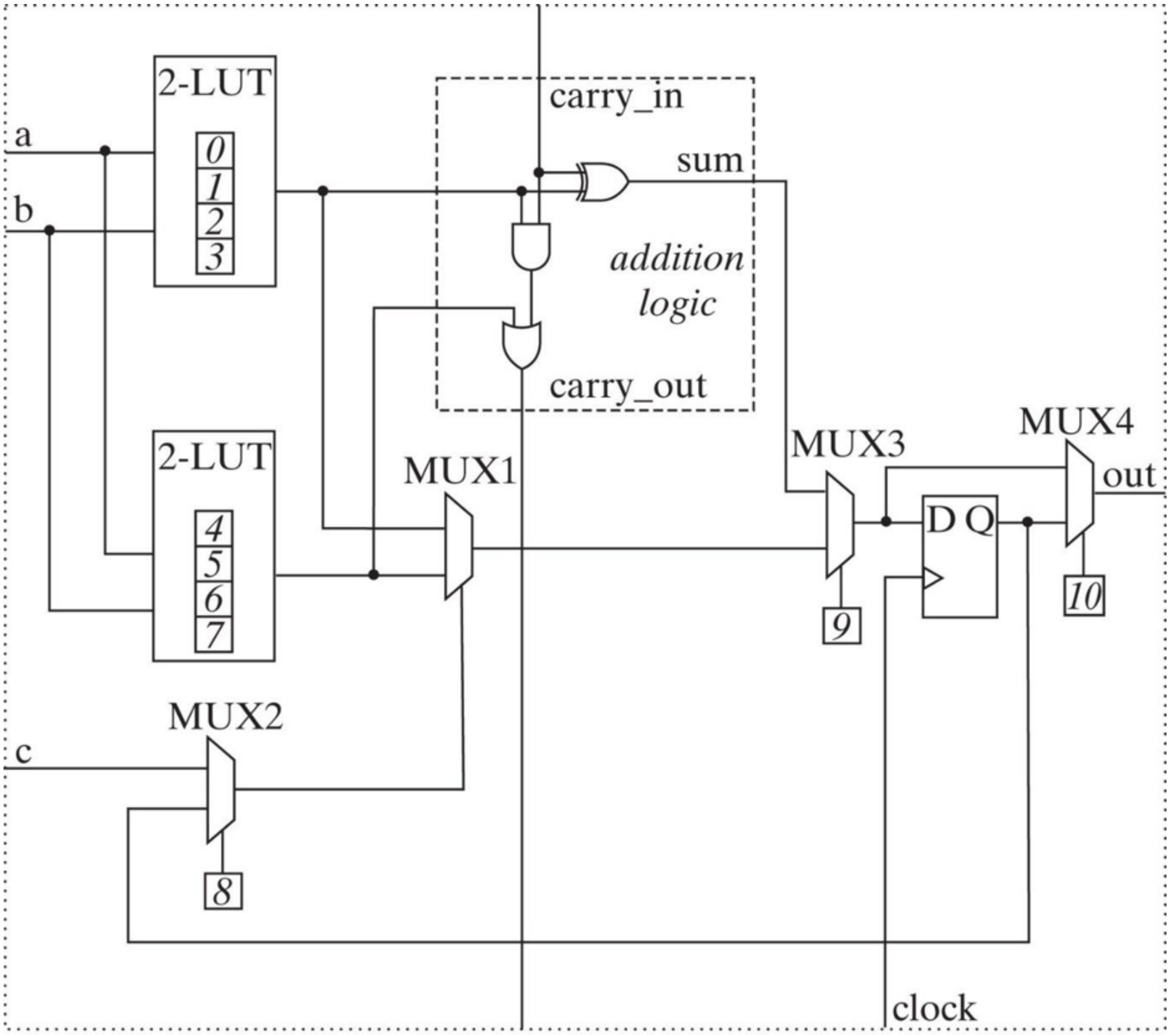

Figure 3. An Example of a Programmed Logic Block

The FPGAs are usually programmed using hardware description languages (HDL) such as Verilog and VHDL. It is important to remember that HDLs are not programming languages, which are highly abstract computer languages. HDL is precisely what its name implies: HDL describes the intended structure of the hardware.

```
module   Reset_Delay(iCLK,oRESET);
input    iCLK;
output reg  oRESET;
reg    [19:0]    Cont;

always@(posedge iCLK)
begin
   if(Cont!=20'hFFFFF)
   begin
      Cont   <= Cont+1;
      oRESET    <= 1'b0;
   end
   else
   oRESET    <= 1'b1;
end

endmodule
```

Figure 4. Sample Verilog Code

APPLICATIONS

Advantages

1. Programmability: field-programmable after manufacture by any user.
2. Portability: since the chip barely has any software, as long as the inputs and outputs match, any FGPA chip can replace the others in the digital system.
3. Real-time: FPGAs are programmed in hardware level. While only instructions are sent to processors. This means FPGA-based systems are much more efficient.
4. Parallelism: unlike commercial sequential processors, FPGA utilizes lookup-tables, and combinational logic, which allows masive parallelism, instead of merely sequential logic.

Disadvantages

1. High power consumption
2. Higher cost to mass-produce: it likely costs the manufacture more to mass-produce FPGAs than to mass-produce general-purpose processors.
3. Volatility: programs are destroyed after poweroff
4. Long boot time: with the chip itself being volatile, the FPGA must rely on integrated non-volatile memory, which takes a long time to load the program.

Usage

1. Finite State Machine: FPGAs are perfect for implementing state machines thanks to its many LUT.
2. Microprocessors/Processors: the FPGA can also become general-purpose system which process instructions.
3. Digital signal processing: thanks to its effective parallelism, the chip can process a massive set of data concurrently.
4. Image processing: before GPUs became powerful and popular, FPGAs were a viable to implement hardware acceleration in computer graphics.
5. Data processing: TangerineSDR
6. Artificial intelligence: many research are being done to effectively execute large and repeated calculations of machine learning on FPGAs.

The sky is the limit!

EXAMPLES

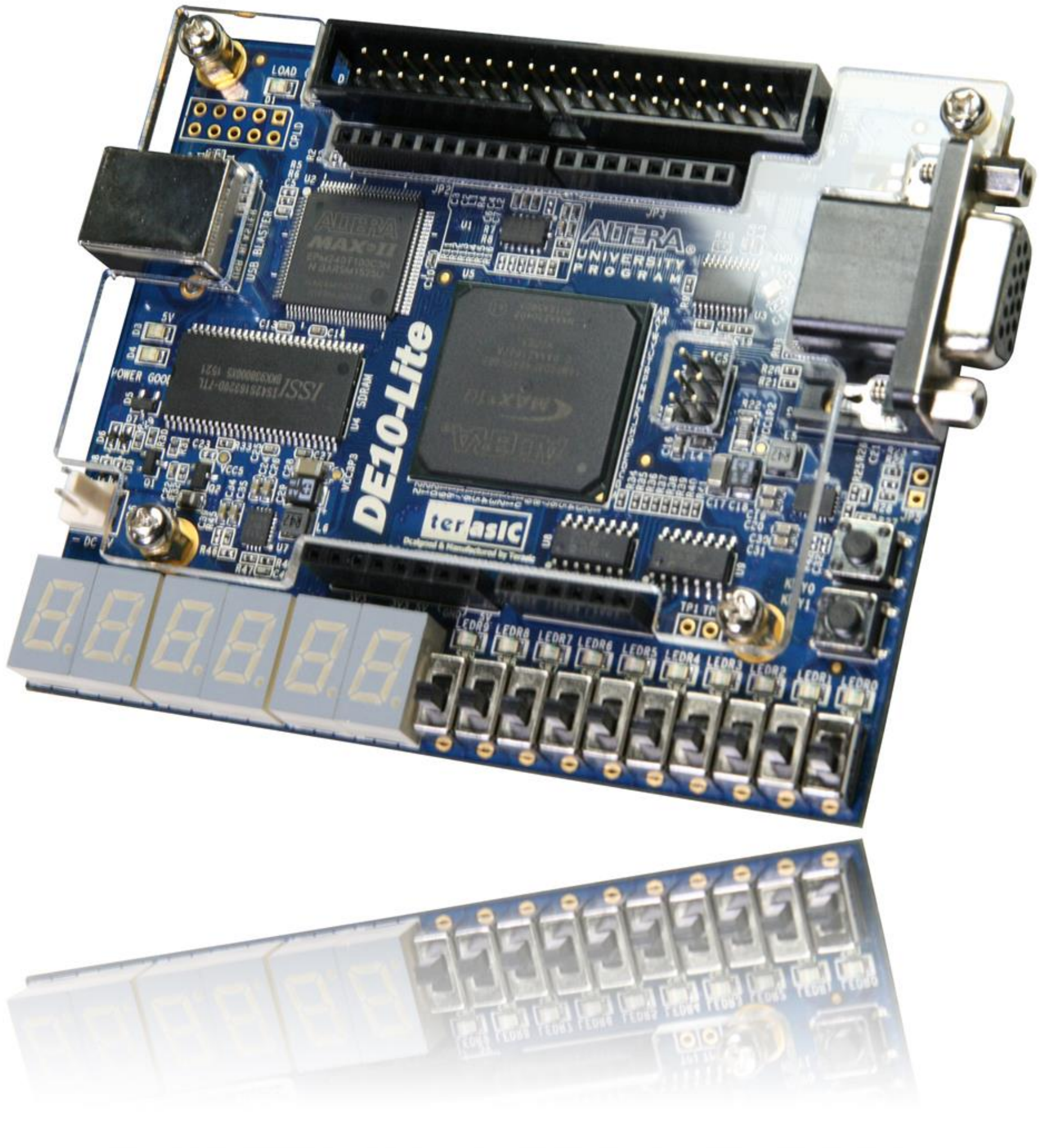

Figure 5. DE10-Lite featuring an Altera MAX 10 FPGA Chip

Some notable characteristics of this FPGA:

- ~50,000 logic elements
- 360 pins
- 200MB of memory
- 288 embedded multiplier 9-bit elements
- 3 internal clocks with max frequency of 50MHz
- 2 ADC blocks
- Internal user-flash memory for non-volatile storage
- An affordable price tag of $85 ($50 for academic purchases)

Demonstrations

These are very primitive demonstrations of the FPGA chips. They barely skim the capability of the technology. The video below shows a 32-bit counter implemented with a MAX 10 FPGA chip on DE10-Lite board. The LEDs are displaying the state of the ten most significant bits. The Verilog program requires less than ten lines.

[VIDEO] https://www.youtube.com/embed/NLFJbkSoHlM?rel=0&fs=1&modestbranding=1&rel=0&showinfo=0

Adding a comparator to the counter, the chip can output PWM signals to control DC motors. Below is a simple line following robot fully controlled by the FPGA board. The robot utilizes variable PWM signals allowing it to slow down on turns and speeds up on straight paths.

[VIDEO] https://www.youtube.com/embed/5zItv1u5jNw?rel=0&fs=1&modestbranding=1&rel=0&showinfo=0

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