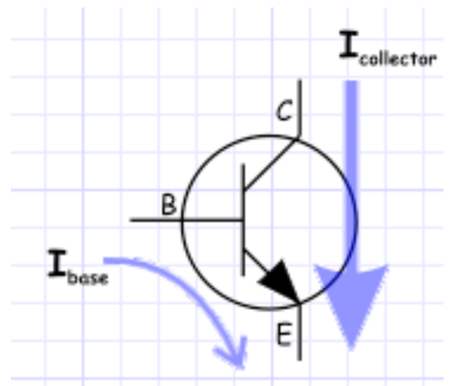
ADVANCED TOPIC: More on Digital Electronics (a whirlwind tour) and the basics of a computer

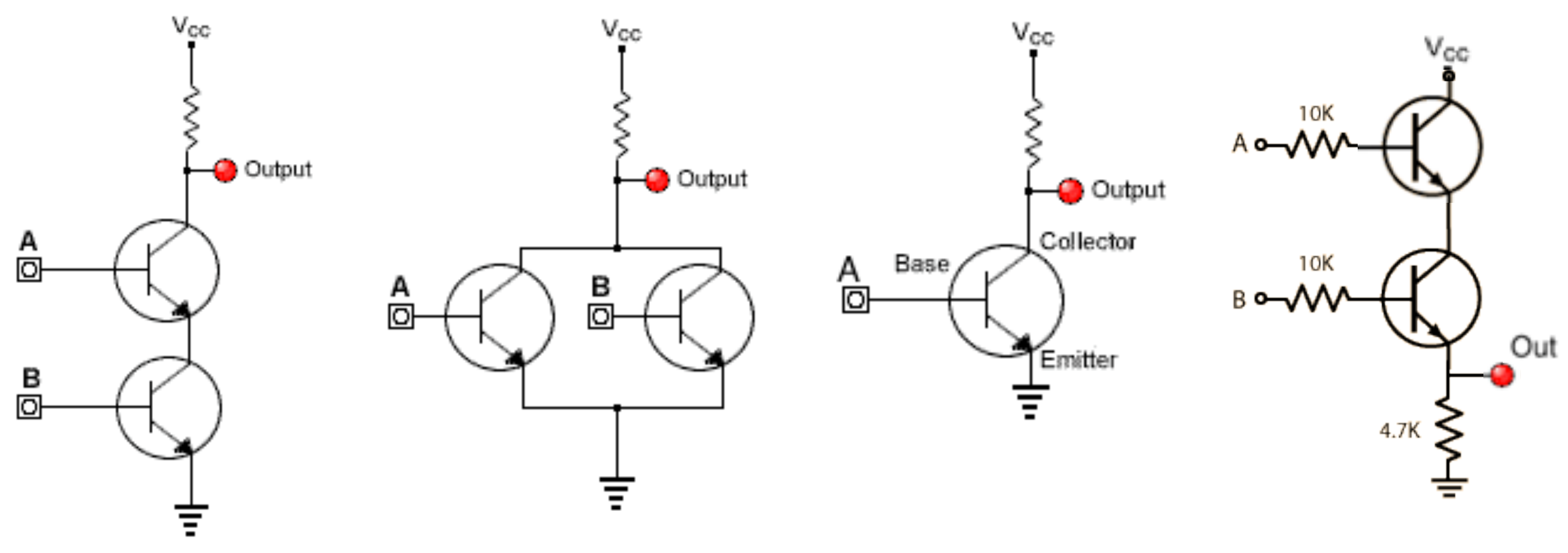
Remember from last time we showed that a basic transistor, invented in 1947, could work as a high-speed switch; pictorially, the first transistor:



The schematic equivalent, for an NPN transistor

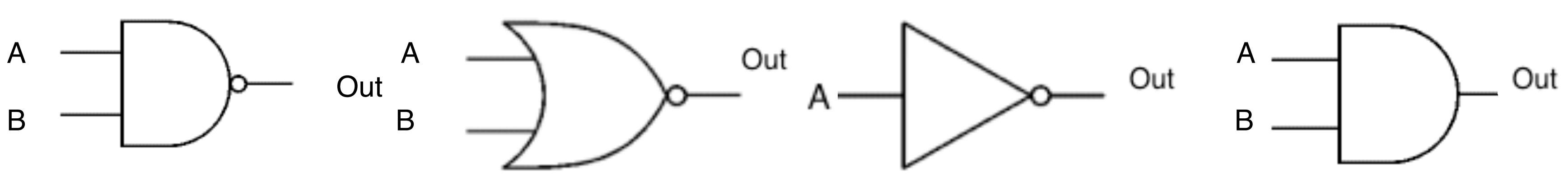
Note that there are three basic parts, the Collector, Base, and Emitter; by controlling the Base, B, electrons will move from the Collector, C, to the Emitter, E. The base is "controlled" by applying a current to the wire associated with B. When a current is applied, electrons flow from C to E; when current is not applied to B, electrons do NOT flow from C to E. Hence the transistor can be used as a high-speed switch.

By using transistors, basic logic circuits can be constructed, including:



NAND NOR NOT AND

Equivalent Symbols (note that the circle after the larger image denotes NOT):



NAND NOR NOT AND

Truth Tables:

NAND:

A	B	Out
0	0	1
0	1	1
1	0	1
1	1	0

NOR:

A	B	Out
0	0	1
0	1	0
1	0	0
1	1	0

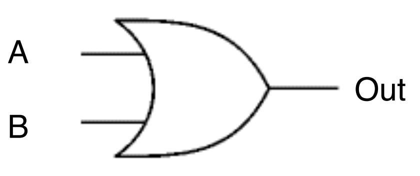
NOT:

A	Out
0	1
1	0

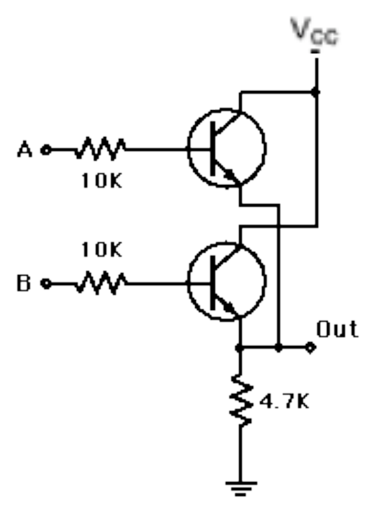
AND:

A	B	Out
0	0	0
0	1	0
1	0	0
1	1	1

For completeness, the OR gate:

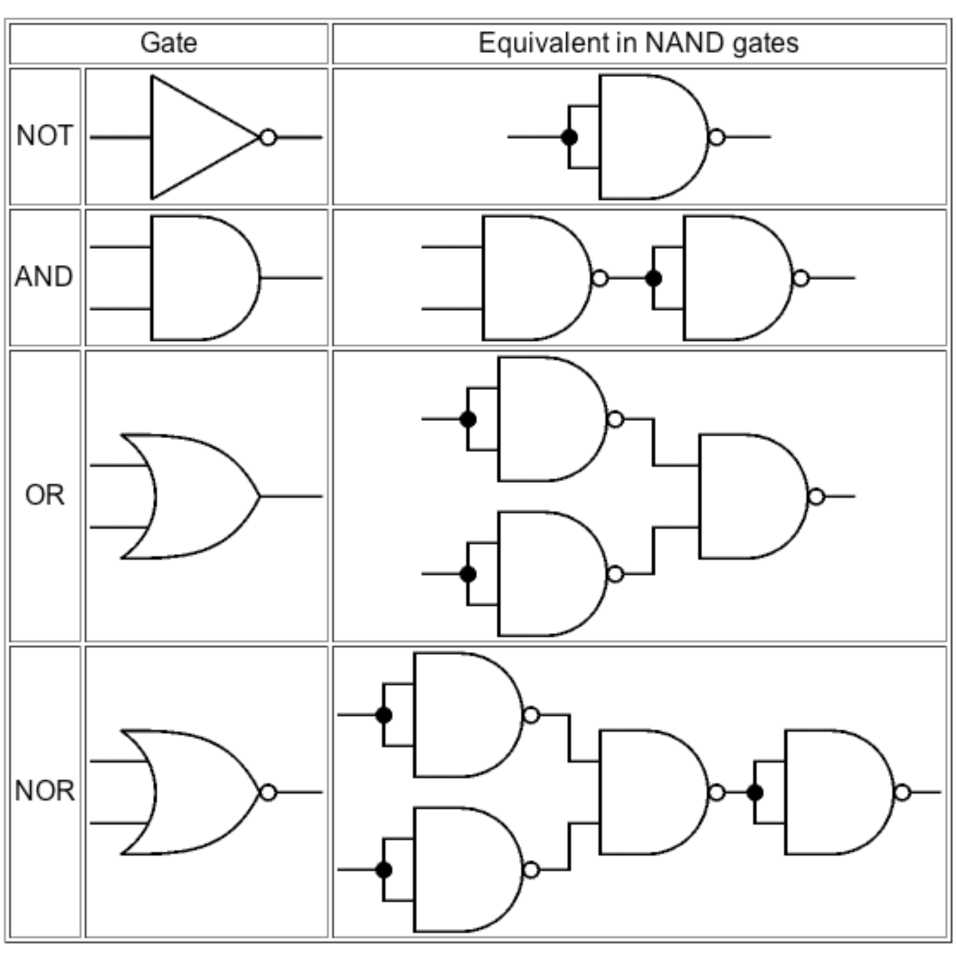


A	B	Out
0	0	0
0	1	1
1	0	1
1	1	1

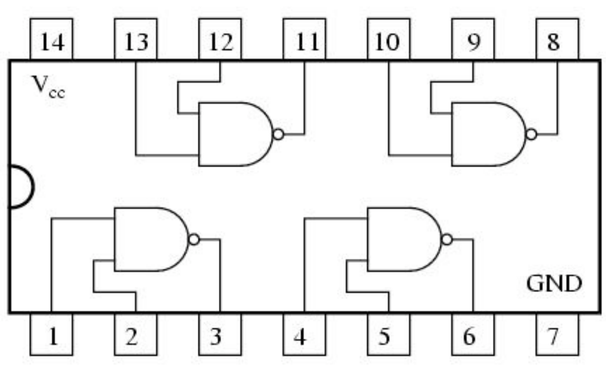


Notes:

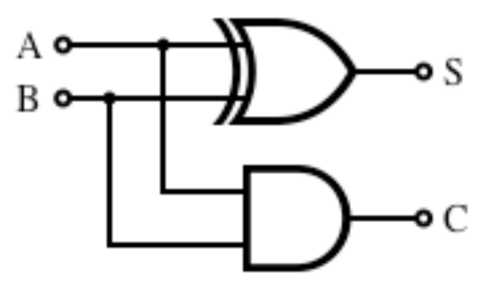
1. There is a significant amount of detail left out in this lecture that spans the basic transistor, to Integrated Circuit to a full-up Central Processing Unit (CPU)
2. NAND gates are frequently used in the "real-world" as most gates/circuits can be constructed from NAND gates, please see below:



3. Packaging of four, two-input, NAND gates on an Integrated Circuit (IC)

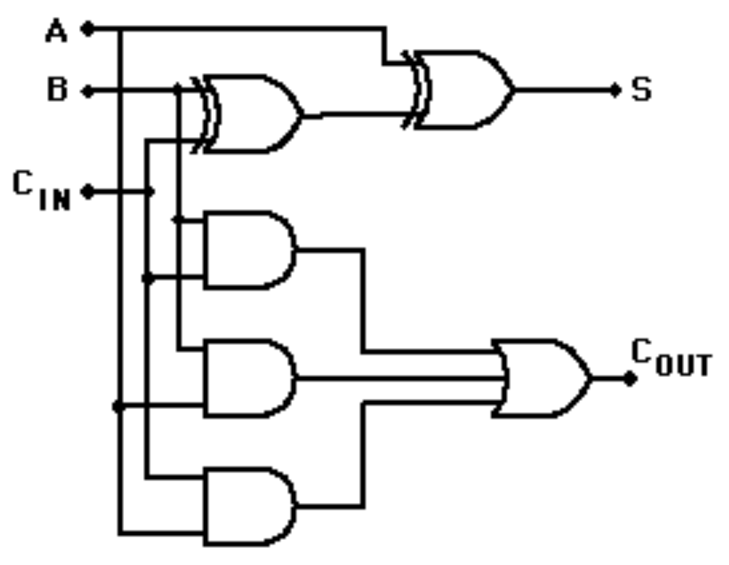


From these very basic logic circuits, more complex circuitry can be created, in this case a Half-Adder:



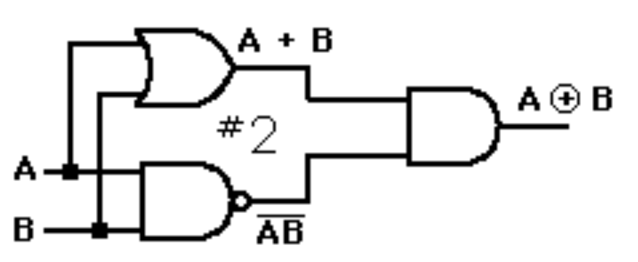
Inputs		Outputs	
A	B	C	S
0	0	0	0
0	1	0	1
1	0	0	1
1	1	1	0

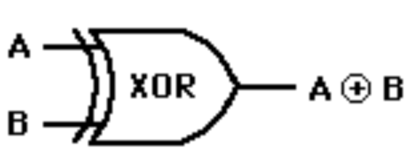
Next a Full-Adder:



Input bit for number A	Input bit for number B	Carry bit input C_{IN}	Sum bit output S	Carry bit output C_{OUT}
0	0	0	0	0
0	0	1	1	0
0	1	0	1	0
0	1	1	0	1
1	0	0	1	0
1	0	1	0	1
1	1	0	0	1
1	1	1	1	1

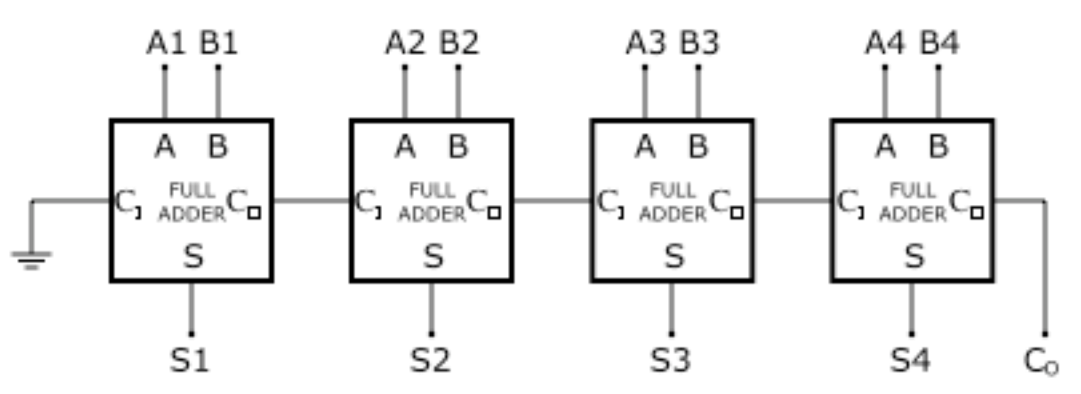
Exclusive Or Gate:





A	B	Out
0	0	0
0	1	1
1	0	1
1	1	0

Adding two four bit numbers (a four bit adder):

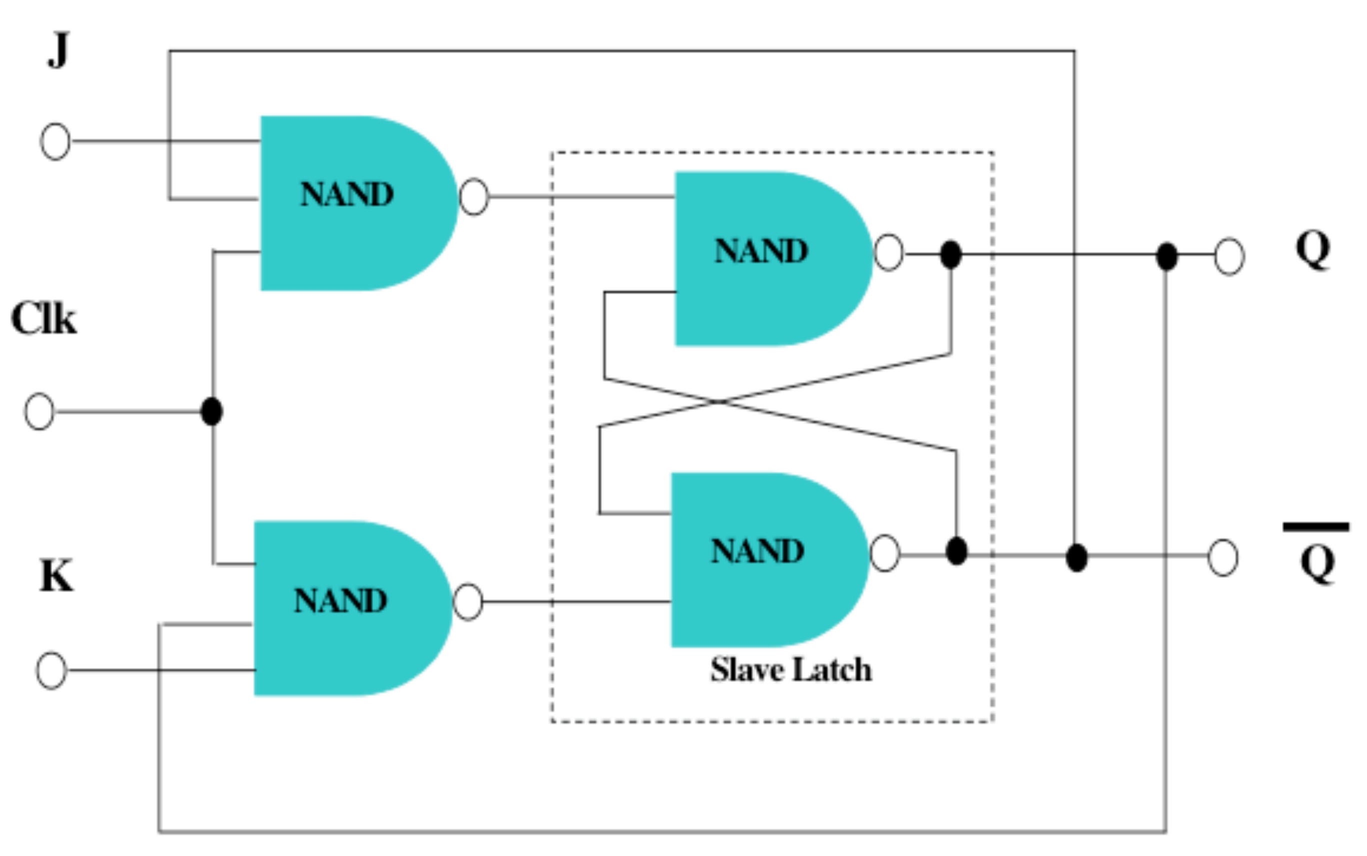


The above circuit certainly works, but how is the data "saved" or "stored" for subsequent operations?

Please see the next page...

Saving/Storing Data:

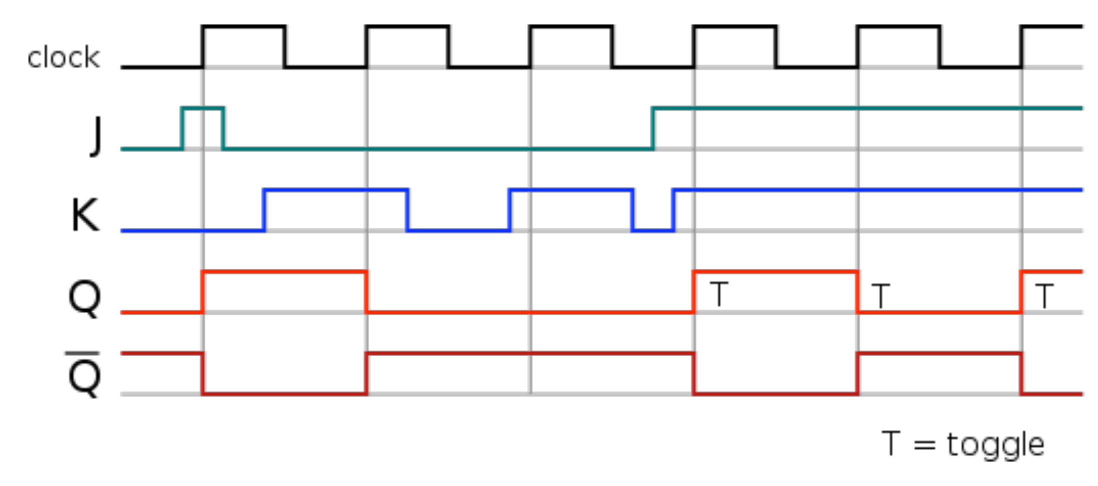
A J-K Flip-Flop, which can be used to create registers to store data (note that the clock, Clk, supports state change:



Truth Table:

J	K	Clk	Q	Q_bar
0	0	Pos-edge	No change	
0	1	Pos-edge	0	1
1	0	Pos-edge	1	0
1	1	Pos-edge	Toggle	

Timing Diagram:



Basic structure of a Central Processing Unit (CPU):

ALU - Arithmetic Logic Unit

Example CPUs:

Intel 8088
Intel i7

Motorola 6152
Motorola 68000

PowerPC 603e
PowerPC G4

ARM A8-Cortex
ARM A4 (PA Semiconductor/Apple)

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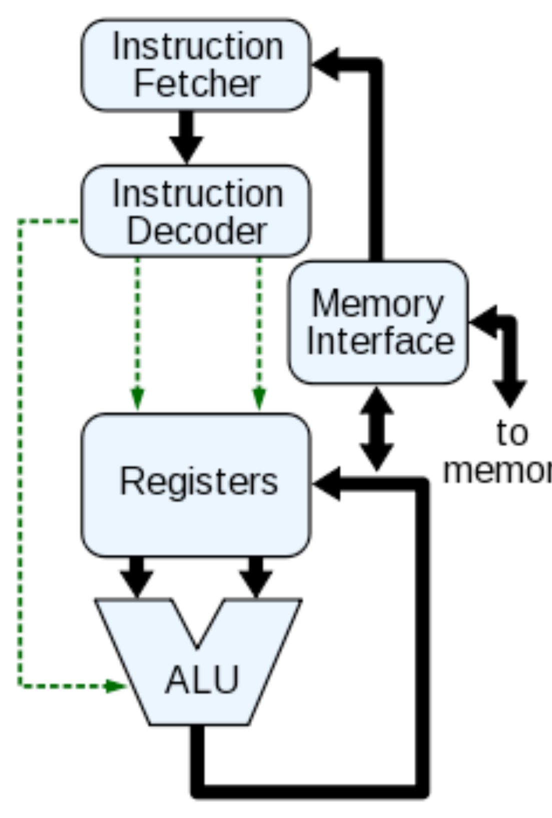
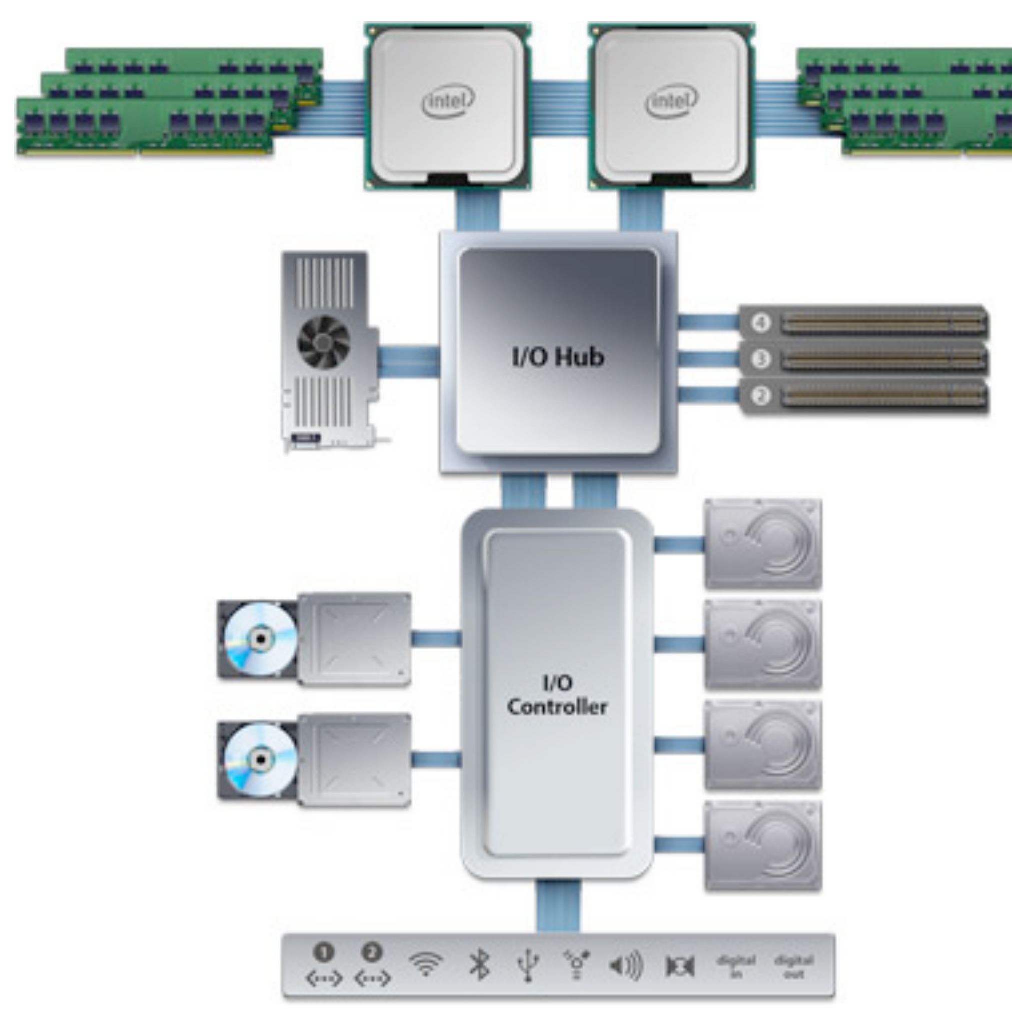


Sample (High-End) Computer Architecture (Apple Mac Pro) includes two CPUs and up to 12 cores:

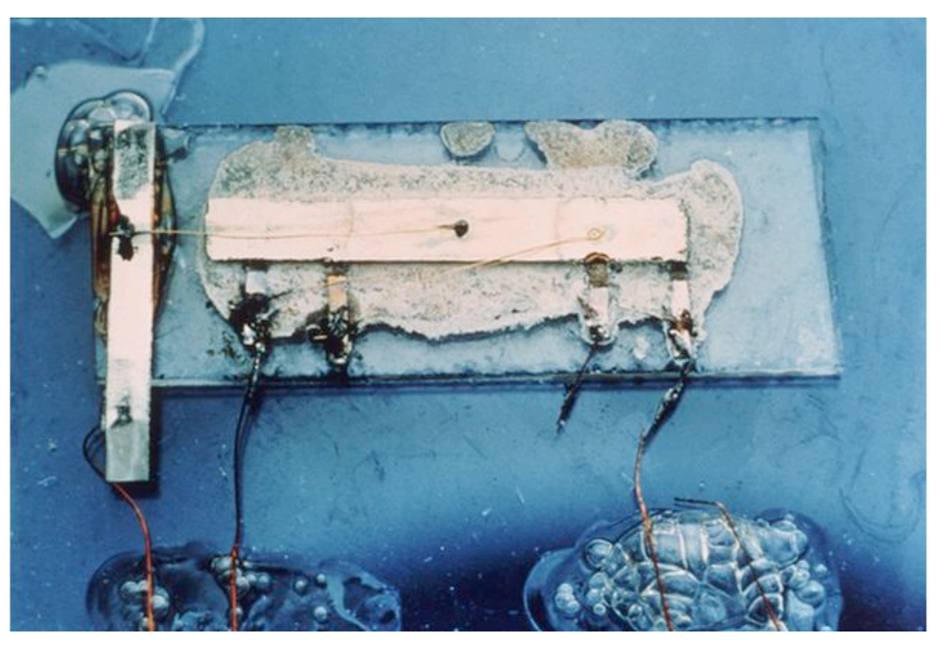


Closing Notes:

1. Flip-flops can be used to create registers that change over time using a clock, which in turn supports a change of state.

2. There are many, many, many details that have been omitted for brevity, many of which are covered in later computer science courses, physics courses, and electrical engineering courses.

3. As Previously noted, the major breakthrough in computing occurred with the invention of the Integrated Circuit (IC) by Jack Kilby on September 12, 1958 (picture below) and six months later by Robert Noyce.



4. The IC solved the ***Tyranny of Numbers*** problem, which in short is:

"For some time now, electronic man has known how 'in principle' to extend greatly his visual, tactile, and mental abilities through the digital transmission and processing of all kinds of information. However, all these functions suffer from what has been called 'the tyranny of numbers.' Such systems, because of their complex digital nature, require hundreds, thousands, and sometimes tens of thousands of electron devices."

-J.A. Morton, Bell Laboratory

Morton was a vice president at the famed Bell Laboratories, and the quote above is taken from an article he wrote celebrating the 10th anniversary of the invention of the transistor. At this time, man was at the point that he has reached so many times: on the brink of a revolution, in need of a visionary to get the ball rolling. Just as chemistry and physics were thought to be almost complete until Heisenberg and Bohr's work transformed them completely, the world of electronics had reached a standstill. Ten years earlier, the transistor had seemed to represent the breakthrough that was needed. Rather than wasting vast amounts of space with vacuum tubes, engineers could now use a small piece of silicon to perform the same functions in a small fraction of the space.

Unfortunately, there was not yet any way of minimizing the size of other components. Resistors, capacitors, and other important components were still huge, and still needed to be connected with wires. As a result, any large circuit was almost impossible to create, and even more difficult to mass produce. This was compounded by the tremendous size of such a circuit. Many people had proposed elaborate circuits to perform elaborate functions, but because of the tyranny of numbers, they were unable to be built. Many large manufacturers of electronics poured vast amounts of money into solving the problem, but it was Texas Instruments who had the first breakthrough.

An electrical engineer named Jack S. Kilby was the first to solve the problem, in what became known as the monolithic idea. He was the first to propose the integrated circuit, although Robert Noyce proposed a similar design independently a short time later. It was these two innovators who are responsible for every integrated circuit in existence.

Sources:

http://en.wikipedia.org/wiki/Tyranny_of_numbers

http://everything2.com/title/The%2520Tyranny%2520of%2520Numbers

The Chip by T. R. Reid; Publisher: Random House; Copyright: 1985, 2001; ISBN: 0-375-75828-3