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, electrons will move from the Collector, C, to the Emitter, E. The transistor is "controlled" by applying a current to the base as appropriate with B. When a current is applied to the base, 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:

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<th>NAND</th>
<th>NOR</th>
<th>NOT</th>
<th>AND</th>
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<tr>
<td><img src="image" alt="NAND Circuit" /></td>
<td><img src="image" alt="NOR Circuit" /></td>
<td><img src="image" alt="NOT Circuit" /></td>
<td><img src="image" alt="AND Circuit" /></td>
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Equivalent Symbols (note that the circle after the larger image denotes NOT):

For completeness, the OR gate:

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<th>A</th>
<th>B</th>
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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 circuits can be created, in this case a Half-Adder:

Exclusive Or Gate:

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:

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<th>J</th>
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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

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 by being too small, many of which are extra 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 problem of the "tyranny of numbers," which was:

"For some time now, electronic man has known how to "intelligently" fix, bundle, and account devices in such ways that he is able to realize thousands and millions of levels of the interworking. Unfortunately, all these functions or a small fraction of the space."

The quote above is taken from an article he wrote celebrating the 10th anniversary of the invention of the integrated circuit (IC). The IC solved the problem of the "tyranny of numbers," 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

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Unfortunately, there was not yet any way of miniaturizing the use 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://everything2.com/title/The%2520Tyranny%2520of%2520Numbers