History of the Z80

The Z80 was introduced in July 1976, and is still available and in use today. The peak of its popularity was during the late 1970s and early 1980s.

The history of the Z80 goes back to the Intel 4004 processor, which was designed in 1970 by a team led by Federico Faggin. One of the other team members was Masatoshi Shima. The 4004 is famous, of course, as the world's first microprocessor. Faggin and Shima worked together at Intel on the highly-popular 8080 microprocessor, which came out in 1974.

At the end of 1974, Faggin became frustrated by Intel's lack of focus on microprocessors. Although it may be hard to imagine now, given Intel's dominance of the microprocessor industry, at the time Intel's main focus was on computer memory. Microprocessors were mainly viewed as a way to sell more memory. In addition, the US economy was in a recession, which was putting stress on Intel. Finally, Faggin was getting less control over microprocessor design.

These factors motivated Faggin to leave Intel and form his own company. He founded Zilog, becoming its CEO. Ralph Ungermann was leading Intel's microprocessor group and also left to join Zilog. They were joined in 1975 by Masatoshi Shima.

Shortly after they started their company - and before it was even named - Zilog came to the attention of Exxon Enterprises, which was an investment subsidiary of Exxon Corporation. Strange as it may seem, Zilog's early financing in came from Exxon. This was fortunate for Zilog, since there was hardly any venture capital funding available in 1975. Exxon Enterprises provided $500,000 to Zilog, and Zilog ended up spending $400,000 to develop the Z80. This amount seems impossibly low given the enormous sums spent on microprocessor development now. Intel spends billions of dollars annuallyon R&D (http://techreport.com/forums/viewtopic.php?f=2&t=79081)

Faggin started designing a single chip microcontroller, which he called the

2001. The chip would have been comparable to the Intel 8048 microcontroller. However, after investigation, he realized that margins were low on microcontrollers, and since Zilog didn't have its own chip fabrication, they wouldn't be able to compete on price.

Instead, Faggin decided to build a microprocessor along with a family of peripheral chips, and called this processor the Super 80. Unlike the 8080, which required three power supplies (+5, -5, and +12), the Super 80 would need just a single 5 volt supply. In addition, the Super 80's external bus would be designed to work well with peripherals, and handle interrupts well.

Faggin proceeded to design the Z80's architecture, starting in February 1975. He wanted it to be machine-code compatible with the 8080, but also include the best features of the 6800: index registers, 16-bit operations, and a better interrupt structure. At this point, he also came up with the idea of a double set of registers that could be exchanged with a single instruction. At this point Shima joined the team and started to flesh out the design, from the chip architecture to the logic design.

Meanwhile, Ungermann was designing the family of peripheral chips to go with the Z80. He also built the software simulator that they used to test the Z80 design.

In those days, laying out the masks for a chip was a manual process, involving drawing the circuits on mylar and forming masks with a translucent plastic masking film called Rubylith. The layout of the Z80 was slow and threatened to delay production of the chip. The 8080's layout took 6 months, and the Z80 had about twice as many transistors as the 8080, so there was a lot of layout to do. Faggin started doing most of the layout himself, putting in 80-hour weeks for 3 1/2 months to get it done in time. Keep in mind that he was the CEO, yet he was doing the manual drafting!

At that point, Zilog was a company of only 11 people. It's hard to imagine such a small team building a successful microprocessor.

Principles of the Z80 design, according to Shima (ref: oral history)

1. Keep binary compatibility with the 8080
2. Provide two index registers, to go after the 6800's market and exceed its functionality.
3. Include two complete sets of registers (including program counter) to provide fast task switching.
4. Provide a flexible system bus, allowing slower memory to be used.
5. Use a one-phase clock instead of a two-phase clock to simplify system design.
6. Add powerful, new instructions to pull users away from both the 8080 and 6800. Specifically, 16-bit data transfers and calculations, bit operations, string operations, and better branch and indexing(?)

Shima also gave seven design challenges:
1. Get higher performance than the Intel 8080 and the Motorola 6800.
2. Expand the instruction set
3. How to differentiate Z80 logic from 8080 logic (?)
4. Use a one-hase clock
5. Make the chip as small as possible.
6. Avoid layout problems. (Shima found the 8080 layout to be difficult and wanted to avoid these issues in the Z80.)
7. Prevent other companies from copying the layout of the Z80.

Design solutions:
Shima used an opcode prefix for index register X and for index register Y. This also provided access to the lower or higher half of the index register, but they didn't publish that. (Undocumented instructions?)

To differentiate the Z80 logic from 8080 logic, he used many new design technologies:
1. One phase clock instead of two-phase
2. 4-bit ALU instead of 8-bit
3. Storing the accumulator and flags in the register file.

He pipelined the 4-bit ALU. He added pipelining among instruction executions. Instruction fetch took at least 4 clocks and instruction execution took at least 4 clocks, but these were overlapped.

The 8-bit internal data bus had large transistors to divide the bus into 4 sections, so it could perform multiple operations concurrently:

1. instruction fetch
2. accumulator-related operations
3. flags-related operations
4. The fourth data bus was inside the ALU

Inside the register file, the general-purpose registers are separated from the PC and Stack Pointer. (Note: this is incorrect; the IR register is with the PC.) This allows concurrent operations.

These changes from the 8080 brought chip size reductions and no problem with ALU performance, and lots of space for flag logic. Due to the different type of transistors, clock speed could be increased 25%.

The external system bus was also improved over the 8080. In the 8080, half a clock was wasted for address output and instruction fetch. The Z80 read address information from the register file, allowing it to be output half a clock sooner. Instruction fetches were also more direct in the Z80, first going to the input buffer and then the instruction register. As a result, the Z80 could use two-clock instruction fetch, compared to three-cycle on the 8080.

Adding new instructions was made very difficult since the 8080 had just 12 unused opcodes. Shima used 6 opcodes for relative branches. Another opcode was used as a prefix for bit operations, rotate operations, and shift operations. Two opcodes provided exchange of the register sets, and exchange of the accumulator/flags. Another instruction prefix supported string operations, 16 bit data transfer, 16 bit addition and subtraction, I/O instructions, register indirect addressing. And two instructions were used for indirection prefixing.

Principle 3 turned out to be too complex, so they ended up with a subset of registers being duplicated.

Manufacturing

Zilog started using Synertek as the fab for their chips, since they didn't have a fab of their own. However, as the Z80 grew in popularity, Synertek wanted to become a second-source, manufacturing and selling Z80 chips themselves. At that point, Zilog started using Mostek as the fab, since Mostek was the only other foundry with the manufacturing process that Zilog needed - the five volt process.

After the Z80 was successful, Exxon Enterprises funded a fab for Zilog. These days a modern fab costs billions of dollars, but back then a fab could be built for 3 or 4 million dollars.

Partnering with another company to second source the chip was a big challenge for Zilog. Many companies won't buy chips unless they are second-sourced, that is there is a second company that manufactures and sells the chip. This reduces the risk for companies buying the parts. If a single manufacturer produces the part, they could discontinue the part, hike up the price, reduce supply, or go out of business entirely. But if a component is second-sourced, the risk is much lower. Since Zilog had a second source for the Z80, while Intel was the sole supplier of the 8080, this was a factor that made customers prefer the Z80.

Building their own fab reduced the risk to Zilog of the second-source company taking over the business entirely, since Zilog was no longer dependent on another manufacturer. Also, they had higher profit margins since they were making the chips. Faggin estimates that Zilog ended up with 60-70% of the Z80 market. One way Zilog prevented Mostek from taking over was they didn't give Mostek access to the development systems and software, so Mostek couldn't get control of the entire value chain.

Although the funding from Exxon was very important at the beginning, Exxon became a problem later on. Exxon had plans to create an information technology company (Exxon Office Systems) to compete with IBM, around 1978-1979. Their company Videc made word processors. Quiz made electronic typewriters. Quip made fax machines. Qume made printers, and they had many other companies. The consequence was that many computer companies viewed Exxon as a competitor, which made them less comfortable with using Zilog chips. Faggin says that this is one of the reasons the IBM PC didn't use the Z80.

Challenges

According to Faggin, the main challenge facing Zilog with the Z80 was producing a successful chip in a short amount of time with limited money. They were worried that Intel would beat them to market with an improved 8080.

The 8085 (a slightly improved 8080 that requires a single 5 volt supply) came out about a year after the Z80. According to Faggin, this chip wasn't a significant competitor to the Z80. Ironically, the peripheral chips that Intel was selling at this point were ones started by Faggin while he was still at Intel, so he ended up competing against his own chips.

The Z80 was about 200x200 mils, with a 5 mil process size. Because Zilog didn't have their own fab, Faggin had to use design rules that would work with multiple fabs, instead of optimizing the design for a specific fab. The minimum line was 6 microns.

Chip scaling was beginning to emerge at this time, and Zilog used this to shrink the Z80 by 20% when moving to Mostek for fabrication. Intel is said to have been slow in adopting scaling, which is interesting given the heavy emphasis Intel puts on scaling chips down now, with their Tick-Tock model.

Zilog used an interesting technique to prevent companies from taking photographs of the Z80 and copying the masks. To prevent this, they realized that they could create depletion load transistors that visually looked like enhancement mode transistors. If a company copied the Z80 based on the visual appearance of the die, the transistors would be wrong and the Z80 clone would fail.

Shima added six traps. He added a transistor that looked like an enhancement transistor to existing enhancement transistors. He said that NEC copied the Z80, but these traps delayed NEC's copy by six months. According to Faggin, NEC was the first customer to purchase a Z80, which they then proceeded to clone. The story is that while Zilog was still packaging up the Z80, someone from NEC came buy with four $100 bills to buy two chips. He was followed by another Japanese company who bought more chips.

These traps caused problems for the visual 6502 team as well. Since the visual 6502 team created masks based on die photos, these transistor traps ended up in the visual 6502 masks. Fortunately we were forewarned about the traps, so we could look for them. A later chapter describes these traps in more detail.

Shima gives a total transistor count for the Z80 of 8200, compared with 4800 transistors for the 8080.

The original price for the Z80 was $200, but the price rapidly dropped. Cromemco was one of the first companies to purchase the Z80; they built lines of high-end Z80 computers as will be discussed later.

Other companies that used the Z80 were the TRS-80 from Radio Shack. Quiz used the Z80 in an editing typewriter. The Videc word processor used the Z80 - Videc was another Exxon Enterprises company.

Because of its string block move instructions, the Z80 was popular with word processing.

Fidelity Electronics used the Z80 in a chess computer, which used between 100,000 and 200,000 chips per month.

Faggin estimates that over two billion Z80s were sold, excluding Z80 cores embedded in ASICs.

The company name originally had the strange capitalization ZiLOG, and came from Integrated LOGic. (“Z for the last word of Integrated Logic”)

The Zilog company was founded by Federico Faggin in 1974.

Reference: Z80 oral history http://archive.computerhistory.org/resources/text/Oral_History/Zilog_Z80/102658073.05.01.pdf

Uses of the Z80

The Z80 could be used in computers such as the Altair 8800 and IMSAI, to replace their 8080 processor. Since these computers used the S-100 bus, the processor card could be removed and replaced with a Z80 card. Such Z80 cards were made by companies such as Ithaca Audio and Technical Design Labs (TDL). Full S-100 computers with the Z80 were the http://en.wikipedia.org/wiki/NorthStar_Horizon, Cromenco, Industrial Micro Systems, and many other companies.
These computers were often soldered together and assembled by hobbyists, with varying degrees of success.

reference:
http://s100computers.com/Hardware%20Folder/IMS/History/History.htm

The Z80 was used in many personal computers. The Osborne 1 portable computer used the Z80 and ran the CP/M operating system. The Radio Shack TRS-80 was a highly-popular home computer running the Z80. Sinclair's ZX80, ZX81, and ZX Spectrum home computers also used this processor. The Commodore 128 computer included a Z80 processor as well as a 6502-family processor.

The Z80 controlled many video games of the 1980s, such as Pacman, Frogger, Galaga, and Dig Dug. It also powered home video games such as the Sega Genesis and ColecoVision.

The Z80 also powered various music synthesizers of the 1980s, such as the Prophet 5, Jupiter 8, MemoryMoog, and E-mu Emulator.

The Z80 was very popular as an embedded processor, and is still in use today, but its use is declining. 8-bit processors are becoming less popular for embedded systems, and 16-bit and 32-bit processors are taking over the market. However, some embedded systems still use the Z80. ZiLOG sells

Z80-based microcontrollers such as the eZ80Acclaim!® Flash Microcontroller.

Ref: wikipedia http://en.wikipedia.org/wiki/Zilog_Z80

One common product that still uses a Z80 is the graphing calculator. In particular, the TI-73, TI-81, TI-83, TI-84, and other models are built around the Z80.