The VLSI revolution at MIT *by Paul Penfield, Jr.*

Remember the VLSI revolution? If you are over 50, you might. If not, you have probably heard about it. In the late 1970s the VLSI (Very Large Scale Integration) revolution opened up the design of integrated circuits to people who did not know anything about device physics or semiconductor processing.

This was first demonstrated here at MIT. Below is the story of the two people, Lynn Conway (photo lower right) and Professor Jonathan Allen (photo right), who made it happen. Ideally, these two should tell the story, and Conway has written a compelling account from her perspective, "MIT Reminiscences: Student years to VLSI revolution", http://ai.eecs.umich.edu/people/conway/Memoirs/MIT/MIT_Reminiscences.pdf. Sadly, Allen died in 2000 but I will try to tell the story from the MIT EECS perspective here. Please read both accounts.

Although in the 1950s and 1960s our department (named EE at the time) was innovative in using physical device models to teach electronics, we consciously decided not to expand research in silicon devices and circuits because we thought industry could do it better.

The rise of computer science made us rethink that decision. In the early 1970s we decided not to split into separate EE and CS departments but stay united, under the new name EECS. Then we realized that our research in computer architecture and digital systems was hindered: testing new ideas in the form of hardware required LSI (large-scale integration) that was available only in industry. Allen knew this both from his own research in speech technology and through serving as Associate Director of the Research Laboratory of Electronics. He wanted fabrication as a service, not something he and other digital hardware designers would have to know how to do.

Meanwhile a revolution was brewing in California. Professor Carver Mead at Caltech had used industry connections to get student projects fabricated and the students loved it. A group centered around Lynn Conway at Xerox PARC (Palo Alto Research Center) set out to make designing integrated systems so simple that lots more people could do it. Both Stanford and Berkeley (who had continued their research in silicon devices) were interested.

In 1977 we decided we had to get on board. Several decisions followed. To keep true to our decision to stay as one department, we needed relevant research in both EE and CS. That meant: a silicon fabrication facility where research on devices and processes was informed by the needs of digital systems; research in digital systems that could use novel processes; and research on design tools to connect the two. This would address the three central questions about integrated systems: how do you make them, how do you design them, and what should they do.

Professor Jonathan Allen was the sixth Director of the Research Laboratory of Electronics, RLE, and a member of the EECS faculty since 1968. Photo courtesy of RLE.

Lynn Conway (left) in her office at Xerox PARC (1983). On Lynn's desk are the Alto computer she used to write the VLSI textbook, and the TI terminal she used to interact with PARC while at MIT. Photo by Margaret Moulton, courtesy Lynn Conway.

Carver A. Mead (right). Photo taken by Emilio Segre in 1985 on the occasion of the Franklin Institute's John Price Wetherhill Medal presentation to Prof. Mead. Courtesy AIP Emilio Segre Visual Archives, *Physics Today* Collection.

The VLSI revolution at MIT, *continued*

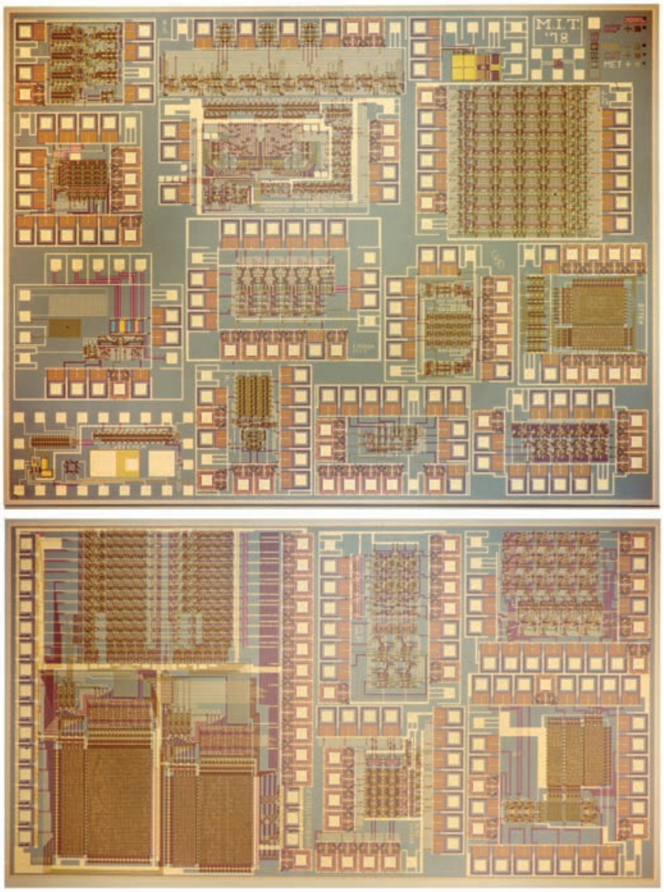
First we wanted to learn what industry was doing. In January 1978 we invited Chuck Botchek to teach to EECS faculty and researchers in many areas (devices, circuits, computer architecture, and AI) a two-week intensive course he had designed for industry. Allen and both EECS Associate Department Heads (Professors Fernando Corbató and Paul Penfield) set the example by attending and doing all the assignments. This was exciting.

But what Conway was doing was even more exciting. She worked intensely with Mead and others to simplify the design process. They recognized that designing a research chip to test out a system idea is not the same as designing a successful chip for an industrial product. You don't have to use an advanced process; on the contrary you are better served by a mature, more reliable, process. You don't have to tweak the layout to minimize space; instead make the layout reflect the logical design of your system so it's easier to debug. You don't need to minimize power usage or maximize speed; instead focus on your innovative ideas. Rapid prototyping is the point, not flawless operation, best performance, or minimum production cost.

Understanding complicated digital systems is helped by abstract modeling, using modules with well defined interfaces. Conway and her colleagues realized that the same is true of the design process itself. They defined standard notations to support designs. One was a language for layouts, CIF (Caltech Intermediate Form) that could be used for the output from layout software programs. Another was simple design rules that had a single length parameter (lambda) that could fit the rules to many processes; this allowed last year's design to be run with next year's process, and also let carefully designed utility circuits be scaled and reused year after year. They even supplied some, including wiring-pad circuits. They knew that modularity and standard interfaces in the design process would stimulate design of VLSI CAD (Computer Aided Design) tools.

They needed to test and refine their simplified design methodology by teaching it. MIT needed to learn the new ideas and contribute to them. So Conway came to MIT and taught a graduate subject in Fall 1978. It was a match made in heaven.

The MIT end of this bargain was handled by Professor Allen. The TA for the course was graduate student Glen Miranker. There were 32 students; several faculty and staff sat in. The course covered the relevant ideas from circuits, devices, switching theory, computer architecture, and digital logic. It also introduced the design abstractions and offered some primitive CAD tools. Students designed projects of their choice and submitted the layout, expressed in CIF. These layouts were combined to form two chips and all this data was sent to Conway's colleagues at PARC who got lithography masks made and delivered to Hewlett-Packard for fabrication. Students got working chips back in the middle of January for testing.

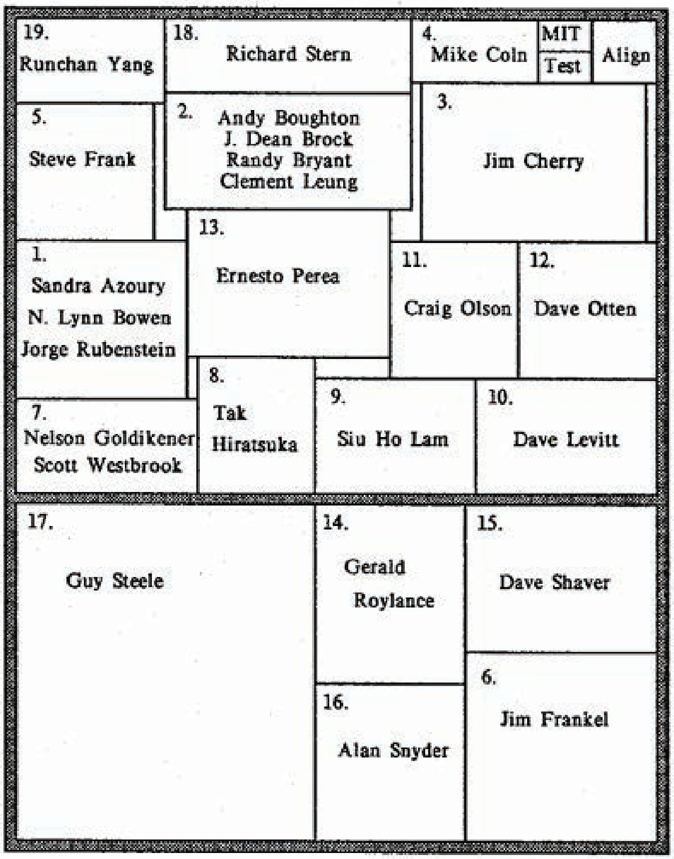


MIT 1978 chip set. Courtesy Lynn Conway

It really worked. This course demonstrated that a person who is not an expert in device physics or semiconductor processes can design an integrated circuit that implements some digital system. This was revolutionary. It was followed by a multi-university multi-project chip in 1979. The Mead-Conway book "Introduction to VLSI Systems" was rapidly published and Conway produced a much-appreciated teacher's guide. Twelve universities offered similar courses in 1979, and 113 as early as 1983. At MIT 6.371 was taught until 2002 by several people, including Professor Allen as recently as 1996.

The VLSI revolution was not just for students. It led to many advances in industrial VLSI design tools, and many custom commercial designs. Eventually the structure of the industry evolved to include large for-profit "foundries" to process custom designs.

The VLSI revolution impacted other areas of manufacturing, not just integrated circuits. Today 3D printing (or additive manufacturing) is becoming very popular. An object is repre-



VLSI project map. Courtesy Lynn Conway

sented by a three-dimensional digital model, created by someone who is not an expert in materials. Then a 3D printer, guided by this model, produces the object. Design and fabrication are separated, just as with VLSI.

At MIT, the new VLSI research program flourished, with the hiring of several new faculty. The new fabrication facility had flexibility that proved ideal for constructing things other than integrated circuits. This has included several innovative MEMS (Micro-Electro-Mechanical Systems) chips with sensors and actuators. Some of these have used variations of CIF to specify layout. There was also a CAF (Computer Aided Fabrication) language developed for specification of processes.

A more general question, which Conway has started to think about, is how the VLSI revolution itself can be repeated in other domains. Perhaps a methodology (with computer tools, of course) can be established for launching other technology revolutions.

EECS should be proud of MIT's contributions to the VLSI revolution. Many of the people with the early ideas were MIT graduates. Many EECS students who took the 1978 course went on to teach similar courses elsewhere, or designed chips using the new methodology at various places.

And, we discovered some 20 years later that even Lynn Conway had an MIT connection we had been unaware of. She had in fact been an undergraduate physics major in the late 1950s, drawing inspiration from the likes of Norbert Weiner and Dudley Buck. (Buck, an EECS faculty member, died in 1959 at age 32).

She did not reveal this connection for a personal reason: although labeled a 'boy' at birth, she had always felt compelled to become a girl. She left MIT while a senior because of the stress of living with this issue. Nine years later she successfully completed her gender-transition, changed her name, and started her career all over again in a new identity. However, she kept her gender history as secret as possible, even after joining the University of Michigan faculty, until about 1999 when reports about her early research work began to circulate. In recent years Lynn has taken a more public position, serving as a role model and advocate for transgender people. She also recently encouraged the IEEE to include anti-discrimination protections for gender identity and gender expression in the IEEE Code of Ethics.

Well done, Lynn.

Thirty years later, Lynn Conway returned to visit the scene of her successful MIT course. Photo, October 6, 2008, courtesy Lynn Conway

Read Lynn Conway's VLSI story: "MIT Reminiscences: Student years to VLSI revolution"

http://ai.eecs.umich.edu/people/conway/Memoirs/MIT/MIT_Reminiscences.pdf