Reconfigurable Computer Origins: The UCLA Fixed-Plus-Variable (F+V) Structure Computer

Gerald Estrin
University of California at Los Angeles

Gerald Estrin and his group at the University of California at Los Angeles did the earliest work on reconfigurable computer architectures. The early research, described here, provides pointers to work on models and tools for reconfigurable systems design and analysis.

Pasta’s challenge
What triggered the UCLA work on reconfigurable computer systems? In the spring of 1959, John Pasta, a highly respected applied mathematician and physicist and chairman of the Mathematics and Computer Science Research Advisory Committee to the Atomic Energy Commission, expressed concern about many vital computational problems whose solutions were beyond the capabilities of existing electronic computers. In his opinion, commercial computer manufacturers had lost interest in exploring risky, innovative computer architectures. Instead, the manufacturers wanted to serve the growing market for conventional computer systems. Consequently, when Pasta visited me at UCLA, he challenged me to propose new ways to organize computer systems in the hope that research advances in the public domain would lead to a surge of computer development in the private domain.

Pasta’s challenge to me was timely. I had come to UCLA from von Neumann’s Electronic Computer Project at the Institute for Advanced Study in Princeton after directing construction of a von-Neumann-type computer at Israel’s Weizmann Institute of Science. Both projects sought to solve problems in applied mathematics and applied physics. The projects motivated me to explore computational concurrency, which had been made more feasible by new semiconductor technology. They also opened the door to departures from the conventional von Neumann machine architecture.

When I joined the UCLA engineering faculty in the fall of 1956, I was partially supported by the Department of Mathematics’ Numerical
Analysis Research Laboratory. NARL was responsible for applied mathematics research and for the Standards Western Automatic Computer (SWAC), whose development had been completed by Harry Huskey in 1952. C.B. Tompkins, head of NARL, had joined Engineering Dean L.M.K. Boelter to aggressively recruit me. During 1957, I was visited by Marshall Yovits, a program manager from the Office of Naval Research (ONR). He suggested that I submit a proposal seeking support for my research at UCLA. In May 1958, I was awarded a contract for research in digital technology. That ONR contract enabled me, in turn, to support research by graduate students and, in the summer of 1959, to totally immerse myself in considering John Pasta’s challenge to extend the capabilities of electronic digital computers.

Reconfigurable architecture response

I presented the first results of my brainstorming at the May 1960 Western Joint Computer Conference in a paper titled “Organization of Computer Systems—The Fixed Plus Variable Structure Computer.” Figure 1, from that paper, illustrates the relations between a fixed general-purpose computer (labeled F) and a variable structure inventory of reconfigurable building blocks (labeled V). The “Reconfigurable Architecture Defined” sidebar quotes from that paper to highlight the primary goal of the proposed new architecture.

Our reconfigurable computer systems research at UCLA sought a new way to evolve higher performance computing from any general-purpose computer. Starting in 1959, we tried to design special-purpose subsystems that could run concurrently with programs in a coupled general-purpose computer. We developed “miniaturized” circuit modules and a removable, replaceable etched signal harness (see Figure 2). We were aware of the gap between available technology and our needs for more automatic electronic control, but the inexorable advances in semiconductor technology were already evident. We had many other computer science and computer engineering issues to deal with if reconfigurable systems were to be realizable. The “Early Researchers” sidebar (on p. 6) highlights the earliest investigations in our group and offers some personal insight about them.
Our early experiments made it clear that we needed a way to predict the performance of different concurrently operational systems, and we realized that we needed computational tools to accelerate the rate at which we could explore new special-purpose designs. Therefore, in the mid-1960s and early 1970s:

- we formalized the UCLA Graph Model of Computation;
- we proposed a dedicated computer as well as

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**Reference**

Early Researchers

Consistent with traditional articles in this journal, I offer some personal insight into the work of the earliest contributors to this work instead of depending on a voluminous bibliography. In the early 1960s, I directed a small cadre of ONR-supported researchers. They added to the ongoing work and critiqued the reconfigurable architecture concept. In every case, I tried to interest them in seeking a solution to a problem of particular interest to each of them. Below, I highlight some of the key people involved in that early research.

David Cantor was a bright young mathematics faculty member who became interested in the challenge of special-purpose design involving both hardware and software. He served on many master’s and doctoral advisory committees. Cantor collaborated with us on two elegant works on computation that set a standard for others.1,2

Aviezri Fraenkel was an Israeli engineer who had worked with me on the Weizmann Institute of Science computer development in Israel in 1954 and 1955. His dedicated and successful work there was rewarded by an opportunity to work with me at UCLA for a year. While at UCLA, Fraenkel became enamored with number theory research. He applied his creativity to, among other things, designing and evaluating a numerical sieve to search a prescribed space of numbers.3 Fraenkel went on to complete his PhD in mathematics at UCLA and returned to the Weizmann Institute to join the mathematics faculty where his outstanding research contributions continue.

Rein Turn, an Estonian immigrant, was challenged by the need to develop a model that would enable a computer to automatically assign tasks to an inventory of software and hardware building blocks in the reconfigurable system. Turn’s systematic thinking and perseverant management of complexity produced groundbreaking results.3,4 Turn later joined RAND, lending his expertise to the ongoing work and critiqued the reconfigurable architecture concept. In every case, I tried to interest them in seeking a solution to a problem of particular interest to each of them. Below, I highlight some of the key people involved in that early research.

Richard H. Fuller had done pioneering work on developing early small computers at Librascope. He was interested in exploring the potential of content-addressable memory systems in which information would be addressed by its content rather than its location in the memory system. His doctoral dissertation was remarkably complete and included novel use of reconfigurable system design to implement the search algorithms. Fuller filed his PhD dissertation in 19637 and went on to become vice president of research at General Instrument until his retirement.

C.R. Viswanathan was a graduate student in physics at UCLA when he joined our research group. At the time, we were studying temperature effects on magnetic materials as part of our computational algorithm research. Viswanathan’s PhD study was concerned with very low temperature research, and his lab experience was critical to our studies. To become better informed about our reconfigurable system research, I encouraged Viswanathan to work on improving the performance of computational algorithms important to his studies. He chose to work on matrix computations—that is, computation of eigenvalues and eigenvectors of real, symmetric matrices.8 Viswanathan was a superb teacher as well as a distinguished researcher. He was recruited into
dedicated software as instruments to measure in vivo computational performance, and

- we showed how to discover and correct pathologies in control flow during concurrent computation.

We experimented with microprogrammable computers, and we also developed the Digital Control Design System to facilitate the design process. From 1976 to 1986, we built and rebuilt a software system, called System Architects Apprentice (SARA). Using SARA, we could model, analyze, and simulate concurrent systems involving hardware and software building blocks to discover and cure problems before physically assembling new systems. Because UCLA had been intimately involved in building the Arpanet, the software system, SARA, was developed remotely on the Honeywell Multics computer system at the Massachusetts Institute of Technology from our UCLA terminals. Anyone with an account at MIT’s Multics system site and access to the Arpanet could use it from their terminals.

The UCLA research program on reconfigurable computing was successfully carried out by small groups of graduate students and faculty. For more than 20 years, it was supported by funding from the US government (around $7 million), the University of California (around $420,000 overhead-free), and industry (around $540,000 in cash or in kind from 10 companies). About 50 graduate students were involved over the years. Then and now, it stands out clearly as an example of US higher education engineering research with dual goals: training future leaders and breaking new research ground.

Transitions

The dedicated work of our project’s graduate students, both those acknowledged in the “Early Researchers” sidebar as well as others, made it possible for us to successfully propose that the Atomic Energy Commission fund our “Research Program for the UCLA Variable Structure Computer System,” which began in March 1962. The period leading up to the program’s kickoff had been intense. From 1958 through 1963, I had supervised completion of more than 30 master’s theses and five doctoral dissertations. I had coauthored more than 10 papers with my students, which culminated with two papers in a special issue of the December 1963 Transactions on Electronic Computers. Ultimately, our initial response to John Pasta’s challenge had demonstrated promise, and we were now ready to support a new group of researchers.

That same year, my personal work was recognized by a Guggenheim Fellowship award to do research on restructurable computer systems with an emphasis on computations in x-ray crystallography. I was fortunate in being able to spend a sabbatical year to think about the future. My wife’s engineering career (with the UCLA Brain Research Institute) had taken off, and we went overseas with support of her Fulbright Fellowship, and with our three young daughters.

Conclusion

The computing community recognized early on that the success of our work at UCLA on...
reconfigurable computers depended heavily on modeling methods and computer-aided tools, which would build confidence that system requirements and observed behavior were mutually consistent. Our 1986 paper reviewed the SARA effort up to that date, detailing the unusual demonstrations of the modeling power, the analysis power, and the effectiveness of the integral help tools that had enhanced the SARA system since its inception.\(^1\) Research continued after 1986 as graduate students sought to enhance tools for collaborative design and design of interactive systems.\(^2\) Although the predicted rate of growth of reconfigurable systems has been slowed by changes in the world economy, the related technology keeps increasing its market penetration. The body of knowledge created in the studies reported here remain openly available for future access.

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### References and notes


Gerald Estrin was a member of John von Neumann’s Electronic Computer Group at the Institute for Advanced Study in Princeton, New Jersey, from 1950 to 1956. He took leave from 1953 to 1955 to direct the WEIZAC computer’s development at Israel’s Weizmann Institute of Science. In 1956, Estrin joined the University of California, Los Angeles, where he built the digital computer engineering academic program and led research on reconfigurable computer architecture and methods and tools to support computer system design. Estrin, involved in ARPA networking projects since 1965, sparked interest of the energy research community in resource sharing through networks. He chaired UCLA’s Computer Science Department from 1979 to 1982 and from 1985 to 1988.

Estrin received a PhD in electrical engineering at the University of Wisconsin, Madison. His honors include AAAS Fellow, Guggenheim Fellow, IEEE Fellow, and IEEE Computer Society Pioneer.

Readers may email Gerald Estrin at estrin@cs.ucla.edu.

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