A Pioneer of the Asynchronous World

Victor I. Varshavsky (1933 – 2005)

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The asynchronous research community has lost one of its pioneers. Victor Varshavsky died on January 3, 2005, after many months of a stoic battle against lung cancer.

The poet H.W. Longfellow once said, "We judge ourselves by what we feel capable of doing while others judge us by what we have done". Victor Varshavsky is no longer with us, and we, his colleagues, disciples, friends and the entire community, should become aware of what was done by him, what his legacy is.

One can say about this man and scientist so much that it is hard to focus on something particular. The best way to begin in this case would be to preface our memorial with some more quotations. D. Hilbert used to say that any physical or mathematical theory passes in its development through ***three phases***: ***naïve, formal and critical.***

Perhaps, the discipline which can now be called Theory of Asynchrony originates from the work of D. Huffman (1954), who proposed the model of an asynchronous finite state machine. This work started the formal phase of this theory, perhaps after a naïve phase of which we are not aware, giving rise to a large amount of research that people associate nowadays with the fundamental mode of operation (from race-free encoding of automata to burst-mode and 3D implementations).

A year later (1955), the world saw the first report of D.E.Muller (D.E. Muller, A Theory of Asynchronous Circuits, report No. 66, University of Illinois, Digital Computer Laboratory, December 1955). This report introduced an approach to building speed-independent circuits, or circuits whose operation was insensitive to gate delays. It started an alternative path in Asynchrony Theory. This and work that followed soon after did not find recognition at the time. Why? The strong adherence of the authors to formalism caused dislike among practitioners, who could not see how it might lead to elegant circuit solutions. Likewise, Muller's attempt to realize his ideas in the Illiac II project was unsuccessful, probably because of the then undeveloped technology level and limited functionality of the basic circuit components.

By the early 1970s, Victor Varshavsky, had already accumulated ample and valuable experience in theory and application of threshold and majority logic, collective behavior of automata (all areas where he was an undisputed pioneer too, cf. [7,8]) and related domains. By coincidence, he then, together with a postgraduate student, tried to understand a seemingly trivial problem, how to formally synthesize a circuit for an asynchronous toggle, known as a Harvard flip-flop. Surprisingly, they could not solve this problem at the time (it was of course solved later). Victor Varshavsky, his colleagues and students, had still not heard about Muller's work. The only solution to this problem, as seen by Victor Varshavsky, was to return from the formal phase back to the naïve phase! He turned to inventions, which often helped him in the past. His incredibly powerful intuition, bordering on serendipity, was the magic engine that always pushed him towards adequate theoretical interpretation of the problems being solved.

Having covered hundreds of sheets of paper with circuit diagrams, formulas and cubes (which he very much liked to use for representing and minimizing Boolean functions), Victor Varshavsky came, independently of the rest of the world, to the idea of separation of the input sequences into two phases, active (working) and passive (spacer). All the transitions in the circuit, that followed such sequences, would become monotonic. He then proposed a structure for a primitive flip-flop with completion detection, which he called a triggeroid. This circuit could work correctly regardless of the actual delays in its gates. The triggeroid could not remember information recorded in it under some input conditions, but together with two other triggeroids (without completion detection), it did solve the problem of creating a self-timed toggle (T-flip-flop).

Victor Varshavsky continued to nurture his idea and initiated a thorough search of the literature on asynchronous systems, which quickly absorbed all the members of his team. By 1975, a detailed analysis of all publications available to date had been carried out. Furthermore, a general approach to building self-timed units and circuits, which embraced all the known results, was developed. Practically, it laid the foundation of the general theory of self-timing. In 1976, the book called "Aperiodic Automata" [2], edited by Victor Varshavsky, was published in Russian. This book systematically presented problems and solutions in the area of self-timing. At the time this book went unnoticed in the rest of the world, in particular in the US, not only because it was in Russian, but also because there was no asynchronous community as such.

Following a relative slowing down of automata theory research after the 1960s, a new scientific theory, called Petri nets, began to actively develop. Progress in this theory was relatively independent, but not in isolation from automata theory. It was rather a branch in general theory of automata, which nicely fills an open niche between finite automata and Turing machines. The overwhelming majority of papers on Petri nets "served" the needs of systems research and parallel programming. Nevertheless, the conceptual part of the problems associated with the class of live and safe Petri nets was very close to problems in self-timing. Victor Varshavsky's book [2] showed the way of translating a Petri net of the above-mentioned class to an asynchronous circuit avoiding complex state-encoding procedures.

Further research in the area of control of asynchronous processes was presented in the second book by Victor Varshavsky's team [3]. This book was published in 1986, with a fairly uninspiring title, which was virtually imposed by the publishers. The translation of this book into English [4] in 1990 made the group's results available to the asynchronous community. Finally, the last book with Victor Varshavsky's involvement [6] was published in 1994. It was more oriented towards formal models, verification and synthesis of asynchronous control circuits. The ideas and methods developed by the authors found their realization in the CAD system FORCAGE, which supported verification and synthesis of self-timed circuits.

Victor Varshavsky was undoubtedly an absolutely extraordinary engineer and inventor. He holds around 150 USSR invention certificates and 7 patent applications in Japan and USA. It is a mystery how he could build self-timed components and circuits by only using standard logic cells (NAND and NOR). They included flip-flops, counters, half-adders, handshake decouplers, pipeline buffers etc. The use of formal techniques would in most cases fail to reproduce his original solution even with the same behavioral specification. Victor Varshavsky never liked "ugly" circuits – he always polished them to perfection. Asynchronous folklore tells the tale of how Muller's C-element was created. (Varshavsky's group called this element a hysteresis-flip-flop or H-flip-flop.) Apparently, the first two attempts made by Muller were labeled A and B, and they were not good enough. It was one named C that made him happy. If we used similar logic to argue about Victor Varshavsky's designs, we would conclude that he would quickly run out of both small and capital letters of the Latin and Cyrillic alphabets! If we paraphrase Dirac, an equation of physics is true only if it is beautiful ("Fundamental equations of physics must be beautiful"). The same can be said about Victor Varshavsky's views about circuits. This reflects the key aspect of his personality as an inventor. If one carefully examines various asynchronous designs that have found practical application, then one may recognize Varshavsky's prototypes in many of them.

Only listing all the asynchronous circuits invented by Victor Varshavsky would have been sufficient to add him to the elite of this community. But one should not forget his contributions to theory of asynchrony and concurrency. He has authored, co-authored and edited 8 books, 5 of them about asynchronous systems (3 of them in English [4-6]), more than 200 papers and reports on research projects, where he acted as Principal Investigator.

Victor Varshavsky contributed to many sub-areas of the theory of asynchrony. Many of his results can claim priority worldwide. It would make sense to draw the attention of the asynchronous community to Victor Varshavsky's main contributions. We should also bear in mind that the terminology used in the originals is often different from the modern one. The reason for that is partly the use of different languages, and partly the natural tendency of many authors to establish their own terminology.

Let us consider the main results of Victor Varshavsky in the Theory of Asynchrony:

- Self-timed implementation of combinational logic and finite automata (dual-rail four-phase with built-in completion detectors) [1] – 1974
- Direct translation of control logic specifications (in parallel asynchronous flow-charts and Petri nets) into asynchronous control circuits – 1976
- Work on self-synchronizing codes with the proof of code optimality, and the implementation of the transition-based (non-return-to-zero) codes – 1981
- Self-timed interfaces, using two-level and three-level lines with and without redundant (with time redundancy) encoding – 1981/1988
- Reliable self-testable and self-recoverable architectures – 1982/1986
- Constructive proof of the functional completeness of two-input gates in the class of semi-modular circuits – 1981/1986
- Desynchronization of synchronous circuits (the representation of circuits as being built of a processing stratum and synchro-stratum, the latter acting as a distributed clock; local interactions between strata use request-acknowledgement signaling) – 1994/1998
- Asynchronous implementations for FIFO and memory circuits – 1988/1993
- Nanotechnology: design of asynchronous circuits using quantum devices (Quantum Dots, Single Electron Transistors and others) – 1995/1996

- Initiation of work on the CAD support for asynchronous circuit design (synthesis and verification) – 1978 - 1993
- Circuits insensitive to delays in transistors and wires – 1987
- Design of pipeline controllers and pipelines with different information density (non-dense, semi-dense and dense) – 1979/1986
- Bridge-based transistor circuits (including those for two and three input C-elements) – 1988

Besides the Theory of Asynchrony, one should mention his results that have become classics in other areas, particularly in:

- threshold logic and artificial neural networks, the latter being his favorite research topic of the last few years (see for example, M.J. Avedillo, VLSI implementation of threshold logic: a comprehensive survey, IEEE Transactions Neural Networks, 14(5), Sept.2003).
- collective behavior of automata, where his work on the behavior of stochastic automata with variable structure has recently attracted rejuvenated interest (see for example, A.A. Economides, A. Kehagias, The STAR automaton: expediency and optimality properties, IEEE Transactions on Systems, Man and Cybernetics, Part B, vol 32 N6 pp 723-737, Dec.2002).

Victor Varshavsky was a brilliant team-builder. The working environments he created always operated as well-oiled mechanisms, which never experienced catastrophic failures, although occasional stoppages and deadlocks, of course, happened. Victor Varshavsky never let anybody get into the state of free sailing – he would always propose a problem, discuss possible ways for solving it, and invariantly remained interested in its solution. Such tight control was normally not stressful in any manner, because it was applied in a friendly way, without the distance that often exists between a leader and his subordinates. Mature colleagues might occasionally quietly grumble – they could have their own ideas to pursue – but a pressure like this was normal, because the reputation of the leader ultimately provided everybody with reliable protection against many unpleasant external factors.

Throughout his life, Victor Varshavsky never stopped learning and teaching. In many ways, his scientific vision formed in the winter schools, held near Leningrad, which he himself created. The idea of building a dream-team from a group of scientists in Estonia was also his. Annual winter seminars run jointly with his Leningrad team were quickly called "Meetings on Elby" (cf. the historic "Meeting on the Elbe", between the Allies at the end of World War II), named after a small village near Pärnu, where the seminar was held. Victor Varshavsky was the key figure in the training of the core of the Estonian academic elite in theory of automata and its applications. One should also mention a number of regular seminars organized and run by him in Leningrad and in the whole USSR.

Victor Varshavsky was also an extraordinary a human being. He had an enormous number of friends and acquaintances, who liked and respected him. He spent many efforts to keep all his contacts and was always ready to help with advice or action. Nobody ever tried to count his PhD students, the number of PhD defenses in which he would brilliantly act as an opponent (external examiner), or the number of books or papers he reviewed (some with sarcasm and a dashing, albeit fair, critique!).

Victor Varshavsky had an unparalleled and unfading sense of humor. Jokes came from him like a stream of water from a hydrant. His witty puns, wordplays, instant reaction, smart and precise characterizations of people and events surrounding him, quickly became part of the scientific folklore. He was an irreplaceable toast-master (tamada) at banquets, and many of his friends, who were themselves remarkable speech-makers, gave way in his presence.

It is a tradition, when talking about someone who passes away, to say only good things or nothing at all. But Victor Varshavsky is an exception to all rules. We would like to mention three of his 'shortcomings'. The first one was that he smoked all his life, like a chimney (up to five packs a day). Sometimes, there were short periods in his life when he, being pressed by his wife Natalie, would attempt to give up. But he would always be seen with a cigarette in his mouth, holding it by the opposite end! Probably, it was smoking that stopped suddenly his wonderful life. But on the other hand, would he have been so productive in his work had he not been a smoker? Who knows…

His second 'problem' was an exceedingly sporty character. During his university years, he was an enthusiastic wrestler and achieved very impressive results. When he began to work he gave up wrestling, but retained an unstoppable will to win. His sport attitude affected not only his work, but also his favorite hobby, chess. He never played chess as a serious competition player, but he adored blitz chess, often bringing his colleagues to despair, because every conversation with him should begin and end with a dozen of chess games.

His third 'problem' was complete absence of a musical ear, which he liked to demonstrate both in group singing and in solo. Being an original man, he often gave his own interpretations to various tunes. They were not based on the melody, but rather on a broken rhythm (perhaps, that is the reason why he went into asynchronous!). Interestingly, his choir performances always caused a catastrophic failure – his co-performers would gradually start to sing 'wrong notes' and then suddenly drop out of the choir! This, however, never upset him.

Victor Varshavsky was not vain. He of course did not underestimate himself, but never strove for power. The position of professor and head of laboratory were completely satisfying his ego, because he never felt comfortable about wasting time. His talent and devotion were entirely for his work, and he was a typical workaholic. He demanded the same from the circle of people surrounding him. It might sound strange, but his reliance on intuition when selecting people to staff his team never let him down. He rarely accepted ideas and opinions from his colleagues and students right at the beginning. One had to overcome him or at least wait for some time. Perhaps, this was due to the fact that he kept generating more and more new ideas, with which he wanted to keep his co-workers busy. It seemed that the "Perpetual

Thinker" of Varshavsky was like a semi-modular circuit, i.e. it would never stop. In spite of illness, he continued to generate, literally, until his last day.

That's what this man was like.

Victor Varshavsky has left many followers, who furthered his ideas and added new inventions and designs to research and engineering practice. While they used to work within Soviet Russia and the communist block in the past, now many of them moved to other parts of the world and joined the asynchronous community. The latter, in our opinion, by and large remains in the formal phase of its evolution. The critical phase still has "just begun". How will it manifest itself and how will it end? We just have to wait. It may be the case that Victor Varshavsky has already sketched some key future developments of the critical phase for the Theory of Asynchrony, his beloved child. They may be his ideas about building circuits insensitive to delays in transistors and wires (Victor Varshavsky suggested to avoid forks in wires, replacing them by forks inside transistors – "by electric field"), but also in desynchronization. Some 20-25 years ago one could feel that asynchronous design was about to celebrate its victory over synchronous. This did not happen though, perhaps because integrated circuit technology marched at a much more rapid pace than the theory of asynchrony. So, would the combination of both approaches be the ultimate winner?

In conclusion, we would like again to get back to quotations. The father of differential geometry Gaspard Monge, once said that the charm that accompanies discovering new laws of nature can overcome the repugnance that men have in general for laborious intellectual work. Victor Varshavsky has certainly demonstrated with all his life the absolute truth of this observation.

We shall always remember him.

L. Rozenblyum, M. Kishinevsky, A. Kondratyev, O. Maevsky, V. Marakhovsky, Yu. Mamrukov, N. Starodoubtsev, A. Taubin, A. Yakovlev, G.Demirev

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