In Memoriam: Carl Adam Petri

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Carl Adam Petri was a visionary who founded an extraordinarily fruitful domain of study in the field of distributed discrete event systems. He was the first computer scientist to identify concurrency as a fundamental aspect of computing. He did so in his seminal PhD thesis from 1962 where in fact he outlined a whole new foundations for computer science. He devoted the rest of his working life to pursuing his ambitious and far reaching research goals. Petri nets -the core model that arose out of his thesis- have established themselves as a central model of distributed systems. They possess a rich theory, have been extended along multiple dimensions and are used in an astonishingly wide variety of domains.

Carl Adam passed away on July 2, 2010. His loss is felt deeply by friends and colleagues around the world. As a tribute, this contribution briefly surveys C. A. Petri's scientific life and impact.

1 The Early Years

Carl Adam Petri was born in Leipzig in 1926. He completed his Abitur in 1944 at the famous Thomasschule and was immediately drafted by the military. He was fortunate to be taken a prisoner of war by the British and remained in England until 1949. He then studied mathematics in Hannover and followed his teacher Heinz Unger to Bonn University as a PhD student. After receiving his PhD in 1962, he formed and managed the computer center of Bonn University. He then founded the Institute for Information Systems Research at the "Gesellschaft für Mathematik und Datenverarbeitung" (GMD) in Birlinghoven (currently a member institution of the Fraunhofer society). He directed this institute until 1991. In 1973 he seriously considered an offer of a Full Professorship at the University of Dortmund but in the end decided to decline.

Petri's early years had a strong influence on his later choice of scientific problems to focus on and on his very individualistic approaches to studying these

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problems. Petri's father was a serious scholar. He had a PhD in mathematics and had met Minkowski and Hilbert. He supported his son's interest in science. From a bookseller's bankrupt estate, Carl Adam received two thick textbooks on chemistry for his 12th birthday, which he worked through. His father also arranged for him special permission for the unrestricted use of the Leipzig central library where he delved into publications of Einstein and Heisenberg as a high school student. Later, as a flak auxiliary in the air force, he watched as his officers estimated the height, distance and speed of approaching aircraft by simple means including visual judgment and hearing. From this point on, the interplay between measurement and estimation and the inevitability of errors and their systematic treatment became a life long interest and influenced much of his scientific work.

2 Petri's Scientific Agenda

Carl Adam launched his scientific career with his dissertation "Kommunikation mit Automaten" ("Communication with Automata"), that he submitted to the Science Faculty of Darmstadt Technical University in July, 1961. He defended his thesis in June, 1962. [2].

This dissertation is a striking piece of work in multiple ways. From the opening lines it is clear one is dealing with an original and bold talent willing to challenge conventional wisdom. It lays out the case for a new theory of communication based on metric-free notions of time, space and causality. It argues for the necessity for such a theory in terms of reliably constructing and using information processing machines. Indeed from the very beginning, an implicit point of departure is that digital computers ought to be viewed as not number crunching numerical tools but as devices for storing, transforming and transmitting information. The ambiguous title of the dissertation which can be interpreted as communication *with* automata or *with the help of* automata also highlights this view ; and this was in 1962!

In order to cast the argument in a concrete setting Petri considers the problem of computing a recursive function using a physical device that obeys the known fundamental principles of physics. Since the amount of storage space needed for the computation can not be known in advance, if one starts with a finite amount of space then one will in general run out of space. However starting then the computation all over again with a larger amount of storage does not solve the problem due to the complexity of recursive functions. One will have to repeat this over and over again without making any progress. In the time domain there is an equally severe difficulty. Since only a bounded amount of information can be stored in a bounded volume (at the atomic level Heisenberg's uncertainty principle enforces this) in a synchronous architecture the clock pulses emanating from the system's central clock will have to travel longer and longer distances. Since there is an upper bound on the velocity of signals propagating through physical media (the special theory of relativity enforces a theoretical upper bound) this in turn will entail repeatedly reducing the clock speed. The inexorable conclusion one reaches is that there can not be a synchronous computing system that can carry out universal computations in an effective way while being embedded in the known physical world.

Petri then offers an alternative approach based on organizing computations through strictly local and asynchronous operations where one part of the system can be extended as the need arises without disrupting the ongoing activities in the rest of the system. Specifically a potentially unbounded stack is constructed and since two such stacks can simulate the tape of a Turing machine one concludes that the proposed approach yields a device that can carry out universal computations while respecting fundamental physical principles.

We have described in some detail here just the technical core of this work. The dissertation as a whole sketches more or less the complete landscape of Carl Adam's research for the rest of his working life. In subsequent work he developed a number of formal notations for describing asynchronous distributed systems including graphical representations, algebraic formulae and topological constructs. He also coined the basic notions of Petri Nets, i.e. "places" and "transitions" to describe local states and actions, respectively to emphasize the core principle that states and changes of states must be represented and treated on an equal footing. Behavioral notions such as conflict, concurrency, causality, confusion and non-sequential processes also started to appear in his vocabulary.

Through the long years following his dissertation and nearly till the end Carl Adam pursued the grand vision laid out in his dissertation. He worked mainly alone but was always happy to explain the various parts of the theory he was trying to construct. This was done enthusiastically and at great length using beautiful examples while consuming endless cups of coffee and an unbroken chain of cigarettes. At the same time he was delighted to see the growth of net theory, especially its expanding application domains. He was an active and friendly presence in workshops, conferences and courses related to Petri nets and he was particularly keen to interact with students and young researchers.

3 The Evolution of the World of Petri Nets

The initial period of the Petri nets domain is somewhat hazy with independent strands of work pursued by different groups including Petri's group at GMD. To illustrate one such strand, the software pioneer Tom DeMarco came across Petri Nets at Bell Telephone Laboratories in the ESS-1 project that was developing the world's first commercial stored program telephone switch. DeMarco was a member of the project's simulation team. In his contribution to the volume on "Software Pioneers" [1], he writes "Among the documents describing the simulation was a giant diagram that Ms. Hoover (who led the team) called a Petri Net. It was the first time I had ever seen such a diagram. It portrayed the system being simulated as a network of sub-component nodes with information flows connecting the nodes. In a rather elegant trick, some of the more complicated nodes were themselves portrayed as Petri Nets....The one document that we found ourselves using most was Erna's Petri Net. It showed how all the pieces of the puzzle were related and how they were obliged to interact. The lower-level network gave us a useful pigeon-holing scheme for information from the subsystem specs. When all the elemental requirements from the spec had been slotted by node, it was relatively easy to begin implementation. One of my colleagues, Jut Kodner, observed that the diagram was a better spec than the spec".

In a larger context, Anatol Holt played an influential role by recognizing the fundamental nature of Petri nets and bringing it to the attention of number of scientists in the US including Jack Dennis and his Computation Structures group at MIT. Suhas Patil, one of Dennis' PhD students saw the potential of Petri nets to specify and analyze asynchronous switching circuits and starting from his dissertation this became one of the early and very fruitful application domains for Petri nets. It was also soon recognized that Petri nets (more specifically, the version known as Place/Transition nets) constitute a very intriguing class of infinite state systems and a rich body of work regarding their relation to formal languages, decision problems and complexity classes began to be developed.

In Europe, the theory and applications of Petri nets grew at an increasing pace with many active groups establishing themselves in Denmark, France, Germany, Italy and Spain (to name a few). Equally important, the fact that concurrency was a fundamental aspect of computing was being recognized with Robin Milner's theory based on process algebras providing a major alternative impetus. Fundamental theoretical developments such as Mazurkiewicz trace theory and event structures as well as formal relationships between different models of concurrency started to appear. From the applications standpoint a crucial development was the formulation of related formalisms of Predicate/Transition nets and Colored Petri nets in which the tokens representing the local states as Boolean or integer-valued values were lifted in a coherent way to represent dynamic extensions of arbitrary multi-dimensional relations. This led to sustained research efforts resulting in a variety of system design tools accompanied by analysis and simulation methods.

As the applications of Petri nets grew so did the number of their variants with each domain demanding its own extension -often minor but sometimes major- of the basic formalism. Currently there are timed, stochastic, continuous and hybrid extensions of Petri nets that are well established. A large community of computer scientists and software engineers employ Petri Nets in a rich variety of settings. Petri nets are also deployed in other branches of engineering. As Prof. Gottzein in his laudatory speech (on the occasion of Carl Adam being awarded the 30th Werner-von-Siemens-Ring) put it: "Petri Nets brought engineers a breakthrough in their treatment of discretely controlled systems. Petri Nets are a key to solve the design problem, as this is the first technique to allow for a unique description, as well as powerful analysis of discrete control systems. Based on Petri Nets, it is now possible to formulate system invariants for discrete systems".

The field is active and constantly growing and what we have sketched here is a very brief, selective and incomplete account. It is perhaps too early to assess the full impact and influence of Carl Adam's contributions. This is particularly so since he has left behind a body of work that contains a wealth of ideas and whose systematic development may well impact emerging alternative computational paradigms such as quantum computing. Independent of such future developments Petri's fundamental contribution to the theory and applications of distributed computing will endure. As Robin Milner in his Turing award lecture said: "Much of what I have been saying was already well understood in the sixties by Carl Adam Petri, who pioneered the scientific modeling of discrete concurrent systems. Petri's work has a secure place at the root of concurrency theory".

4 What Will the Future Bring?

In his invited speech at the 26th International Conference on Application and Theory of Petri Nets in Miami in June 2005, Petri appreciated the diversity and the quality of applications of his theory. But he called for a substantial expansion of the theory: Not in terms of additional Petri Net classes or more sophisticated analysis algorithms but rather for reaching the aims outlined in his dissertation. On this front, much remains to be explored! It may only be a matter of time until breakthroughs in hardware technologies coupled with vast demands of software will require the kind of net theory envisioned by Carl Adam. For instance conservation principles for information processing analogous to the conservation laws present in physics and chemistry may well be required in the future -as Petri speculated- to design and construct software interfaces connecting vast sources of dynamic data and applications that process such data.

The rapid rise of informatics has been driven mainly by technological advances and the economic imperative. Given its fundamental nature and its all encompassing influence, a rigorous *science* of informatics is undeniably needed. Such a science can evolve only by addressing the basic and far reaching questions raised by visionaries like Carl Adam Petri.

5 Conclusion

We wish to end on a personal note. Carl Adam was shy, modest and gentle. He had no guile or malice. He was a warm, gracious and entertaining host. He wore his exceptional scholarship lightly and it was a delight to be in his company. For those of us who got to know him well it was a priceless privilege.

References

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