Wolfgang Reisig
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Carl Adam Petri: Ideas, Personality, Impact

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Preface

This book is a tribute to Carl Adam Petri (1926–2010), a highly original and visionary computer scientist. He was a pioneer of several key research directions in computer science and a towering figure in the field of distributed information processing systems. The ideas proposed by Petri were revolutionary and much ahead of their time; they constitute deep, broad, and lasting contributions to the field.

The multitude of models which are based on the conceptual framework proposed by Petri are collectively referred to as *Petri Nets*. Their strength is based on the combination of impressive theoretical foundations with very broad and impressive applications. In fact, *Petri Nets* has become a yardstick for other models of concurrent and distributed systems.

Petri was an interdisciplinary scientist, in particular he was deeply interested and knowledgeable in physics. As a matter of fact, he always stressed that his ideas originated in physics and his goal was to create foundations of informatics which are rooted in the laws of physics. His broader goal (dream) was to provide net-theoretical foundations for physics.

He is perhaps the best known and most influential German computer scientist. However, in Germany Petri did not receive the recognition that he deserved. This may be partially explainable by the fact that he was totally uninterested in the social and political rituals that (much too) often play an important role in recognition by the academic world.

He was a very modest man with a remarkable personality, a "pure scientist". Science was the essence of his life, everything else was a burden imposed upon him. Conversations with Petri were fascinating and enriching, as he was a patient listener while he also passionately and convincingly argued for his own deep and original ideas.

Carl Adam Petri became a source of inspiration to many. This book is a collection of reflections about Petri and his ideas by individual scientists. Some contributions are recollections of his remarkable personality by people who knew him, some are stories of how Petri's ideas influenced various people's scientific developments and careers, while others are more technical expositions (in a style accessible to a broader audience) of various ideas of Petri. Altogether, these individual stories constitute a unique source of information about Carl Adam Petri and his ideas, and a touching tribute to a remarkable scientist.

Our invitations to contribute to this book were enthusiastically received. We are grateful to all authors for their contributions and fruitful interactions during the editing process. We are also thankful to Ronan Nugent from Springer-Verlag for pleasant and efficient cooperation in producing this book.

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Part I
Perspectives on Petri’s Work

Discovering Petri Nets: A Personal Journey

Wil M. P. van der Aalst

1 Introduction

Carl Adam Petri (12 July 1926–2 July 2010) pioneered the computer science discipline and is one of the founding fathers of the wonderful field of concurrency. He single-handedly started a new subfield of computer science focusing on *concurrency* [6]. As Robin Milner phrased it in the acceptance speech for his Turing Award in 1991: "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!" Petri nets have become a standard tool for modeling and analyzing processes where concurrency plays a prominent role. The ideas have been embedded in many other process modeling notations. For example, the widely used BPMN (Business Process Model and Notation) models use token-based semantics [4], After working with Petri nets for over 30 years, I remain surprised by the elegance of the formalism. Using a few basic concepts (places, transitions, arcs, and tokens) and the simple firing rule, one enters a new "world" where it is possible to model a wide range of behaviors and study non-trivial phenomena (conflict, concurrency, confusion, etc.).

According to [7], Petri invented Petri nets in 1939 at the age of 13 for the purpose of modeling chemical processes. However, many refer to his Ph.D. thesis, defended in 1962 [5], as the starting point for Petri nets. This is only partially true, since his Ph.D. thesis does not show the characteristic diagrams we know today. These emerged in the mid-1960s and subsequently conquered the world. Petri nets are used in a wide range of domains, directly benefiting from the theoretical foundations developed over the last 50 years.

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In the remainder, I will describe how I got submerged into Petri nets and how it has affected my research and scientific career. Moreover, I will link two of Petri's guiding principles to my current research area:

- **GP1:** *Concurrency should be a starting point for system design and analysis and not added as an afterthought* (*locality of actions*).
- **GP2:** *A formalism should be consistent with the laws of physics and not take any shortcuts at the foundational level.*

Anyone familiar with Petri's work and his lectures will recognize these guiding principles. I will relate these two principles to process mining and the broader field of Business Process Management (BPM). Process mining can be viewed as the missing link between model-based process analysis and data-oriented analysis techniques [12]. Many process mining techniques use Petri nets or related formalisms and directly benefit from the above two principles proposed by Carl Adam Petri. This paper concludes by discussing Petri's heritage.

2 Personal Journey into the Wonderful World of Petri Nets

I met Carl Adam Petri for the first time in 1989 in Bonn while attending the 10th International Conference on Applications and Theory of Petri Nets. I was doing my Ph.D. at the time and it was a very exciting and inspiring experience. This was my first Petri net conference, and I did not know that many Petri net conferences would follow. Over the last 30 years, I have served as a program committee chair (twice, in 2003 and 2017), organized the conference once, served as a steering committee member since 2003, and played many other roles (e.g., chairing different workshops and committees).

For my Master's project [9], I worked in the research group of Kees van Hee on a language and tool called *ExSpect*. In a way we "rediscovered" Petri nets, not knowing the seminal work done by Petri. Initially, we used triangles for places rather than circles and there were also other differences. However, the similarities between our work and (colored) Petri nets were striking. Therefore, we soon joined the Petri net community. I was responsible for adding time to our high-level *ExSpect* nets. *ExSpect* was developed concurrently with *Design/CPN* (which later evolved into *CPN Tools*, still hosted by our research group in Eindhoven). Both languages used colored tokens and provided hierarchy notions. During my Ph.D. I continued to work on *ExSpect*. My main focus was on the analysis of temporal behavior using both model checking and simulation [10]. The primary application domain for my work was the broader field of logistics. We analyzed supply chains, distribution centers, railway transport, container terminals, etc. using *ExSpect*.

After a few years I became the leader of a small research group in Eindhoven and my interests shifted to workflow management [13]. I noted the huge potential for applying Petri nets in this up and coming domain. We developed a framework for modeling and analyzing workflow processes based on Petri nets. This led to seminal notions such as WorkFlow nets (WF-nets) and soundness. Interestingly, we were able to use Petri net notions such as invariants, siphons, traps, reduction rules, etc. to verify the (in)correctness of workflow models stored in commercial systems such as *Staffware*.

After designing several workflow languages and developing several workflow management systems (YAWL, Declare, etc.), I got more and more interested in the *relationship between models and reality*. This was fueled by the repeated observation that simulation models (modeled in *CPN Tools* or *ExSpect*) rarely behave like real organizations, machines, and people. At the same time, workflow management research shifted from automation to *Business Process Management* (BPM). See [11] for a survey describing this transition. The scope of BPM extends far beyond workflow automation, including the understanding of why processes and organizations achieve particular performance levels (time, quality, costs, compliance, etc.). Process improvement requires a deep understanding of processes that cannot be obtained through modeling alone.

The desire to link models and reality naturally evolved into the new field of *process mining* around the turn of the century. We developed the first process mining algorithms around 1999. Initially, we used the term “workflow mining” rather than “process mining.” Process mining starts from event data and uses process models in various ways, e.g., process models are discovered from event data, serve as reference models, or are used to project bottlenecks onto. Many process mining techniques use Petri nets for obvious reasons. Later, I will elaborate on the role of Petri nets and Petri’s guiding principles in process mining.

Although I worked on very different topics (logistics, simulation, workflow verification, workflow automation, BPM, and process mining), all of my research was (and still is) related to Petri nets in some form.

Concurrently, I moved up the academic ranks and became assistant professor (1992), associate professor (1996), and full professor (2000). In 2003, I organized the Petri net conference in Eindhoven together with Kees van Hee. This conference was a big success and quite special because Carl Adam Petri gave a talk after not having attended the conference for many years (Fig. 1). Grzegorz Rozenberg (who can be considered to be the “godfather” of our wonderful Petri net community) encouraged me to organize a co-located event along side the Petri net conference. This resulted in the first Business Process Management conference (BPM 2003). Also within the BPM community Petri nets were adopted as a standard tool for modeling, analyzing, and enacting business processes. BPM is just one of many fields using Petri nets, illustrating the foundational nature of Petri’s ideas.

Fig. 1 Carl Adam Petri (middle) and Grzegorz Rozenberg (left) during the Petri net conference we organized in 2003. The photo was taken just after Petri was honored with the prestigious title "Commander in the Order of the Netherlands Lion" by Her Majesty the Queen of the Netherlands

3 Concurrency is Key

Petri's first guiding principle is "Concurrency should be a starting point for system design and analysis and not added as an afterthought (locality of actions)" **(GP1)**. Many other modeling approaches start from a sequential view of the world and then add special operators to introduce concurrency and parallelism. Petri nets are inherently concurrent. Although Petri nets are often seen as a procedural language, they can be viewed as declarative. A Petri net without any places and a set of transitions T allows for any behavior involving the activities represented by T. Adding a place is like introducing a constraint. The idea that transitions (modeling activities or actions) are independent (i.e., concurrent) *unless specified otherwise* is foundational! This allows us to model things in a natural manner and also facilitates analysis. Actions are local and this allows us to understand things better while enabling "divide and conquer" approaches (e.g., decomposing analysis problems).

Mainstream notations for modeling processes use token-based semantics adopted from Petri nets. The de facto standard for business process modeling—BPMN (Business Process Model and Notation) [4]—uses token passing. Also UML activity diagrams use token-based semantics and a notation similar to Petri nets. Unfortunately, these languages provide a plethora of control-flow constructs, basically killing the elegance of the original proposition. However, in the back end of such languages and supporting systems, one can often find Petri nets. For example, BPMN models are often translated into classical Petri nets for verification.

4 Process Mining: Relating Observed and Modeled Behavior

Petri's second guiding principle is "A formalism should be consistent with the laws of physics and not take any shortcuts at the foundational level" **(GP2)**. He often related concurrency theory to physics [2, 8]. However, the principle can also be applied to everyday discrete event processes (e.g., in manufacturing, healthcare logistics, luggage-handling systems, software analysis, smart maintenance, website analytics, and customer journey analysis). We seek models adequately describing these real-world phenomena. Interestingly, the digital universe and the physical universe are becoming more and more aligned, making it possible to study these discrete event processes much better. The spectacular growth of the digital universe, summarized by the overhyped term "Big Data," makes it possible to record, derive, and analyze *events*. Events may take place inside a machine (e.g., an X-ray machine, an ATM, or a baggage-handling system), inside an enterprise information system (e.g., an order placed by a customer or the submission of a tax declaration), inside a hospital (e.g., the analysis of a blood sample), inside a social network (e.g., exchanging e-mails or twitter messages), inside a transportation system (e.g., checking in, buying a ticket, or passing through a toll booth), etc. [12]. Events may be "life events," "machine events," or "organization events." I coined the term *Internet of Events* (IoE) to refer to all event data available [12].

The event data that are abundantly available allow us to relate real-life behavior to modeled behavior. More specifically, we can learn process models from such event data (process discovery) or replay event data on models to see discrepancies (conformance checking). This is exactly what process mining aims to do.

Process mining starts from *event logs*. An event log contains event data related to a particular process. Each event in an event log refers to one process instance, often called a case. Events related to a case are ordered. Events can have attributes. Examples of typical attribute names are activity, time, costs, and resource. *Process discovery* is one of the most challenging process mining tasks. Based on an event log, a process model is constructed thus capturing the behavior seen in the log. Dozens of process discovery algorithms are available and many produce Petri nets. Input for *conformance checking* is a process model with executable semantics and an event log. Discrepancies between the log and the model can be detected and quantified by replaying the events in the log. Simple conformance-checking approaches try to play the token game and count missing and remaining tokens. More sophisticated approaches solve optimization problems to find modeled behavior most related to the observed behavior. Some of the discrepancies found may expose undesirable deviations, e.g., conformance checking signals the need for better controls. Other discrepancies may reveal desirable deviations and can be exploited to improve process support.

The empirical nature of process mining immediately exposes formalisms that are not able to capture real-life behavior. Choosing the wrong "representational bias" results in discovered models that are poorly fitting (observed behavior is not allowed or the model is overfitted or underfitted) [12].

Petri nets are attractive for process mining given the abundance of analysis techniques. For example, conformance-checking techniques use the marking equation to dramatically reduce the search space when computing alignments. Moreover, the fact that “a Petri net without any places and a set of transitions T allows for any behavior involving the activities represented by T” is a great starting point for process discovery. Obviously, such a Petri net is underfitted, but additional constraints can be introduced by adding places. This is related to the seminal idea of *regions* (both language-based regions and state-based regions) [1, 3]. The synthesis of Petri nets based on regions is one of the cornerstones of process discovery, very much in the spirit of Petri’s second guiding principle.

5 Petri’s Heritage

This short paper focused on two of Petri’s guiding principles: (1) concurrency should be a starting point for system design and analysis (and not added as an afterthought), and (2) a formalism should be consistent with the laws of physics and not take any shortcuts at the foundational level. I linked these two principles to my own research over the last 30 years and discussed how these principles relate to the emerging field of process mining. Obviously, concurrency of behavior and consistency with reality are key notions in process mining. However, above all, this paper described a personal journey reflecting on the influence of Petri’s work on my career and research aimed at discovering Petri nets from events.

Carl Adam Petri discovered his nets at a time when information processing was viewed as something sequential. Formal notations for concurrency and asynchronous distributed systems were uncovered by Petri’s seminal work. Petri nets are used in many domains and the strong theoretical foundation often helps to solve “wicked problems” and avoid reinventing the “wheels of concurrency.” For example, numerous workflow management, BPM, and process mining approaches directly build on Petri nets.

However, it remains crucial to invest in the foundations of non-sequential processes. Einar Smith’s book on Petri’s life and achievements [8] provides interesting insights into the “good old days” of scientific research at the Gesellschaft für Mathematik und Datenverarbeitung (GMD). At GMD in Schloss Birlinghoven there was still time to work on the theoretical foundations of computing. This is in stark contrast with today’s research practices driven by “quick wins” and application-oriented projects rather than long-term scientific goals. Today’s scientists simply do not have the time to take a step back and ask long-term questions in the way Carl Adam Petri did. *Would Petri have survived today’s research environment?* As part of his heritage we should ask ourselves this question repeatedly. This may help us to create better research environments for work on the true foundations of computing.

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Observations of a Lateral Entrant

Einar Smith

1 Meeting Petri

Helga Genrich put down the telephone receiver: “Carl Adam is in his office, he can receive you right away.” That is how in January 1984, I was introduced to Petri and his world. I had come to know Helga through a common friend, and at that time Helga worked on a research programme on Information and Law within the Petri-Institute in the GMD. In this context Petri was looking for somebody with a background in formal logic, and mathematical logic was in fact what I had specialised in during my university years.

Already my first encounter with Petri was fascinating. We discussed whether the Cartesian product in sets is associative (it is not), whether Keynesian economics was based on a sound mathematical model, and of course, what consequences Einstein’s views on simultaneity and causality had for a mathematical understanding of real-world processes.

When I had returned to Helga’s office, Petri phoned her and said: “He made an excellent impression.” So it came that I was offered a position as research assistant beginning on March 1st. However, since as a Norwegian citizen, I had to apply for a work permit in Germany through the German embassy in Oslo, I asked to postpone the entry date by, say, a month. Petri’s answer was laconic: “Your first duty will be to study the literature; and where you do that is up to you.”

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2 The Society of Followers

What soon became clear for a lateral entrant was that Petri's words were often considered as eternal truths by his followers, almost approaching apotheosis within his lifetime. Many of the concepts Petri introduced were taken at face value, and studied for their mathematical properties rather than the deeper meaning Petri intended to express.

Density and Completeness For instance, books were filled with theorems on Petri's K-density and his first attempts at Dedekind completeness in discrete partial orders. Concerning K-dense orders Petri himself notes that the "requirement can only be violated if an infinite number of sequential processes have to wait for each other, i.e., in a situation of no practical interest." With K-density and Dedekind completeness, what Petri wanted was to consolidate the intuitive sensation of continuity on one hand and the discrete articulation of actual observations on the other. In this respect the first attempt to formulate Dedekind completeness did not turn out to be sufficiently sustainable.

In his second version, I was invited to take part as a co-author, an honour and privilege I was of course overwhelmed by [1]. Petri must have appreciated my (to be honest, very marginal) contribution, since also later I was once more invited to join him in a publication, see e.g. [2].

A detailed discussion of the concepts mentioned above, as well as many other aspects of Petri's work, can be found in [4].

Contact Other important examples where Petri's word was taken too literally concern the notions of contact, conflict and confusion. (Details can again be found in the biography mentioned above.)

On contacts, Petri often advocated the view that they are a consequence of badly designed models. As a consequence contacts were often excluded in the works of his followers.

However, on the other hand, Petri himself often also noted that contacts are important to detect unsafe situations: "An elementary particle can not occupy the space already occupied by another one, but a car unfortunately can, and so can a record of data."

Conflict As he expressed time and again, Petri believed that the world is causally deterministic, and conflicts only exist in partial systems; for instance: "If a transition set contains a conflict, then the system described by it possesses a non-empty environment."

Confusion This has an immediate and unfortunate consequence for the concept of confusion: Simply, that confusions cannot exist, because how can a border between system and environment exist such that (1) on one hand, the condition required for conflict resolution is located *outside* the system, but (2) on the other hand, there is possibly *no such condition at all*, simply because there is no conflict?

In Petri's own words: "When we encounter such a situation we may conclude that we have drawn the boundary between the system and its environment in an awkward manner, and that we should draw it somewhere else, in order to reduce confusion to mere conflict resolution. It follows that we really don't need to set up a theory of confusion - which would indeed be difficult to do. It has, in fact, been tried more than once and seems almost impossible."

In Petri's closer vicinity, the belief that confusion was to be—and could be—avoided, often gave reason to concentrate research activities on special limited net classes, where confusion was in fact excluded by construction.

However, later it turned out that—on the contrary—confusion is ubiquitous; it will inevitably appear, whenever the consequences of independent events have to be synchronised [3].

An often-overlooked implication of this theorem is that Petri's own construction of a conflict-free OR-gate in his dissertation cannot be correct.

In a later private conversation, Carl Adam commented with a sigh: "Before I used to claim that confusion can easily be avoided; now I claim the opposite."

'Time' Is a Four-Letter Word Closely related to confusion is the determination of order between independent events. The belief in pure causality among Petri's followers sometimes approached the surrealistic. The innocent remark that the winner of a 100-m dash is surely determined by the order between the independent events of the runners crossing the finish line could be met with a smile somewhere between sardonic and patronising: "Who knows if there is not some connecting causal parameter hidden in the background?"

In the most programmatical form, the reluctance towards confusion and timing was probably expressed by Anatol Holt: "Thus an extra causal factor, not represented explicitly in choices…has entered the scene, *namely the factor of relative timing*…This 'extra factor' is both technically and philosophically unacceptable. It is technically unacceptable because it destroys the possibility of tracing the outcomes of choices to the outcome of other choices…one of the key objectives, in my opinion, of an adequate system model."

Regarding the philosophical significance of the time factor, Holt remarks: "Communication and only communication establishes causal connections between choices. Concurrency was to express the relative freedoms that remain in the light of these relative causal constraints." According to Holt, something that may influence causality must be an element of communication, and that is not the case for the time factor.

In essence, Holts conclusion amounts to the view that what *should not* exist actually also *does not* exist. This is in complete concordance with a well-known observation by the German satirical poet Cristian Morgenstern in a poem "Die unmögliche Tatsache" (The impossible fact): "Weil, so schließt er messerscharf, nicht sein kann, was nicht sein darf." (For, he reasons pointedly, That which must not, can not be.)

3 The Competitors

In the modelling of distributed systems, Petri nets encountered existing competition, mainly from models based on sequential automata theory, where the concept of arbitrary interleaving became the standard method of formulating independence.

Petri nets appeared as late arrivals in this business. To be accommodated the net-representatives had to show they could do everything the others could, and even more so; as in the musical ‘Annie get your gun’: “Anything you can do, I can do better.”

But the rules of the game were set by the others. This meant in particular that concepts not expressable in interleaving approaches were not propagated offensively by net-followers. Unfortunately this concerned the main topics discussed above, such as contact and confusion.

In many scientific approaches other ideas are occasionally neglected with the remark “not invented here”. In net theory the opposite phenomenon “not invented by others” occasionally seems to prevail.

4 Consequences

Perhaps it is time to review some of Petri’s fundamental and seminal ideas in the world of non-sequential processes and distributed systems. This includes the admission that even a genius like him was sometimes caught in a web of contradictory thoughts. Adapting Petri’s own words (actually originally referring to the German writer Johann Wolfgang von Goethe), we should “liberate ourselves from the prejudice that whatever is written by Petri must be great and good, simply because it is by Petri.”

In my opinion, the main obstacle Petri encountered was one he laid himself, namely to take philosophical determinism at face value. Without this hindrance, he had already developed all the tools necessary to deal with the ubiquitous timing issues in synchronisation.

In his approach to measurement theory, he noted that measurement is ultimately based on a notion of similarity, which is by nature non-transitive, a non-transitivity which however can be limited to a ± 1-deviation. (For details again see [4].)

This approach can be carried over to the timing of independent events, and the design of corresponding system models.

At the Bus Stop As a simple illustration, consider a bus approaching a bus stop. If there is a passenger waiting, the driver has to stop and pick him up. If nobody is waiting, the driver may pass by without stopping. Now a client has complained to the bus company that he *was* waiting, but the bus nonetheless did not stop. The driver, on his side, contends that he had actually first noted the passenger in the rear mirror, because he definitely had arrived too late. It is one person’s word against another, and the case will probably not be resolved.

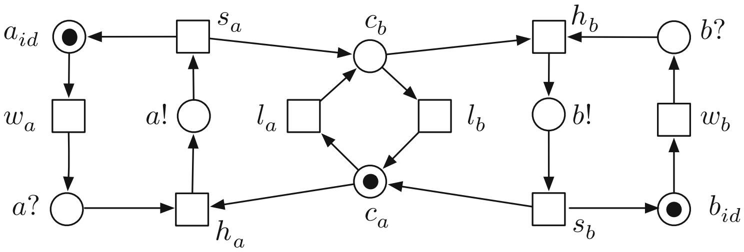

Fig. 1 Controlled access to a printer shared by two agents *a* and *b*

But one thing *does* result: If there was a dispute about *this* bus, then the passenger is undoubtedly in time for the *next* one. Hence also in this case there is a typical ±1-problem lurking in the background. If the frequency of bus departures is sufficiently high, the negative consequences can be limited.

Distributed Access We present a somewhat larger example, in which conflict, confusion and the main timing ideas above are discussed in a model to control the access to a shared resource, say a printer, by two agents *a* and *b* (Fig. 1).

The system has to ensure that at any time *only one* user has access, and—on the other hand—that every user that requires the printer will eventually get it. Presently both agents are in states where they do not request access, represented by the tokens on the places a_{id} and b_{id} (the tag "id" is short for "idle"). In this situation a, say, can issue a request. In the model this is represented by the occurrence of w_a, after which the condition a? is satisfied (depicted graphically by moving the token).

The printer access control is based on a mechanism that alternately polls the demands of the agents. This is represented by the inner circle c_a-l_a-c_b-l_b. The token on c_a indicates that the printer is currently offered to a because now h_a is enabled. Occurrence of h_a withdraws the two input tokens and puts a token on a!, reserving the exclusive access for a. The transition s_a terminates the use; a returns to the state "idle", c_b, is marked, and the printer is now ready for user b.

Assume that the control has been designed such that whenever agent a has issued a request (token on the condition a?), and the control unit is ready to accept it (token on c_a), then the printer will in fact be assigned to a. If additionally we can assume that signals will stabilise within one cycle, the worst case that can happen is that a is passed over *once*, when for example the request signal on a? has not yet stabilised.

As in the bus example above we again get a ±1-problem, with which we can live, but probably also have to live, since no decisively different solution seems viable: A system design without confusion appears impossible, and the control must rely on a priority management that decides on the temporal order of the concurrent independent events in the confusion. (However we stress the point that such temporal relationships are only evaluated in the *immediate vicinity of a potential conflict.* This does not imply any assumption whatsoever of a global time concept.)

Challenge for adherents to the deterministic tradition outlined above: Develop an equivalent model without confusion and local timing.

Final Words In this author's opinion the more promising alternative is to extend the traditional approach to include confusion and its consequences in the theory.[1] To formulate it with a famous quotation, attributed to various people, not least to the great Austrian composer Gustav Mahler: "Tradition is not the adoration of the ashes, but the passing of the flame."

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[1] A preliminary study on the semantics of nets with local priority constraints can be obtained on request.

Nets, Cats and Pigs: Carl Adam Petri and His Slides

Giorgio De Michelis

Carl Adam Petri (1926–2010) never wrote a book, and his papers, amounting to a total of 13 during his scientific career, are generally not written in accordance with the standard format of scientific papers—they are so rich and dense that they constitute a serious challenge for the readers, even those who are already experts in the themes he treats. Moreover, except for the lemma dedicated to Petri Nets in Scholarpedia (2008) that he wrote together with Wolfgang Reisig [1], he did not write any paper after 1996. These simple facts are sufficient to show that he did not consider written texts to be the main way to state and record his ideas and to make them available to the public.

On the other hand, he dedicated great care to his slides. He prepared a new collection of slides for almost every talk he gave, at least in the last 35 years of his career, and, sometimes, he prepared them also for different occasions as personalized accounts of his scientific work. In a paper I wrote recently I discuss a slide that is quite important for understanding some 'philosophical' aspects of his work whose content never appeared explicitly in his writings [2]. It is therefore interesting to investigate in depth the role of slides in his scientific experience, also taking into account that technological innovation seriously influenced their preparation in the last 30 years.

The sets of slides he prepared for different occasions frequently contained some recurrent subsets of slides, dedicated to particular aspects of his theoretical work, The slides he used to support one of his talks, were, in some sense, a selection and/or a combination of slides taken from a virtual collection of all his slides, which was his 'complete' reference material. He continually updated this collection adding new slides to it, substituting and/or 'modifying some of them.

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