Un demi-siècle des RdPs

- Un demi-siècle du travail définissant un point de repère dans la théorie des systèmes dynamiques à événements discrets (SDEDs) mérite d'être souligné.
- On ne prétend que faire une modeste commémoration de sa vie et vision, et présenter des traces sur la discipline créé, sachant que la science et la technique sont des constructions sociales.
- Manuel Silva: **"Half a century after Carl Adam Petri's Ph.D. thesis: A perspective on the field",** ***Annual Reviews in Control*** **37**:2, 191-219, 2013.
  Online publication date: 1-Dec-2013.

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1. **Introduction**
2. **About Carl Adam Petri**
3. **Petri Nets: On Basic Properties and ways of approach**
4. **Petri Nets: A modeling paradigm**
5. **On five interactions over twenty five years**

Carl Adam Petri: Half a century after his PhD

When in **Computer Science** the paradigm was **local computations on mathematically intricate problems…**

… Carl Adam Petri look for a **Systems Theory**, far beyond what was the problematic in Computer Science, applicable in a broad landscape of research fields:

- **Automatic Control, Operations Research, Informatics…**
- Automation of manufacturing, transport and logistic systems, communications protocols, software and hardware engineering, (bio)chemistry, epidemiology, law/rights, demography…

Carl Adam Petri: Half a century after his PhD

Interested in the description of some real-life situations, as mathematician he essentially worked at ***conceptual level***, "opening windows" (i.e., providing foundations for new ways of thinking), what may be viewed as a speciality less frequently exercised with success than **"theorem prover".**

At the personal level he always was a **warm-hearted** person

Science and Technology are social constructions

- Nevertheless, in their development some people contribute in outstanding ways.
- The recognition of their achievements is **sometimes** partially done by giving his/her name to some measurement unit, universal constant, algorithm, etc.
  - *International System of Units* (newton, coulomb, ampere, volt, farad…)
  - Coriolis, Young, Avogadro, Kirchoff, Minkowsky-Farkas, Donsker, Floyd, Dijikstra, Wiener, Kalman, **BCMP**…
  - Naming an entire subfield is much less frequent: ***Markov Chains***, ***Hilbert Spaces, Galois Fields, Petri Nets…***

Continuous ("natural") *vs* Discrete ("artificial")

- **Continuous Systems:** *300 years of optimal control: from the brachystochrone to the maximum principle* (Sussmann and Willems,1997).
- From **logic/discrete automatisms** to **DEDS** (Ho et al., 1980)
- **Discrete Event System Specification** (DEVS; simulation: Zeigler, 1976)

  [after: SIMSCRIPT, SIMULA, GPSS…]
- Like ***Le Bourgeois Gentilhomme*** of Molière, users or developers on topics related to **automata, Markov chains, queueing networks, Petri nets, process algebras, max/plus algebra,** etc., realized that **we were speaking not in prose, but "in DEDS".** ☺

Continuous ("natural") *vs* Discrete ("artificial")

- In ***Future directions in control theory: a mathematical perspective*** (Fleming, 1988):

  there exist no formalisms for DEDS mathematically as compact or computationally as tractable as the differential equations are for continuous systems.
- **"Natural" selection (Darwinism…), but NOT monism…**
- **But, ideas organized in modeling paradigms**

PNs: an option (more than a question of taste, but...)

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Carl Adam Petri (Leipzig,1926-Bonn, 2010)

- His father, professor of mathematics, enjoys friendly relationships with mathematicians as David Hilbert and Hermann Minkowski.
- Obliged to join the German army (1944), he becomes prisoner in England (till 1946), where later he teaches Latin and chemistry.
- Petri returns to Germany in 1949, studying mathematics at the Technical University of Hannover (till 1956);
- From 1959 until 1962 he works at the University of Bonn;
- **In 1962 he gets the PhD degree from the Technical University of Darmstadt.**
- Until 1968 Petri is working at the University of Bonn, becoming head of the computer installations.
- In 1968 was founded the GMD. He become later one of the directors of the Institute for Methodological Foundations.
- He retires from GMD in 1991, but in 1988 was named Honorary Professor at University of Hamburg.

Petri nets: When? Were? How?

- Against what it is frequently quoted, in his PhD dissertation the graphical notation on PNs **does not appear!!!**
- The well-known bipartite graphs with conditions/places and events/transitions will come some three years later.
- But he claims to invent

  it in a playful mood in August 1939, and practiced it intensively for the purpose of memorizing chemical processes, using ***circles for substances*** and ***squares for reactions***.
- A. Holt (MIT, Project MAC) give his name to the bipartite nets
- Replacing temporal order by causal order, he looked concurrency as mutually causal independent occurrences (*synchronization* as *rendez-vous)*
- *Causal orders* and *preservation laws* were inspired to Petri by the **laws of Physics**

Robin Milner (Turing Award, 1991)

- In the 1970s, Robin Milner focusses his view of concurrent systems on the **"interactions of smaller components"**, being one of the more celebrated steps in the definition of **process algebras**.
- In other words, Milner pays central attention to the process of construction of the model:

  [Petri] pioneered the scientific modeling of discrete concurrent systems. Petri's work has a secure place at the root of concurrency theory…What I always wanted to advance, to complement Petri net theory, is the synthetic or compositional view of systems which is familiar from programming. (1993)

PNs & international meeetings

- Since 1980 it exists an annual conference devoted to PNs, the **Int. Conf. on Application and Theory of Petri Nets and Concurrency** (ICATPN; in fact, from 1980 until 1988 it was known as International Workshop, IWATPN).
- From 1985 till 2003, ten editions of the **IEEE/ACM Int. Symp. on Petri Nets and Performance Models** (PNPM) took place. This meeting merged in 2004 with others, as that on **Process Algebra and Performance Models** (PAPM), giving light to the annual **Int. Conf. on Quantitative Evaluation of Systems** (QEST).
- But what is more impressive is the number of meetings in which PNs is a topic explicitly mentioned, frequently devoting special sessions to them. For example, in "The Petri Nets: Meetings and Events" we can count more that 150 during 2005-2011, so **more than twenty per year.** (What is truly a lower bound!!!)

Among other important recognitions to Carl Adam Petri

- The ***Konrad-Zuse-Medal*** (1993);
- The ***Society for Design and Process Science*** established the Carl A. Petri Distinguished Technical Achievement Award (1997);
- The ***Werner-von-Siemens-Ring*** (1997), one of the highest ranked award for technical sciences in Germany, delivered every three years;
- The **Doctorate *Honoris Causa*** by the Universidad de Zaragoza, in 1999.
- The ***Order of the Dutch Lion***, as Commander (2003);
- ***IEEE Computer Pioneer*** (2008):

  For establishing Petri net theory in 1962, which not only was cited by **hundreds of thousands of scientific publications** but also significantly advanced the fields of parallel and distributed computing.

Most of the recognitions to Carl Adam Petri, a mathematician, came from engineering.

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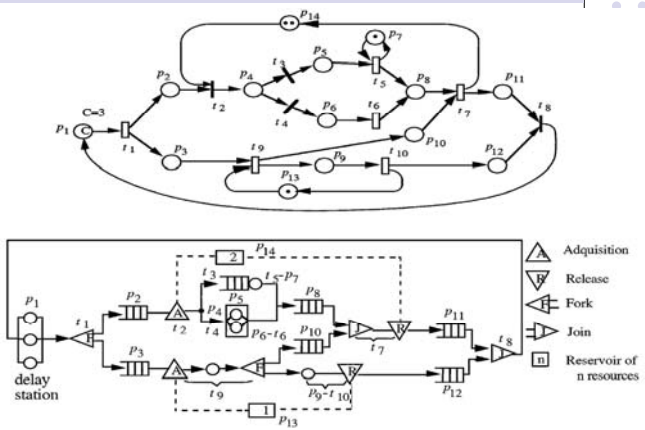
Petri Nets are *operational* formalisms (*how* the system works, vs *what* it does)

Among the qualities that they enjoy are:

- ***Minimality in the number of primitives*** (trade-off between the engineering and scientific perspectives).
- ***Locality and structuration*** (parallelism, synchronization, conflicts, etc.) >>>
  - ***Cooperation* & *Competition* relationships.**
  - ***Top-down* & *Bottom-up* model building.**
- ***Non-determinism*** *(humble position---time unpredictability).*
- ***Temporal realism and occurrence nets.***

Minimality-understanding (theory) *vs* rich ontology-use (engineering)



… ways of approach to PNs

if all roads lead to Rome …
more than "probably", Rome was/is important!

… to "the town" of Petri Nets (with several nuances) we may arrive using different **roads …**:

- An **axiomatic** view (the **C.A. Petri**), +++
- **Continuous System Theory**, from state transition (…like in **VAS**)
- **Theory of Regions**: a kind of field-coding in labelled graphs (synthesis problem / "mon cher **Philippe Darondeau**"…)
- **Non-monotonic logic**: *Linear logic*, **Girard** / **R. Valette**

From 1950's to 1960's

Salient features:

- Bipartite --- dual objects !
- Locality --- compositionality !
- Timed ***vs*** untimed ?
- Discrete ***vs*** fluid views ?

		Reservoirs	*Activities*
1957...	**QNs**	**Queues**/ Clients	**Stations**/ Servers
1961...	**FDs**	**Deposits**/ Levels	**Valves**/ Flows
1962...	**PNs**	**Places**/ Conditions	**Transitions**/ Events

P/T systems constitute a "frontier formalism"

- P/T systems are able to model **infinite state** (i.e., unbounded) systems.
- Constitute a **"frontier formalism"**:
  - Are **very expressive** and most of classical properties are **decidable**,
  - But "small" extensions transform it into a formalism able to simulate ***Turing machines***, thus **excellent expressivity**, but plenty of **undecidabilities**.
  - Among the evoked extensions, just the addition of:
    - ***inhibitor*** (or ***zero test***) *arcs*,
    - ***priority levels*** to the firing of transitions; or
    - certain ***time-interpretations***.

One "children" of ordinary PNs: The Grafcet

- **GR**aphe de l'**AFCET** (**A**ssociation **F**rançaise de **C**ybernétique **É**conomique et **T**echnique)
- **GRA**phe (**F**onctionnel) de **C**ommande **É**tape-**T**ransition
- "Like" an ordinary P/T net system in which a *flip-flop* approach is used for implementing places, even if they are not 1-bounded; also problems with unresolved conflicts! **(be careful because this destroy the tokens conservation laws!)**

***Sequential Function Chart* (SFC)**
Norms IEC 848 (1988) + IEC 61131-3 (1993)

LES AUTEURS DU RAPPORT Grafcet

Ce rapport est le fruit d'un travail collectif des 24 membres de la « commission de normalisation de la représentation du cahier des charges d'un automatisme logique » — Groupe de travail AFCET « Systèmes logiques » dont voici les noms :

BLANCHARD, ex-*CERT-DERA-Toulouse*
BOERI, *LASSY-Nice*
BONS, *USSI-Bagneux*
BORREL, *Automobiles Peugeot-Montbéliard*
BRARD, *La Télémécanique Électrique-Rueil*
DAVID, *Lab. Automatique-Grenoble*
DESMOULINS, *SEMS-Échirolles*
ESQUISSAUD, *EDF-Chatou*
FRACHET, *ISMCM-Saint-Ouen*
GIRARD, *Le Carbone-Lorraine-Gennevilliers*
LEEMANS, *Merlin Gerin-Grenoble*
MARIN, *LASSY-Nice*
MOALLA, *IMAG-Grenoble*
PEIRANO, *C.E.A.-Cadarache*
POTET, *EFCIS-Grenoble*
PRUNET, *Lab.-Automatique-Montpellier*
ROUSSEAU, *EFCIS-Grenoble*
SIFAKIS, *IMAG-Grenoble*
SILVA SUAREZ, *Lab. Automatique Grenoble*
THUILLIER, *La Télémécanique Électrique-Carros*
TOULOTTE, *C. Automatique-Lille*
TOURRES, *EDF-Clamart*
VALETTE, *LAAS-Toulouse*
ZAHND, *E.P.F.-Lausanne*
Animateur du Groupe de travail AFCET « Systèmes logiques » : Michel BLANCHARD.

ISO norm (mainly) in the framework of software engineering.

- *International Standard Organization* (ISO)
- *International Electrotechnical Commission* (IEC)
- The ISO/IEC 15909, publicized into two parts:

  (1) ***Systems and software engineering - High-level Petri nets – Part 1: Concepts, definitions and graphical notation***, 2004;

  (2) ***Systems and software engineering - High-level Petri nets – Part 2: Transfer format***, 2011

Maturity & engineering disciplines

The necessity of **formal methods** is beyond question in mature engineering disciplines.

Maturity of an engineering discipline requires:

- **Formalisms** ("secure reasoning")
- **Methodological support** (easiness of use, reusability…)
  - Existence of expertise (e.g., in terms of catalogs of models and methods for specific domains)
  - Analysis techniques
  - Synthesis procedures
  - (Software) Tools
  - Standards & international norms (ISO, IEC…)
  - Implementation with different technologies (+ fault-tolerance, etc.)

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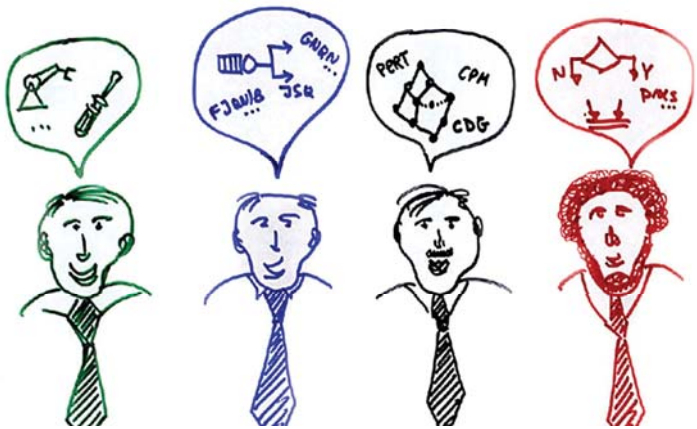
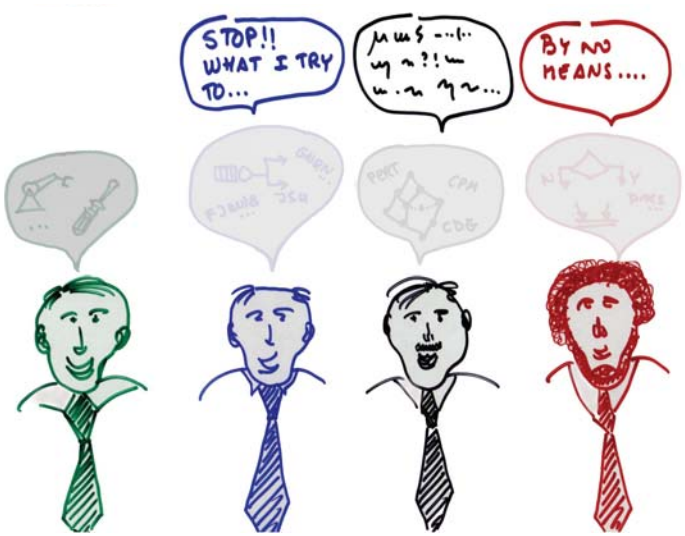




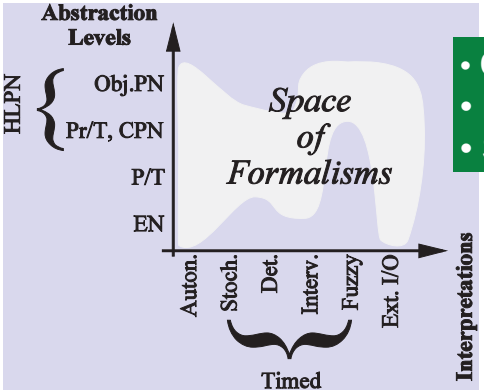
… même si tous du petit village! (société ...)

From a "formalism" *vs* a "modeling paradigm"

- Long ***life-cycle*** of many systems >>> ***family* of related formalisms** rather than a collection of "unrelated" formalisms.
- A ***paradigm*** is (Kuhn, 1962):
  [...] the total pattern of perceiving, conceptualizing, acting, validating, and valuing associated with a particular image of reality that prevails in a science or a branch of science.
- A ***modeling paradigm*** is a conceptual framework that allows to obtain formalisms from some common concepts and principles.
- But ***multidisciplinarity*!!!**… also multiformalisms…

the Kuhn's

PNs constitute a *modelling paradigm*



- **Coherence**
- **Economy**
- **Synergy**

+ relaxions:
- Hybrid
- Continuous

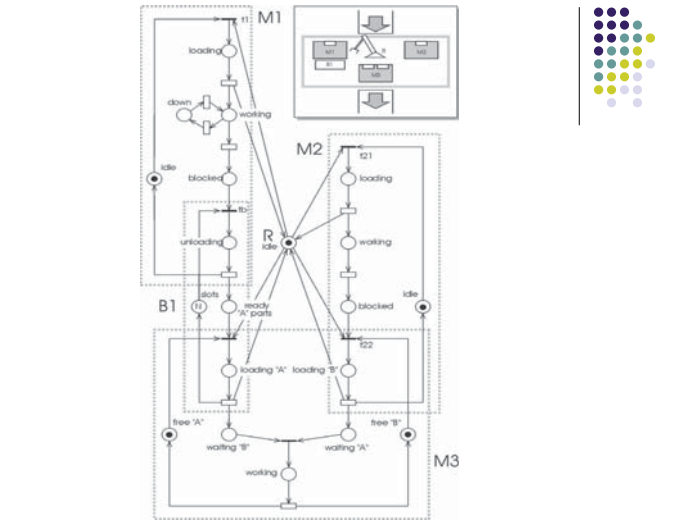
An elementary example: Basic manufacturing cell & life-cycle

- Performance ***vs*** buffer capacity: monotonicity (?)
- Frequential view: ***filtering effect*** due to the buffer
- Gantt diagrams: two ***scheduling*** strategies
- Marking diagram: ***control***
- Error detection & correction:
  - Duplication ***vs*** observation
  - Observable view

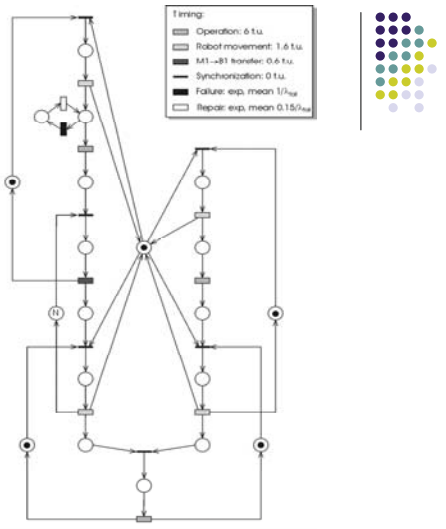
The basic manufacturing cell & life-cycle

- Two processing machines (M1 and M2)
- An assembly machine (M3)
- A robot (for transportation purposes, R)
- A buffer (inventory, deposit,...) to uncouple upstream and downstream of M1

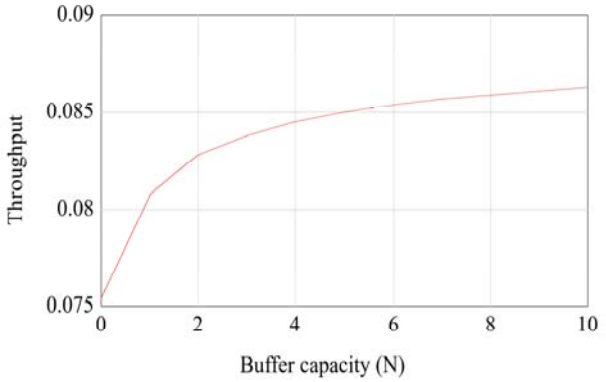
- **Cooperation relationships (3 machines)**
- **Machine-buffer-machine: decoupling**
- **Competition (mutex-robot)**



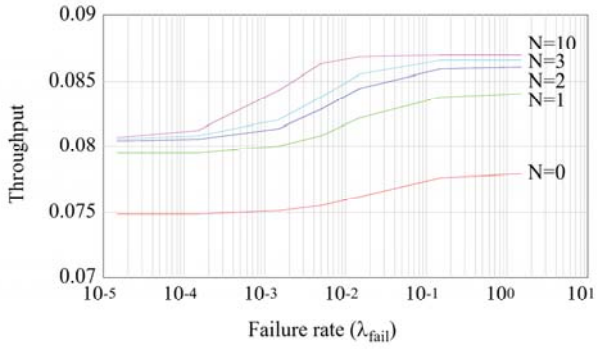
Stochastically Timed model



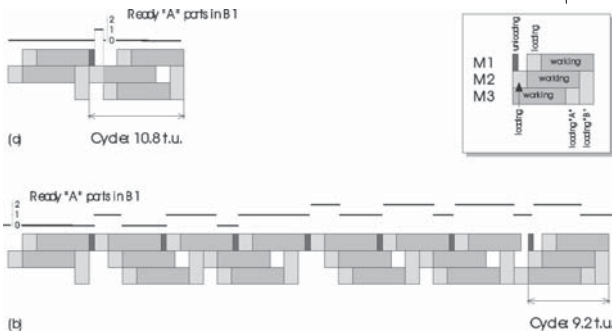
Performance *vs* Capacity. Monotonicty (not always)



Frequential view: "filtering effect" due to the buffer



Gantt diagrams: two scheduling strategies

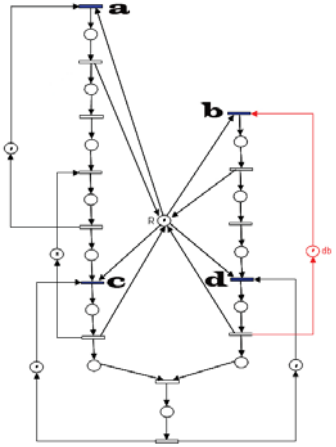


Performance *optimization: Scheduling // Control*

Deterministically Timed model

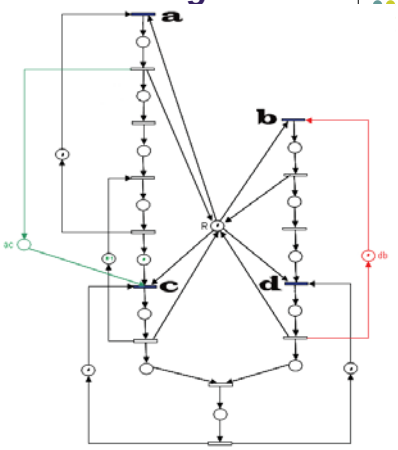
- Pb.: how to order the firing of *a,b,c,d*?
  - **Cyclic: 3!=6 cases**

BUT: db → 2! = 2 cases!



Performance *optimization: Scheduling-Control*

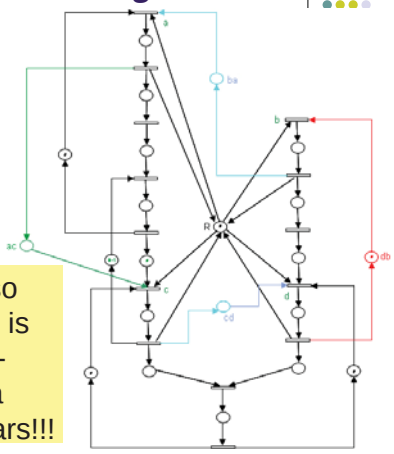
- Pb.: how to order the firing of *a,b,c,d*?
  - repetitive: 3!=6 cases
- ✓ db → 2! = 2 cases !
- ✓ ac → 1! = 1 case !!!



Performance *optimization: Scheduling-Control*

- Pb.: how to order the time of *a,b,c,d*?
  - repetitive: 3!=6 cases

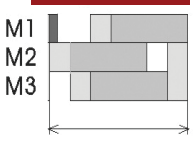
With: ac → 1! = 1 case !!!



R becomes **implicit** (so places {db,ac,cd,ba} is an optimal schedule-control): remove it, a marked graph appears!!!

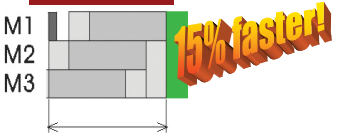
Performance *optimization: Scheduling-Control*

Autonomous

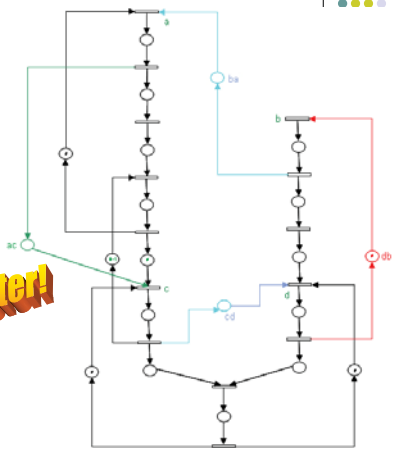


Cycle: 10,8 t.u.

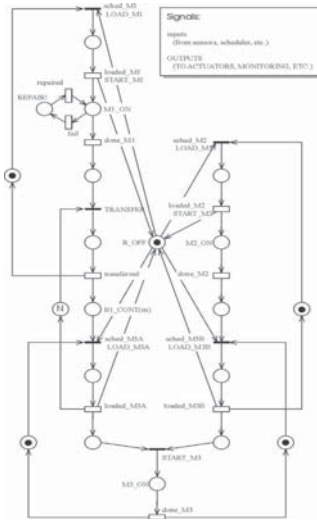
Controlled



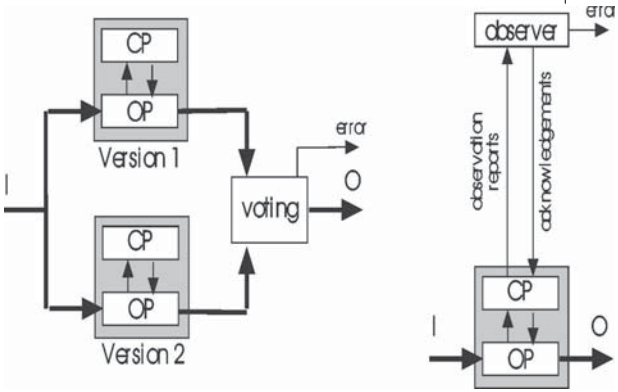
Cycle: 9,2 t.u.



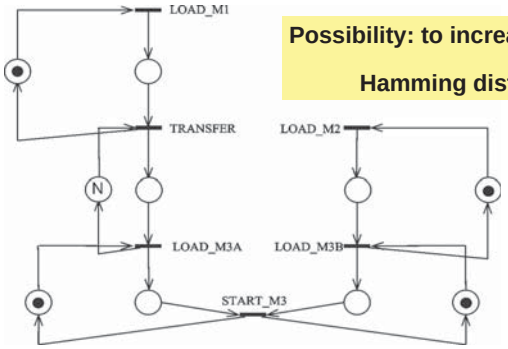
Distributed State Diagram: *Marking Diagram*



Duplication *vs* Observation



Checking points: Observable view



Possibility: to increase the Hamming distance

+ Fault detection & diagnostic… (consistent markings…)

multiformalisms… multi-paradigmatic bridges

- **even if we believe that PNs constitute an adequate conceptual framework or paradigm for the operational description of DEDS:**

  "we do not believe that it is always possible to select a single formalism, or family of them, to deal in a reasonable way with every aspect of every DEDS. The complexity and variety of systems suggest instead the interest of having *multi-paradigm* environments where the existence of sound and efficient bridges between different paradigms becomes a major issue" (Silva and Teruel, 1996).

- **In a different, but close context:**

  "I reject the idea that there can be a unique conceptual model, or one preferred formalism, for all aspects of something as large as concurrent computation." (Milner, 1993)

The important fact: the existence of inter-paradigmatic transformations **(bridges)**

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5. On five interactions over twenty five years

In this part I will consider five points of contact with Carl Adam, over more than 25 years.

The first recall our ***fully disjoint*** set of interests at the given time (1976)

Synchronic relations and ***fluidization*** are two topics I sporadically discuss with him, Carl Adam showing big interest. Even sometimes we arrive to agree on ***"doing something together"***, **but…**

Just five points… over more than a quarter of century

1. **A student in Grenoble, 1976**
2. **At the Bocconi University & Oxford, 1986**
3. **At he European Workshop on Petri Nets, Zaragoza, 1987**
4. **Carl Adam Petri, Doctor *Honoris Causa* by the University of Zaragoza, 1999**
5. **The International Conference on Petri Nets and Related Models, Miami, 2005**

I. I was a PhD student in Grenoble, LAG (+ENSIMAG), 1975-1978

- The first time I meet C.A. Petri was at the **ENSIMAG** (Mme. Saucier, **J. Sifakis**…), 1976
- My interest was important because months before I abruptly change the topic of my PhD from:
  - **interconnected automata & modular hardware synthesis (CUSAs / "hazards under control")** to
  - **Petri nets & programmable logic controllers (PLCs)**
- The topic of his talk? --Synchronic distance related…?
- But at that period I deal with problems of quite different nature (***software implementation*** issues, ***performance evaluation***…/ he does not like explicit timing…)

Just five points… over more than a quarter of century

1. A student in Grenoble, 1976 (¿1977?)
2. At the Bocconi University & Oxford, 1986
3. The European Workshop on Petri Nets, Zaragoza, 1987
4. Carl Adam Petri, Doctor *Honoris Causa* by the University of Zaragoza, 1999
5. The International Conference on Petri Nets and Related Models, Miami, 2005

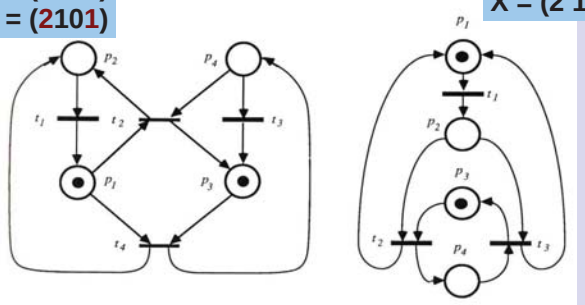
II. At the Bocconi University & EWPN-Oxford, 1986

- The context (Bocconi Univ.: **A. Pagnoni**):
  - I was interested on *transitions firing dependences* in "generalized" (weigthed) PNs (P/T)
  - Petri (1975/76): Synchronic Distance, S-completion…
  - Other previous works by: J. Sifakis, U. Golz, I. Suzuki, T. Kasami, T. Murata…
  - My cooperation with **T. Murata** (USA-Spain Joint Com. for Scientific & Technological Research, 1985/88)
- The fact: existence on "**Non-linear** Synch. Relations"
- I did show Carl Adam one (the) "smallest" ordinary, pure, live & bounded net system…

II. At the Bocconi University & EWPN-Oxford…: Synchrony Theory

X1 = (1011)
X2 = (2101)

X = (2 1 1)



Synchrony Theory: a branch of **General Net Theory** devoted to the study of transitions firing dependences

II. At the Bocconi University & EWPN-Oxford…: Synchrony Theory

Linearly based synchronic properties:
Synchronic lead & Distance

A new way of measuring: ***SD is a metric***

Basic **finite delay** synchronic properties:
B-deviation & B-fairness

Quantitative dependences (value) & **synchronic relations** (boundedness)

Synchronic relations: **behavioural** (given m_0) **& structural** (for any m_0)

II. At the Bocconi University & EWPN-Oxford…: Synchrony Theory

- **SD-relation ► BF-relation,** the reverse does not hold
- Structural BF & SD relations (SBF; SSD):
  - are ***equivalence*** relations and
  - can be computed in ***polynomial time***.
- In bounded systems, realizability of min-T-semiflows ►
  ► ***Behavioural = Structural* Synchronic relations**

DUALITY:
T-views (T-semiflows) *vs*
P-views (implicit places, eventually on partial nets)

Just five points… over more than a quarter of century

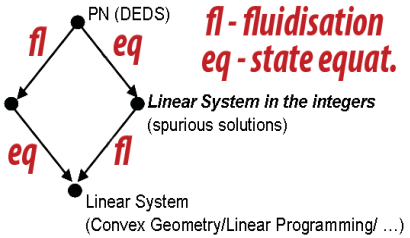
1. A student in Grenoble, 1976 (¿1977?)
2. At the Bocconi University & Oxford, 1986
3. The European Workshop on Petri Nets, Zaragoza, 1987
4. Carl Adam Petri, Doctor *Honoris Causa* by the University of Zaragoza, 1999
5. The International Conference on Petri Nets and Related Models, Miami, 2005

III. The European Workshop on Petri Nets, Zaragoza, 1987

- "On the computation of structural synchronic invariants in P/T nets", co-authored with **J.M. Colom.**
- The idea: **systematic use of LPP**, weak & strong duality theorems, unboudness theorems & alternatives theorems.
- **Polynomial time** computation of **bounds** ("like" **fluid** relaxation) of the synchronic values, and of the structural synchronic relations (lead, distance, deviation & B-fairness).
- Precedents on the use of:
  - LPP: **H.J. Genrich** & **K. Lautenbach,** for ***marked graphs*** (but exact values, because the incidence matrix is ***unimodular***)
  - Farkas' lemma / alternatives theorems: **G. Memmi** & **J. Sifakis**

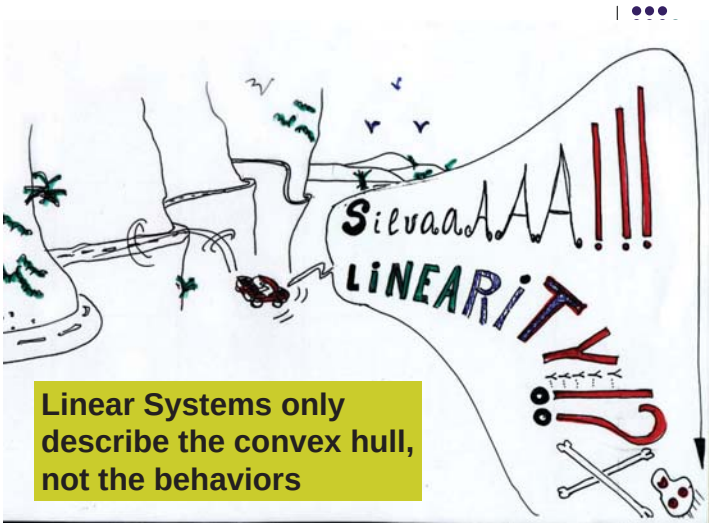
III. The European Workshop on Petri Nets, Zaragoza, 1987

- **Continuous Petri Nets**
  - ***Explicitly*** (net level): **R. David & H. Alla**
  - ***Implicitly*** (relaxation at the state equation level): Systematic use of LPP
- **A topic received with reluctances in the EWPN / ICATPN (like stochastic PNs were sometime before)**



fl - fluidisation
eq - state equat.

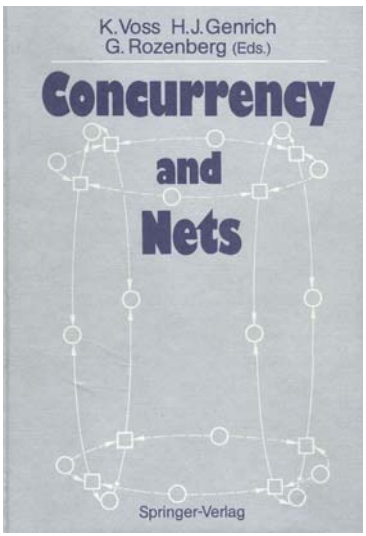
(A small technicality:
- consistency &
- no-empty siphon at the initial marking)



Linear Systems only describe the convex hull, not the behaviors

III. The European Workshop on Petri Nets, Zaragoza, 1987

- ***Concurrency & Nets*** (60th birthday of C. A. Petri), **K. Voss, H.J. Genrich & G. Rozenberg**, eds.
- The book was offered by the PN community to Carl Adam in Zaragoza, in a kind of **"birthday party",** at the gala diner of the EWPNs, June 1987.
- "**Towards a synchrony theory for P/T nets**" (a first global view of the topic)



III. EWATPNs, Zaragoza, 1987

EWATPN, Zaragoza 1987

Just five points… over more than a quarter of century

1. **A student in Grenoble, 1976 (¿1977?)**
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IV. C.A. Petri, Doctor *Honoris Causa* by the University of Zaragoza, 1999

- Foundation of the University of Zaragoza:
  from **«Universitas magistrorum»**
  to **«Universidad general de todas las ciencias»**
  - ***Privilege of the Emperor*** & King Charles V, 1542
  - ***Papal Bull*** of Julius III, 1554.
- … but "no funding", until some 40 years later…: Pedro Cerbuna, 1582.
- **Engineering** (***E.T.S. Ingenieros Industriales***: **Mechanical & Electrical**) & **Economics** : 1974
- As dean of **Engineering, 1989**: I obtain the transformation of the **ETSII** into **Centro Politécnico Superior**
  (+Telecommunication, + Informatics, + Chemical, …)

IV. C.A. Petri, Doctor *Honoris Causa* by the University of Zaragoza, 1999

- The opportunity:
  - **25 years** of the foundation of the Engineering School: 1974-1999
  - **10 years** of the transformation in Polytechnic Faculty ("High School"): 1989-1999
  - The dean of Engineering: prof. **Javier Martínez**, the first PhD on Petri Nets at the University of Zaragoza
- The ***first three HC on engineering*** at Zaragoza

IV. C.A. Petri, Doctor *Honoris Causa* by the University of Zaragoza, 1999

- The program was conceptually based on three basic pillars of technology, and three outstanding personalities:
  - ***Materials***: Prof. **Steve Tsai**, pioneer in Composite Materials, from Stanford University.
  - ***Energy***: Prof. **Amable Liñán**, pioneer in the fluid - mechanics perspective for Combustion Engineering, from the Polytechnic University of Madrid.
  - ***Information***: Prof. **Carl Adam Petri**, as representative of System Theory & Computer Science, Univ. of Hamburg (ex-GMD, Bonn).

The day before (14-IV-99): an international seminar in his honor

- **G. Balbo (Universitá di Torino):**
  On PNs and Performance Evaluation: The GSPN case
- **J. Billington (University of South-Australia):**
  On the ISO/IEC Petri Net standard (15909)
- **D. de Frutos (Universidad de Madrid):**
  Decidable properties in Timed Petri nets
- **M. Koutny (University of Newcastle upon Tyne):**
  Combining Petri Nets and Process Algebras
- **M. Silva (Universidad de Zaragoza):**
  On continuous Petri Nets

The entourage: towards the Paraninfo

UZAR, Paraninfo: the 15 of April at 12h

Accipe pileum…: the academic cap

The speech

Just five points… over more than a quarter of century

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5. The International Conference on Petri Nets and Related Models, Miami, 2005

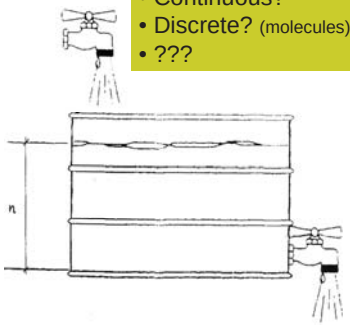
V. The Int. Conf. on Petri Nets and Related Models, Miami, 2004

- Context for ***fluid models***:
  - System Theory
  - Automatic Control Theory (observability, controllability…)
  - Operations Research
  - Scalability of models with "large populations" (**QNs, Compartmental Systems, SFGs, FDs…**)
- A "last" chapter in the PhD of **Laura Recalde**, 1998

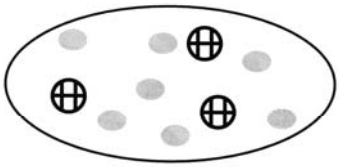
V. The Int. Conf. on Petri Nets and Related Models, Miami, 2005

- ***Continuisation of Timed Petri Nets: From Performance Evaluation to Observation and Control*** (inv. lecture)
- We (re)comment on "fluid views"
- Molecules ***vs*** mols:
  - Fractions of moles
  - He found "not surprising" my (first) degree on Chemical-engineering ☺

- Discrete: {1,2,3}
- Continuous?
- Discrete? (molecules)
- ???



Systems are NOT…:
- **we always manage *models*: "views" of systems**
- **are we able to move form one to another level? (i.e., when are we able? / how? / …)**

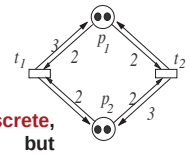


Predator/prey: Volterra-Lotka equations…

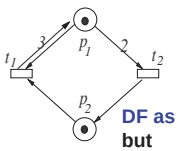
Manufacturing engineers, sometimes seems to be hydraulic engineers

On Unfluidisable Models

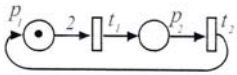
- Deadlock-freeness: discrete *vs* continuous (?)



Dealock as discrete, but DF as continuous



DF as discrete, but Deadlock as continuous



ZENO

- Liveness: yes or not?: **lim-reachability** (!)

On fluid / continuous PNs

if there is no dead transition (no siphon unmarked):
- all the potential repetitive sequences are realizable
- **Behavioural** and **structural** synchronic relations coincide (in particular bounded= ***structurally*** bounded)
- Therefore synchronic relations can be computed in ***polynomial time***!!

For ***hybrid*** and ***discrete*** net systems, the above is not necessarily true (usually false)

timed models: *infinite server* semantics-*minimum*

Infinite Servers Semantics (*variable speed*)

$$\mathbf{f}(\tau)[t] = \lambda[t] \cdot \mathrm{enab}(t,\mathbf{m}) = \lambda[t] \cdot \min_{p \in {}^\bullet t} \left\{ \frac{\mathbf{m}[p]}{\mathbf{Pre}[p,t]} \right\}$$

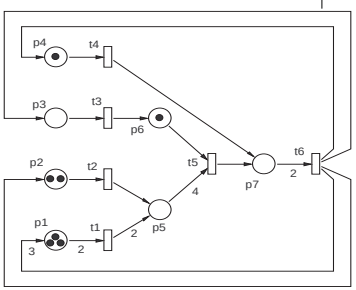
Firing rate: proportional to the input "level"
Analogous to the discrete "markovian" case

A set of ***switching*** differential linear systems

$$\begin{cases} \dot{\mathbf{m}}(\tau) = \mathbf{C} \cdot \mathbf{f}(\tau) \\ \mathbf{f}(\tau)[t] = \lambda[t] \cdot \min_{p \in {}^\bullet t} \left\{ \frac{\mathbf{m}[p](\tau)}{\mathbf{Pre}[p,t]} \right\} \end{cases}$$

example: *infinite* server semantics-*minimum*

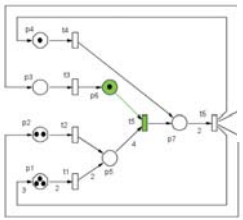
piecewise linear system

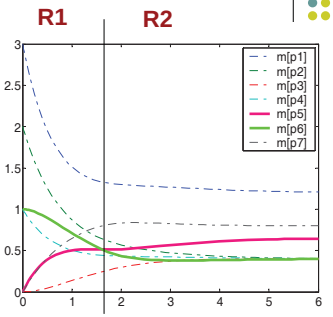


$$\mathbf{f}(\tau)[t_1] = \lambda[t_1] \cdot \mathbf{m}(\tau)[p_1]/2$$
$$\mathbf{f}(\tau)[t_2] = \lambda[t_2] \cdot \mathbf{m}(\tau)[p_2]$$
$$\mathbf{f}(\tau)[t_3] = \lambda[t_3] \cdot \mathbf{m}(\tau)[p_3]$$
$$\mathbf{f}(\tau)[t_4] = \lambda[t_4] \cdot \mathbf{m}(\tau)[p_4]$$
$$\mathbf{f}(\tau)[t_5] = \lambda[t_5] \cdot \min\{\mathbf{m}(\tau)[p_5]/4, \mathbf{m}(\tau)[p_6]\}$$
$$\mathbf{f}(\tau)[t_6] = \lambda[t_6] \cdot \mathbf{m}(\tau)[p_7]/2$$

$$\mathbf{f}(\tau)[t_5] = \lambda[t_5]\cdot\mathbf{m}(\tau)[p_5]/4$$

$$\mathbf{f}(\tau)[t_5] = \lambda[t_5]\cdot\mathbf{m}(\tau)[p_6]$$

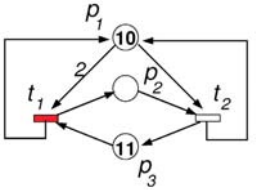


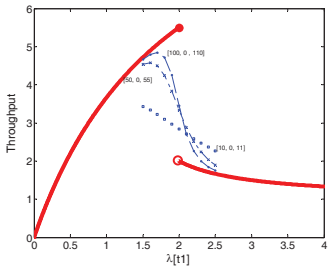


configurations & ***regions***

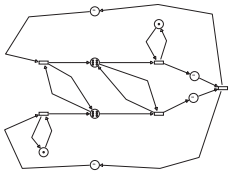
one of the counterintuitive properties in timed (infinite servers semantics) models

- No performance monotonicities with respect to **firing speeds**
- **Discontinuities,** bifurcations

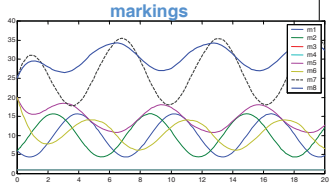




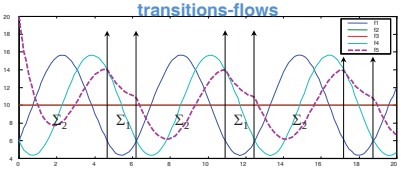
infinite number of switchings



markings



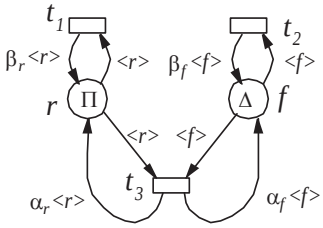
transitions-flows



Continuous PNs under infinite servers semantics simulate TURING Machines:
expressivity *vs* analyzability!!!

decolouring and net interpretation-*product*

- Population dynamics: basic ***predator/prey*** model

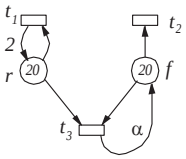


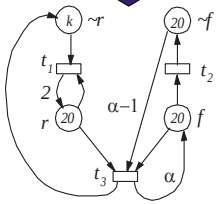
- ***rabbits***
- ***foxes***

Consequende of product-semantics: it is possible to simulate the Lorentz's equation.... chaos !!!

decolouring and net interpretation-*product*

+ bounds on populations

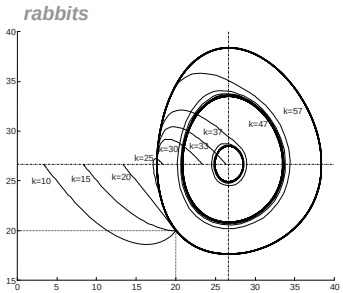




P/T models of the predator/prey system, with α_r=0, α_f=α, β_r=2, β_f=0, $|\Pi|=|\Delta|$=20. They can be seen either as discrete or as continuous PN.

$$\begin{cases} \dot{r} = \lambda_1 \cdot r - \lambda_3 \cdot r \cdot f \\ \dot{f} = \lambda_3 \cdot (\alpha - 1) \cdot r \cdot f - \lambda_2 \cdot f \end{cases}$$

synchronisations leads to ***products***



Trajectories obtained with

$\lambda[t1]$=0.75, $\lambda[t2]$= $\lambda[t2]$=20, α=2,

$\mathbf{m_o}[r]$= $\mathbf{m_o}[f]$=20, $\mathbf{m_o}[\sim f]$=40, $\mathbf{m_o}[\sim r]$=k

Discrete (Stochastic)	**Continuous** (Deterministic)
(Un)bounded	Bounded
Non-live	Live

Concluding the selected points …

- As a difference with other experiences, usually my conversations with Carl Adam Petri were not really long, I try to keep on very concrete things.
- We should remember Carl Adam as:
  - the **founder of a field**, that influence others, that combine **conceptual elegance** & **pragmatism**;
  - a **close** & **warm-hearted** person.

…and to conclude with an image-souvenir…