On synchronic relations and on fluidization

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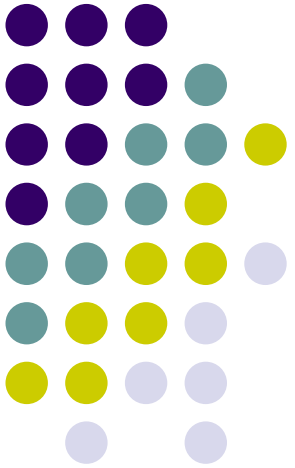


Carl Adam Petri Memorial Symposium, Berlin, February 4, 2011

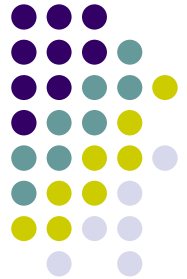
Carl Adam Petri Memorial Symposium

In this presentation I will consider five points of contact with Carl Adam, over more than 25 years. The first recall our **disjoint** set of interests at the given time (1976)

The title deal with two topics I sporadically discuss with him, Carl Adam showing big interest. Even sometimes we arrive to agree on “doing something together”, **but…**

The presentation is a modest tribute to his memory, a (certainly biased) commemoration of his life & work.

Carl Adam Petri Memorial Symposium



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

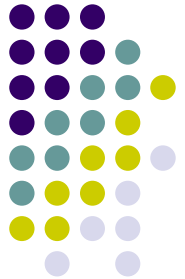
… Carl Adam Petri look for a **Systems Theory**, beyond what is the problematic in Computer Science, applicable to many types of systems in a broad landscape of research fields (law, manufacturing, transportation, chemistry, epidemiology, demography…)

Carl Adam Petri Memorial Symposium

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 less frequently exercised with success speciality than “theorem prover”.

At the personal level he always was warm-hearted.

Just five points… over more than a quarter of century



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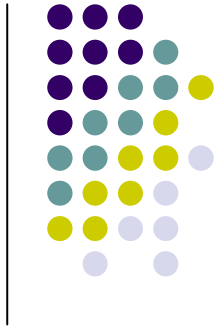
I. A student in Grenoble, 1976 / 77

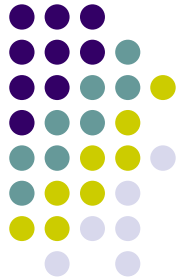


- The first time I meet C.A. Petri was at the **ENSIMAG** (Mme. Saucier, **J. Sifakis**…)
- My interest was important because months before I abruptly change the topic of my PhD from:
  - **interconnected automata & modular hardware synthesis (CUSAs / "hazards under control")** to
  - **Petri nets & 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, ***performan-ce evaluation***…/ he does not like explicit timing…)

From 1950's to 1960's

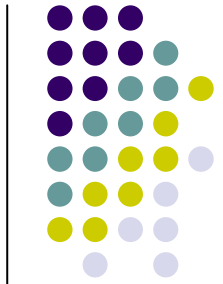
Salient features:

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



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

I. A student in Grenoble, 1976 / 77



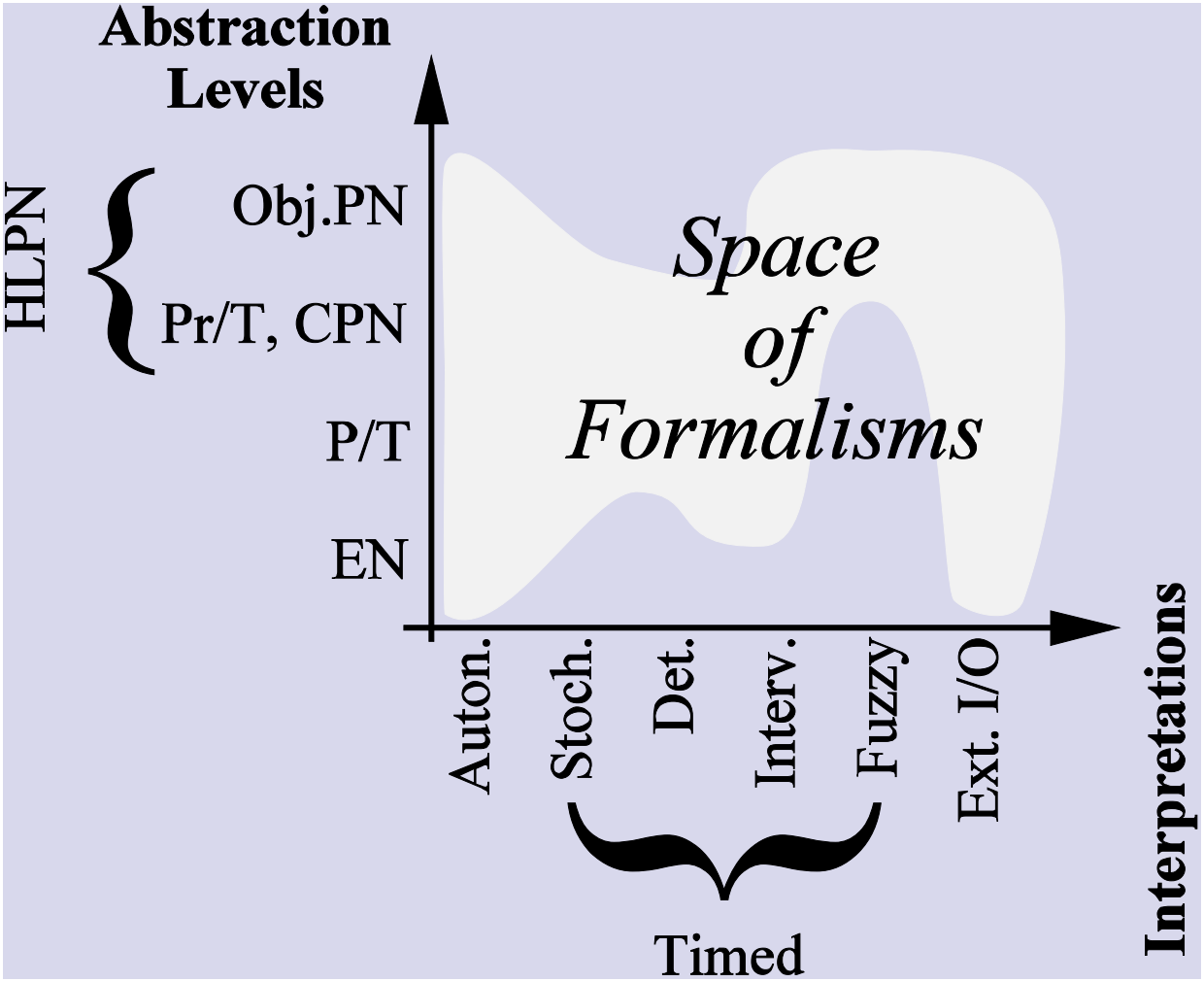
Years later I realise that to “the town” of Petri Nets (with several nuances) we may arrive using different **roads …**:

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

if all roads lead to Rome …

more than “probably”, Rome should be important!

PNs are not just a set of formalisms: they constitute a modelling paradigm

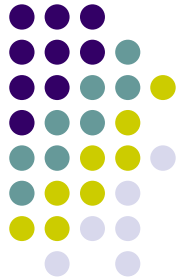


- Coherence
- Economy
- Synergy

+ relaxions:

- Hybrid
- Continuous

Just five points… over more than a quarter of century



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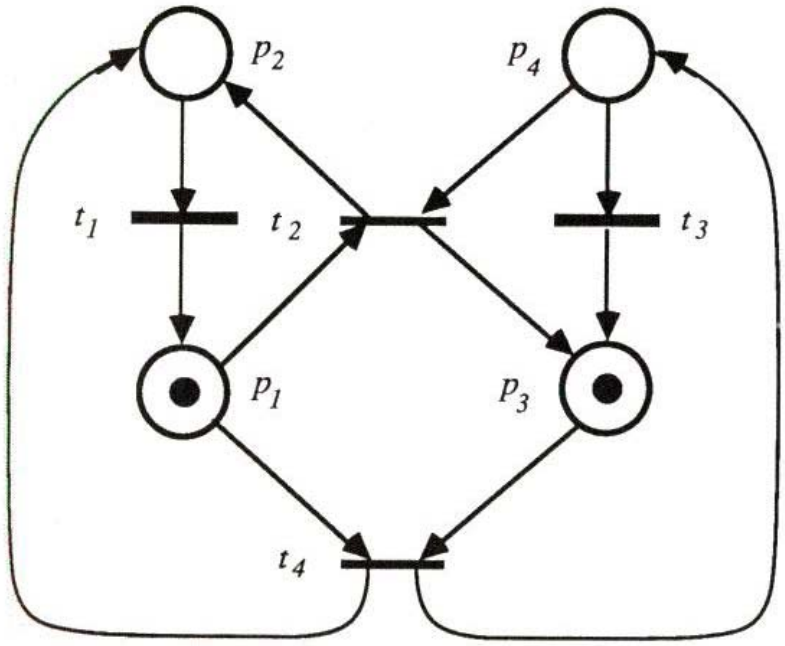
II. At the Bocconi University & EWPN-Oxford, 1986

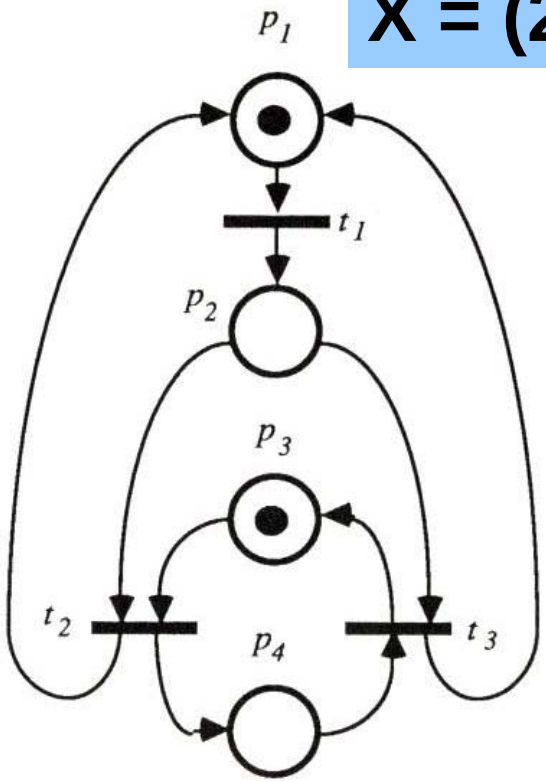
- The context (Bocconi Univ.: **A. Pagnoni**):
  - I was interested on *transitions firing dependences* in "generalized" (weigthed) PNs (P/T)
  - Petri (1975/76): Synchronic Distance, S-completion…
  - Other previous works by: J. Sifakis, U. Golz, I. Suzuki, T. Kasami, T. Murata…
  - My cooperation with **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, 1986

X1 = (1011)
X2 = (2101)

X = (2 1 1)





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

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

Basic **finite delay** synchronic properties:

B-deviation & B-fairness

Linearly based synchronic properties:

Synchronic lead & Distance

Quantitative dependences (value) &

synchronic relations (boundedness)

Synchronic relations: **behavioural** (a given m_0) & **structural** (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)

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

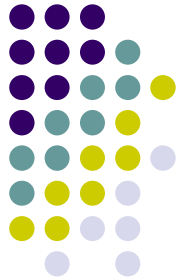
- If *(ti, tj)* are in BF-relation, then ***both or none*** are live
- Generalization: **Group-synchronic relations (SL, SD, DB, FB)**

One interpretation: in (bio-)chemistry

- **(Str.) Synchronic Distance relation --- *Stoichiometric relation***

  (quantitative relationships between the reactants and products in chemical reactions: the proportion at long term is fixed)
- **Structural B-fairness rel**.: sometimes "rebaptized" as ***dependency*** **(in fact, only a particular case of "dependency")**
- The equivalence classes are in a case "renamed as": *abstract dependent transitions* (ADTs)

Just five points… over more than a quarter of century



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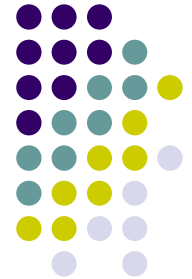
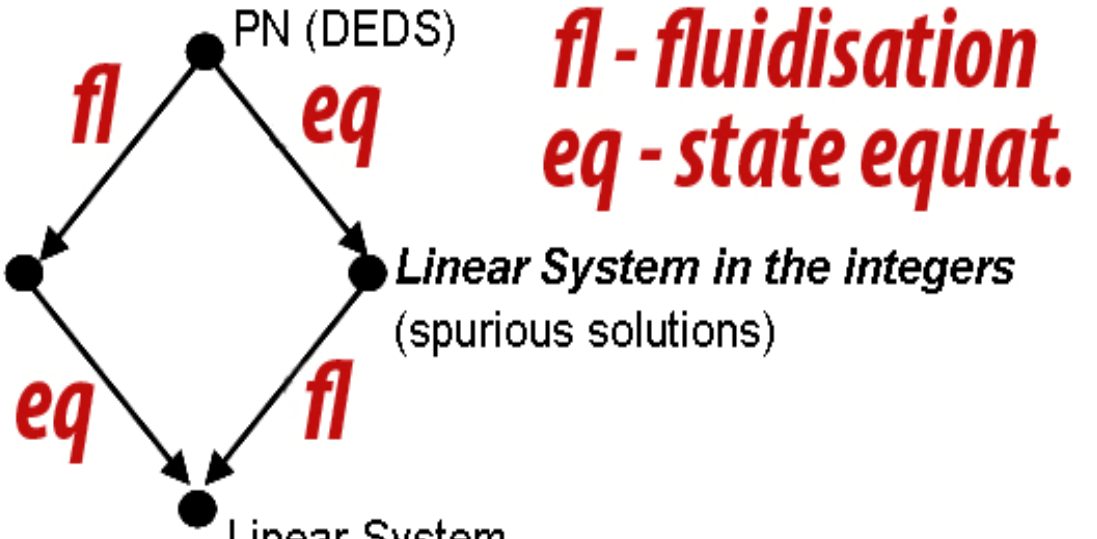


- "On the computation of structural synchronic invariants in P/T nets", co-authored with **J.M. Colom.**
- The idea: **systematic use of LPP**, (weak & strong) duality and unboudness theorems (+ alternatives theorems).
- **Polynomial time** computation of **bounds** ("like" **fluid** relaxation) of the 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

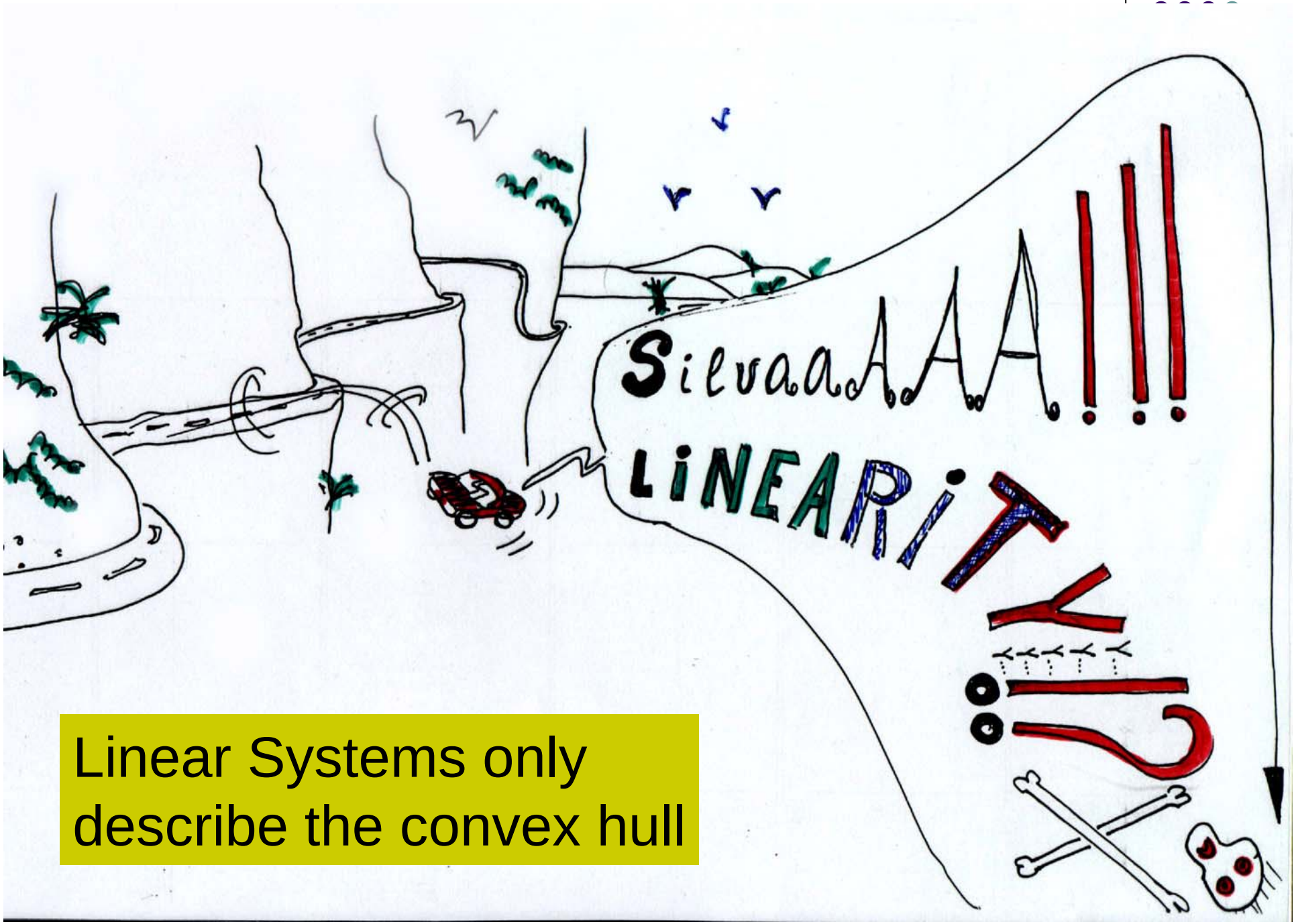
- **Continuous Petri Nets**
  - ***Explicitly*** (net level):
    R. David & H. Alla
  - ***Implicitly*** (relaxation at the state equation level): Systematic use of LPP

- **A topic received with reluctances in the EWPN / ICATPN (like stochastic PNs were sometime before)**



fl - fluidisation
eq - state equat.

(Technically:
Consistency & no-empty siphon)



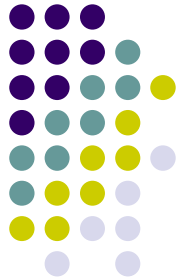
Linear Systems only describe the convex hull

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

- *Concurrency & Nets* (60th birthday of 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)


EWPN, Zaragoza 1987

Just five points… over more than a quarter of century



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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**: 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***: Dr. **Carl Adam Petri**, as representative of System Theory & Computer Science, from GMD, Bonn.

The day before: 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

UZAR, Paraninfo: the 15 of April at 12h

The Paraninfo (the place of the EWPN'87)


Laude
candidatorum
D.O.M.
S.M.C. D.ña MARIA CRISTI
DE HAPSBURGO-LORENA.
HIJO D. ALFON
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The medal

The speech


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ANDO S.M.C.D.ÑA
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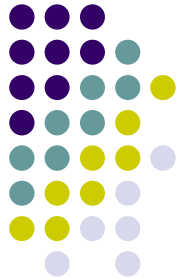
Just five points… over more than a quarter of century



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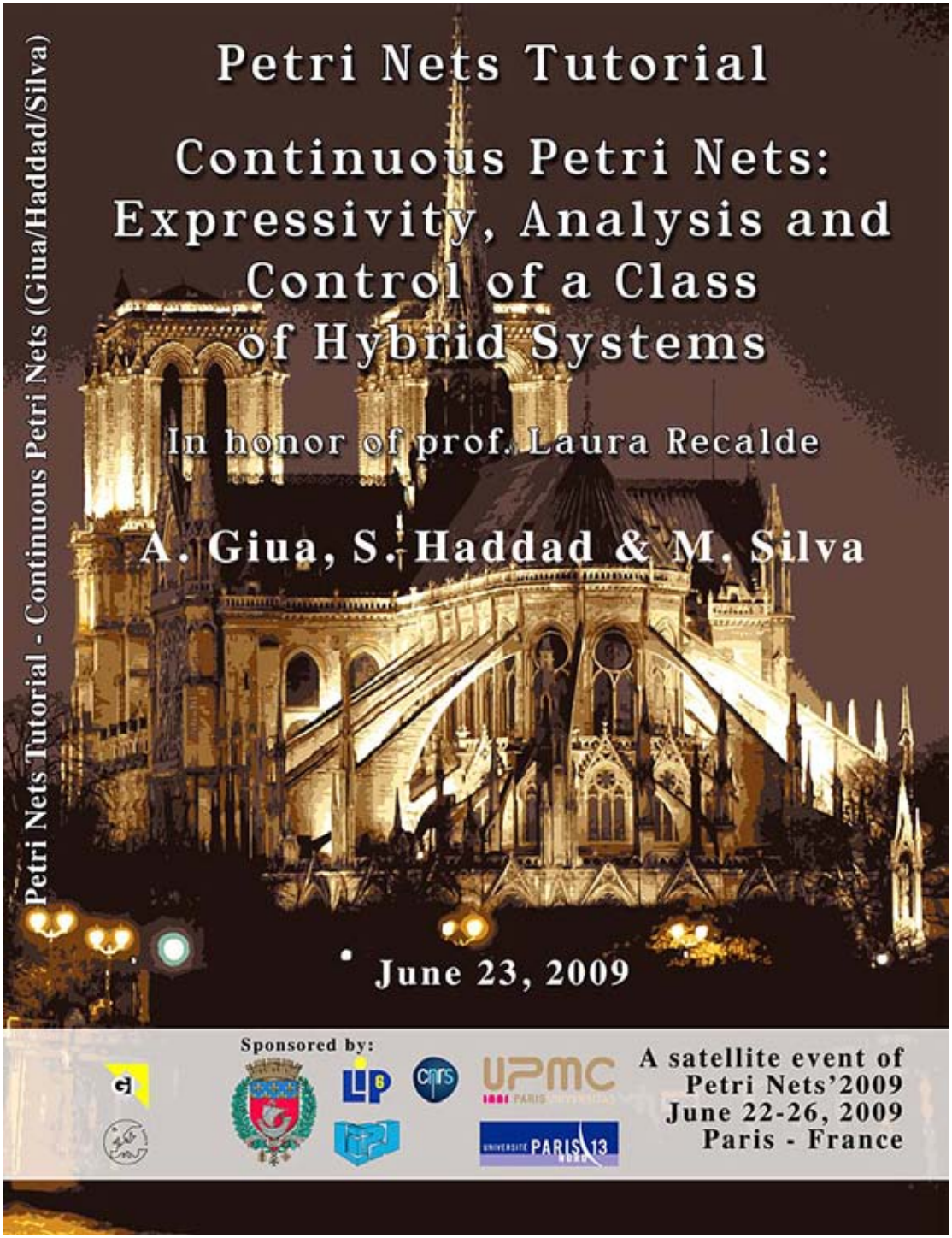
V. The Int. Conf. on Petri Nets and Related Models, Miami, 2004

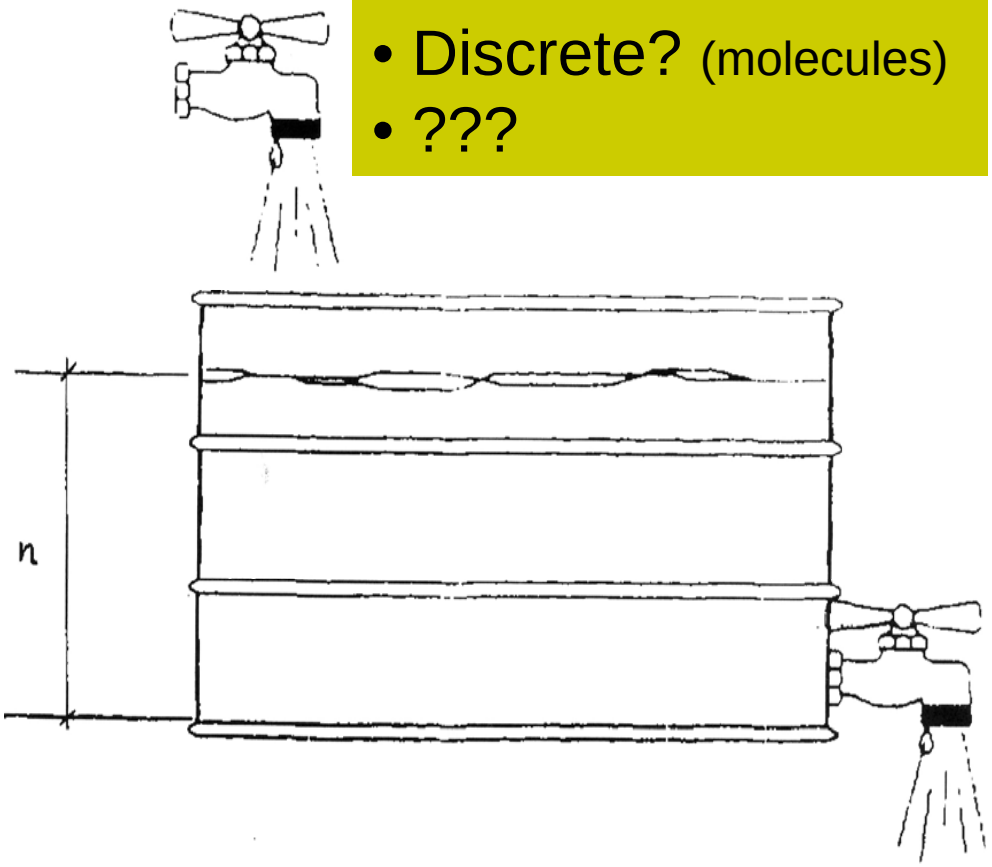
- Context for ***fluid models***:
  - System Theory
  - Automatic Control Theory (observability, controlla-bility…)
  - Operations Research
  - Scalability of models with "large populations" (**QNs, Compartmental Systems, SFGs, FDs…**)
- A "last" chapter in the PhD of **Laura Recalde**, 1998


Petri Nets Tutorial - Continuous Petri Nets (Giua/Haddad/Silva)
Petri Nets Tutorial
Continuous Petri Nets: Expressivity, Analysis and Control of a Class of Hybrid Systems
In honor of prof. Laura Recalde
A. Giua, S. Haddad & M. Silva
June 23, 2009
Sponsored by:
A satellite event of Petri Nets'2009
June 22-26, 2009
Paris - France

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

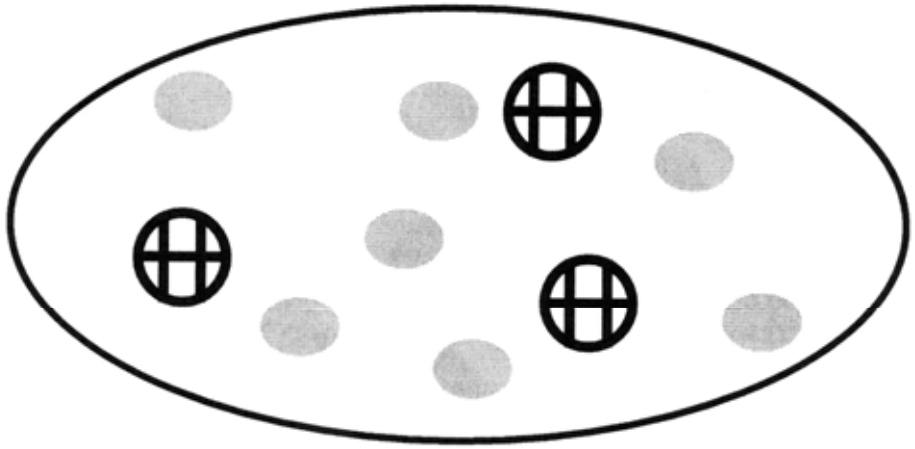
- ***Continuisation of Timed Petri Nets: From Performance Evaluation to Observation and Control*** (inv. lecture)
- *Special lecture by* **Carl Adam Petri**: ***New Dimensions for Nets***
- We (re)comment on fluid “views”
- Molecules ***vs*** mols: He found “not surprising” my (first) degree on Chemical- engineering ☺

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



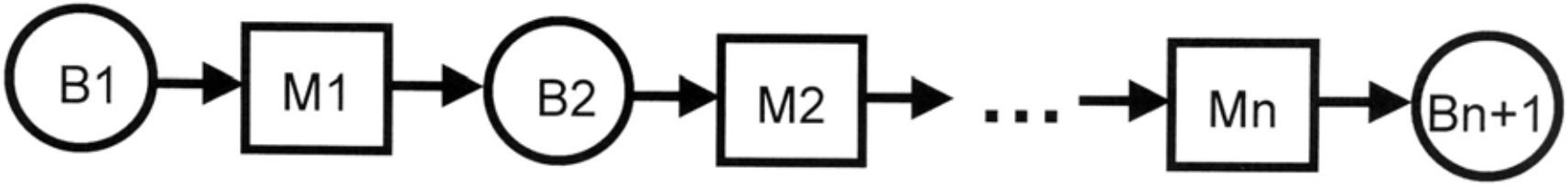
Systems are NOT…:

- **we always manage "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…

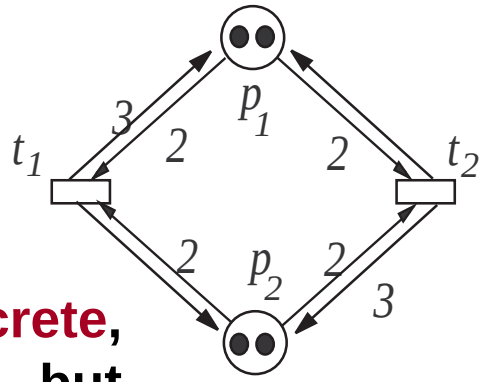
Manufacturing engineers, sometimes seems to be hydraulic engineers

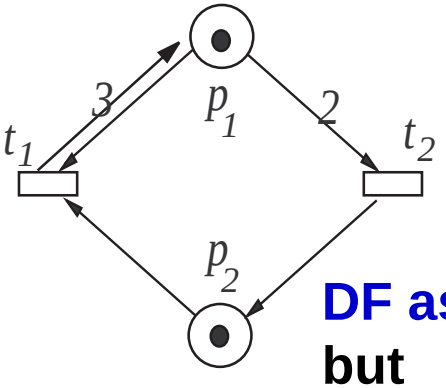


On Unfluidisable Models

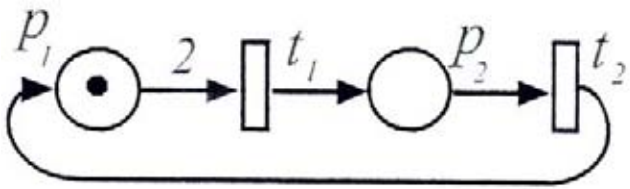
- Deadlock-freeness: discrete *vs* continuous (?)

Dealock as discrete,
but
DF as continuous





DF as discrete,
but
Deadlock as continuous



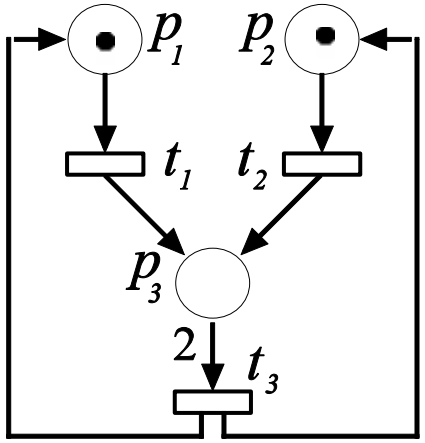
ZENO

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

Continuous vs Discrete Behaviour

Even in bounded systems, infinite sequence exists such that all the intermediate markings are different

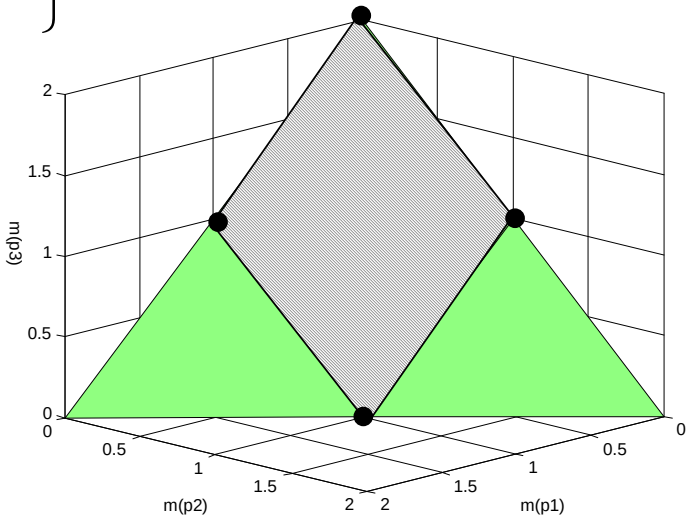
Choice free



$$\sigma_k = t_1\left\{\frac{1}{2^k}(t_3 t_1)\right\}^*$$

lim-reachability:

$$\mathbf{m_0}\left[\lim_{k\to\infty}\sigma_k\right\rangle [002]$$



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*)

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

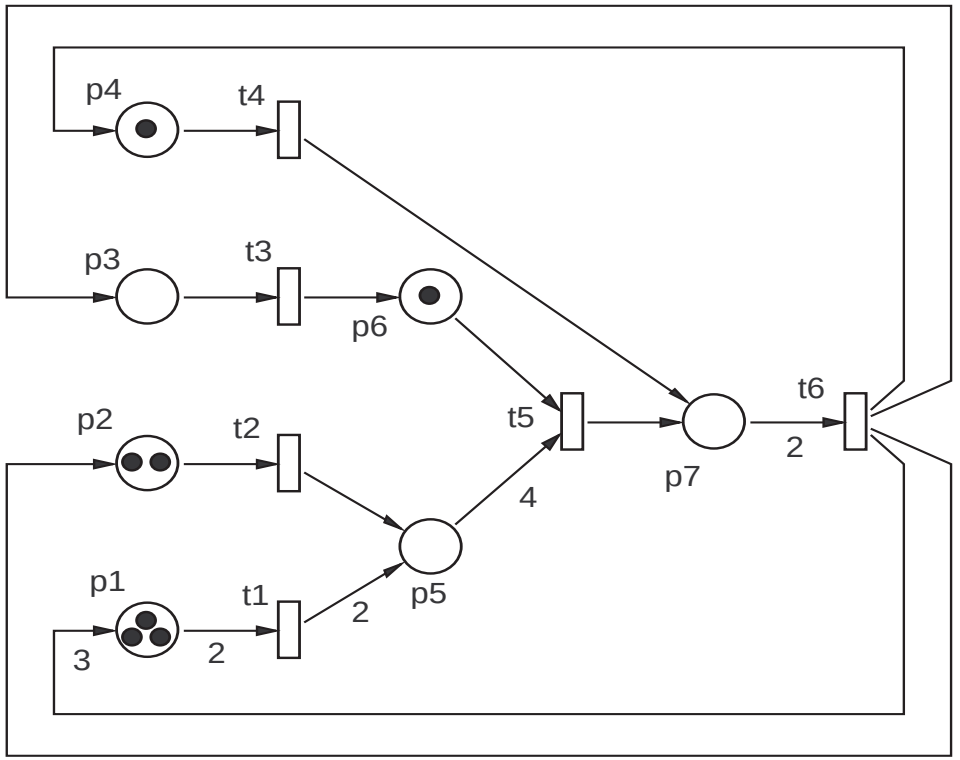
Firing rate: proportional to the input "level"
Analogous to the discrete "markovian" case

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

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

example:
infinite server semantics-*minimum*

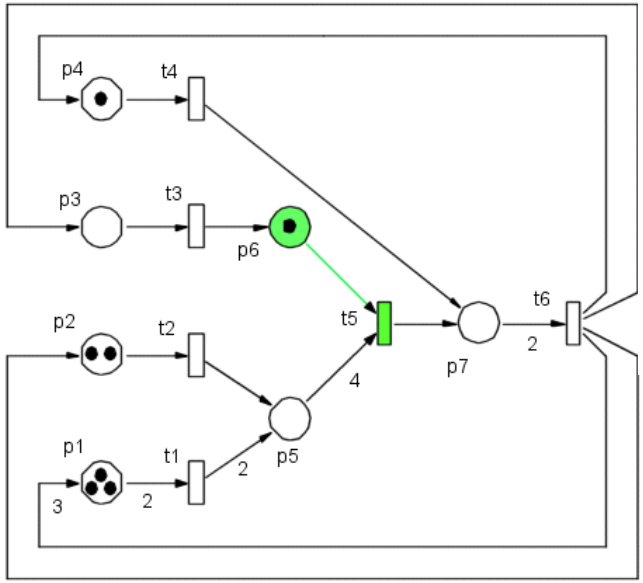
piecewise
linear system

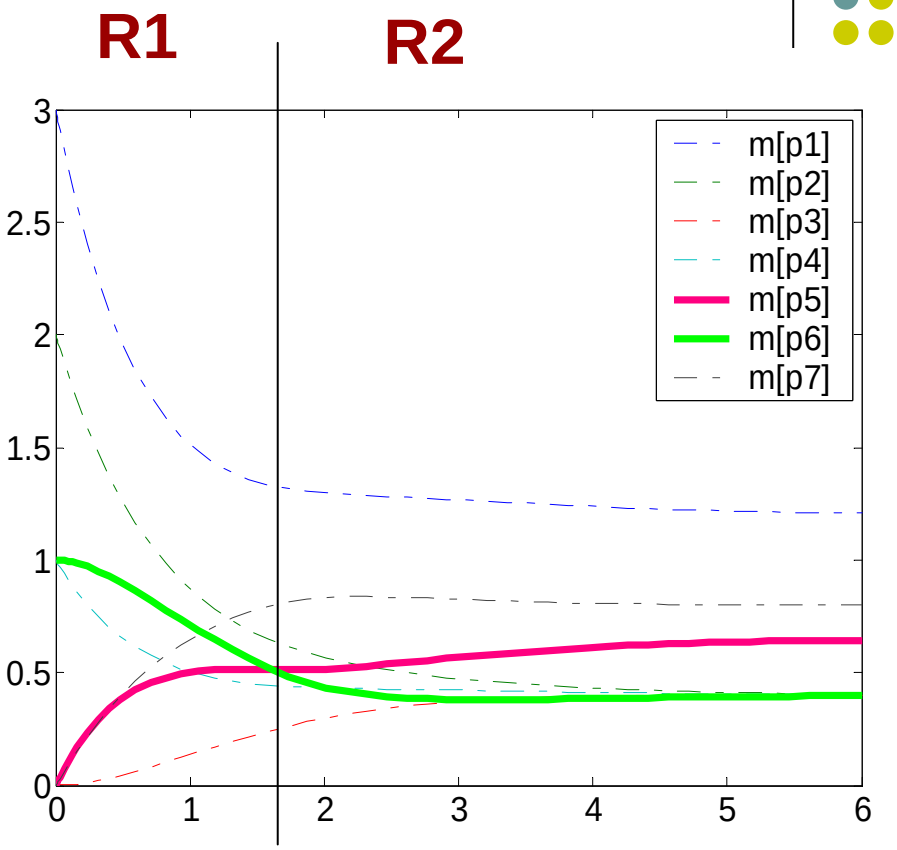


$$\mathbf{f}(\tau)[t_1] = \lambda[t_1] \cdot \mathbf{m}(\tau)[p_1]/2$$
$$\mathbf{f}(\tau)[t_2] = \lambda[t_2] \cdot \mathbf{m}(\tau)[p_2]$$
$$\mathbf{f}(\tau)[t_3] = \lambda[t_3] \cdot \mathbf{m}(\tau)[p_3]$$
$$\mathbf{f}(\tau)[t_4] = \lambda[t_4] \cdot \mathbf{m}(\tau)[p_4]$$
$$\mathbf{f}(\tau)[t_5]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

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

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



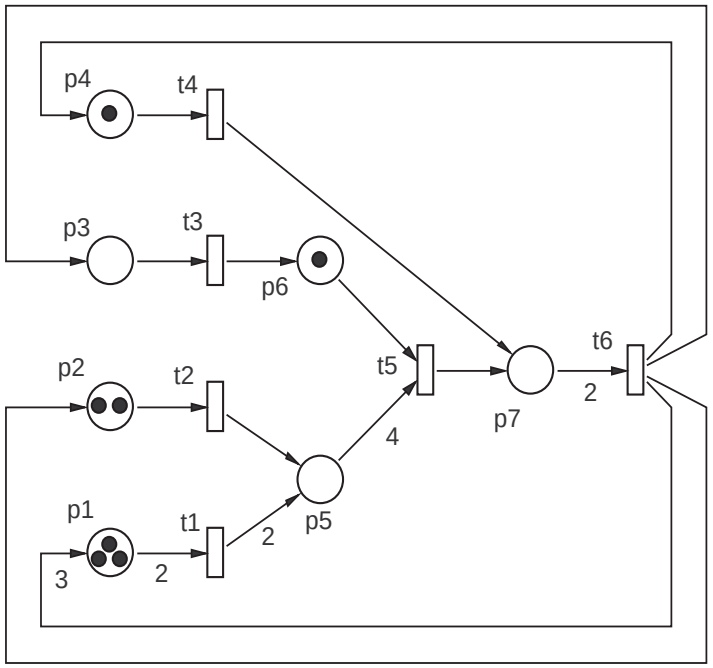


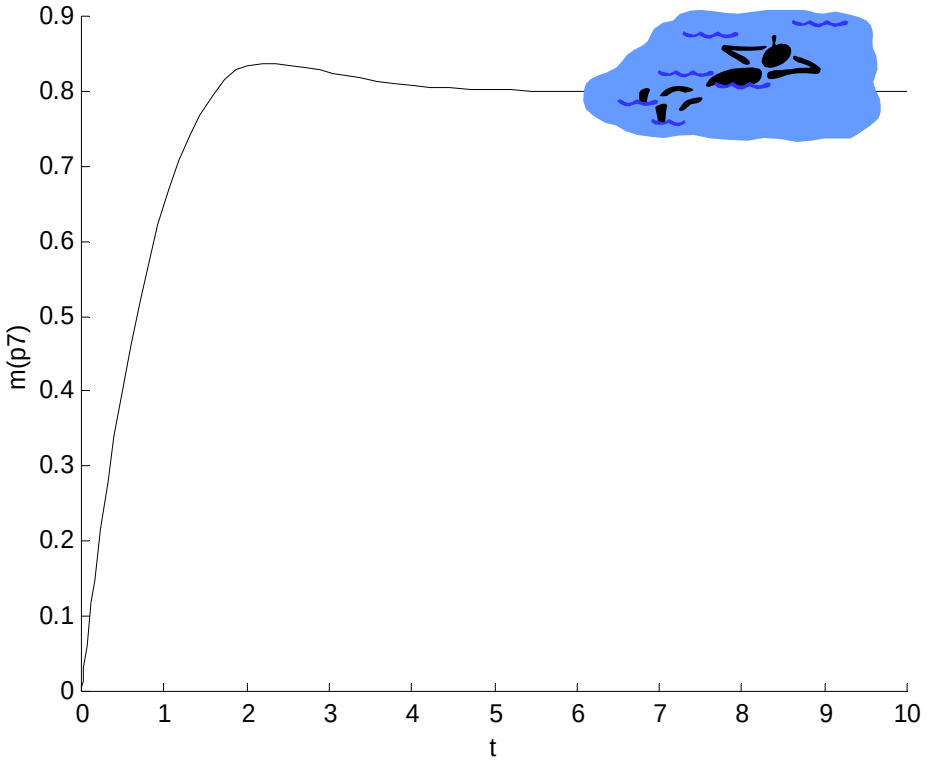
configurations & regions

steady-state for bounded continuous PN systems under infinite servers semantics

(**min** operator in synchronizations)

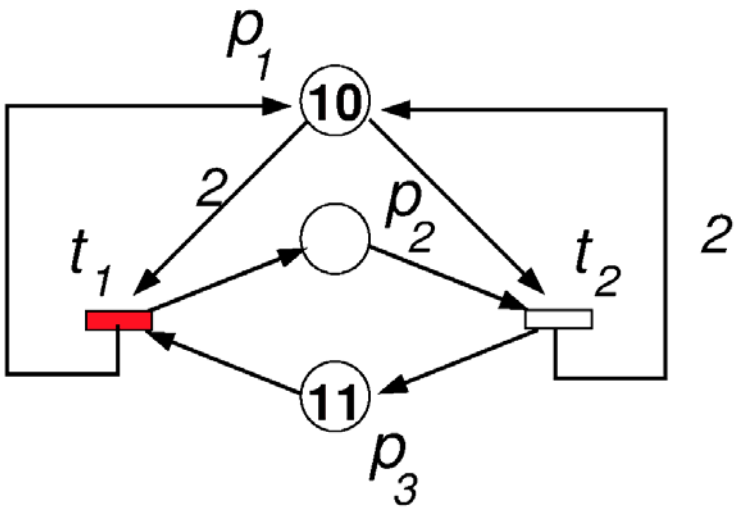
Equilibrium

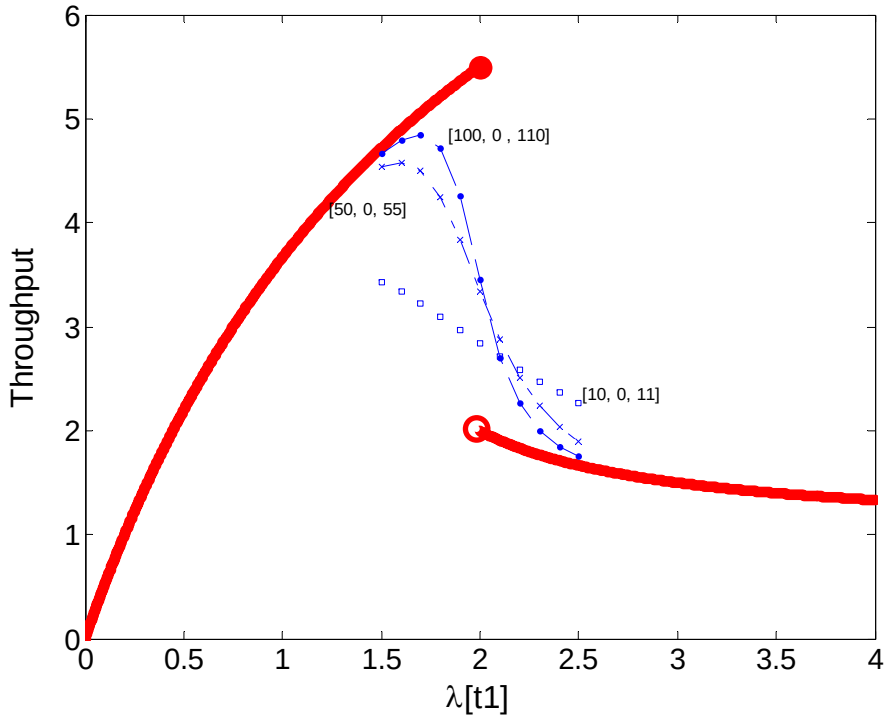




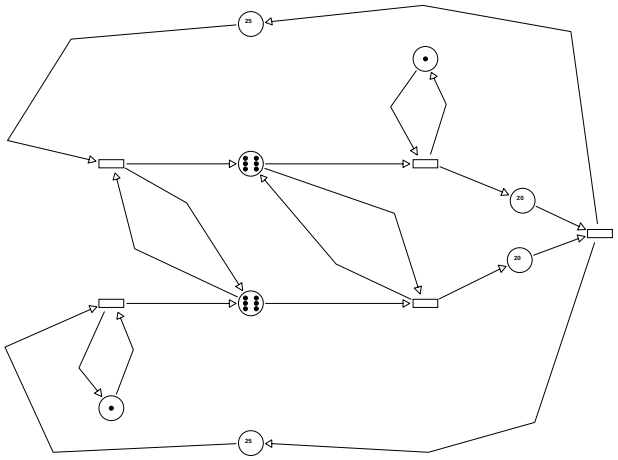
one of the counterintuitive properties in timed (infinite servers semantics) models

- No performance monotonicities with respect to **firing speeds**

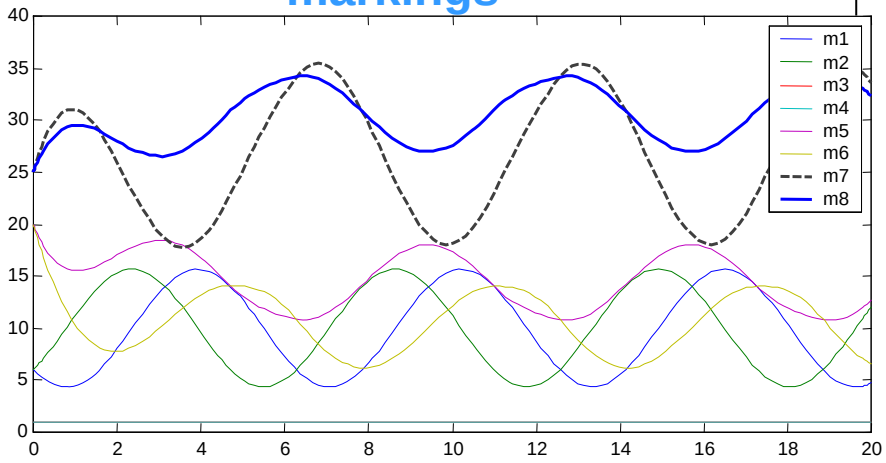




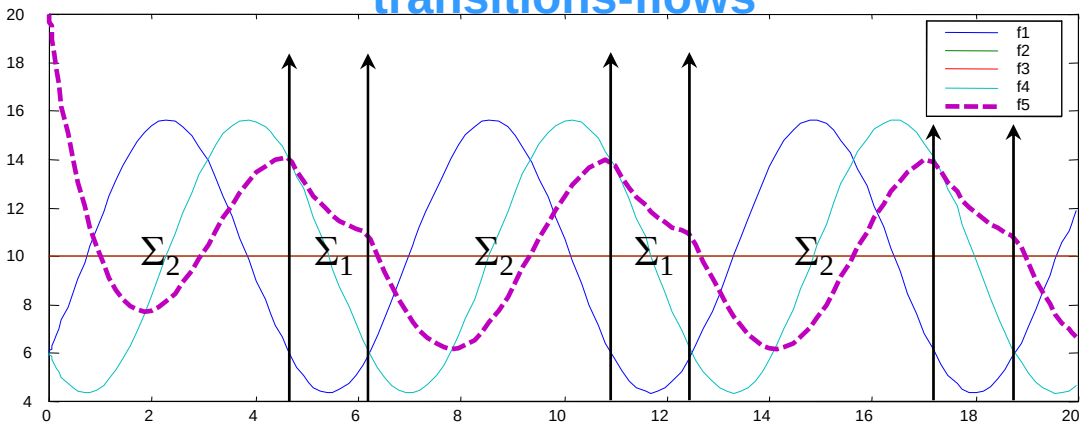
infinite number of switchings



markings



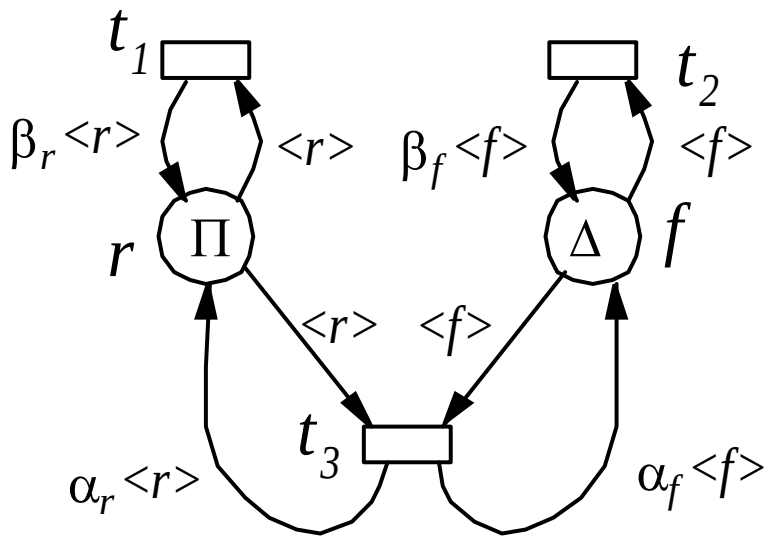
transitions-flows



A cooperation with S. Haddad: Continuous PNs under infinite servers semantics simulate TURING Machines

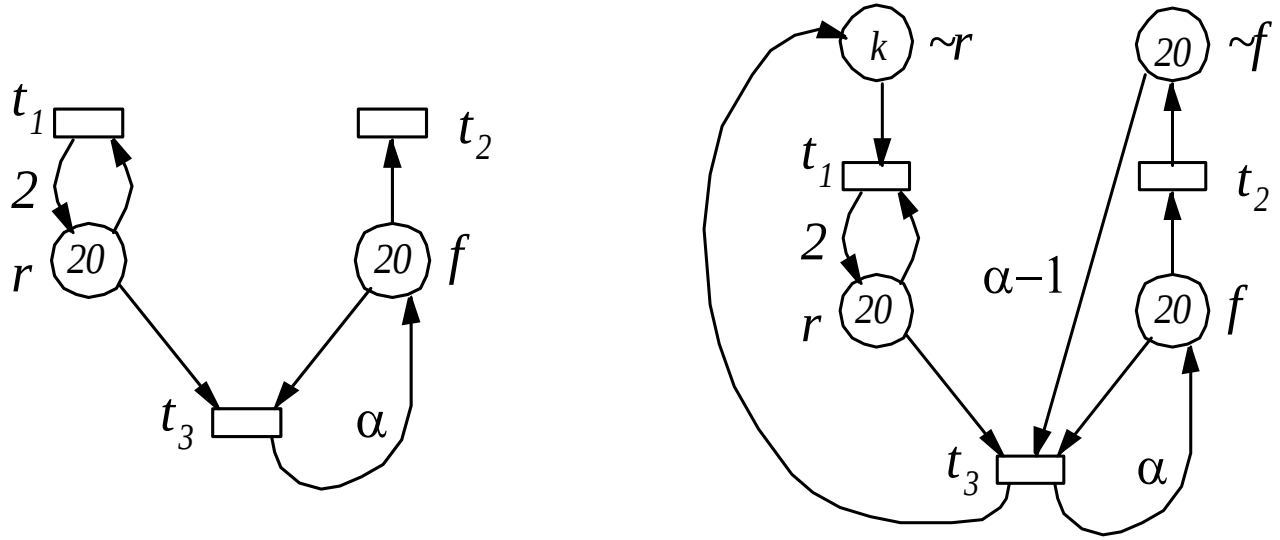
decolouring and net interpretation-*product*

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



- *rabbits*
- *foxes*

decolouring and net interpretation-*product*

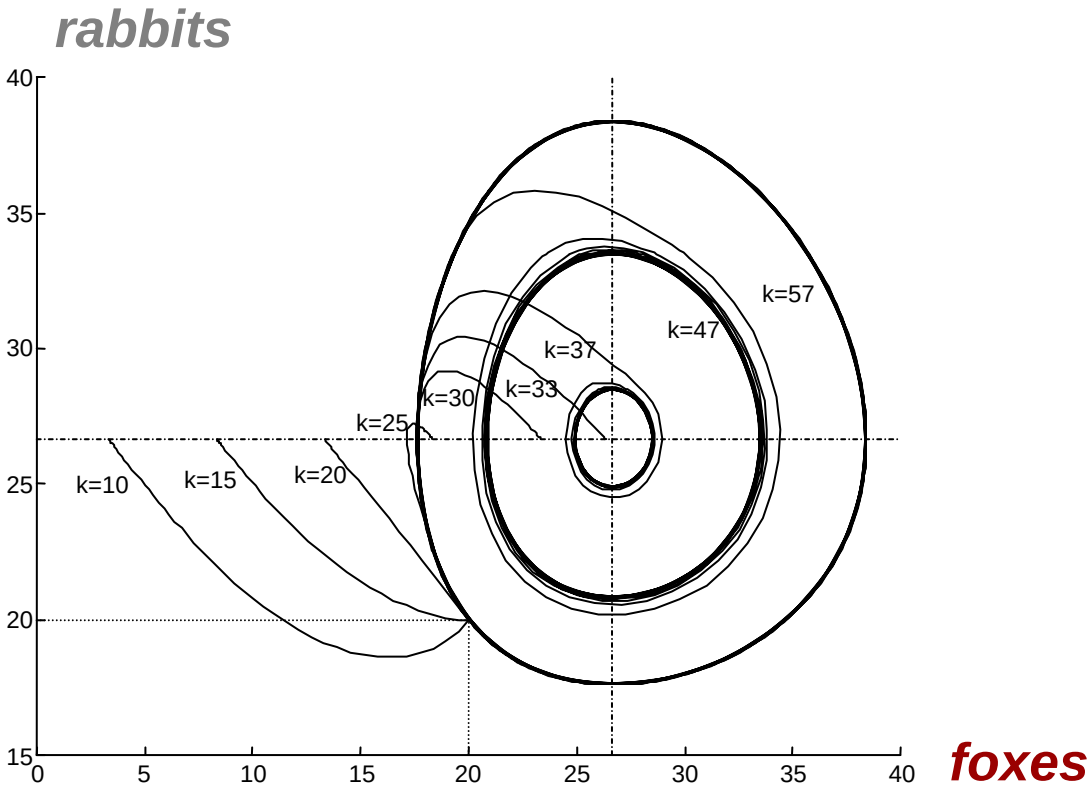


P/T models of the predator/prey system, with α_r=0, α_f=α, β_r=2, β_f=0, $|\Pi|$=$|\Delta|$=20. They can be seen either as discrete or as continuous PN.

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

synchronisations

leads to ***products***



Trajectories obtained with

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

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

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

Concluding the selected five points …

- The five (among…) points have been presented
- 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 him as:
  - the founder of a field, that influence others, that combine conceptual elegance & pragmatism
  - always a **close** & **warm-hearted** person

…and to conclude with an image-souvenir…

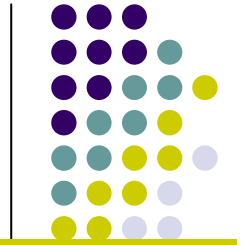
Part of the family…

Zaragoza,
Thursday 15 of April 1999


Zaragoza,
Thursday 15 of April 1999
Gracias por su atención

Some of the alluded works

(most correspond to keynotes / invited contributions)



Petri nets are a Modelling Paradigm…

- M. Silva & E. Teruel: "A System Theory perspective of Discrete Event Dynamic Systems: The Petri Net Paradigm", in *Procs. of IMACS/IEEE SMC, Computational Engineering in Systems Applications, CESA'96:* Symposium on *Discrete Event and Manufacturing Systems,* pp. 1-30. (Lille, France, July 1996).
- M. Silva & E. Teruel: "DEDS Along Their Life-Cycle: Interpreted Extensions of Petri Nets", *IEEE Int. Conf. on Systems, Man and Cybernetics*, 1998. (La Jolla, San Diego, USA, October, 1998.)

On Synchrony Theory…

- M. Silva: "Towards a Synchrony Theory for P/T Nets", in *Concurrency and Nets (K. Voss, H. Genrich & G. Rozenberg, eds.)*, Springer-Verlag, pp. 435-460, 1987.
- M. Silva & J.M. Colom: "On the Computation of Structural Synchronic Invariants in P/T Nets", *Advances in Petri Nets (G.Rozenberg, ed.), LNCS,* 340: 386-417, Springer-Verlag, 1988.
- M. Silva & T. Murata: "B-Fairness and Structural B-Fairness in Petri Net Models of Concurrent Systems", *Journal of Computer and System Sciences*, 44(3):447-477, June 1992.
- M. Silva: *Las redes de Petri en la Automática y en la Informática*, Editorial AC, Madrid, 1985 (2nd Edition, Thomson-Editorial AC, Madrid, 2002, 429 pp.).

On fluid/continuous Petri nets…

- M. Silva & L. Recalde: "Petri Nets and Integrality Relaxations: A view of Continuous Petri Net Models". *IEEE Transactions on Systems, Man and Cybernetics,* November, 2002, vol. 32 (4): 314-327.
- M. Silva & L. Recalde: "On fluidification of Petri Nets: from discrete to hybrid and continuous models", *Annual Reviews in Control* 28: 253-266, 2004.
- M. Silva & L. Recalde: "Continuisation of Timed Petri Nets: From Performance Evaluation to Observation and Control", in *Applications and Theory of Petri Nets 2005*, Springer-Verlag, *LNCS*, 3.536: 26-47, 2005. (Miami, June, 2005.)
- M. Silva & L. Recalde: "Redes de Petri continuas: Expresividad, Análisis y Control de una clase de sistemas lineales conmutados", *Revista Iberoamericana de Automática e Informática Industrial (RIAI),* 4(3): 5-33, 2007.
- M. Silva et alii.: *Continuous and Hybrid Petri Nets: The GISED perspective, TR-GISED, July 2010.* http://webdiis.unizar.es/GISED/sites/default/files/MISi09.pdf