Industrial Automation

(Automação de Processos Industriais)

DES and Industrial Automation

http://users.isr.ist.utl.pt/~jag/courses/api1112/api1112.html

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Rev. 2011/2012 Prof. José Gaspar

Syllabus:

Chap. 7 – Analysis of Discrete Event Systems [2 weeks]

...

Chap. 8 - DESs and Industrial Automation [1 week]

GRAFCET / Petri Nets Relation

Model modification

Tools adaptation

Analysis of industrial automation solutions by analogy with Discrete Event Systems

...

Chap. 9 – Supervision of DESs [1 week]

Some pointers to Discrete Event Systems

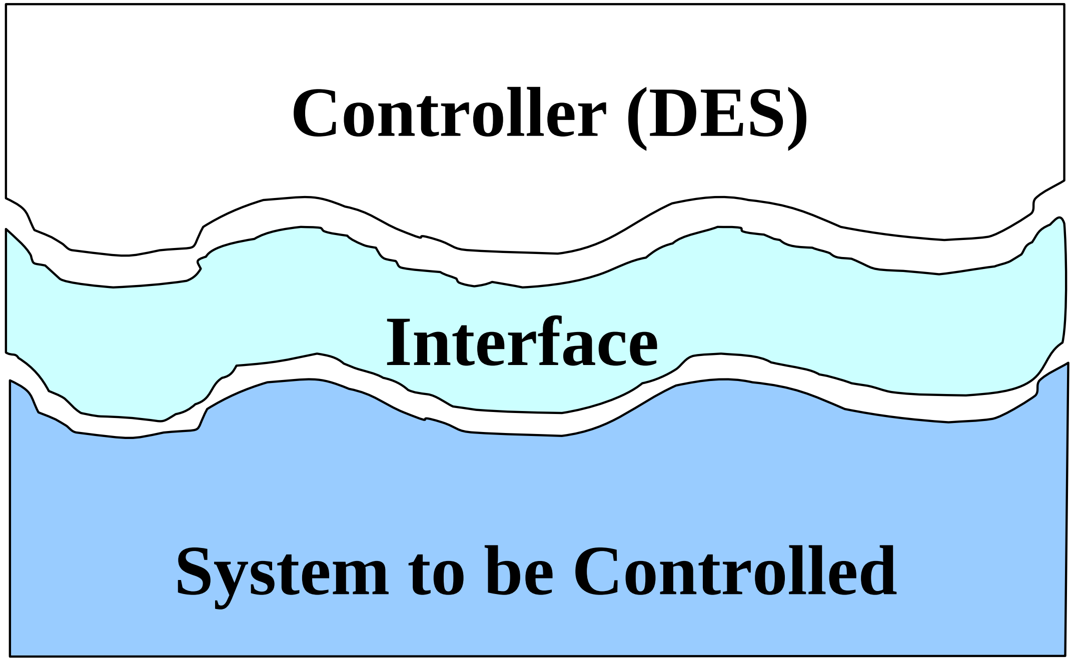
History: http://prosys.changwon.ac.kr/docs/petrinet/1.htm

Tutorial:
http://www.eit.uni-kl.de/litz/ENGLISH/members/frey/VnVSurvey.htm
http://vita.bu.edu/cgc/MIDEDS/
http://www.daimi.au.dk/PetriNets/

Analysers, and Simulators:
http://www.ppgia.pucpr.br/~maziero/petri/arp.html (in Portuguese)
http://wiki.daimi.au.dk:8000/cpntools/cpntools.wiki
http://www.informatik.hu-berlin.de/top/pnk/download.html

Bibliography:
* **Petri Nets and GRAFCET: Tools for Modelling Discrete Event Systems**
R. DAVID, H. ALLA, New York : PRENTICE HALL Editions, 1992

DES Implementation: Models



Besides modelling the **DES** it is required to design **models** of the **System to be controlled** and of the **Interface** to be used

Given a Discrete Event System how to implement it?

1. Use a GRAFCET

a) Less modeling ability

b) Implementation in PLCs is straightforward

c) No analysis (or very scarce) methods available

2. Use a Petri Net

a) More modeling capacity

b) No direct implementation in PLCs (therefore indirect or special software solutions required)

c) Classical analysis methods available

(3. Use an Automaton)

Analysis of solutions

GRAFCET and Petri Nets

Similarities to exploit:

a) Places and steps are similar

b) Transitions compose both tools

c) Places can be used to implement counters and binary variables

d) Logic functions can be rewritten resorting to the firing of transitions

Differences to be taken into account:

a) Firing rules (mutual exclusion)

b) Conflicts

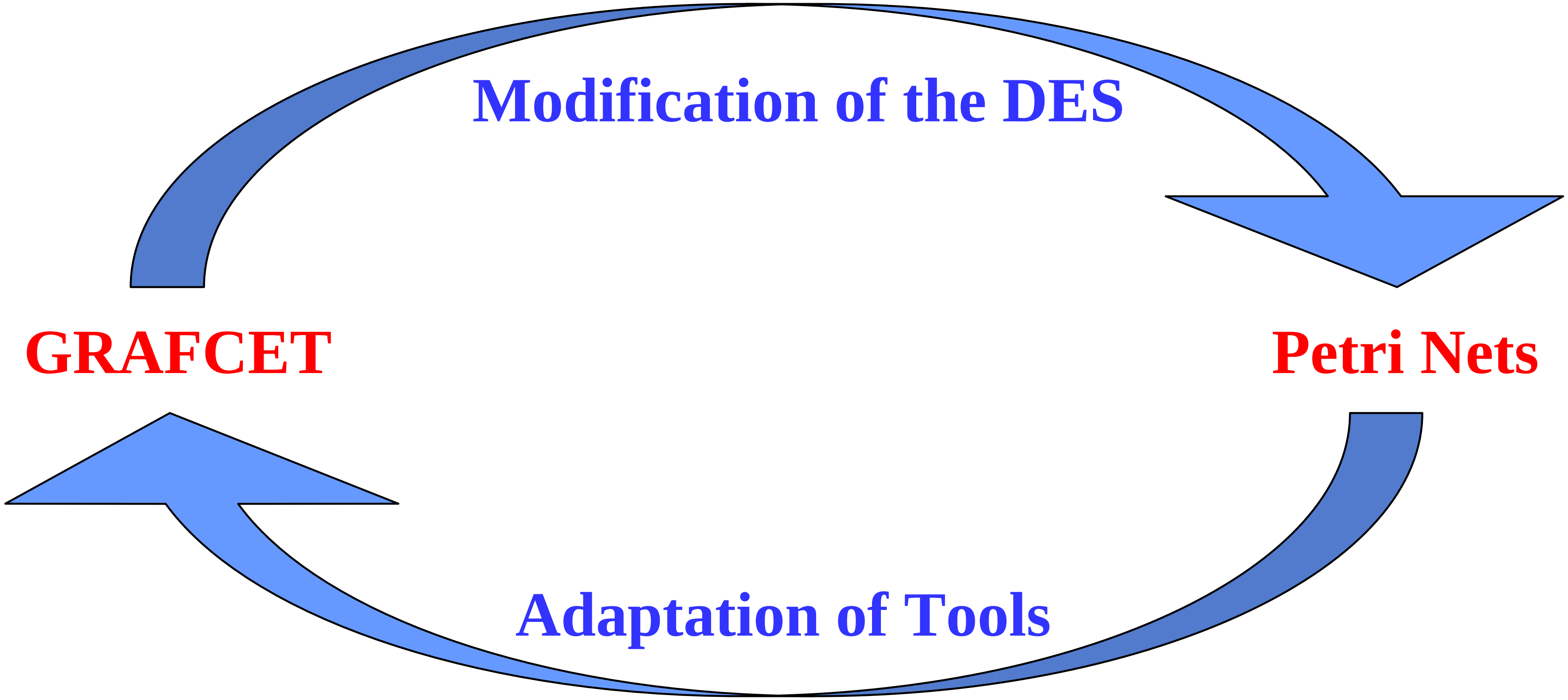
c) Binary activation of stages

d) Interface with the system to be controlled

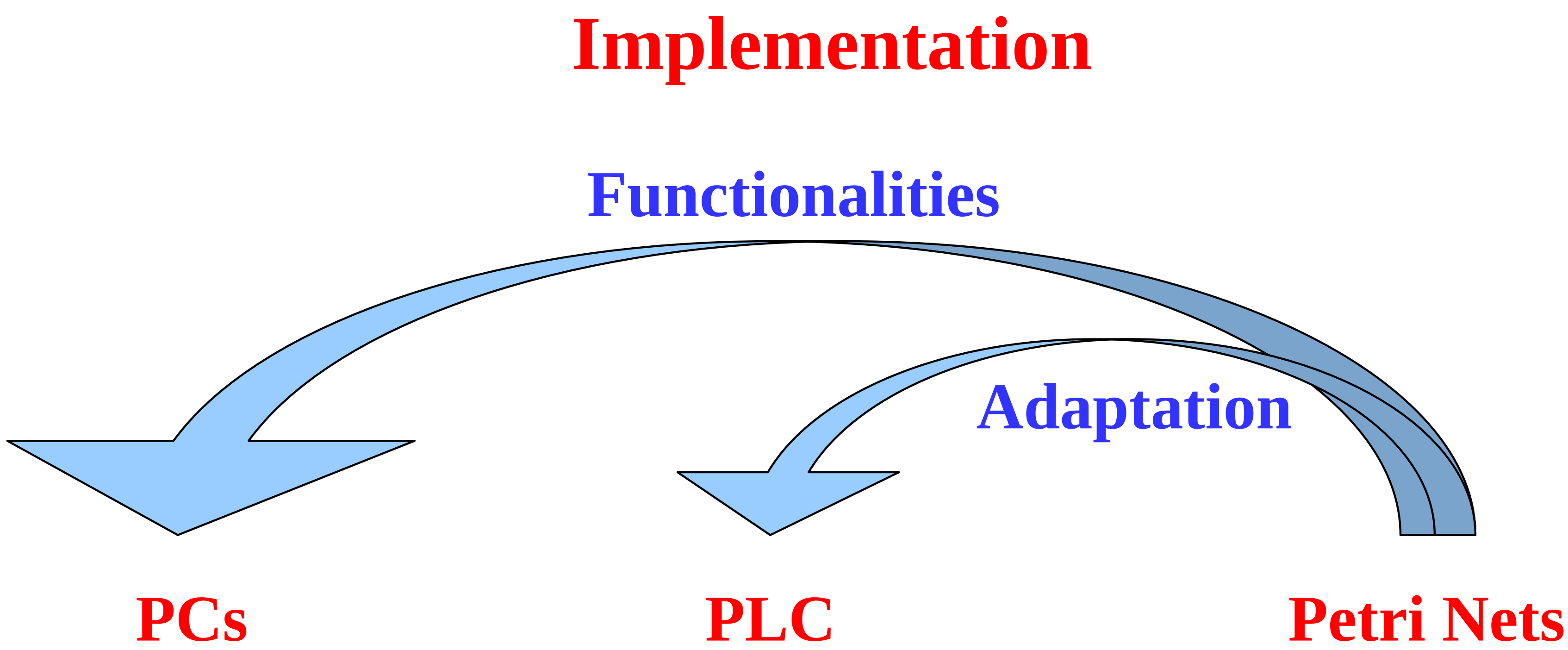
e) Activation functions

Implementation of DES using GRAFCET

Analysis



Implementation of DES using Petri Nets



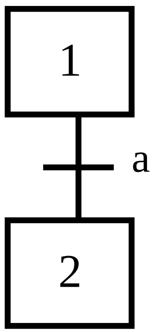
Both solutions are valid.

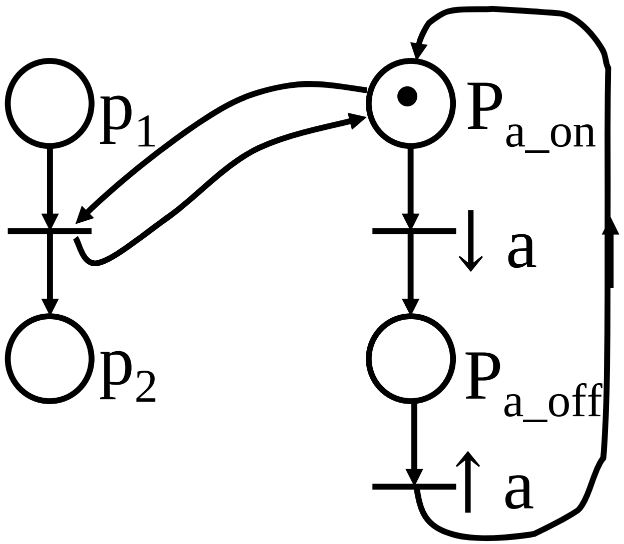
Out of the scope of this course.

Analysis of solutions

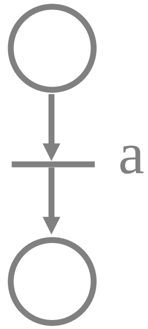
GRAFCET → Petri Nets

Representation of variables active on level





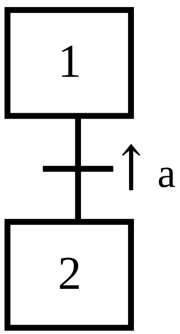
In the course we accept the generalization of the PN

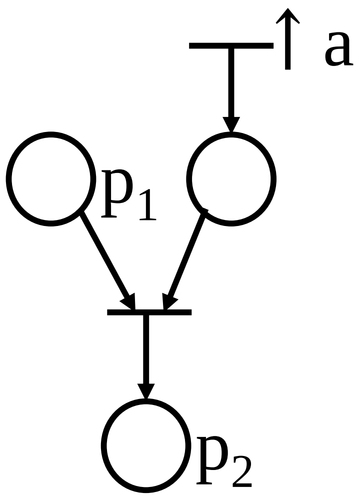


Analysis of solutions

GRAFCET → Petri Nets

Representation of variables active at edge





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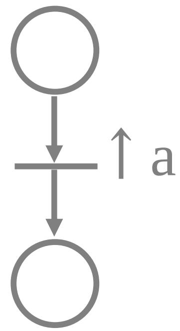


Analysis of solutions

Petri Nets → GRAFCET

Adaptation of Tools:

1) Reachability Tree → Reachability Graph

2) Method of the Matrix Equations
   to describe the state evolution

Petri Nets → GRAFCET

Reachability Graph

Is a graph containing the reachable makings.
Is composed by two types of nodes:

- terminal
- interior

The duplicated nodes are not represented.
They become connected to the respective copies.

~~The symbol infinity (ω) is introduced,
to obtain finite trees, when a marking covers other(s).~~

Petri Nets → GRAFCET

Reachability Graph

Theorem - If a reachability graph has terminal nodes then the corresponding GRAFCET has deadlocks.

This method will be used to study the properties introduced in Chapter 6.

Petri Nets → GRAFCET

Reachable Set

Given the GRAFCET G=(S, T, I, O, μ_0) with initial marking μ_0, the set of all markings that are reachable is the reachable set $\mu' \in R(C, \mu)$.

Remark: the Reachable Set **is not infinite!**
Given a GRAFCET with m steps it has at most 2^m nodes.

Petri Nets → GRAFCET

Boundness and Limitation

The GRAFCET G=(S, T, I, O, μ_0) is always secure!

The same does not occur with some auxiliary elements of the GRAFCET, e.g., counters and buffers.

For those elements the analysis methods studied for Petri Nets can be used directly.

Petri Nets → GRAFCET

Conservation

A GRAFCET G=(S, T, I, O, μ_0) is **strictly conservative** if for all $\mu' \in R(C, \mu)$

$$\sum_{p_i \in P} \mu'(p_i) = \sum_{p_i \in P} \mu(p_i).$$

A GRAFCET G=(S, T, I, O, μ_0) is **conservative** if there exist a weight vector ω, without null elements, for all $\mu' \in R(C, \mu)$ such that it is constant the quantity

$$\sum_{p_i \in P} \omega(p_i)\, \mu(p_i).$$

Petri Nets → GRAFCET

Liveness of transitions: The transition t_j is live of

Level 0 - it can never be fired.

Level 1 - if it is potentially firable, e.g. if there exist $\mu' \in R(C, \mu)$ **such that** t_j **is enabled in** μ'.

Level 2 - if, for each positive *n*, there exist a sequence of firings where occurs *n* firings of t_j **.**

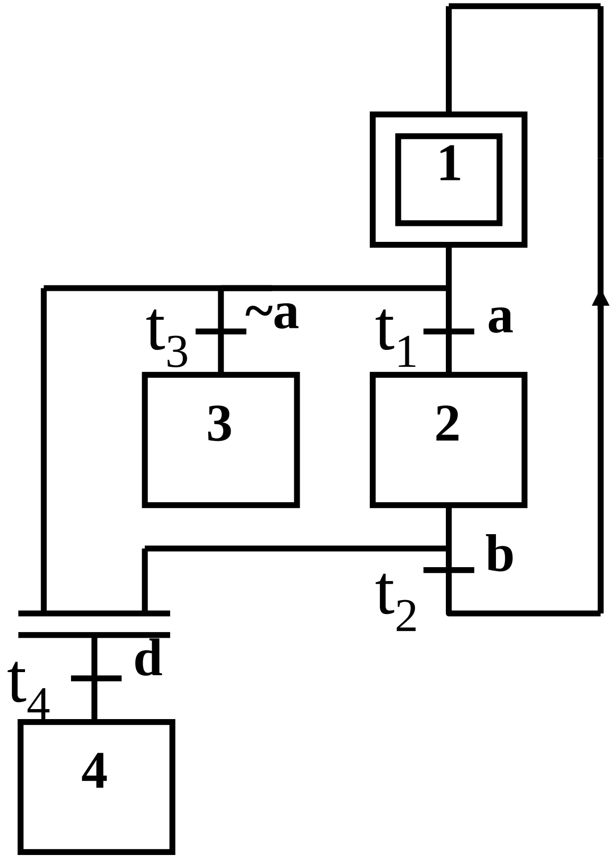
Level 3 - if there exist a sequence of firings where an infinite number of firings of t_j **occurs .**

Level 4 - if for each $\mu' \in R(C, \mu)$ **there exist a sequence** σ **that enables the firing of** t_j **.**

Petri Nets → GRAFCET

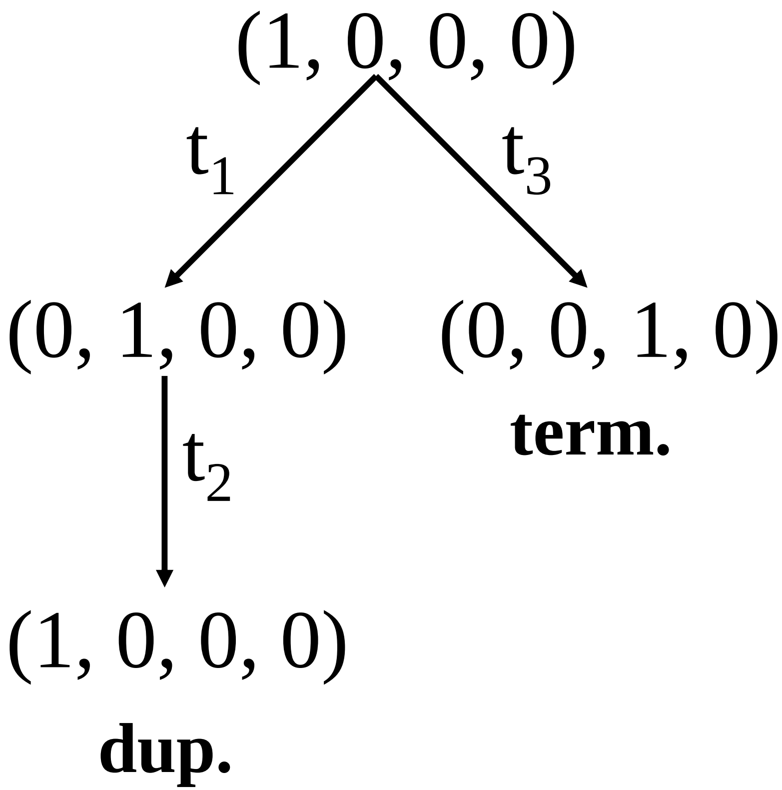
Example of GRAFCET

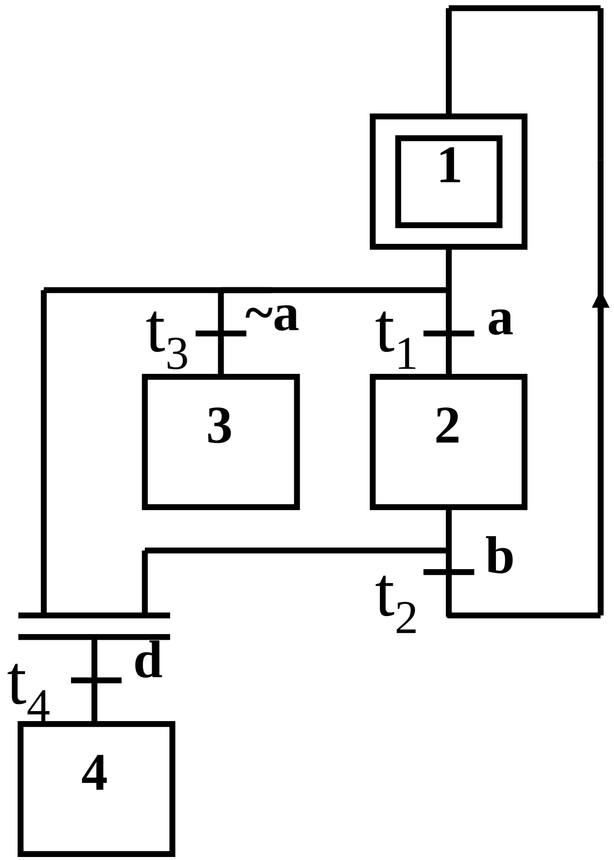
- t_4 is level 0.
- t_1 is level 3.
- t_2 is level 3.
- t_3 is level 1.



Petri Nets ⟶ GRAFCET

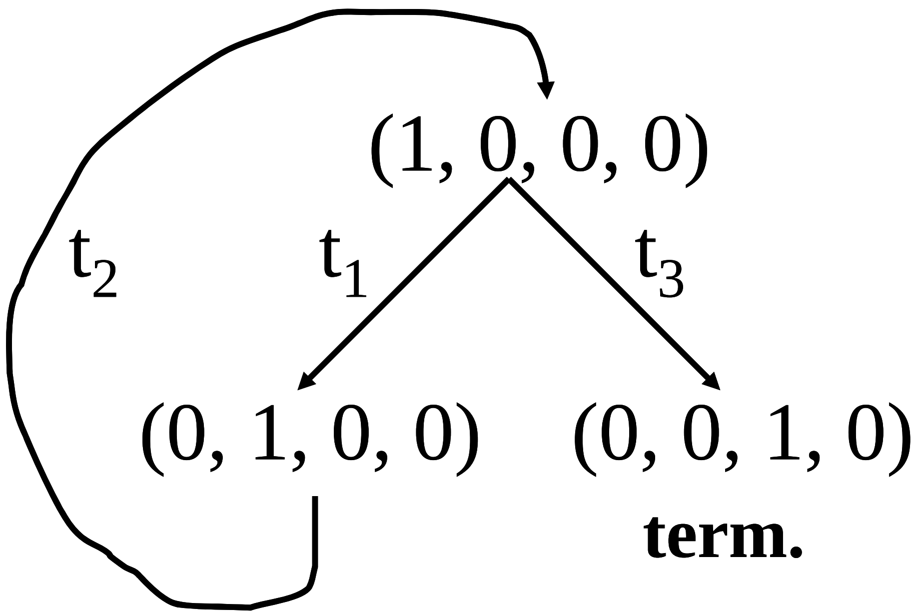
Example of GRAFCET

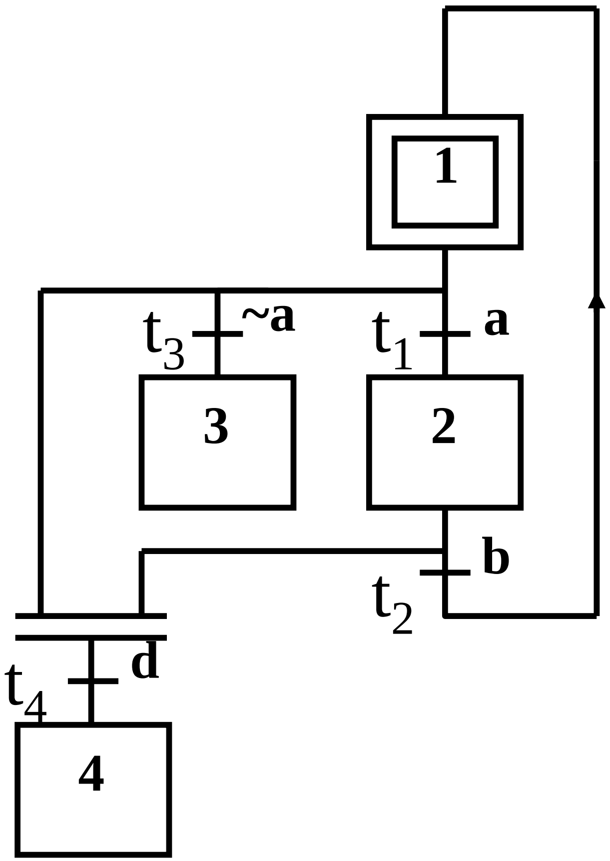




Petri Nets → GRAFCET

Example of GRAFCET





Strictly conservative.

Petri Nets → GRAFCET

Method of Matrix Equation (for the state evolution)

The evolution of a GRAFCET can be written in compact form as:

$$\mu' = \mu + Dq$$

where:

μ ’	- desired marking (vector column vector)
μ	- initial marking
q	- column vector of the transition firings
D	- incidence matrix. Accounts for the token evolution as a consequence of transitions firing.

Petri Nets → GRAFCET

Problems that can be addressed resorting to the Method of Matrix Equations

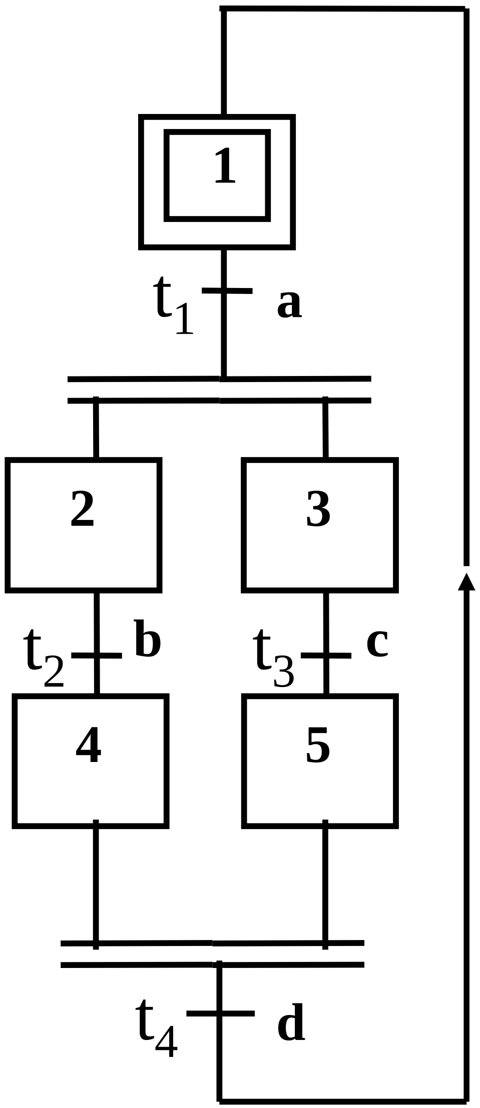
- Reachability (sufficient condition)

> Theorem – if the problem of finding the vector of firings, for a GRAFCET without conflicts, from the state μ to the state μ' has no solution using the Method of Matrix Equations, then the problem of reachability of μ' is impossible.

- Conservation – the conservation vector can be computed automatically.

- Temporal invariance – cycles of operation can be found.

Example of GRAFCET



$$\mu' = \mu + Dq$$

$$D = \begin{bmatrix} -1 & 0 & 0 & 1 \\ 1 & -1 & 0 & 0 \\ 1 & 0 & -1 & 0 \\ 0 & 1 & 0 & -1 \\ 0 & 0 & 1 & -1 \end{bmatrix}$$

Conservation $x^T D = 0$

$$\begin{cases} -x_1 + x_2 + x_3 = 0 \\ -x_2 + x_4 = 0 \\ -x_3 + x_5 = 0 \\ x_1 - x_4 - x_5 = 0 \end{cases}$$

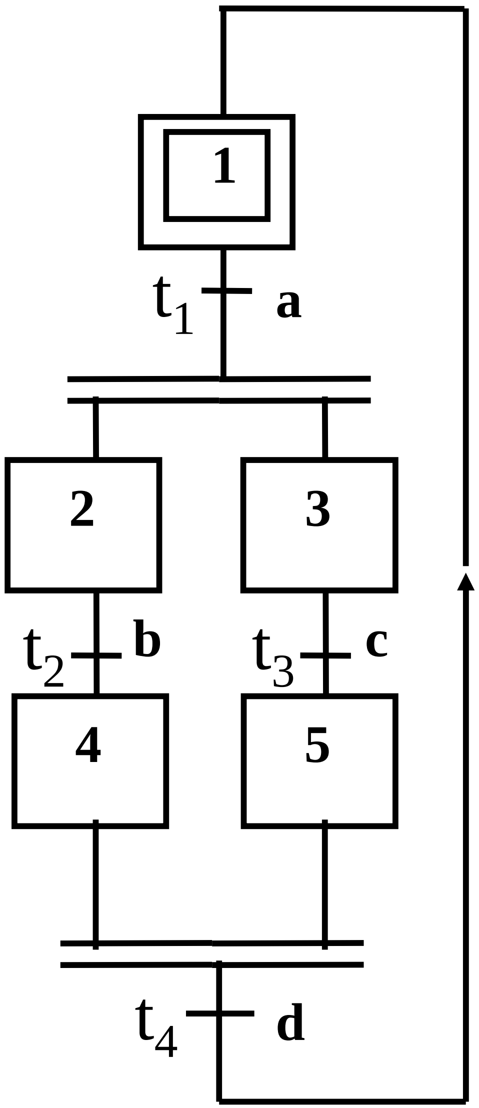
$$x_1 = x_3 + x_4$$
$$x_1 = x_2 + x_5$$
$$x_2 + x_3 = x_4 + x_5$$

Solution:
Undetermined
set of equations

$$x = \begin{bmatrix} 2 \\ 1 \\ 1 \\ 1 \\ 1 \end{bmatrix}.$$

Example of GRAFCET

$$\mu' = \mu + Dq$$



$$Dq = 0$$

$$D = \begin{bmatrix} -1 & 0 & 0 & 1 \\ 1 & -1 & 0 & 0 \\ 1 & 0 & -1 & 0 \\ 0 & 1 & 0 & -1 \\ 0 & 0 & 1 & -1 \end{bmatrix} \quad q = \begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \\ \sigma_4 \end{bmatrix}$$

Temporal invariance

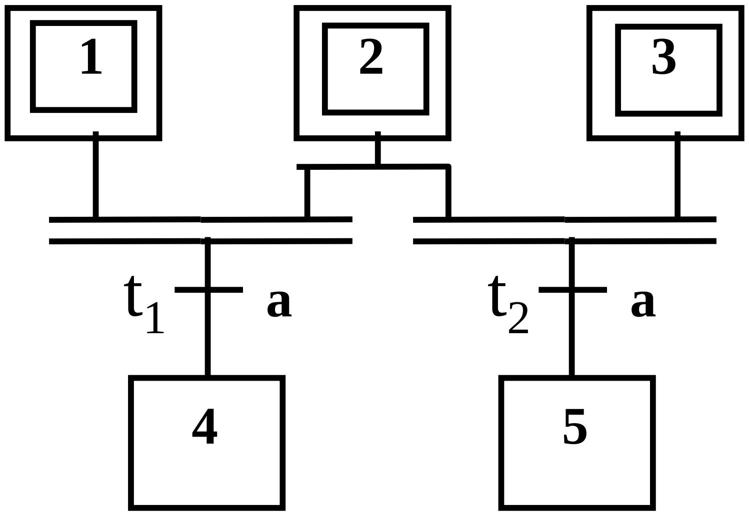
Solution:
Set of equation
with one solution

$$\begin{cases} -\sigma_1 + \sigma_4 = 0 \\ \sigma_1 - \sigma_2 = 0 \\ \sigma_1 - \sigma_3 = 0 \\ \sigma_2 - \sigma_4 = 0 \\ \sigma_3 - \sigma_4 = 0 \end{cases}$$

$$\sigma_1 = \sigma_2 = \sigma_3 = \sigma_4 = 1.$$

Example of GRAFCET

$$\mu' = \mu + Dq$$



$$\mu' = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \\ 1 \end{bmatrix} \quad \mu = \begin{bmatrix} 1 \\ 1 \\ 1 \\ 0 \\ 0 \end{bmatrix} \quad D = \begin{bmatrix} -1 & 0 \\ -1 & -1 \\ 0 & -1 \\ 1 & 0 \\ 0 & 1 \end{bmatrix} \quad q = \begin{bmatrix} \sigma_1 \\ \sigma_2 \end{bmatrix}$$

$$\begin{cases} 0 = 1 - \sigma_1 \\ 0 = 1 - \sigma_1 - \sigma_2 \\ 0 = 1 - \sigma_2 \\ 1 = \sigma_1 \\ 1 = \sigma_2 \end{cases}$$

Set of Equations impossible
Therefore marking not reachable.
WRONG!

The method fails if there are conflicts!