Industrial Automation

(Automação de Processos Industriais)

DES and Industrial Automation

http://www.isr.ist.utl.pt/~pjcro/courses/api1011/api1011.html

Prof. Paulo Jorge Oliveira
pjcro @ isr.ist.utl.pt
Tel: 21 8418053 or 2053 (internal)

Syllabus:

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

…

Chap. 8 - SEDs 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 Sistemas de Eventos Discretos

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

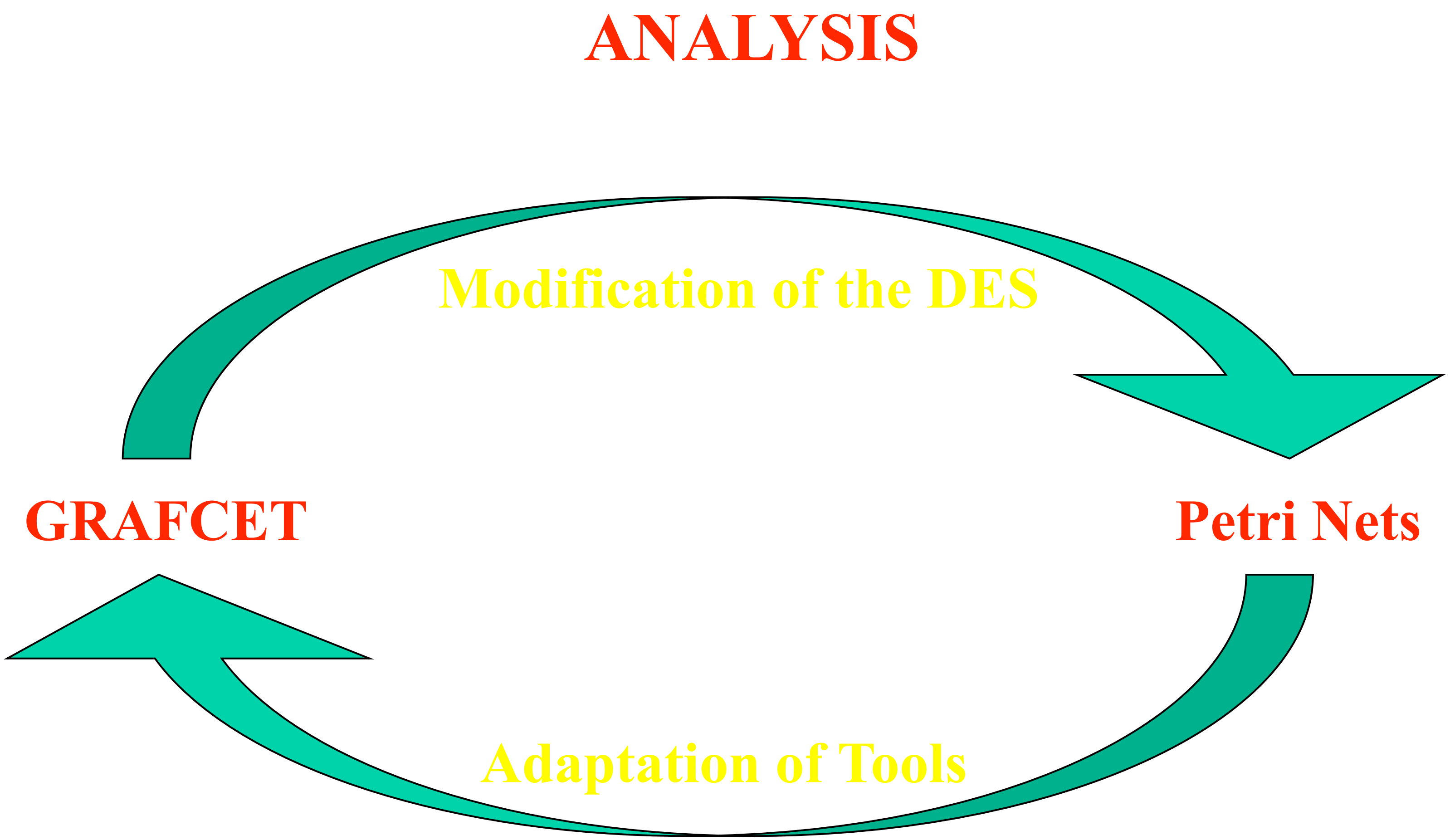
Given a Discrete Event System how to implement it?

1. **Use a GRAFCET**
   a) **Less modelization hability**
   b) **Implementation in PLCs straightforward**
   c) **No analysis (or very scarse) methods available**

2. **Use a Petri Net**
   a) **More modelization capacity**
   b) **No direct implementation in PLCs (therefore indirec Or special software solutions required)**
   c) **Classical analysis methods available**

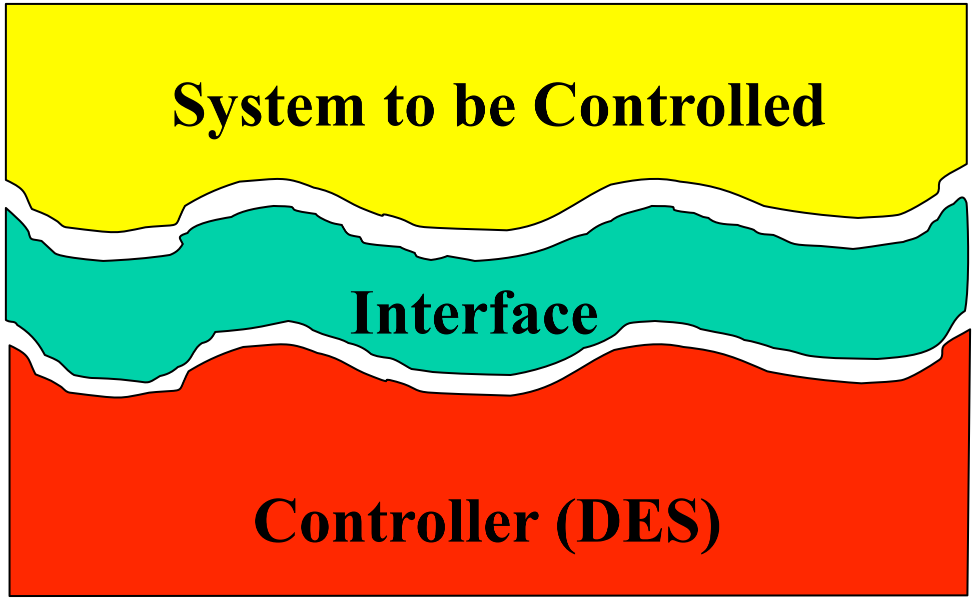
(3. Use an Automata)

Implementation of DES using GRAFCET



DES Implementation

Models of the DES and of the Controlled system required



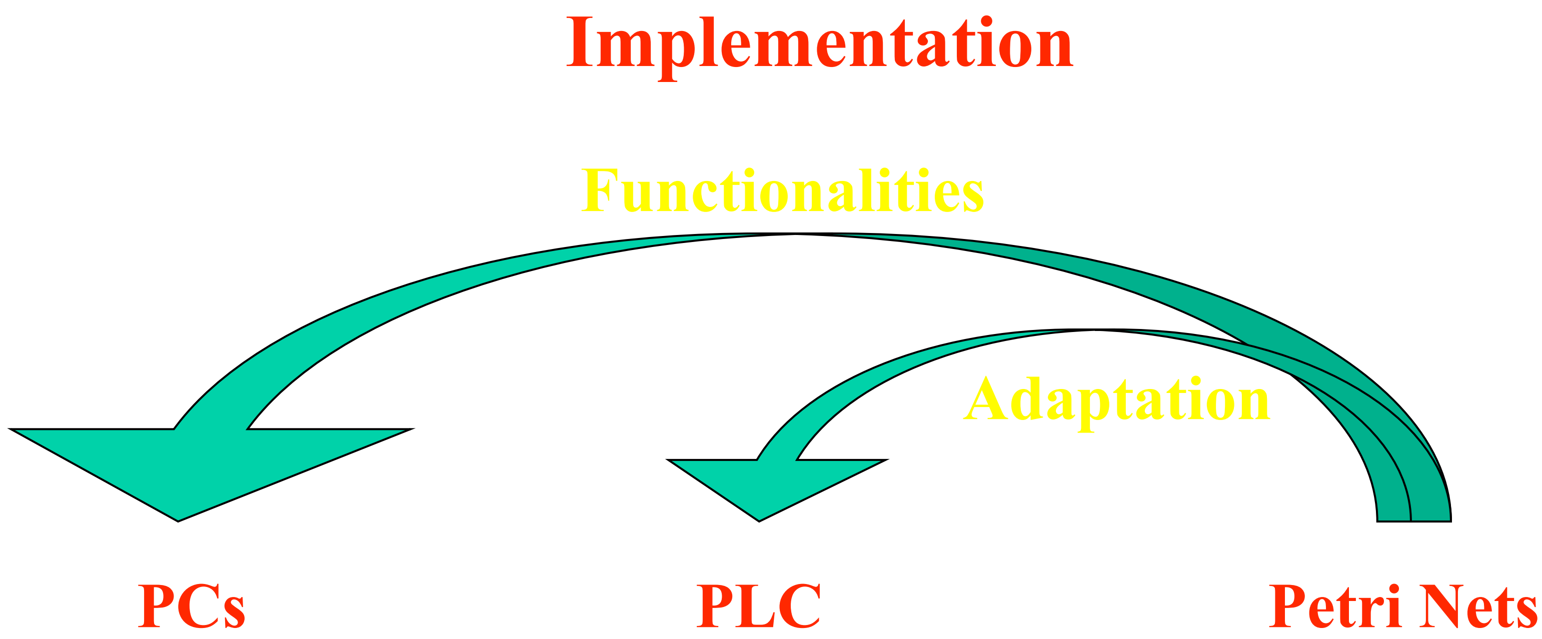
It is required

To design models of the

System to be controlled and of the

Interface to be used...

Implementation of DES using Petri Nets



Both solutions are valid.
Out of the scope of this course.

Analysis of solutions

GRAFCET and Petri Nets

Similarites to exploit:

a) Places and steps are similar

b) Transistions 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

Analysis of solutions

GRAFCET and Petri Nets

Differences to be taken into account:

a) **Firing rules (mutual exclusion)**

b) **Conflits**

c) **Binary activation of stages**

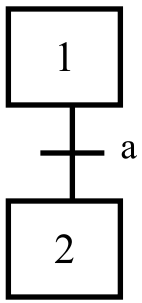
d) **Interface with the system to be controlled**

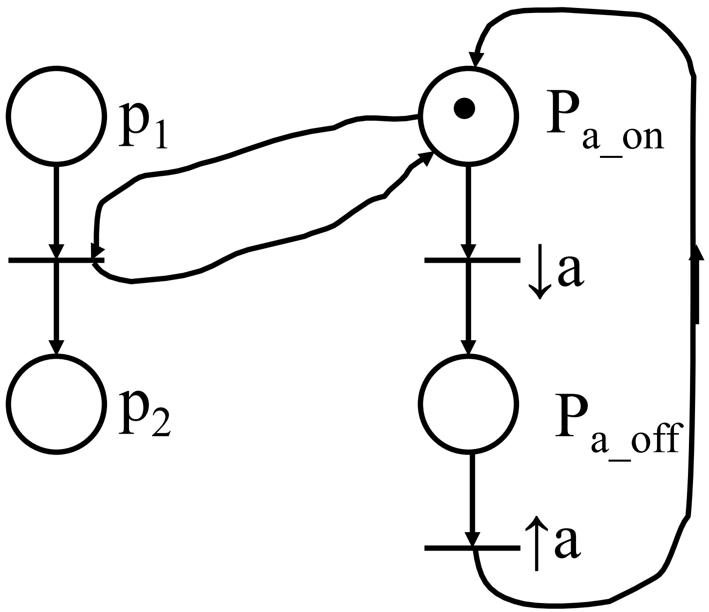
e) **Activation functions**

Analysis of solutions

GRAFCET → Petri Nets

Representation of variables active on level

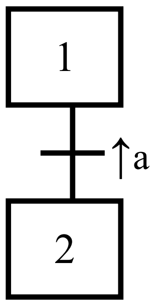


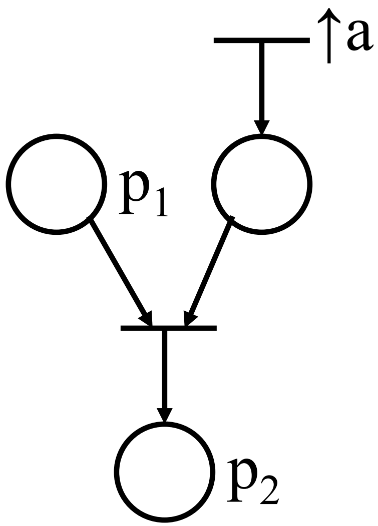


Analysis of solutions

GRAFCET → Petri Nets

Representation of variables active at edge





Note on the memory effects.

Analysis of solutions

Petri Nets → GRAFCET

Adaptation of Tools:

Reachability Tree

⇓

Reachability Graph

Method of the Matrix Equations to describe the state evolution

Petri Nets → GRAFCET

Reachability Graph

To build a graph with the reachable makings.
Composed by two types of nodes:

- terminal

- interior

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

The symbol infinity (w) 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: IT IS NOT INFINITE!

Given a GRAFCET with m steps it has 2^m nodes at most.

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 **stricly conservative** if for all m' ∈ R(C, μ)

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

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

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

Petri Nets ⟶ GRAFCET

Liveness of transições: 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 m’ $\in R(C,\mu)$ **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 **.**

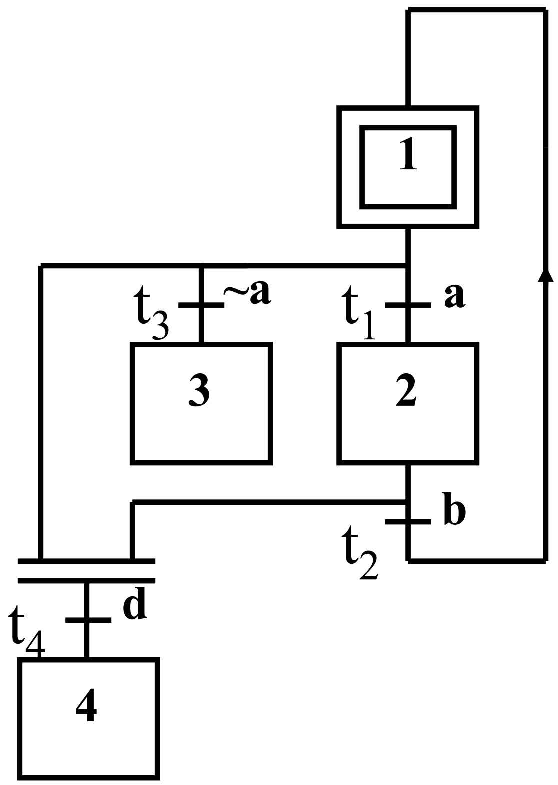
Level 3 - if there exist a sequence of firings where an infinite number of firings of t_j **occurs .**

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

Petri Nets → GRAFCET

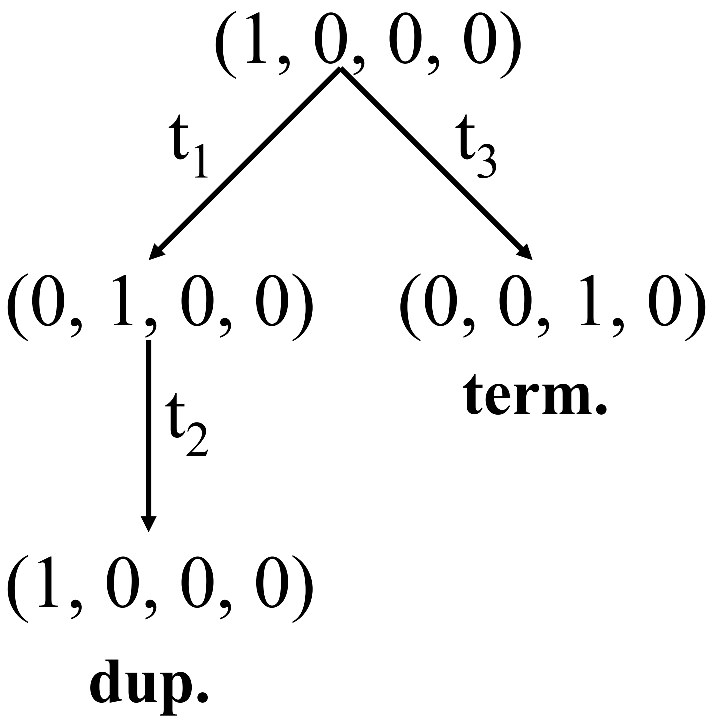
Example of GRAFCET

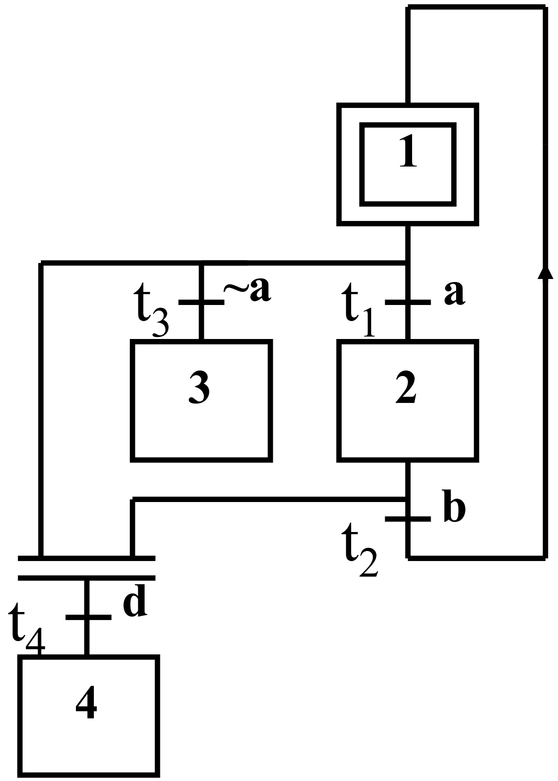
- t_4 é de nível 0.
- t_1 é de nível 3.
- t_2 é de nível 3.
- t_3 é de nível 1.



Petri Nets → GRAFCET

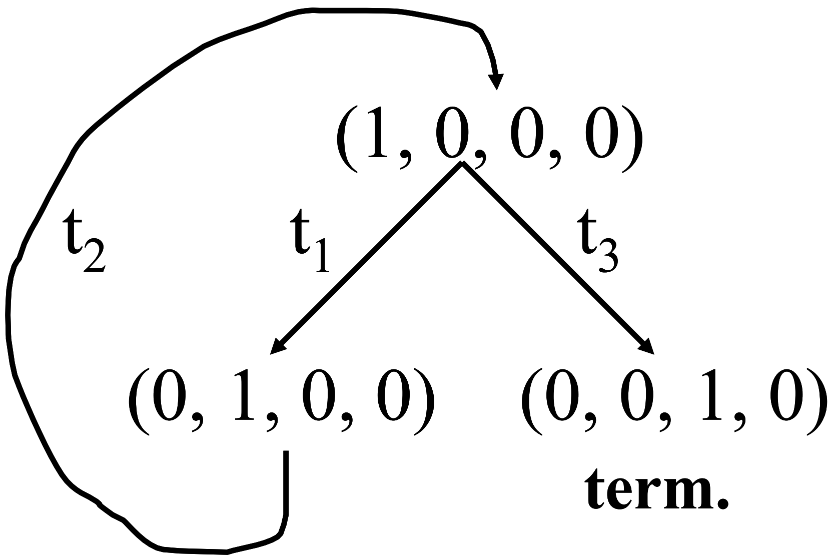
Example of GRAFCET

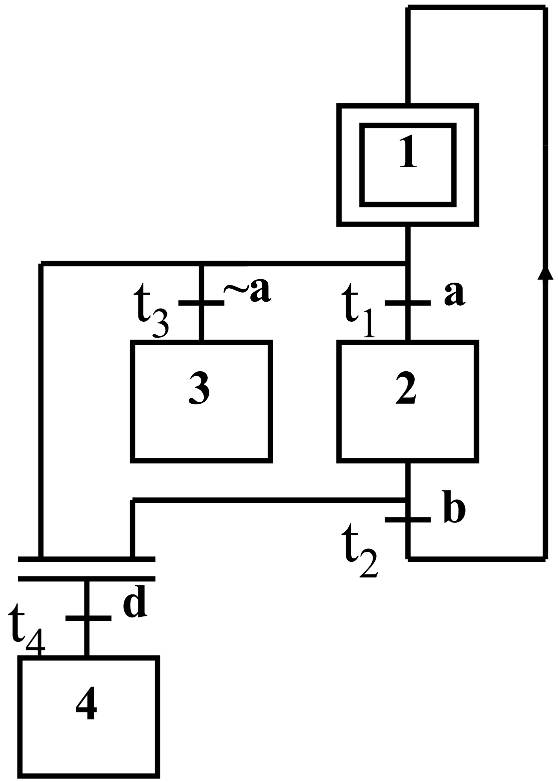




Petri Nets → GRAFCET

Example of GRAFCET





Strictly conservative.

Petri Nets → GRAFCET

Metoth of Matrix Equation (for the state evolution)

The evolution of a GRAFCET can be written in compat 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

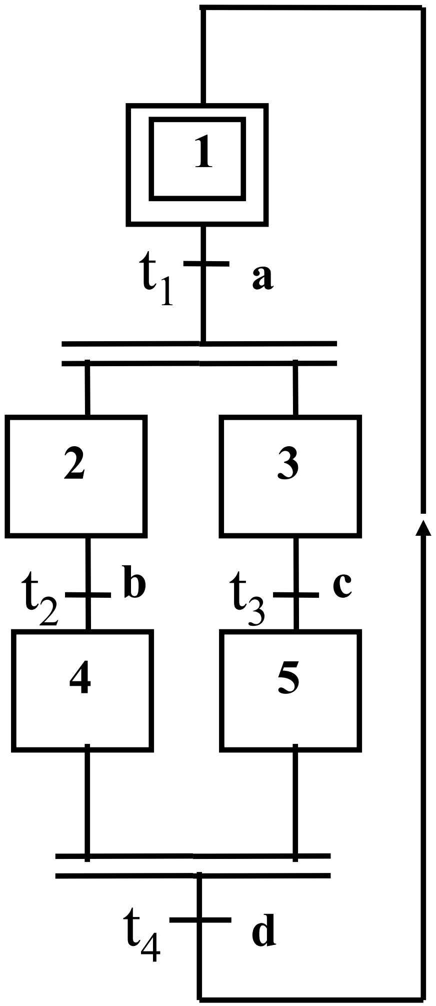
- Reachability (sufficient condition)

> 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 m' is impossible.

- Conservation – the conservation vector can be computed automaticaly.

- 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 $x^T D = 0$

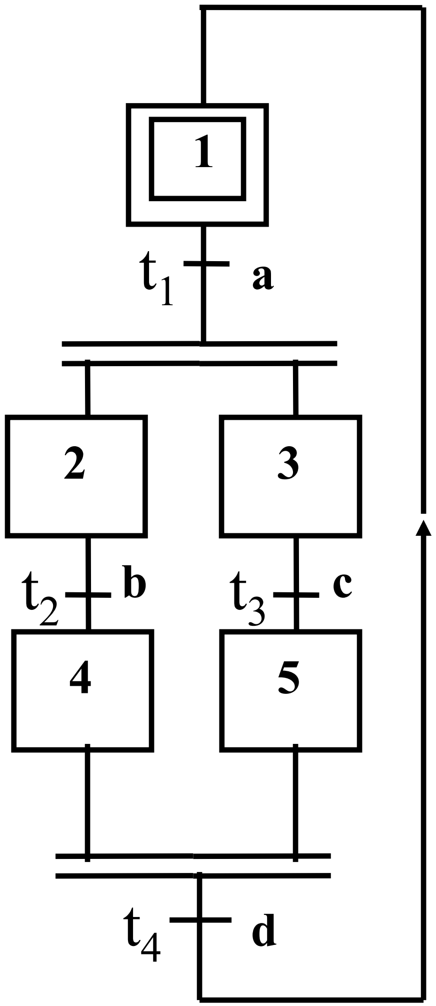
$$\begin{cases} -x_1 + x_2 + x_3 = 0 \\ -x_2 + x_4 = 0 \\ -x_3 + x_5 = 0 \\ x_1 - x_4 - x_5 = 0 \end{cases}$$

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

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

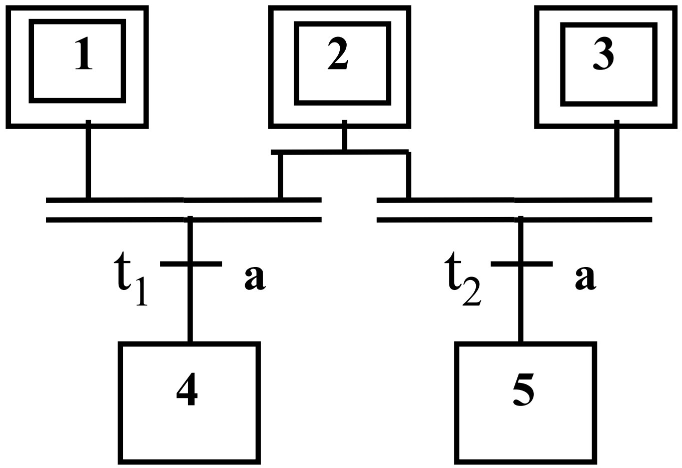
Solution:
Set of equation
with one solution

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

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

Example of GRAFCET

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



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

Set of Equations implossible
Therefore marking not reachable.
WRONG!

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

The method fails if it exist conflicts!