Industrial Automation

(Automação de Processos Industriais)

GRAFCET

(Sequential Function Chart)

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

Slides 2010/2011 Prof. Paulo Jorge Oliveira
Rev. 2011/2012 Prof. José Gaspar

Syllabus:

Chap. 3 – PLCs Programming Languages [2 weeks]

...

Chap. 4 - GRAFCET *(Sequential Function Chart)* [1 week]

The GRAFCET norm.

Elements of the language.

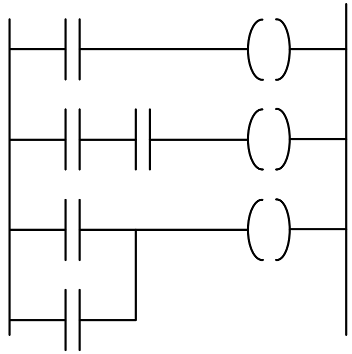
Modelling techniques using GRAFCET.

...

Chap. 5 – CAD/CAM and CNC Machines [1 week]

PLCs Programming Languages
(IEC 1131-3)

Ladder Diagram



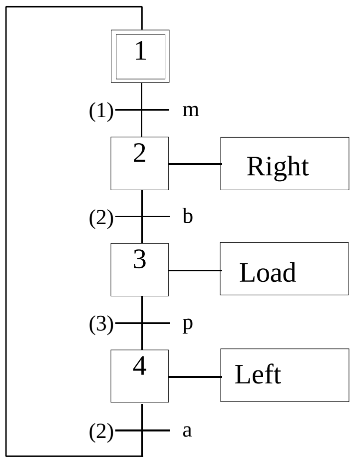
Structured Text

```
If  %I1.0  THEN
  %Q2.1 := TRUE
ELSE
  %Q2.2 := FALSE
END_IF
```

Instruction List

```
LD      %M12
AND     %I1.0
ANDN    %I1.1
OR      %M10
ST      %Q2.0
```

Sequential Function Chart (GRAFCET)



Some pointers to GRAFCETs (SFCs)

History: http://www.lurpa.ens-cachan.fr/grafcet/groupe/gen_g7_uk/geng7.html

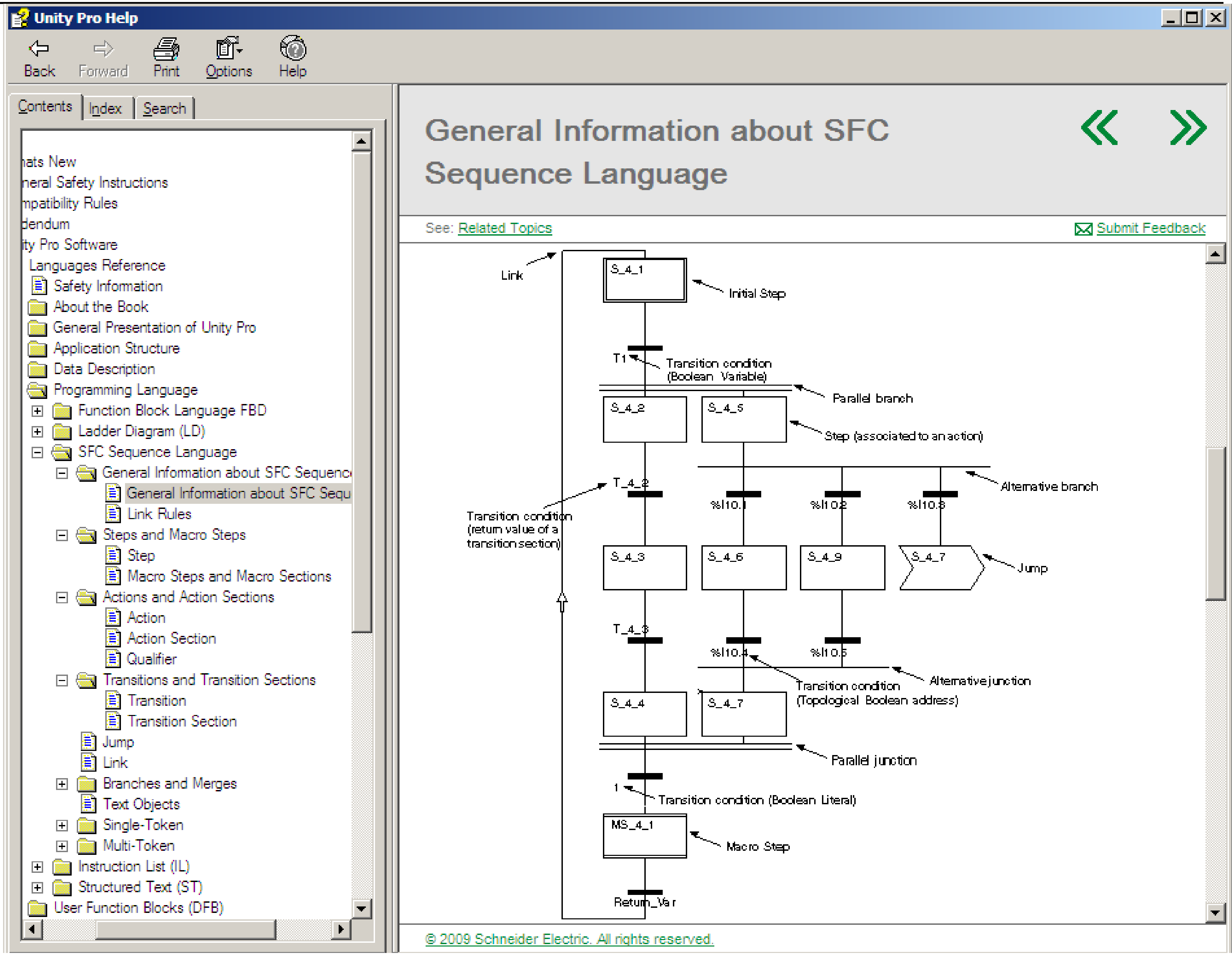
Tutorial: http://asi.insa-rouen.fr/~amadisa/grafcet_homepage/tutorial/index.html
http://www-ipst.u-strasbg.fr/pat/autom/grafce_t.htm

Simulator: http://asi.insa-rouen.fr/~amadisa/grafcet_homepage/grafcet.html
http://www.automationstudio.com (See projects)

Bibliography:

-- **Petri Nets and GRAFCET: Tools for Modelling Discrete Event Systems**
R. David, H. Alla, New York : PRENTICE HALL Editions, 1992
-- **Grafcet: a powerful tool for specification of logic controllers**, R. David, IEEE Trans. on Control Systems Tech., 1995 v3n3 pp253-268 [online]
-- **Programação de Autómatos**, Método GRAFCET, José Novais, Fundação Calouste Gulbenkian
-- **Norme Française NF C 03-190 + R1 : Diagramme fonctionnel "GRAFCET" pour la description des systèmes logiques de commande**

Homepage: http://www.lurpa.ens-cachan.fr/grafcet/


Unity Pro Help
Back
Forward
Print
Options
Help
Contents
Index
Search
hats New
neral Safety Instructions
mpatibility Rules
dendum
ity Pro Software
Languages Reference
Safety Information
About the Book
General Presentation of Unity Pro
Application Structure
Data Description
Programming Language
Function Block Language FBD
Ladder Diagram (LD)
SFC Sequence Language
General Information about SFC Sequenc
General Information about SFC Sequ
Link Rules
Steps and Macro Steps
Step
Macro Steps and Macro Sections
Actions and Action Sections
Action
Action Section
Qualifier
Transitions and Transition Sections
Transition
Transition Section
Jump
Link
Branches and Merges
Text Objects
Single-Token
Multi-Token
Instruction List (IL)
Structured Text (ST)
User Function Blocks (DFB)
General Information about SFC Sequence Language
See: Related Topics
Submit Feedback
Link
S_4_1
Initial Step
T1
Transition condition (Boolean Variable)
Parallel branch
S_4_2
S_4_5
Step (associated to an action)
T_4_2
%I10.1
%I10.2
%I10.3
Alternative branch
Transition condition (return value of a transition section)
S_4_3
S_4_6
S_4_9
S_4_7
Jump
T_4_3
%I10.4
%I10.5
Transition condition (Topological Boolean address)
Alternative junction
S_4_4
S_4_7
Parallel junction
1
Transition condition (Boolean Literal)
MS_4_1
Macro Step
Return_Var
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GRAFCET History

- 1975 – Decision of the workgroup "Logical Systems" da AFCET (Association Française de Cybernétique Economique et Technique) on the creation of a committee to study a standard for the representation of logical systems and automation.

- 1977 – GRAFCET definition (Graphe Fonctionnel de Commande Etape-Transition).

- 1979 – Dissemination in schools and adopted as research area for the implementation of solutions of automation in the industry.

- 1988 - GRAFCET becomes an international standard denominated as "Sequential Function Chart“, pela I.E.C.

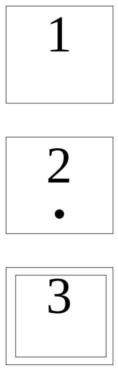
GRAFCET Basic Elements

Steps

Inactive

Active

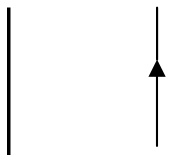
Initial



Actions can be associated with **Steps**.

Connections

Directed Arc



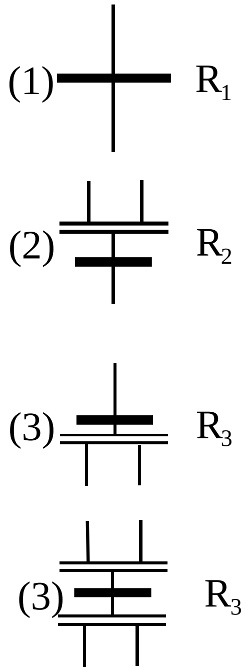
Transitions

Simple

Joint (parallel junction)

Fork (parallel branch)

Joint e *fork*



A **logical receptivity** function can be associated with each **Transition**.

GRAFCET Basic Elements

Oriented connections (arcs)

In a GRAFCET:

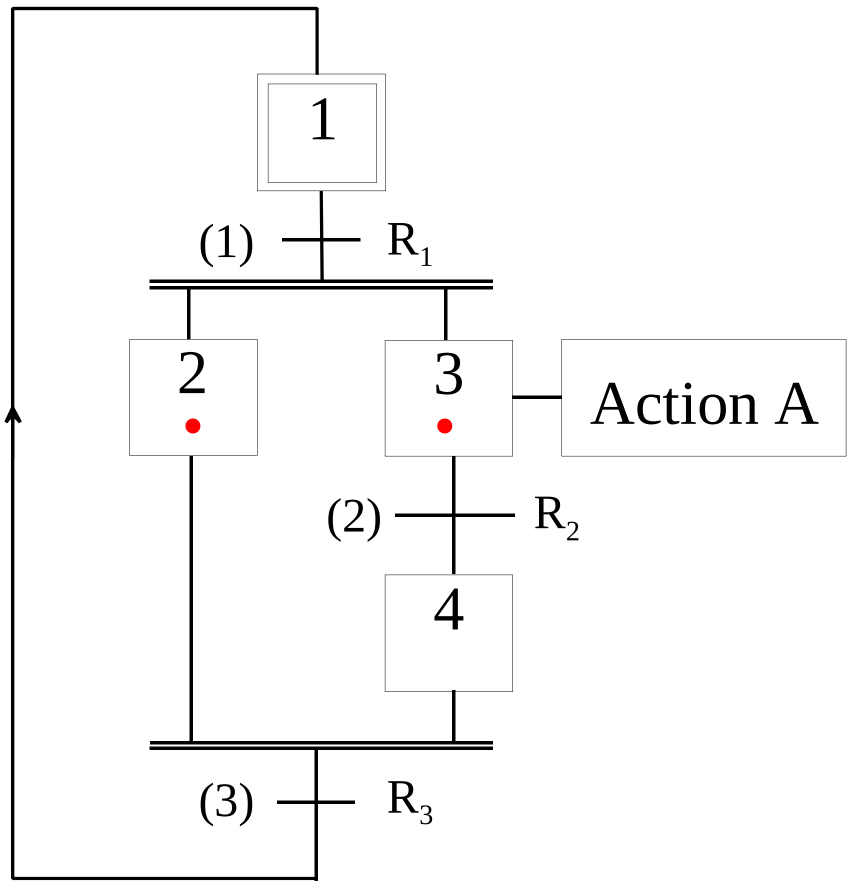
An Arc can connect Steps to Transitions

An Arc can connect Transitions to Steps

A Step can have no Transitions as inputs (source);

A Step can have no Transitions as outputs (drain);

The same can occur for the Transitions.



GRAFCET

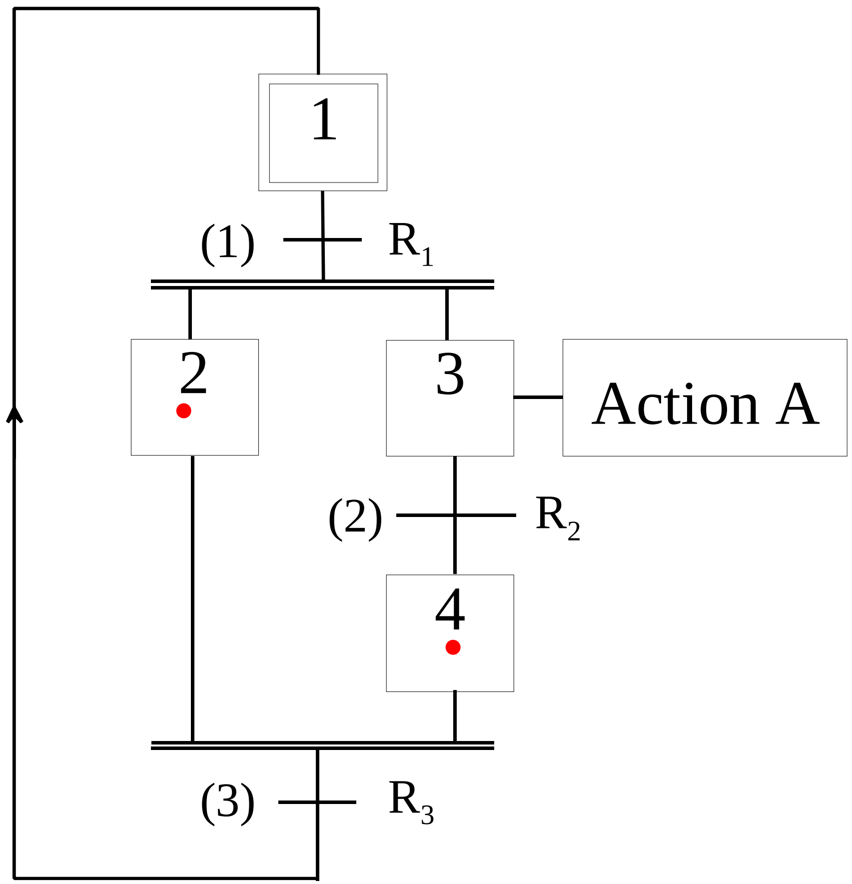
State of a GRAFCET

Definition of State:

The set of markings of a GRAFCET constitutes its state.

Question:

How does the state of a GRAFCET evolve?



GRAFCET **State Evolution:**

- **Rule 1: Initial State**

It is characterized by the active Steps at the beginning of operation (at least one).

- **Rule 2: Transposition of a Transition**

A Transition is active or enabled only if all the Steps at its input are active (if not it is inactive).

A Transition can only be transposed if it is active and is true the associated condition (receptivity function).

- **Rule 3: Evolution of active Steps**

The transposition of a Transition leads to the deactivation of all the Steps on its inputs and the activation of all Steps on its outputs.

- **Rule 4: Simultaneous transposition of Transitions**

All active Transitions are transposed simultaneously.

- **Rule 5: Simultaneous activation and deactivation of a Step**

In this case the activation has priority.

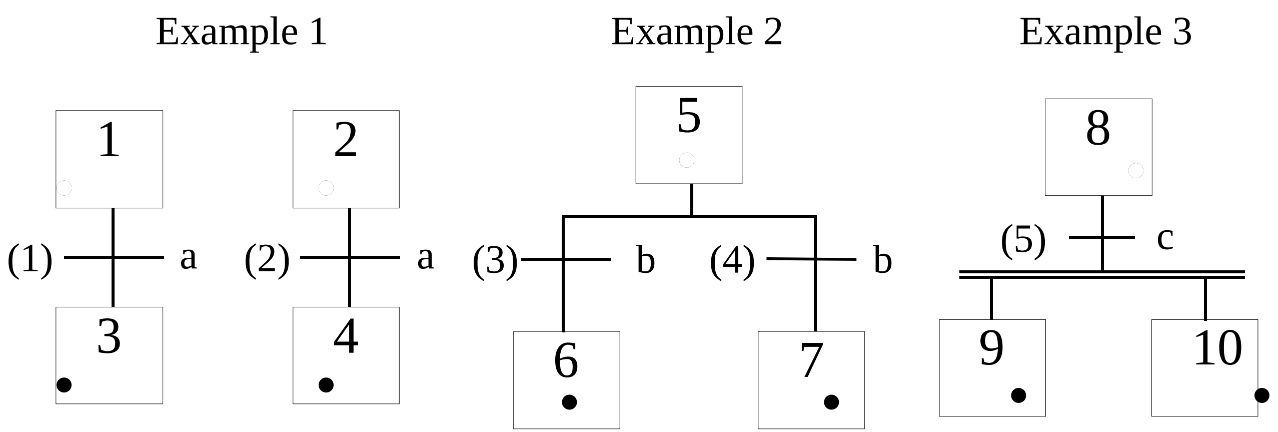
GRAFCET State Evolution:

• **Rule 2a:**

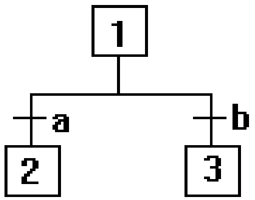
All active Transitions are transposed immediately.

• **Rule 4:**

Simultaneous active Transitions are transposed simultaneously.



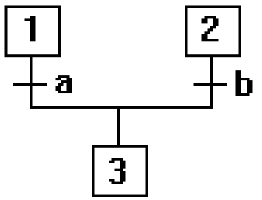
OR Divergences:



If Step 1 is active and if **a** is TRUE then Step 1 is deactivated and Step 2 is activated (state of Step 3 is maintained).

If **a** and **b** are TRUE and Step 1 is active then Step 1 is deactivated and Steps 2 and 3 are activated (for any previous state of Steps 2 and 3).

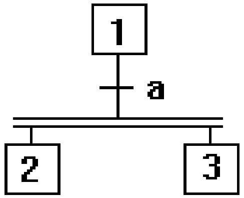
OR Convergences:



If Step 1 is active and if **a** is TRUE then Step 1 is deactivated and Step 3 is activated (state of Step 2 remains unchanged). The same happens for Step 2 and **b**.

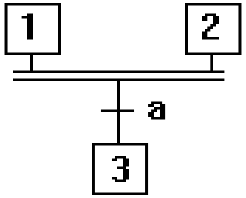
If both Steps 1 and 2 are active and **a** and **b** are TRUE then Steps 1 and 2 are deactivated and Step 3 is activated.

AND Divergences:



If Step 1 is active and if **a** is TRUE then Step 1 is deactivated and Steps 2 and 3 are activated.

AND Convergences:



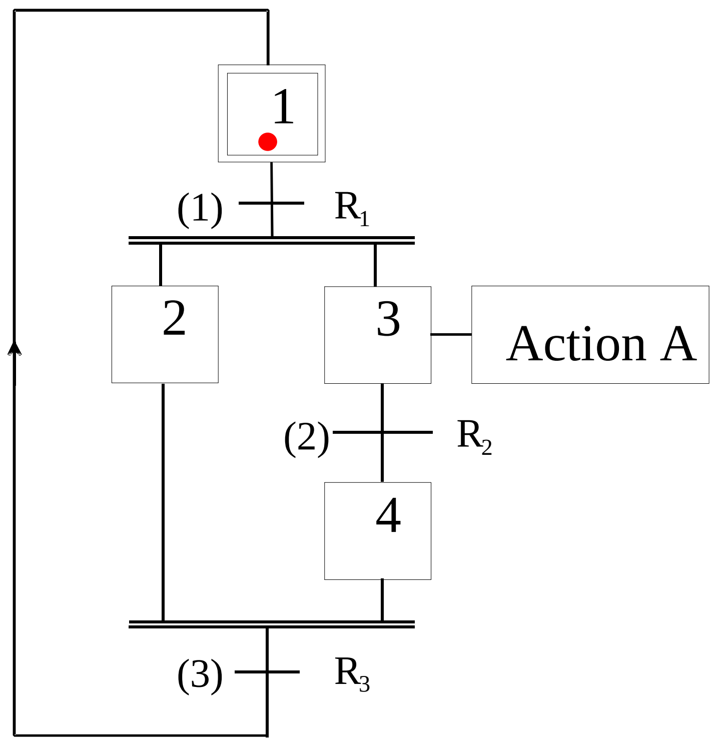
If Steps 1 and 2 are active and if **a** is TRUE then Steps 1 and 2 are deactivated and Step 3 is activated (if only one of the input steps is active, the state remains).

GRAFCET

Example:

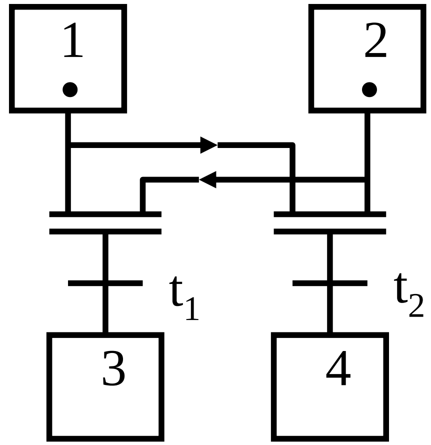
GRAFCET state evolution

Level activated Action. Actions can also be activated during transitions - see next.



GRAFCET

Modelling problem:



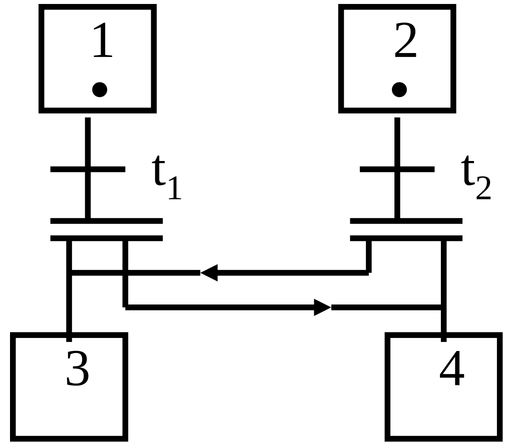
Given 4 Steps (1 to 4) and 2 Transitions (t1 and t2) write a segment of GRAFCET to solve the following problem:

In the case that the Steps 1 and 2 are active:

- if t1 is TRUE, activate Step 3 (and deactivate Steps 1 and 2);
- if t2 is TRUE, activate Step 4 (and deactivate Steps 1 and 2);
- otherwise, the state is maintained.

GRAFCET

Other modelling problem:



Given 4 Steps (1 to 4) and 2 Transitions (t1 and t2) write a segment of GRAFCET to solve the following problem:

If Step 1 is active and t1 is TRUE

OR

If Step 2 is active and t2 is TRUE

THEN

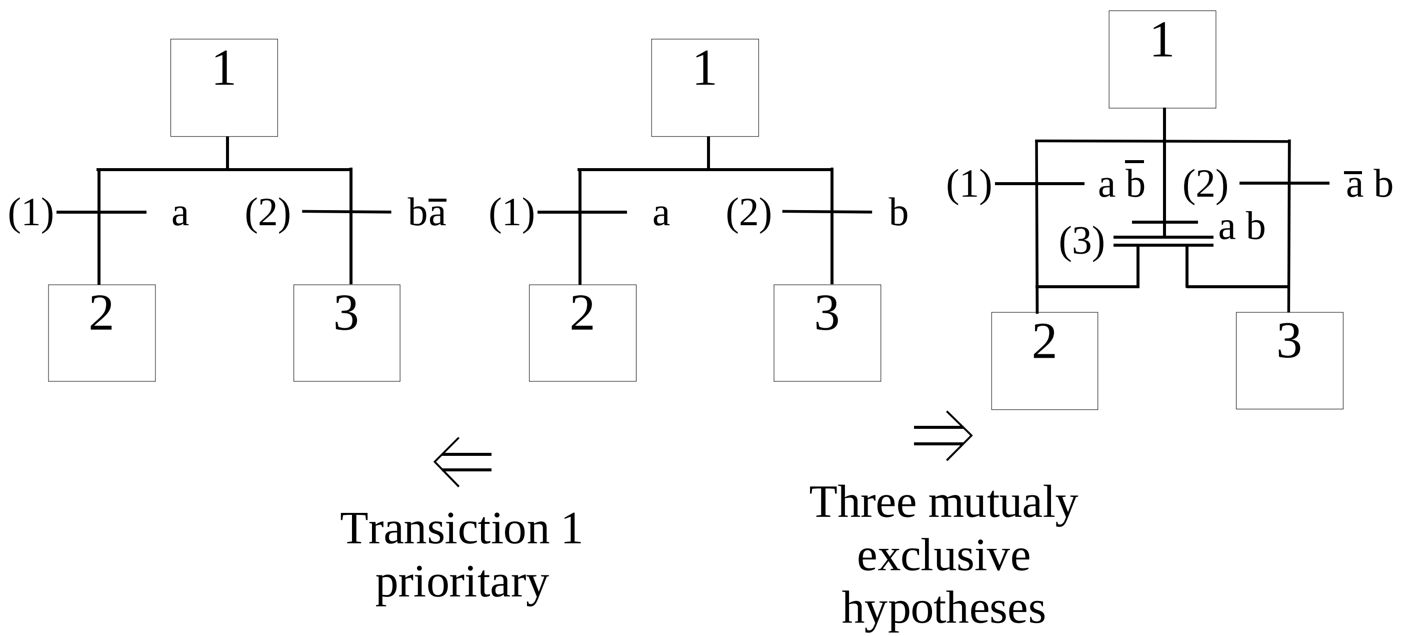
Activate Steps 3 and 4.

GRAFCET

GRAFCET state evolution, Conflicts:

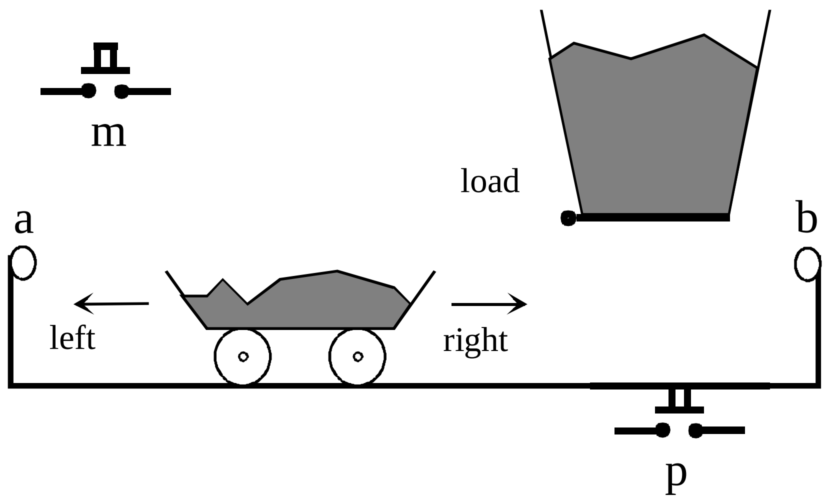
There exist Conflicts when the validation of a Transition depends on the same Step or when more than one receptivity functions can become true simultaneously.

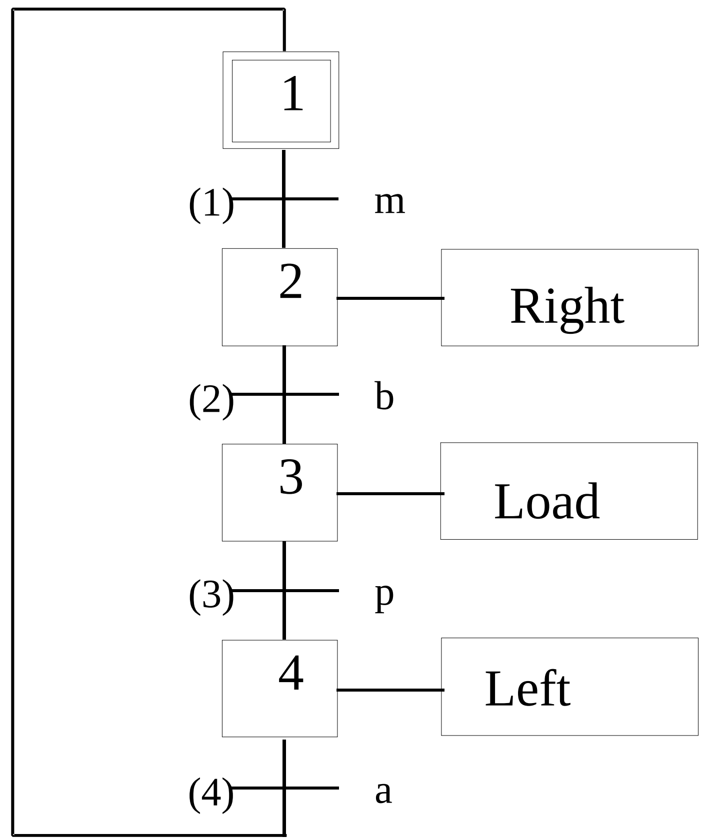
Solutions:



GRAFCET

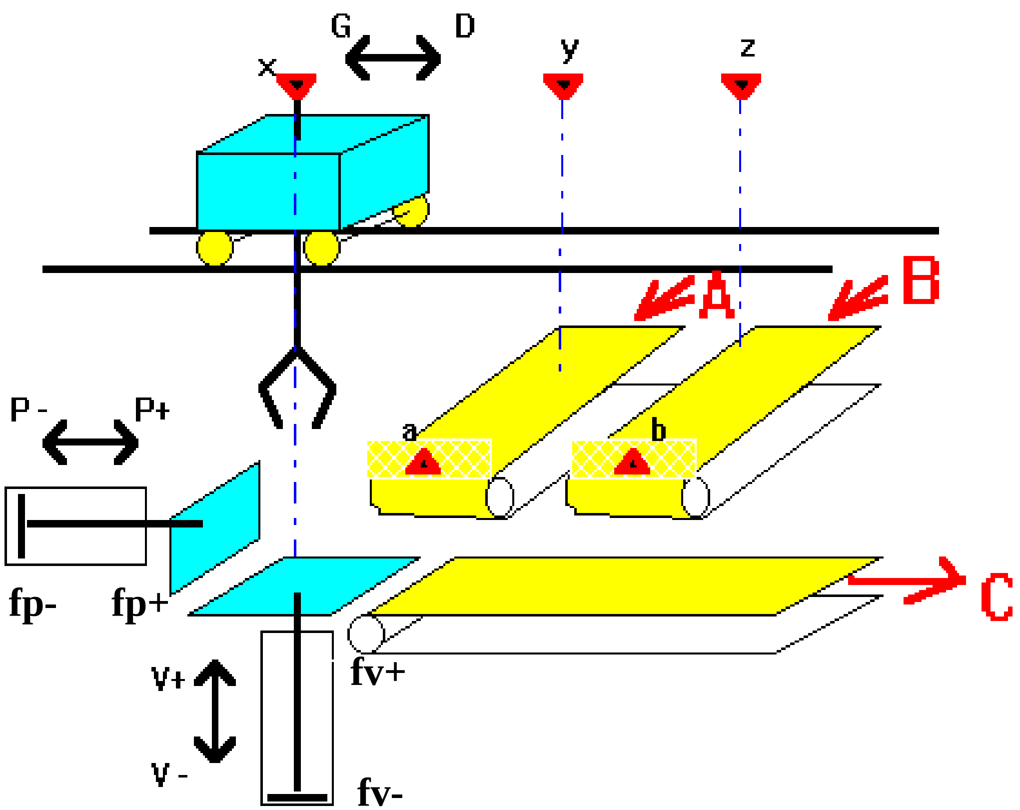
Example 1: modeling a control/automation system





GRAFCET

Example 2: modeling a automated transport workcell



* Conveyor **A** brings parts (sensor **a** detects part ready to lift)

* Conveyor **B** brings parts (sensor **b** detects part ready to lift)

• Hanging crane, commanded with **D (droit)** e **G (gauche)**, uses sensors **x, y** e **z** to detect crane over the base, over A, or over B, respectively.

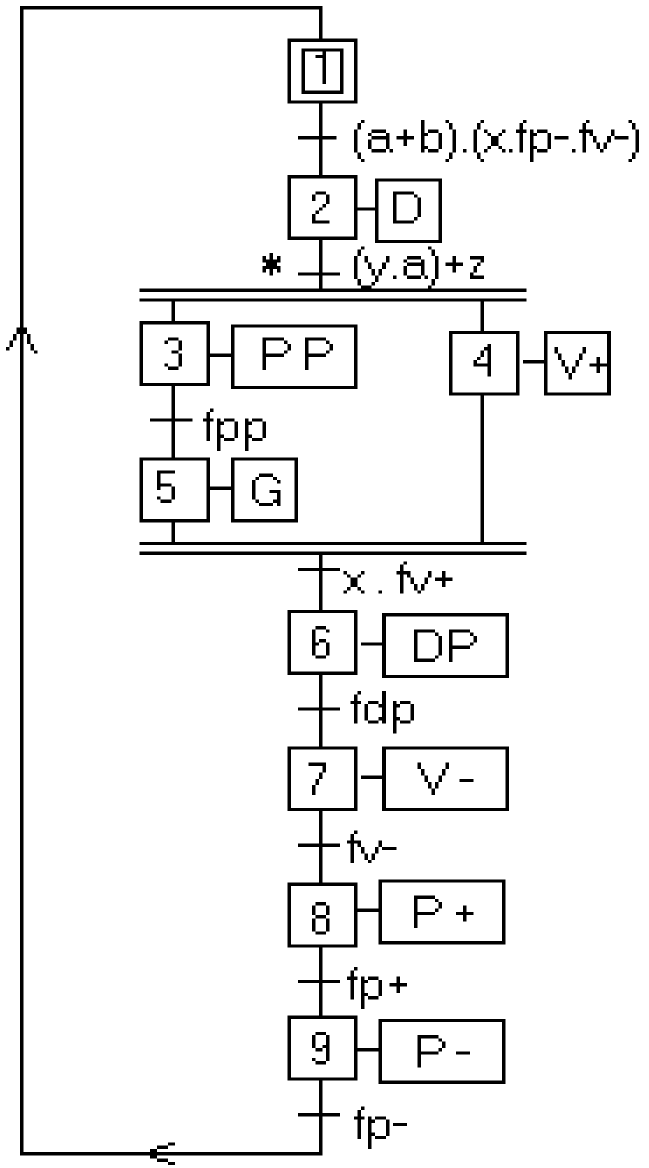
• Clamp of the crane grabs and releases parts with commands **PP** and **DP**. Limit switches **fpp** and **fdp** indicate grabbed and released part. A holding platform has two extreme positions, top and bottom, detected by switches **fv+** and **fv-**. Part release can only be done having the holding platform up.

* Effector pushes parts with commands **P+** e **P-.** Limit switches **fp+** and **fp-** indicate max and min pushing positions.

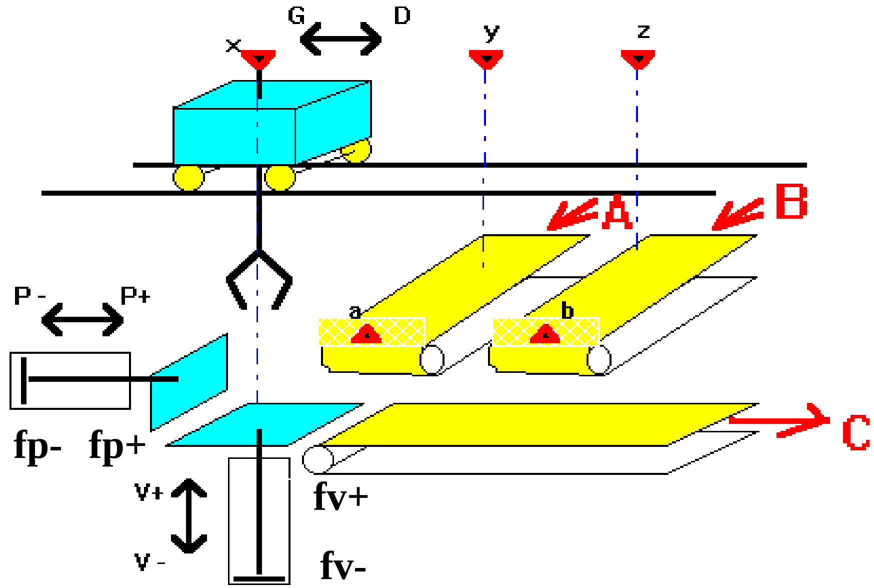
* The output conveyor is always ON.

* Conveyors **A** e **B** are commanded by other automata, independent of this workcell.

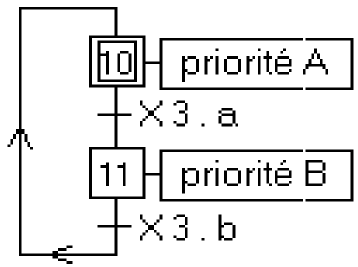
GRAFCET Example 2 (cont)



← *Solution*



To guarantee alternating A and B, modify the program, adding the following GRAFCET:



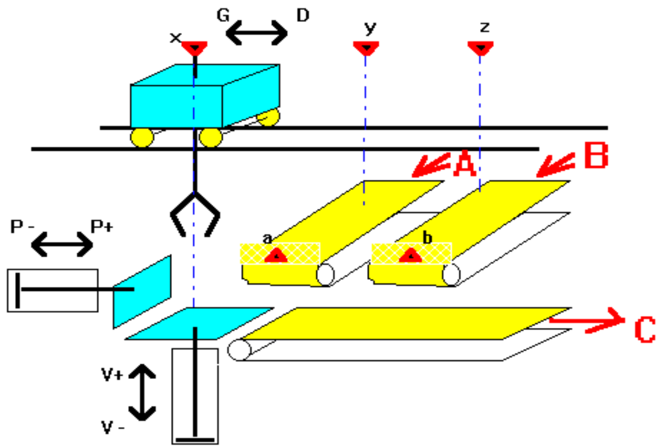
and changing the receptivity function * to: $y.a.(\overline{b}+X10)+z$

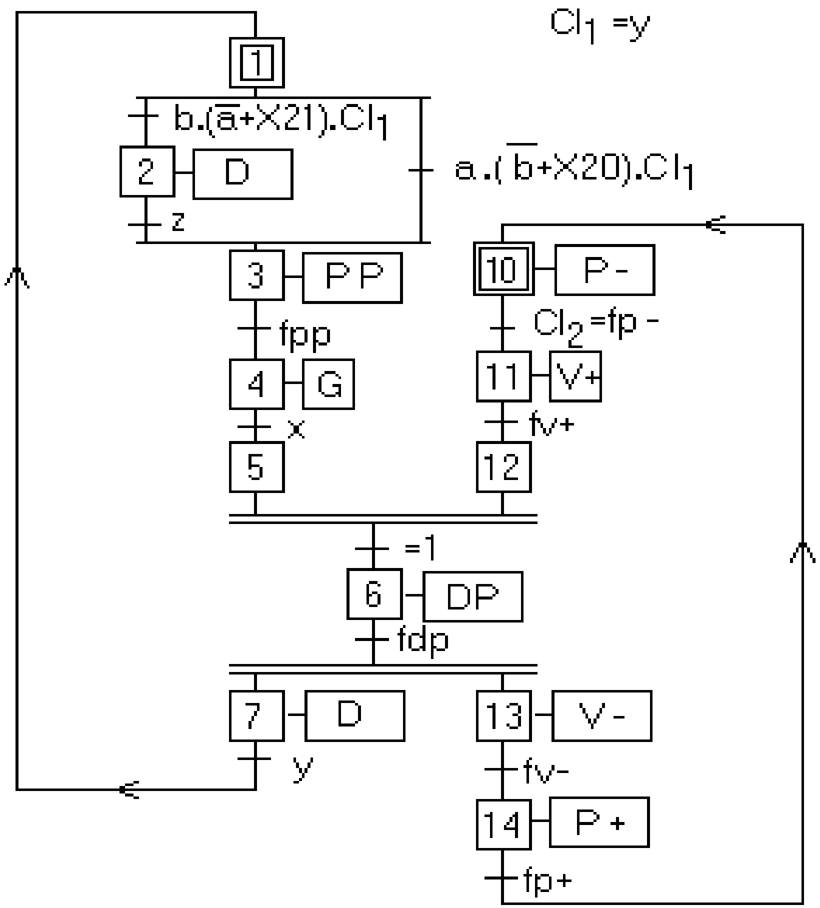
*Explanation: grab part in **y**, if there exists part in **a** and if **b** has not the priority; if **b** is true and has priority, then grab part in **z**.*

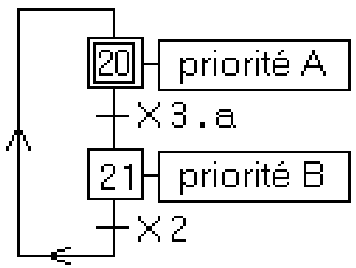
Note: terminology X10 of PL7 changes to S_1_10 in Unity Pro

GRAFCET Example 2 (cont)

Improved solution:







a) After processing one part (P+) prepare immediately to receive the next one: **fv+**.

b) Move crane (D) to an optimal waiting location (i.e. location that reduces delays): **y**.

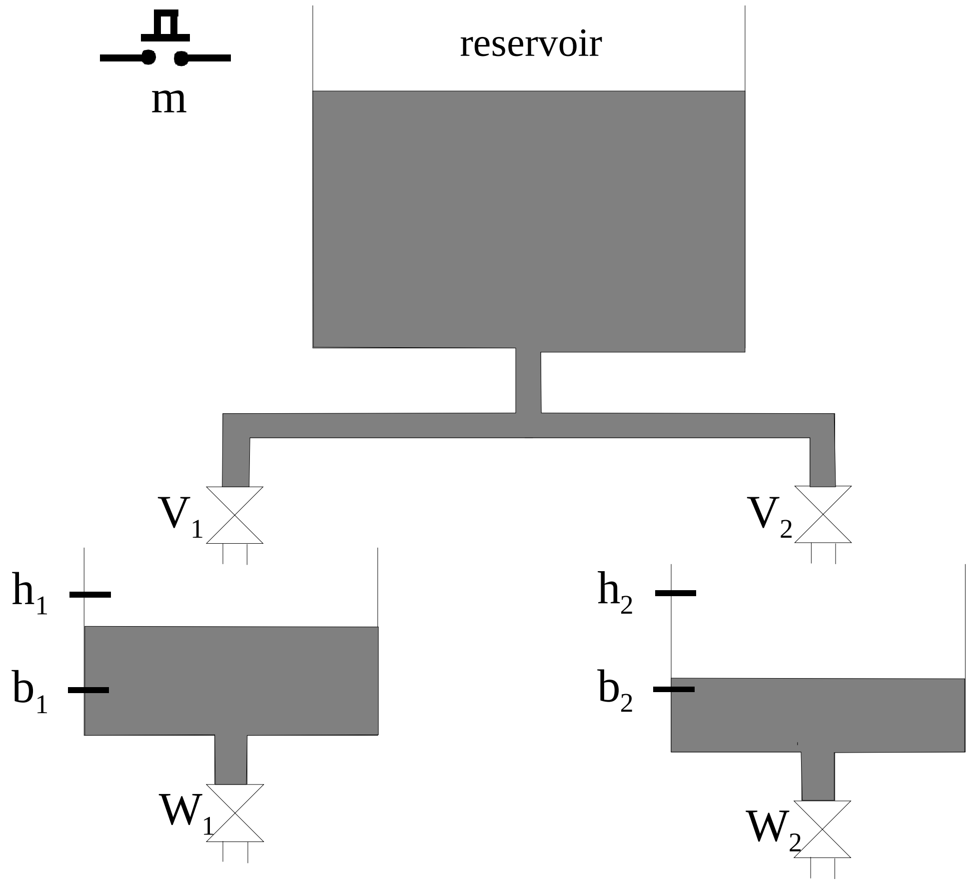
GRAFCET

Example 3: modeling and automation of a distribution system

Objective:
fill 1&2, empty 1&2
refill only after both empty

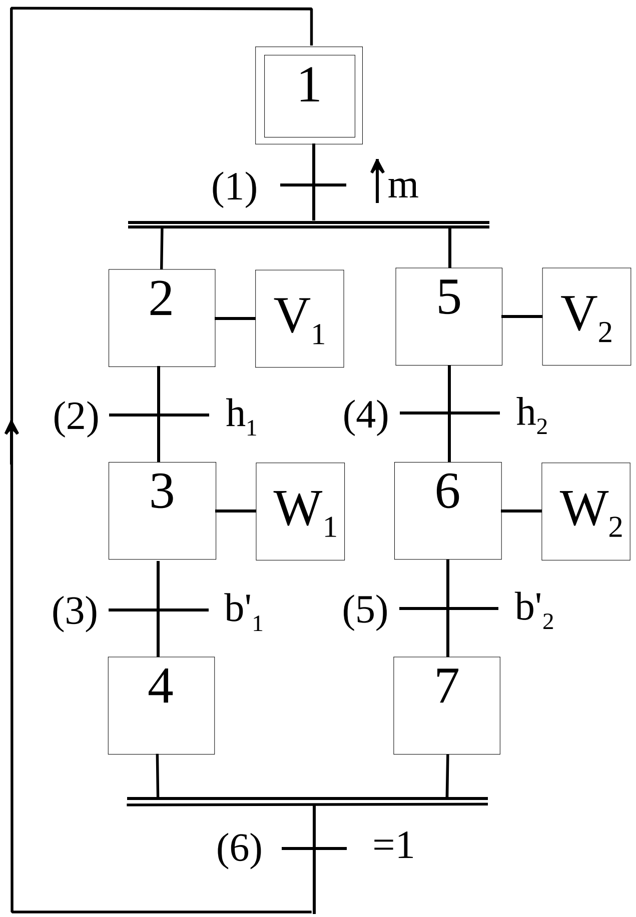
Sensors:
m = ON/OFF
b_1, h_1, b_2 h_2 = level

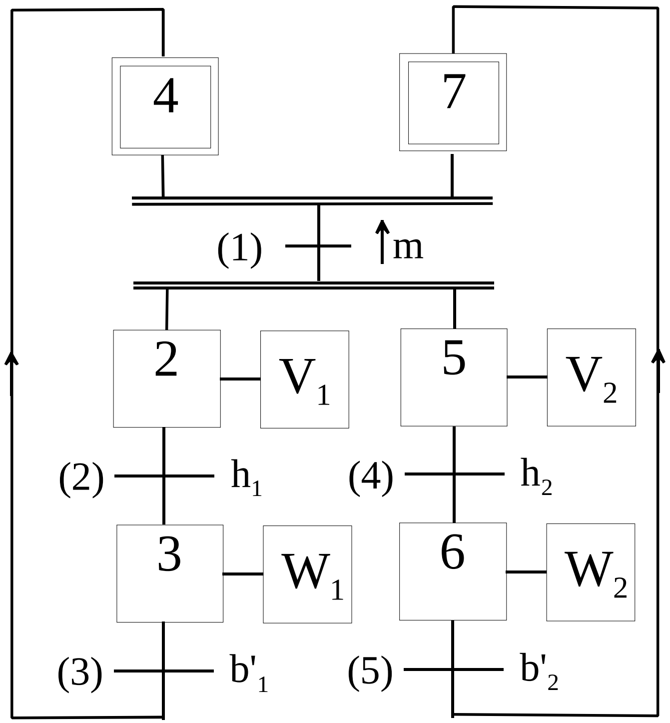
Actuators:
V_1, V_2, W_1 W_2 = admit/exhaust



GRAFCET

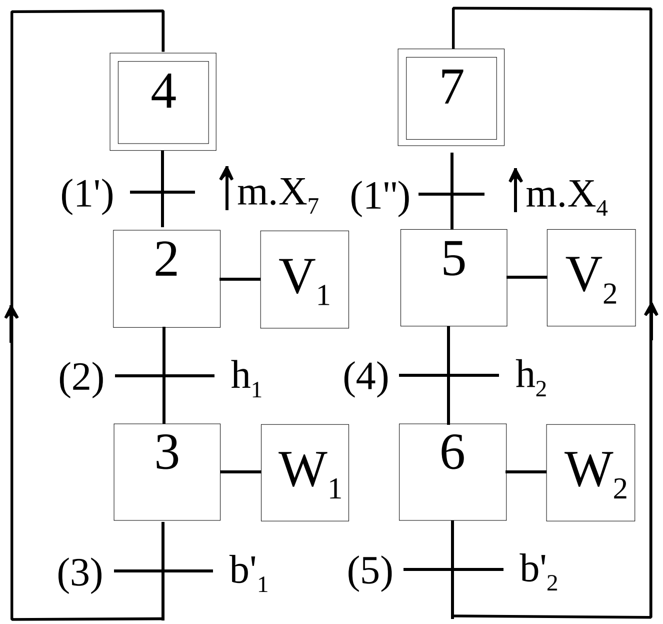
Example 3: modeling and automation of a distribution system

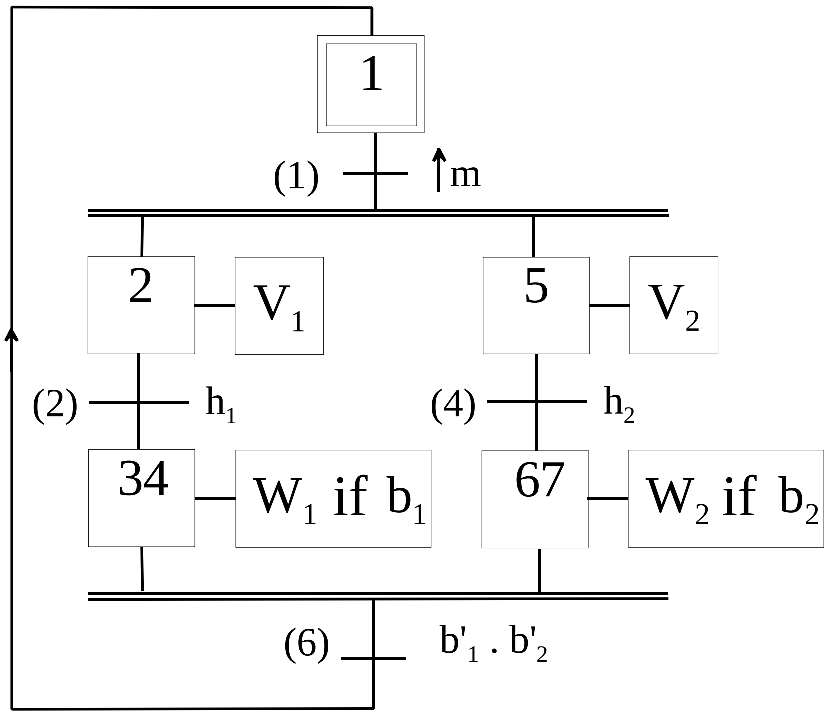




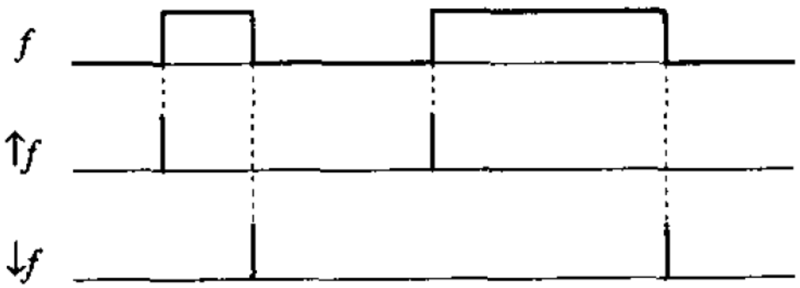
GRAFCET

Example 3: modeling and automation of a distribution system

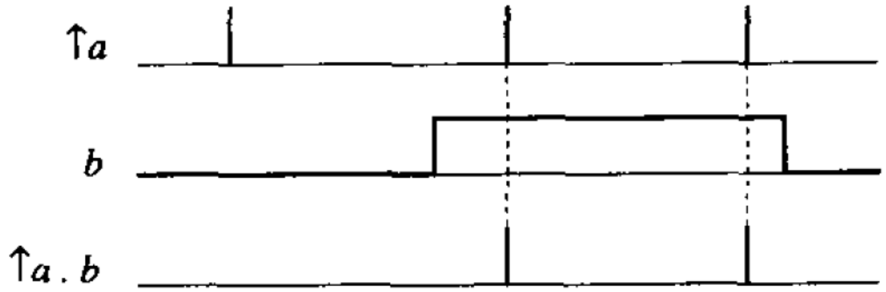




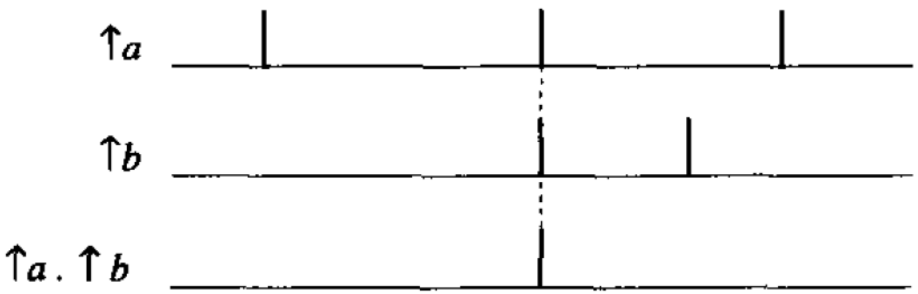
GRAFCET Transitions can be conditions, events and conditions mixed with events



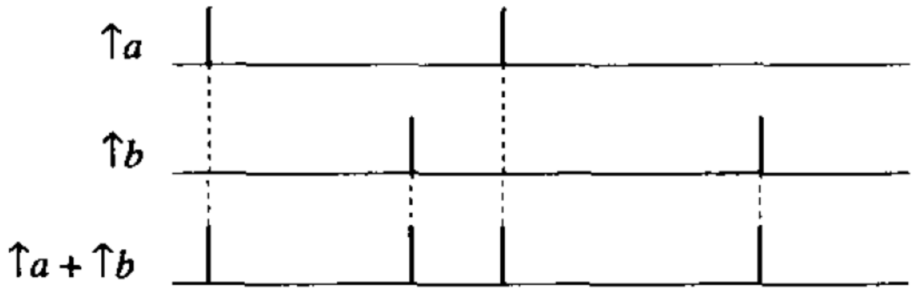
(a) Events ↑ f and ↓ f obtained from a condition f



(b) Event ↑ a.b obtained from event ↑ a and condition b



(c) Event ↑ a. ↑ b obtained from events ↑ a and ↑ b



(d) Event ↑ a + ↑ b obtained from events ↑ a and ↑ b

Grafcet: a powerful tool for specification of logic controllers, R. David, IEEE Trans. on Control Systems Tech., 1995 v3n3 pp253-268

GRAFCET Transitions can be conditions, events and conditions mixed with events

Properties of events (edge triggers) mixed with conditions (Boolean variables):

$\uparrow a = \downarrow a'$

$\uparrow a \,.\, a = \uparrow a$, $\quad \uparrow a \,.\, a' = 0$, $\quad \downarrow a \,.\, a' = \downarrow a$, $\quad \downarrow a \,.\, a = 0$

$\uparrow a \,.\, \uparrow a = \uparrow a$, $\quad \uparrow a \,.\, \uparrow a' = 0$

$\uparrow (a \,.\, b) = \uparrow a \,.\, b + \uparrow b \,.\, a$, $\quad \uparrow (a + b) = \uparrow a \,.\, b' + \uparrow b \,.\, a'$

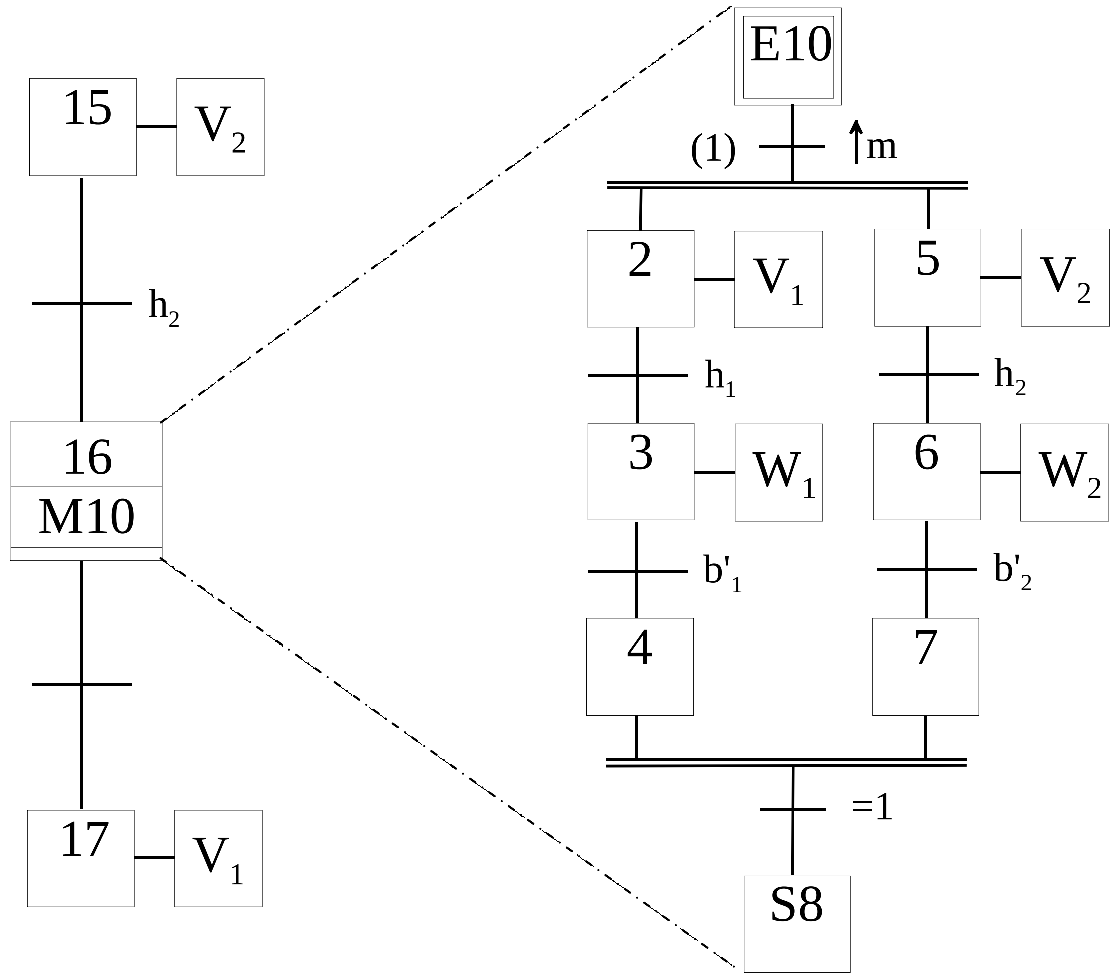
$\uparrow (a \,.\, b) \,.\, \uparrow (a \,.\, c) = \uparrow (a \,.\, b \,.\, c)$

In general, if events a and b are independent

$\uparrow a \,.\, \uparrow b = 0$

GRAFCET Other auxiliary mechanisms

Macro-steps



GRAFCET Other auxiliary mechanisms

Pseudo Macro-steps

Macro Actions

- **Force actions**
- **Enable actions**
- **Mask actions**

GRAFCET **Implementation in DOLOG80**

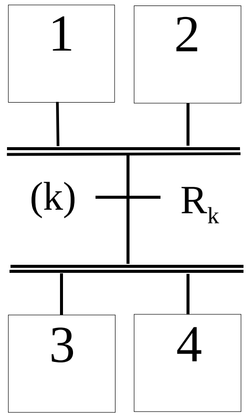
The activity of each Step is stored in an auxiliary memory.

At startup do:
AM128
SLMx
...
AM128
SLMy
(initial steps)
RLM128

Store R_k evaluation in M100

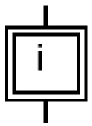
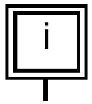
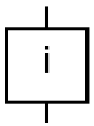
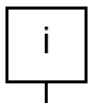
AM1
AM2
AM100
SLM3
AM1
AM2
AM100
SLM*4*

AM3
AM4
RLM1
AM3
AM4
RLM2



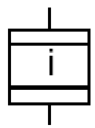
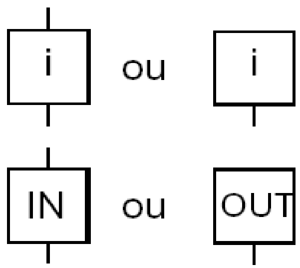
GRAFCET Implementation in the TSX3722/TSX57

Steps

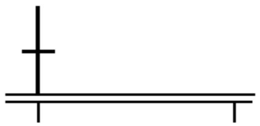
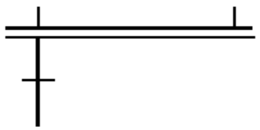
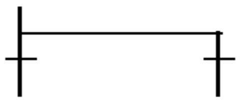
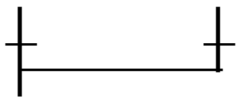
Name	Symbol	Functions
Initial steps (	 ou 	symbolize the initial active steps at the beginning of the cycle after initialization or re-start from cold.
Simple steps (	 ou 	show that the automatic system is in a stable condition. The maximum number of steps (including the initial steps) can be configured from: • 1 - 96 for a TSX 37-10, • 1 - 128 for a TSX 37-20, • 1 - 250 for a TSX 57. The maximum number of active steps at the same time can be configured.

GRAFCET Implementation in the TSX3722/TSX57

Macro-steps

Name	Symbol	Functions
Macro steps		Symbolize a macro step: a single group of steps and transitions. The maximum number of macro steps can only be configured from 0 - 63 for the TSX 57.
Stage of Macro steps		Symbolizes the stages of a macro step. The maximum number of stages for each macro step can be configured from 0 - 250 for the TSX 57. Each macro step includes an IN and OUT step.

GRAFCET Implementation in the TSX3722/TSX57

Name	Symbol	Functions
Transitions		allow the transfer from one step to another. A transition condition associated with this condition is used to define the logic conditions necessary to cross this transition. The maximum number of transitions is 1024. It cannot be configured. The maximum number of valid transitions at the same time can be configured.
AND divergences		Transition from one step to several steps: is used to activate a maximum of 11 steps at the same time.
AND convergences		Transition of several steps to one: is used to deactivate a maximum of 11 steps at the same time.
OR divergences		Transition from one step to several steps: is used to carry out a switch to a maximum of 11 steps.
OR convergences		Transition of several steps to one: is used to end switching from a maximum of 11 steps.

GRAFCET Implementation in the TSX3722/TSX57

Arcs/Connectors

Name	Symbol	Functions
Source connectors	n 	"n" is the number of the step "it comes from" (source step).
Destination connector	 n	"n" is the number of the step "it's going to" (target step).
Links directed towards: • top • bottom • right or left		These links are used for switching, jumping a step, restarting steps (sequence).

Information associated with Steps in the GRAFCET:

Name		Description
Bits associated with the steps (1 = active step)	%Xi	Status of the i step of the main Grafcet
		(i from 0 - n) (n depends on the processor)
	%XMj	Status of the j macro step (j from 0 - 63 for TSX/PMX/PCX 57)
	%Xj.i	Status of the i step of the j macro step
	%Xj.IN	Status of the input step of the j macro step
	%Xj.OUT	Status of the output step of the j macro step
System bits as-sociated with Grafcet	%S21	Initializes Grafcet
	%S22	Grafcet resets everything to zero
	%S23	Freezes Grafcet
	%S24	Resets macro steps to 0 according to the system words %SW22 - %SW25
	%S25	Set to 1 when: ● tables overflow (steps/transition), ● an incorrect graph is run (destination connector on a step which does not belong to the graph).

Information associated with Steps in the GRAFCET (bis):

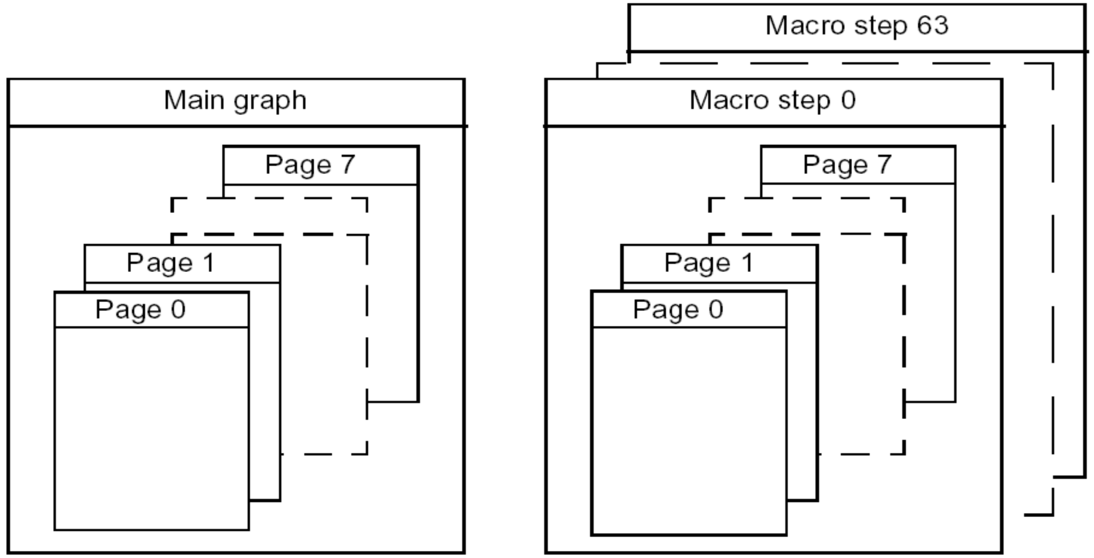
Name		**Description**
Words associated with steps	%Xi.T	Activity time for main Grafcet step i.
	%Xj.i.T	Activity time for the i step of the j macro step
	%Xj.IN.T	Activity time for the input step of the j macro step
	%Xj.OUT.T	Activity time for the output step of the j macro step
System words associated with Grafcet	%SW20	Word which is used to inform the current cycle of the number of active steps, to be activated and deactivated.
	%SW21	Word which is used to inform the current cycle of the number of valid transitions to be validated or invalidated.
	%SW22 à %SW25	Group of 4 words which are used to indicate the macro steps to be reset to 0 when bit %S24 is set to 1.

And where to find information related with Transitions?

Does not make sense state or activity nor timmings (only number of occurences).

GRAFCET

General structure:



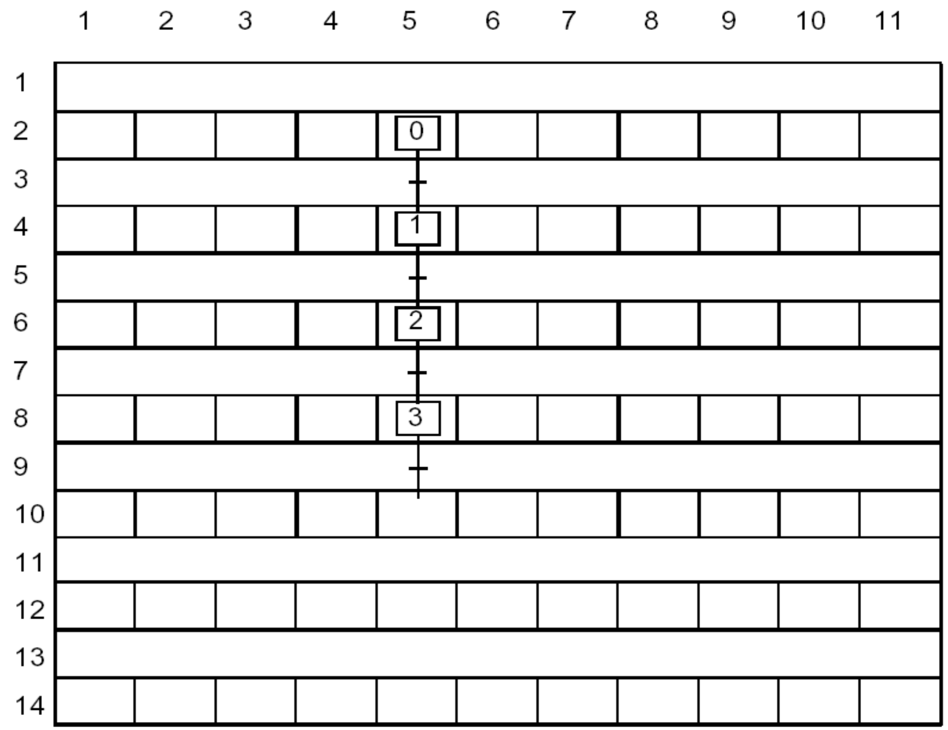
Characteristics:

Number	TSX 37 -10		TSX 37 -20		TSX 57	
	Default settings	Maxi-mum	Default settings	Maxi-mum	Default settings	Maxi-mum
Main graph steps	96	96	128	128	128	250
Macro steps	0	0	0	0	8	64
Macro step steps	0	0	0	0	64	250
Step total	96	96	128	128	640	1024
Steps active at the same time	16	96	20	128	40	250
Transitions valid at the same time	20	192	24	256	48	400

GRAFCET

Editor: 8 pages

- Pages 0 to 7
- 154 cells (14*11)



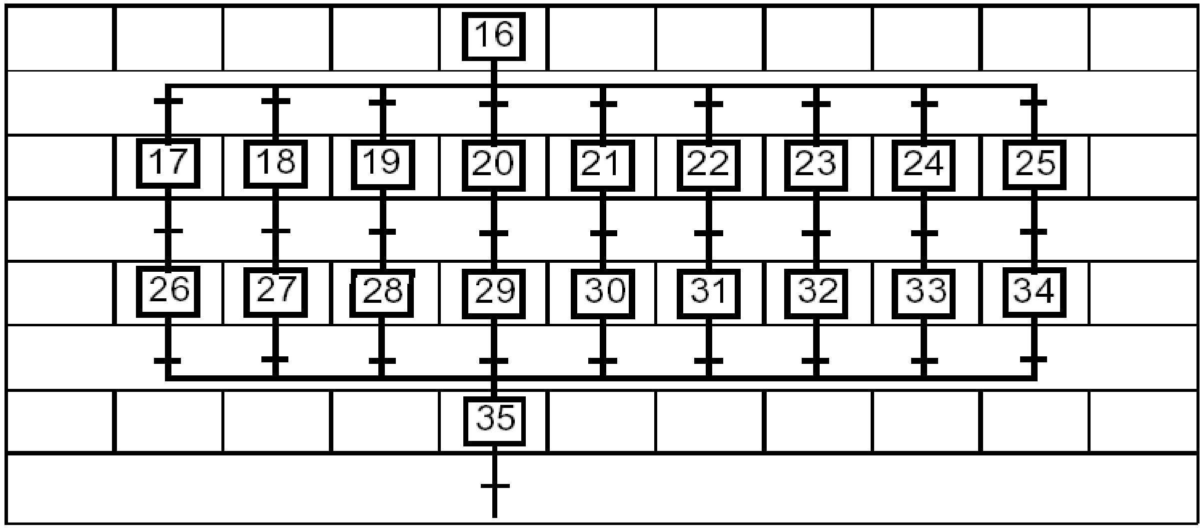
Characteristics:

- The first line is used to enter the source connectors.
- The last line is used to enter the destination connectors.
- The even lines (from 2 - 12) are step lines (for destination connector steps),
- The odd lines (from 3 - 13) are transition lines (for transitions and source connectors).
- Each step is located by a different number (0 - 127) in any order.
- Different graphs can be displayed on one page.

GRAFCET

OR divergences

(OR convergences)



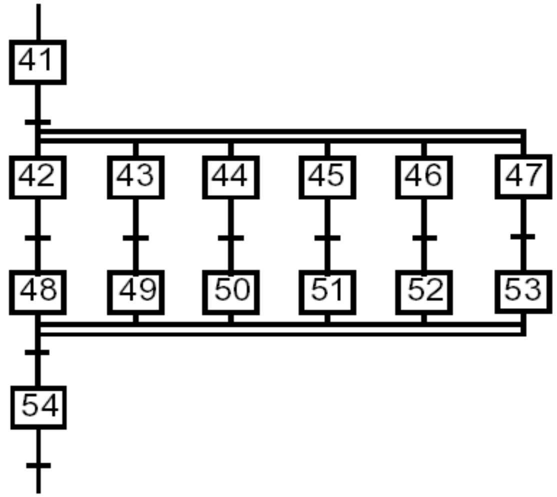
Characteristics:

- The number of transitions upstream of a switching end (OR convergence) or downstream of a switching (OR divergence) must not exceed 11.
- Switching can be to the left or to the right.
- Switching must general finish with switching end.
- To avoid crossing several transitions at the same time, the associated transition conditions must be exclusive.

GRAFCET

AND divergences

(AND Convergences)

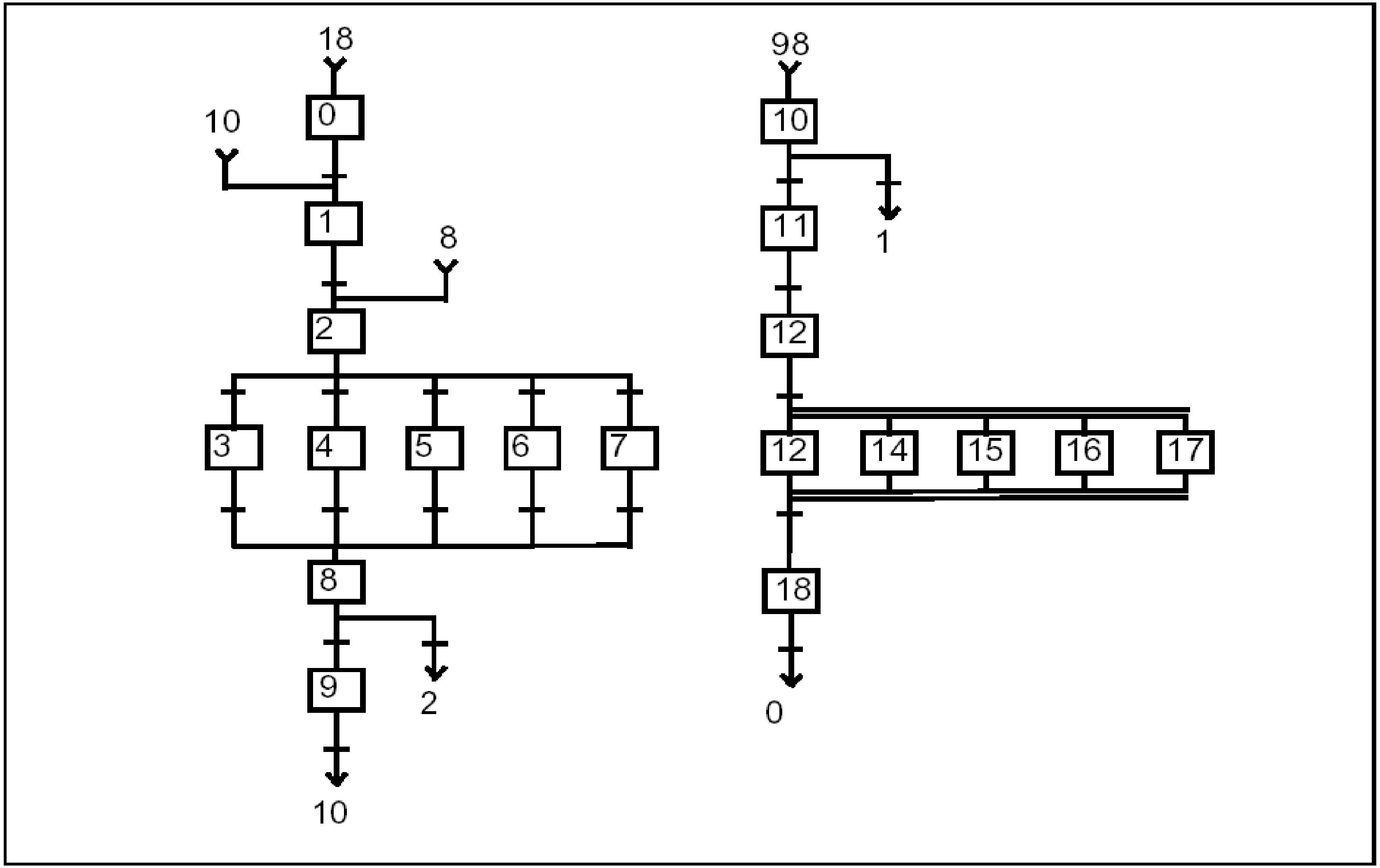


Characteristics:

- The number of steps downstream from a simultaneous activation (AND divergence) or upstream from a simultaneous deactivation (AND convergence) must not exceed 11.
- Simultaneous activation of steps must usually end with a simultaneous deactivation of steps.
- Simultaneous activation is always shown from left to right.
- Simultaneous deactivation is always shown from right to left.

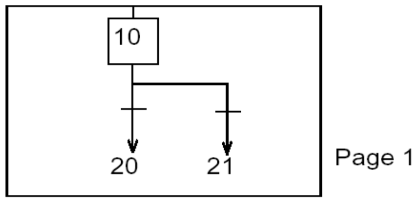
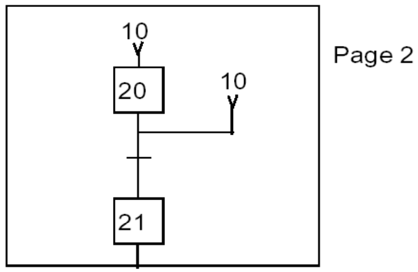
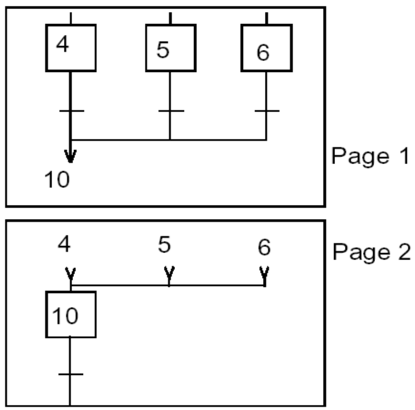
GRAFCET

Arcs/Connectors

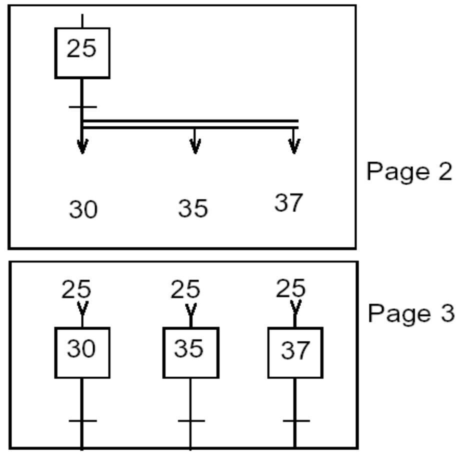
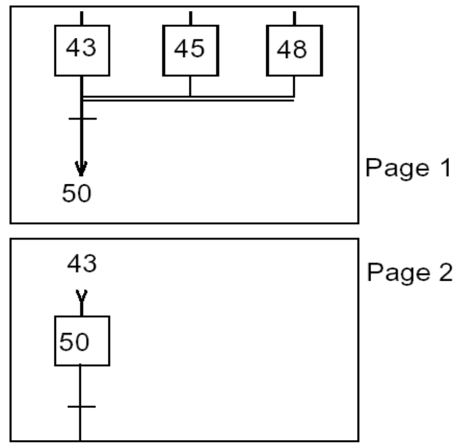


Rules for divergences and convergences:

OR

Rule	Illustration
For switching, transitions and destination connectors must be entered on the same page.	
To end switching, the source connectors must be entered on the same page as the destination step.	
For an end to switching followed by a return to destination, there must be as many source connectors as steps before the end of switching.	

AND

Rule	Illustration
To activate steps simultaneously, the destination connectors must be on the same page as the divergence step and transition.	
To deactivate simultaneously, the convergence steps and transition must be on the same page as the destination connector. When several steps converge onto one transition, the source connector has the number of the furthest upstream step on the left.	

GRAFCET

Programming Actions

The PL7 software allows three types of action:

- **actions for activation** : actions carried out once when the step with which they are associated passes from the inactive to the active state.
- **actions for deactivation** : actions carried out once when the step with which they are associated passes from the active to the inactive state.
- **continuous actions** : these actions are carried out for as long as the step with which they are associated is active.

Note: One action can include several programming elements (sequences or contact networks).

These actions are located in the following manner:

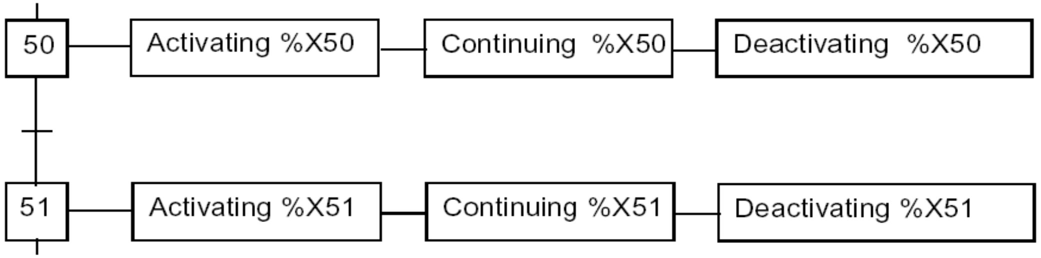
MAST - <Grafcet section name> - CHART (or MACROk)- PAGE n %Xi x
with
x = P1 for Activation, x = N1 Continuous, x = P0 Deactivation
n = Page number
i = Step number

Example: MAST - Paint - CHART - PAGE 0 %X1 P1 Action for activating step 1 of page 0 of the Paint section

GRAFCET

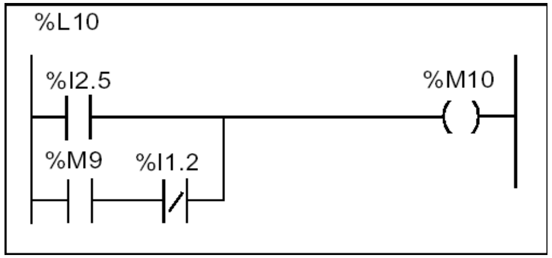
Programming Actions

Example of execution of Actions



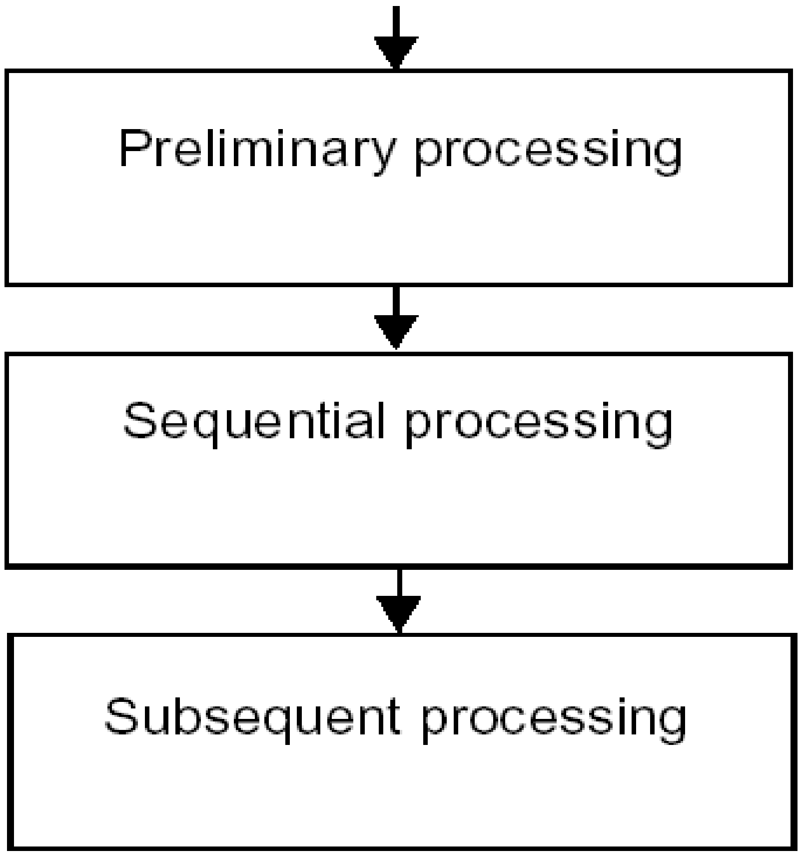
Example of Activation/deactivation

Example of continuous Action



GRAFCET

GRAFCET Section Sctructure



LD, IL, ST

GRAFCET

LD, IL, ST

GRAFCET

GRAFCET Section Initialization

Initializing the Grafcet is done by the system bit %S21.
Normally set at state 0, setting %S21 to 1 causes:

- active steps to deactivate,
- initial steps to activate.

The following table gives the different possibilities for setting to the system bit %S21 to 1 and 0.

Set to 1	Reset to 0
• By setting %S0 to 1 • By the user program • By the terminal (in debugging or animation table)	• By the system at the beginning of the process • By the user program • By the terminal (in debugging or animation table)

GRAFCET

GRAFCET Section Reset

The system bit %S22 resets Grafcet to 0.

Normally set at 0, setting %S22 to 1 causes active steps in the whole of the sequential process to deactivate.

Note: The RESET_XIT function used to reinitialize via the program the step activity time of all the steps of the sequential processing. (See (See Reference Manual, Volume 2)).

The following table gives the different possibilities for setting to the system bit %S22 to 1 and 0.

Set to 1	Reset to 0
• By the user program • By the terminal (in debugging or animation table)	• By the system at the end of the sequential process

Properties of Transition Sections (Unity Pro)

Transition sections have the following properties:

- Transition sections only have one single output (transition variable), whose data type is BOOL. The name of these variables are identical to the names of the transition sections.
- The transition variable can only be used once in written form.
- The transition variable can be read in any position within the project.
- Only functions can be used, function blocks or procedures cannot.
- Only one coil may be used in LD.
- There is only one network, i.e. all functions used are linked with each other either directly or indirectly.
- Transition sections can only be used once.
- Transition sections belong to the SFC section in which they were defined. If the respective SFC section is deleted then all transition sections of this SFC section are also deleted automatically.
- Transition sections can be called exclusively from transitions.