Logic control of electro-pneumatic systems

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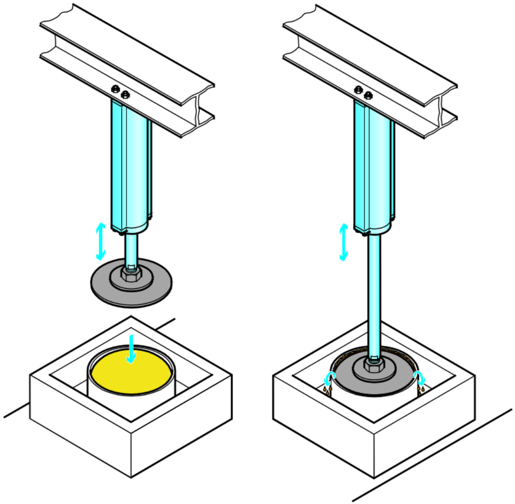
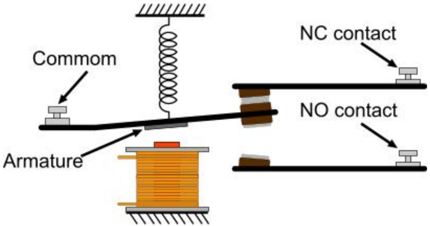
Cheese pressing example, sequence A+A-

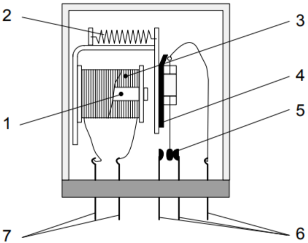


From FESTO Didactic

They Relay



From pcbheaven.com



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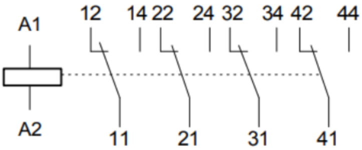

From FESTO didactic

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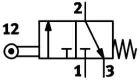
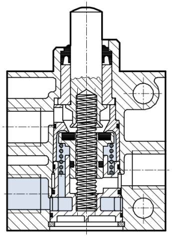
Other key components

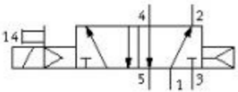
Sources: FESTO didactic, electroschematics.com, automation-insights.blog

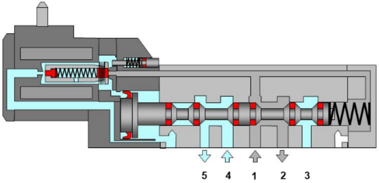
Limit switch



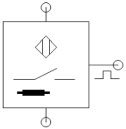


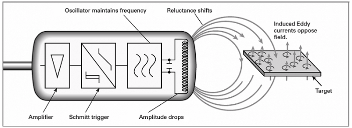
Solenoid valve

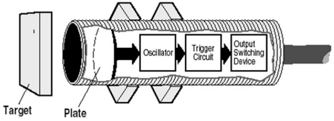




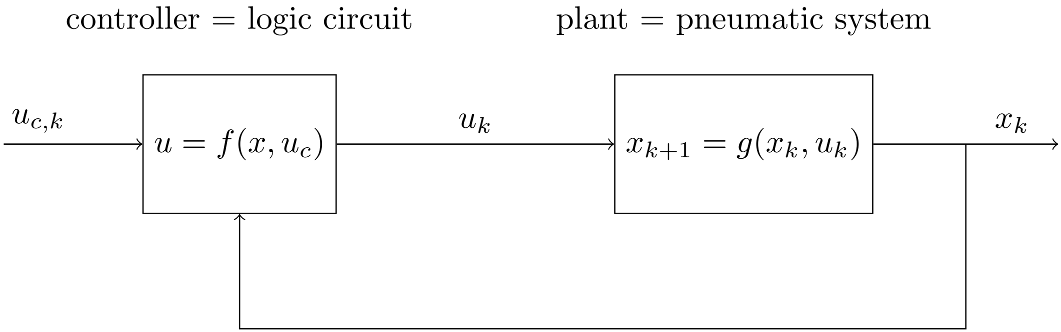
Proximity sensor







A logic control loop

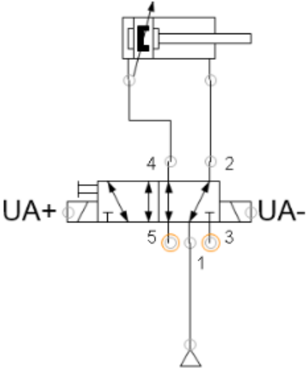


Cheese pressing example - Variables

Activating solenoid UA+ extends the cylinder, activating UA- retracts the cylinder.

State variable

$$x = \begin{cases} 0 & \text{Cylinder retracted} \\ 1 & \text{Cylinder extended} \end{cases}$$



Control signal

$$u = \begin{bmatrix} u_1 \\ u_2 \end{bmatrix},$$

with

$$u_1 = \begin{cases} 0 & \text{Don't activate UA+} \\ 1 & \text{Activate UA+} \end{cases}$$

$$u_2 = \begin{cases} 0 & \text{Don't activate UA-} \\ 1 & \text{Activate UA-} \end{cases}$$

Command signal

$$u_c = \begin{cases} 0 & \text{Button unpushed} \\ 1 & \text{Button pushed} \end{cases}.$$

Cheese pressing example - Plant dynamics and control law

Activating solenoid UA+ extends the cylinder, activating UA- retracts the cylinder.

Plant dynamics $x_{k+1} = g(x_k, u_k)$

		state	
$u_{1,k}$	$u_{2,k}$	x_k	x_{k+1}
0	0	0	0
0	1	0	0
1	0	0	1
(1)	(1)	(0)	(0)
0	0	1	1
0	1	1	0
1	0	1	1
(1)	(1)	(1)	(1)

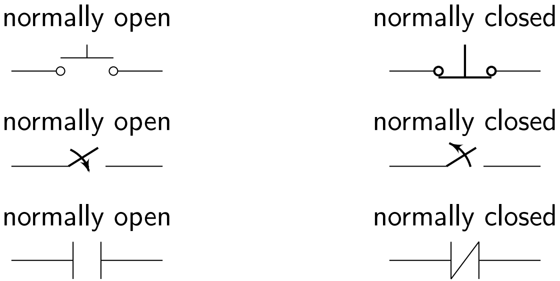
Control law $u_k = f(x, u_c)$

x	u_c	u_1	u_2
0	0	0	1
1	0	0	1
0	1	1	0
1	1	0	1

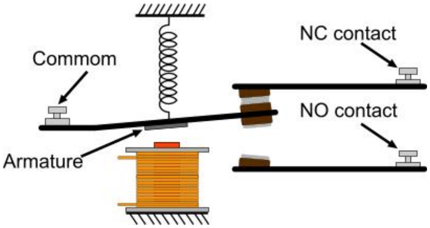
$$u_1 =$$

$$u_2 =$$

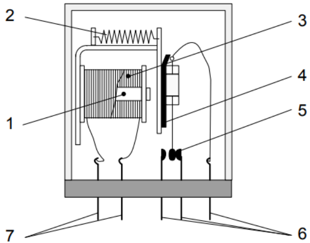
Cheese pressing example - implementing the control law



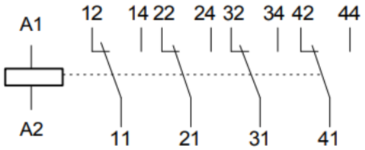
Intermezzo - An electrical circuit with memory



From pcbheaven.com



From FESTO didactic



From FESTO didactic

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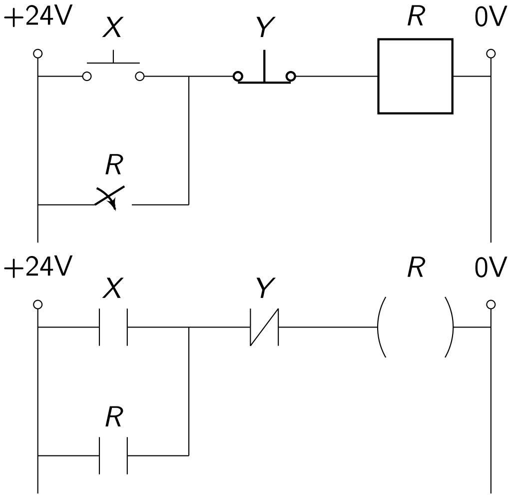
Intermezzo - An electrical circuit with memory

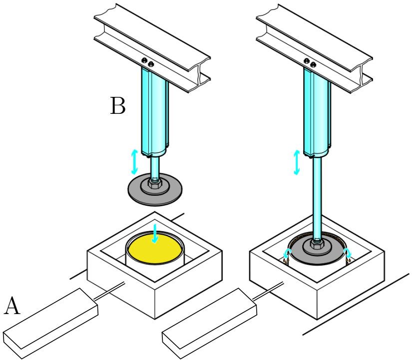
Latching circuit

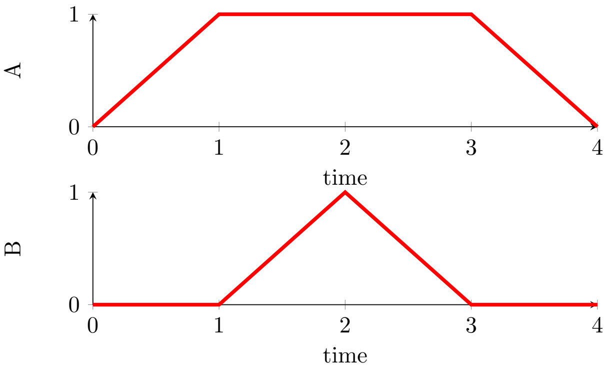


Truth table

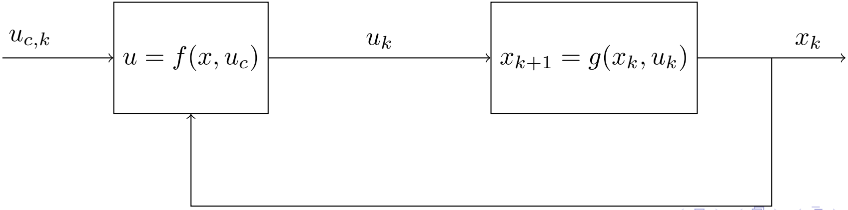
X	Y	R_k	R_{k+1}
0	0	0	
0	0	1	
0	1	0	
0	1	1	
1	0	0	
1	0	1	
1	1	0	
1	1	1	

The lab assignment

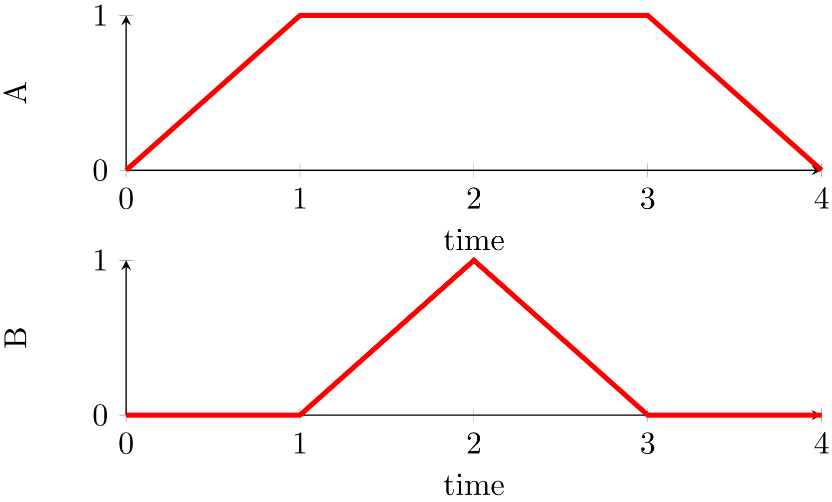




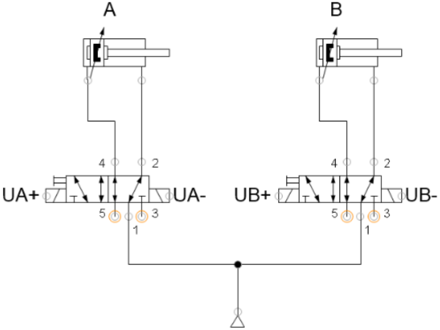
controller = logic circuit   plant = pneumatic system

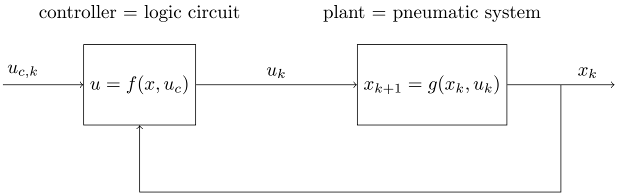


Implementing the sequence A+B+B-A-



Implementing the sequence A+B+B-A-, control signal





Control signal

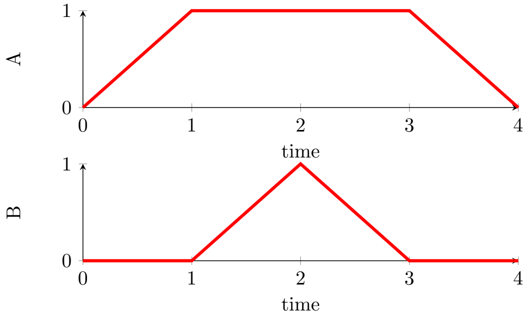
$$u = \begin{bmatrix} u_A+ & u_A- & u_B+ & u_B- \end{bmatrix}^T,$$

with

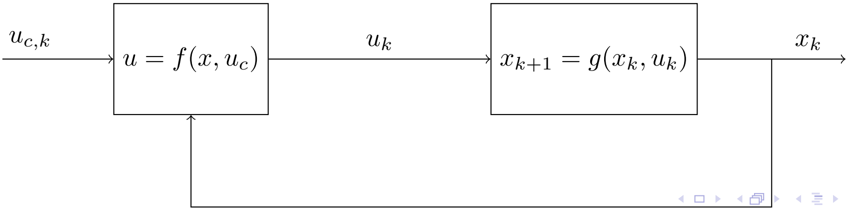
$$u_A+ = \begin{cases} 0 & \text{Solenoid extending A is not activated} \\ 1 & \text{Solenoid extending A is activated} \end{cases}, \qquad \text{and similar for B}$$

Implementing the sequence A+B+B-A-, the problem

The correct control signal (action) is not uniquely defined by the position of the cylinders



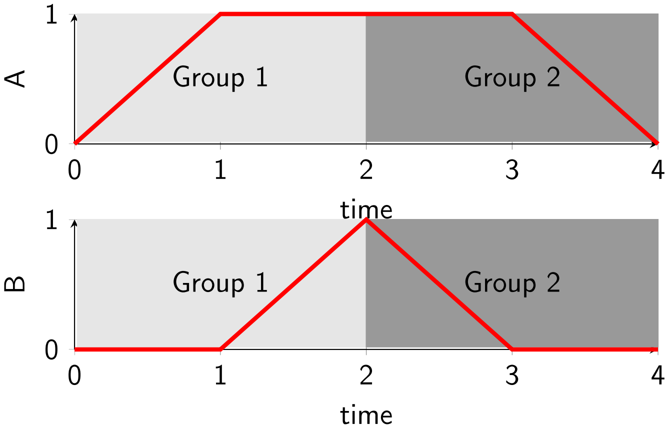
controller = logic circuit plant = pneumatic system



Implementing the sequence A+B+|B-A-

Dividing the sequence into groups (a.k.a. cascade method) Each group contains as many steps as possible without repeating a letter.

$$\underbrace{\text{A+B+}}_{\text{Group 1}} \mid \underbrace{\text{B-A-}}_{\text{Group 2}}$$

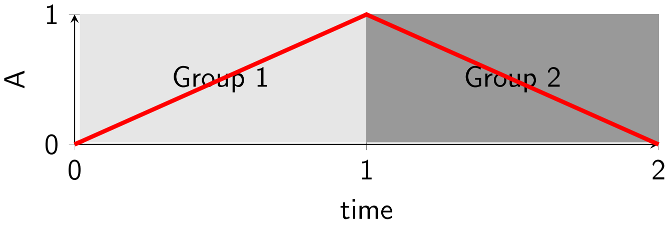


The cascade method applied to A+A-

The cascade method applied to A+A-

Divide the sequence is to groups, where each group is as long as possible without repeating the same letter.

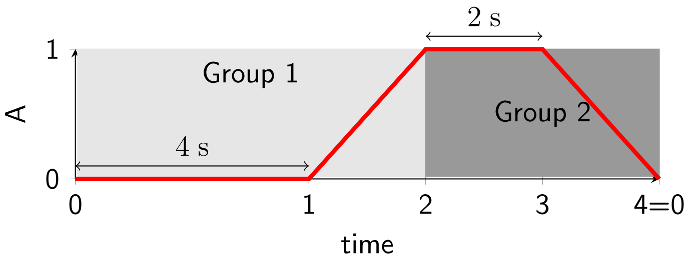
$$\underbrace{\text{A+}}_{\text{Group 1}} \mid \underbrace{\text{A-}}_{\text{Group 2}}$$



The cascade method applied to A+A- with delays

Let's add some delays. The process is cyclic and automatic. It takes 4 seconds to replace the mold under the press. The cheese needs to be pressed during 2 seconds before the cylinder retracts.

$$\underbrace{T_{4s}\,\text{A+}}_{\text{Group 1}} \mid \underbrace{T_{2s}\,\text{A-}}_{\text{Group 2}}$$



State variables

State variables

$$x = \begin{bmatrix} x_A & x_{G1} & x_{G2} & x_{T4} & x_{T2} \end{bmatrix}^T,$$

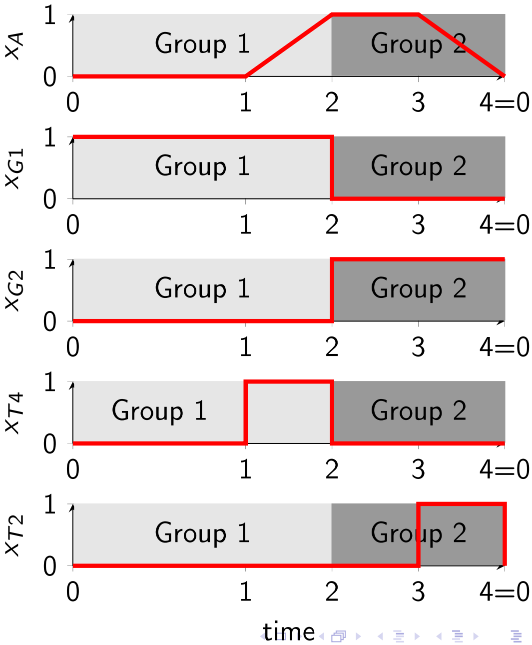
where

$$x_A = \begin{cases} 0 & \text{Cylinder A retracted} \\ 1 & \text{Cylinder A extended} \end{cases}$$

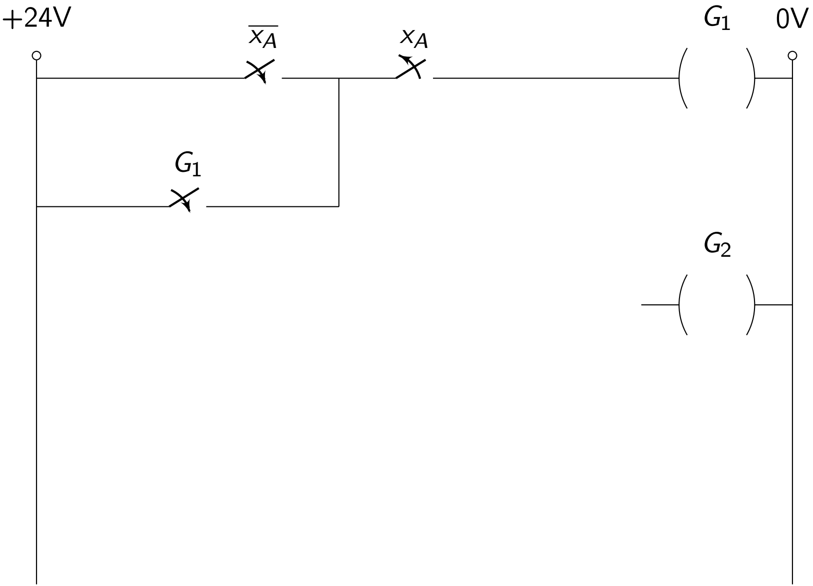
$$x_{Gi} = \begin{cases} 0 & \text{Group } i \text{ not active} \\ 1 & \text{Group } i \text{ active} \end{cases}$$

$$x_{Ti} = \begin{cases} 0 & \text{Timer of } i \text{ s not completed} \\ 1 & \text{Timer of } i \text{ s completed} \end{cases}$$

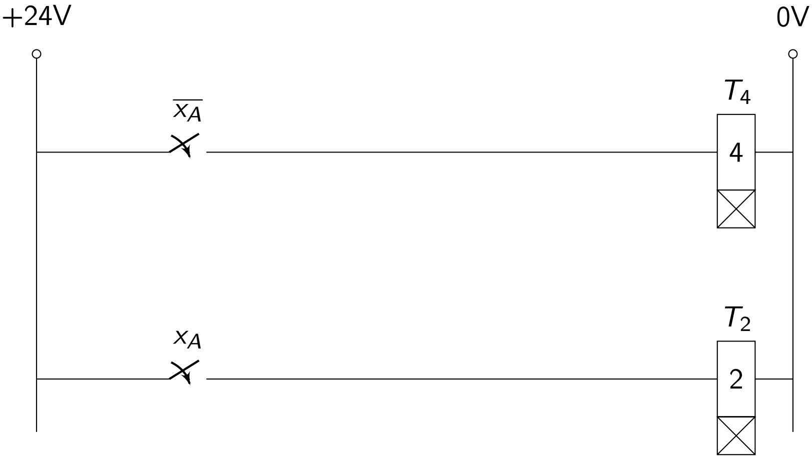
State transitions



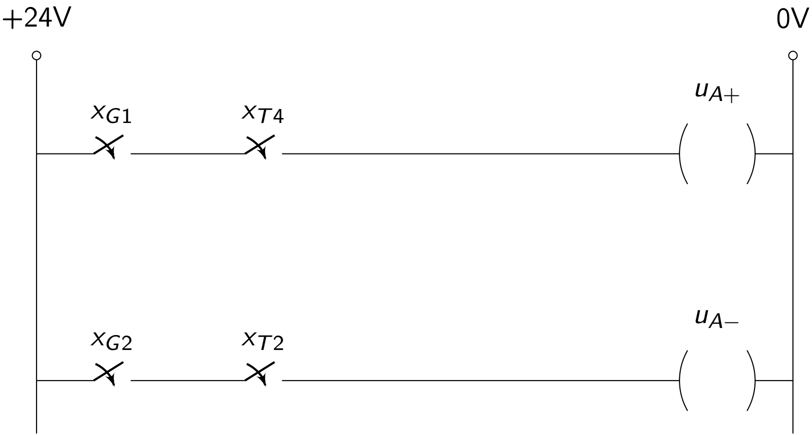
Group transitions



The timers



The control law



Implementing the sequence A+B+|B-A-, state variables

State variables

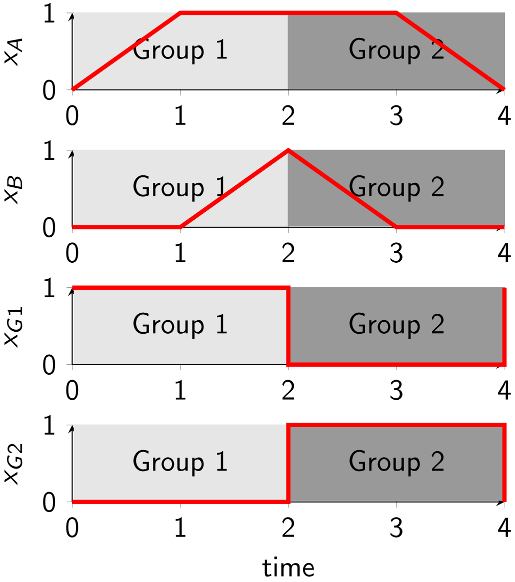
$$x = \begin{bmatrix} x_A & x_B & x_{G1} & x_{G2} \end{bmatrix}^T,$$

with

$$x_{\{A,B\}} = \begin{cases} 0 & \text{Cylinder \{A,B\} retracted} \\ 1 & \text{Cylinder \{A,B\} extended} \end{cases}$$

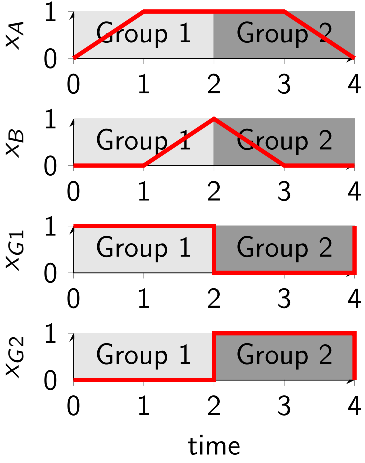
$$x_{Gi} = \begin{cases} 0 & \text{Group } i \text{ not active} \\ 1 & \text{Group } i \text{ active} \end{cases}$$

State transitions



Implementing the sequence A+B+|B-A-, control law

State transitions

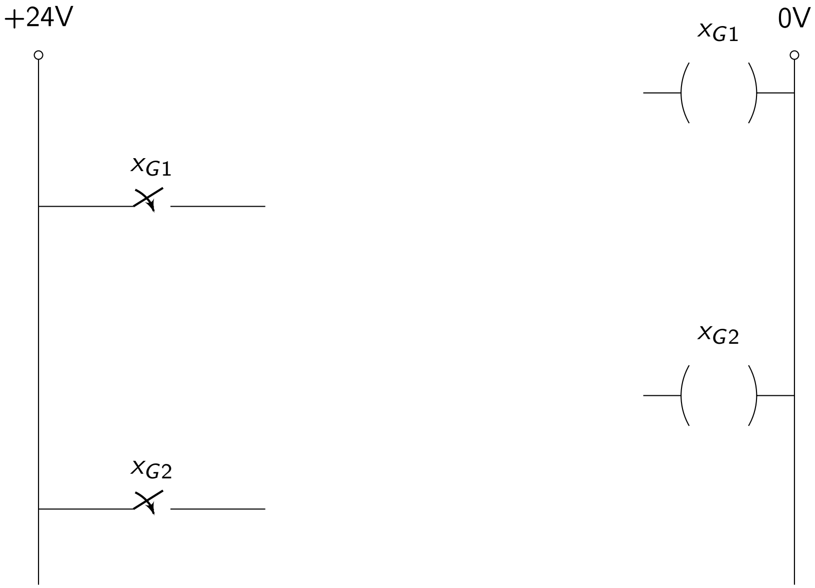


Control law

x_A	x_B	x_{G1}	x_{G2}	u_A+	u_A-	u_B+	u_B-
0	0	1	0				
1	0	1	0				
1	1	0	1				
1	0	0	1				

Implementing the control law

Implementing the group transitions



Implementing the proximity sensor circuit