

# **Industrial Automation**

**(Automação de Processos Industriais)**

## **PLC Programming languages**

***Structured Text***

<http://users.isr.ist.utl.pt/~jag/courses/api1213/api1213.html>

Slides 2010/2011 Prof. Paulo Jorge Oliveira  
Rev. 2011-2013 Prof. José Gaspar

# Syllabus:

**Chap. 2 – Introduction to PLCs [2 weeks]**

...

**Chap. 3 – PLC Programming languages [2 weeks]**

Standard languages (IEC-1131-3):

*Ladder Diagram; Instruction List, and **Structured Text**.*

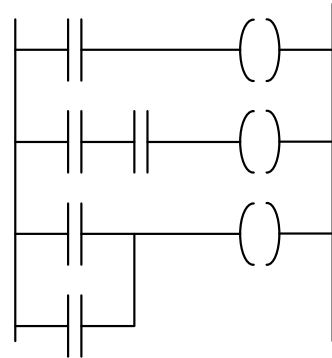
Software development resources.

...

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

# PLC Programming Languages (IEC 61131-3)

## *Ladder Diagram*



## *Structured Text*

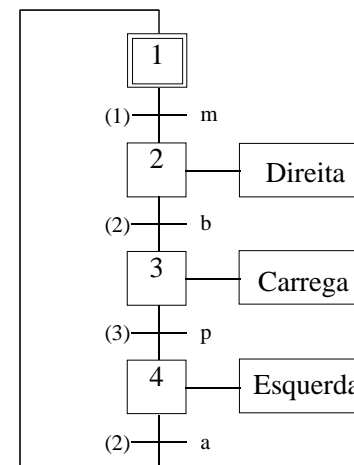
```

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)*



## Structured Text

```
(*  
Searching for the first element that is not zero in a  
table of 32 words (table = words %MW100 till %MW131).  
  
Input:  
%M0 works as an enable bit (run search iff %M0 is 1)  
%MW100 till %MW131 is the table to search  
  
Output:  
%M1 is set to 1/0 if the not zero element was/was-not found  
%MW10 is the non-zero value found  
%MW11 is the location of the non-zero value  
  
Auxiliary:  
%MW99 is the table index  
*)  
  
IF %M0 THEN  
  FOR %MW99:=0 TO 31 DO  
    IF %MW100[%MW99]<>0 THEN  
      %MW10:=%MW100[%MW99];  
      %MW11:=%MW99;  
      %M1:=TRUE;  
      EXIT; (* exit the loop *)  
    ELSE  
      %M1:=FALSE;  
    END_IF;  
  END_FOR;  
ELSE  
  %M1:=FALSE;  
END_IF;
```

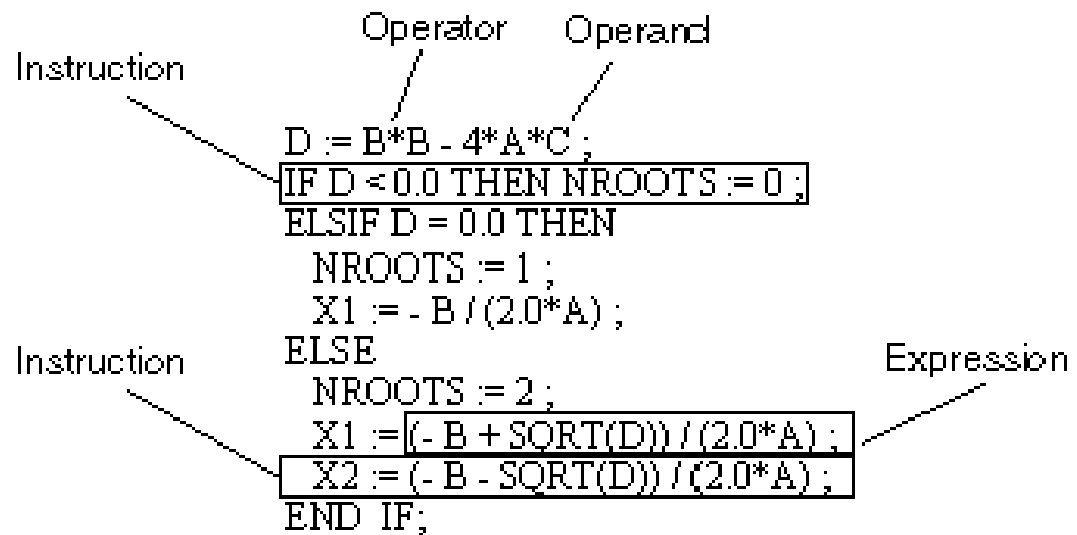
## Structured Text

**PLC Program = {Sections}, Section = {Sequences}**

One sequence is equivalent to one or more rungs in *ladder diagram*.

Each section can be programmed in Ladder, Instruction List, or **Structured Text**

Representation of  
an ST section:

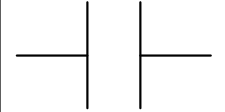
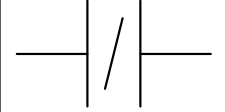
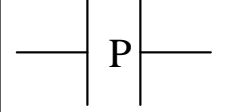
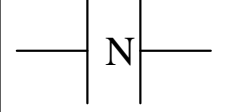


The **length of an instruction line** is limited to 300 characters. The **length of an ST section is not limited** within the programming environment. The length of an ST section is only limited by the size of the PLC memory.

# Structured Text

## Basic Instructions

### *Load*

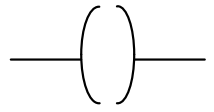
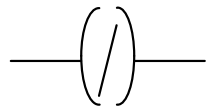
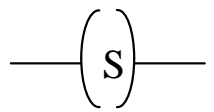
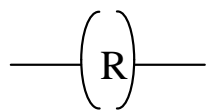
<b>:=</b>		Open contact: contact is active (result is 1) while the control bit is 1.
<b>:=NOT</b>		Close contact: contact is active (result is 1) while the control bit is 0.
<b>:=RE</b>		Contact in the rising edge: contact is active during a scan cycle where the control bit has a rising edge.
<b>:=FE</b>		Contact in the falling edge: contact is active during a scan cycle where the control bit has a falling edge.

Examples: `%M0 := %I0.2.0;`    `%M0 := NOT %I0.2.0;`    `%M0 := RE(%I0.2.0);`

## Structured Text

### Basic Instructions

#### *Store*

<b>:=</b>		The result of the logic function activates the coil.
<b>:=NOT</b>		The inverse result of the logic function activates the coil.
<b>SET</b>		The result of the logic function energizes the relay (sets the latch).
<b>RESET</b>		The result of the logic function de-energizes the relay (resets the latch)..

Examples: `%MW100 := 123 ; %Q0.4.0 := NOT %M1 ; %M0 := TRUE ; SET(%Q0.4.0) ;`

## Structured Text

### Basic Instructions

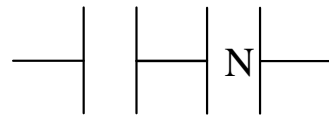
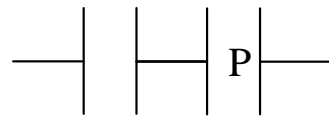
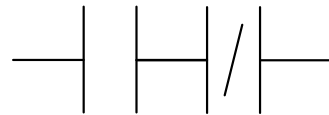
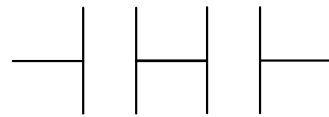
# AND

**AND**

**AND(NOT...)**

**AND(RE...)**

**AND(FE...)**



AND of the operand with the result of the previous logical operation.

AND of the operand with the inverted result of the previous logical operation.

AND of the rising edge with the result of the previous logical operation.

AND of the falling edge with the result of the previous logical operation.



## Structured Text

### Basic Instructions

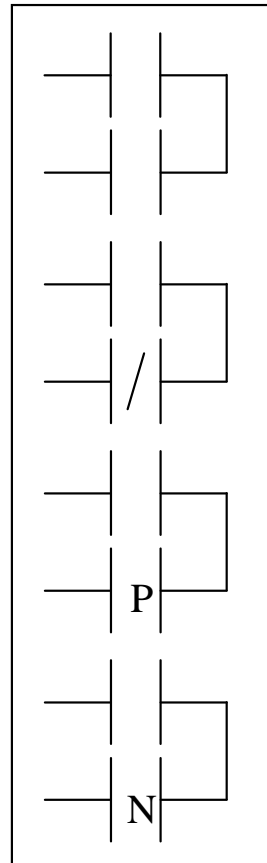
# OR

**OR**

**OR(NOT...)**

**OR(RE...)**

**OR(FE...)**



OR of the operand with the result of the previous logical operation.

OR of the operand with the inverted result of the previous logical operation.

OR of the rising edge with the result of the previous logical operation.

OR of the falling edge with the result of the previous logical operation.

## Structured Text

### Example:

```

%Q2.3 := %I1.1 OR %M1;
%Q2.2 := %M2 OR (NOT %I1.2);
%Q2.4 := %I1.3 OR (RE %I1.4);
%Q2.5 := %M3 OR (FE %I1.5);

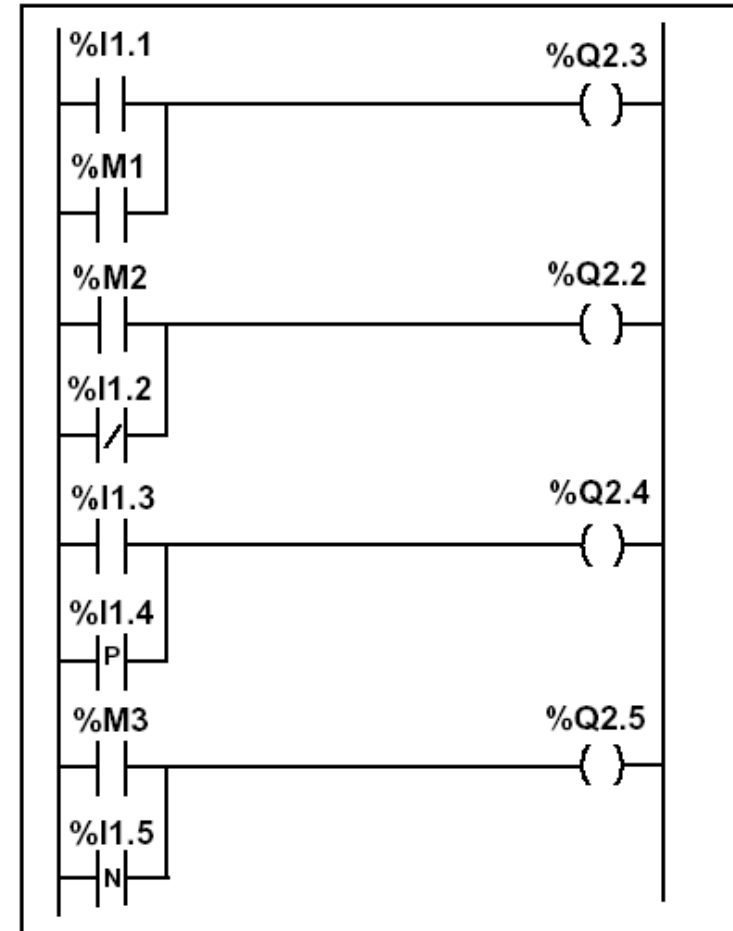
```

### Unity Pro (Premium PLC):

```

%Q0.4.3 := %I0.2.1 OR %M1;
%Q0.4.2 := %M2 OR (NOT %I0.2.2);
%Q0.4.4 := %I0.2.3 OR RE(%I0.2.4);
%Q0.4.5 := %M3 OR FE(%I0.2.5);

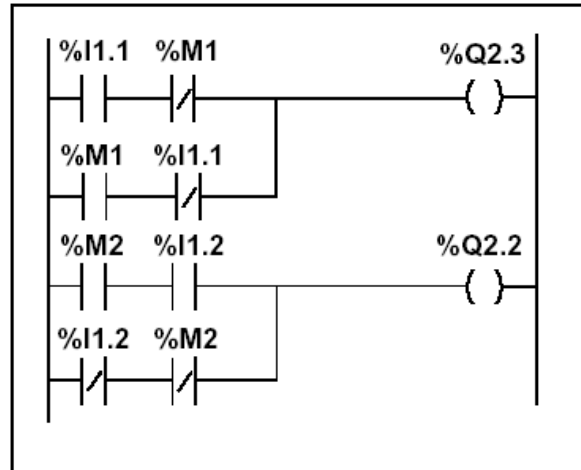
```



# Structured Text

## Basic Instructions

### XOR



```

%Q2.3 := %I1.1 XOR %M1;
%Q2.2 := %M2 XOR (NOT %I1.2);
%Q2.4 := %I1.3 XOR (RE %I1.4);
%Q2.5 := %M3 XOR (FE %I1.5);
    
```

### Unity Pro (Premium PLC):

```

%Q0.4.3 := %I0.2.1 XOR %M1;
%Q0.4.4 := %I0.2.3 XOR RE(%I0.2.4);
    
```

```

%Q0.4.2 := %M2 XOR (NOT %I0.2.2);
%Q0.4.5 := %M3 XOR FE(%I0.2.5);
    
```

Instruction list	Structured text	Description	Timing diagram
XOR	XOR	OR Exclusive between the operand and the previous instruction's Boolean result	
XORN	XOR (NOT...)	OR Exclusive between the operand inverse and the previous instruction's Boolean result	
XORR	XOR (RE...)	OR Exclusive between the operand's rising edge and the previous instruction's Boolean result	
XORF	XOR (FE...)	OR Exclusive between the operand's falling edge and the previous instruction's Boolean result.	

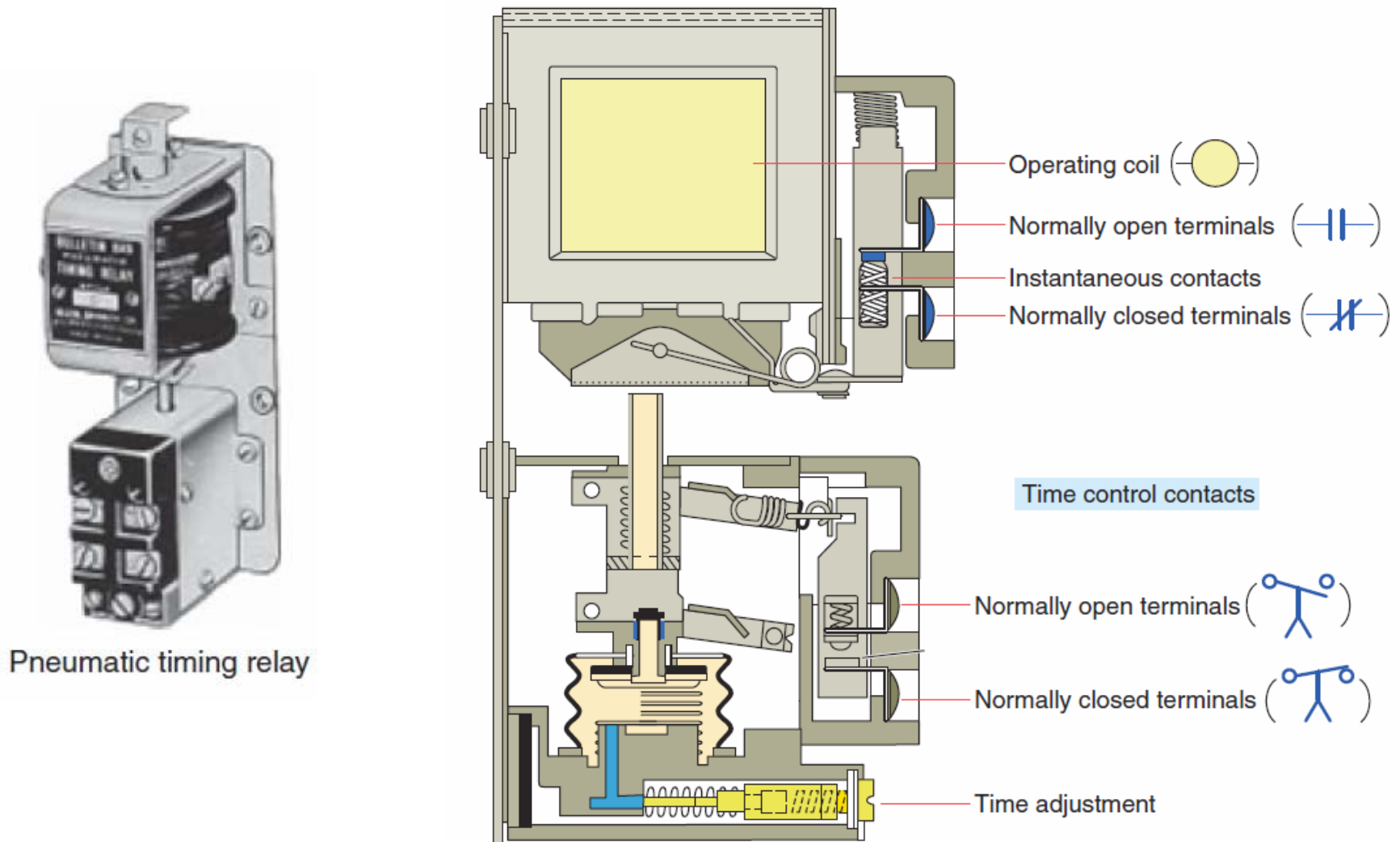
## Structured Text

### Basic Instructions to Manipulate Bit Tables

Designation	Function
Table:= Table	Assignment between two tables
Table:= Word	Assignment of a word to a table
Word:= Table	Assignment of a table to a word
Table:= Double word	Assignment of a double word to a table
Double word: = Table	Assignment of a table to a double word
COPY_BIT	Copy of a bits table in a bits table
AND_ARX	AND between two tables
OR_ARX	OR between two tables
XOR_ARX	exclusive OR between two tables
NOT_ARX	Negation in a table
BIT_W	Copy of a bits table in a word table
BIT_D	Copy of a bits table in a double word table
W_BIT	Copy of a word table in a bits table
D_BIT	Copy of a double word table in a bits table
LENGHT_ARX	Calculation of the length of a table by the number of elements

**Structured Text**

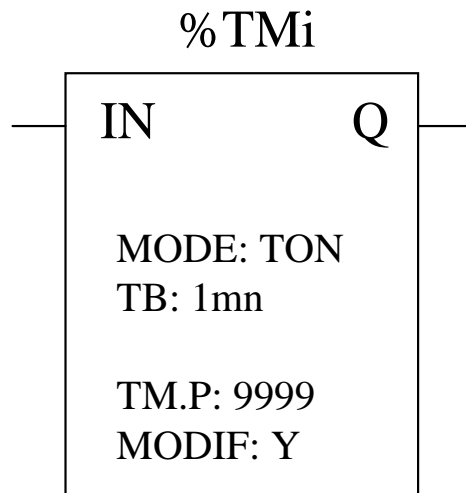
*Temporized Relays or Timers (pneumatic)*



The **instantaneous** contacts change state as soon as the timer coil is powered.  
 The **delayed** contacts change state at the end of the time delay.

# Structured Text

## *Temporized Relays or Timers*

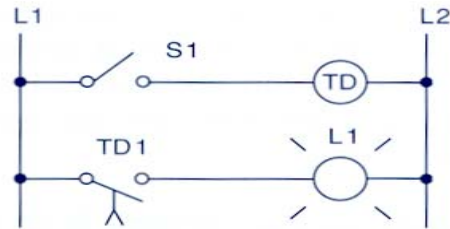


### Characteristics:

Identifier:	%Tmi	0..63 in the TSX37
Input:	IN	to activate
Mode:	<b>TON</b>	On delay
	<b>TOFF</b>	Off delay
	<b>TP</b>	Monostable
Time basis:	TB	1mn (def.), 1s, 100ms, 10ms
Programmed value:	%Tmi.P	0...9999 (def.) period=TB*Tmi.P
Actual value:	%Tmi.V	0...Tmi.P (can be real or tested)
Modifiable:	Y/N	can be modified from the console

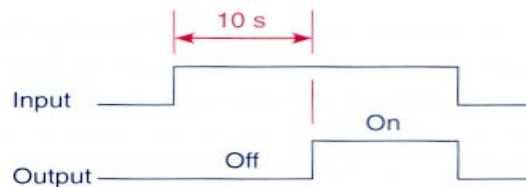
# Structured Text

## Example:



Sequence of operation:  
 S1 open, TD de-energized, TD1 open, L1 off.  
 S1 closes, TD energizes, timing period starts, TD1 is still open, L1 is still off.  
 After 10 s, TD1 closes, L1 is switched on.  
 S1 is opened, TD de-energizes, TD1 opens instantly, L1 is switched off.

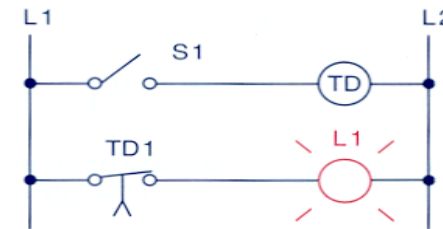
(a)



(b)

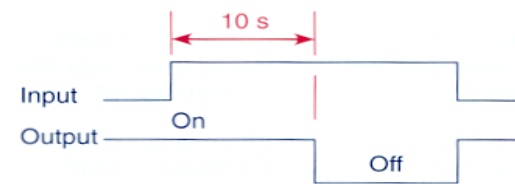
**Fig. 7-3**

On-delay timer circuit (NOTC contact). (a) Operation. (b) Timing diagram.



Sequence of operation:  
 S1 open, TD de-energized, TD1 closed, L1 on.  
 S1 closes, TD energizes, timing period starts, TD1 is still closed, L1 is still on.  
 After 10 s, TD1 opens, L1 is switched off.  
 S1 is opened, TD de-energizes, TD1 closes instantly, L1 is switched on.

(a)



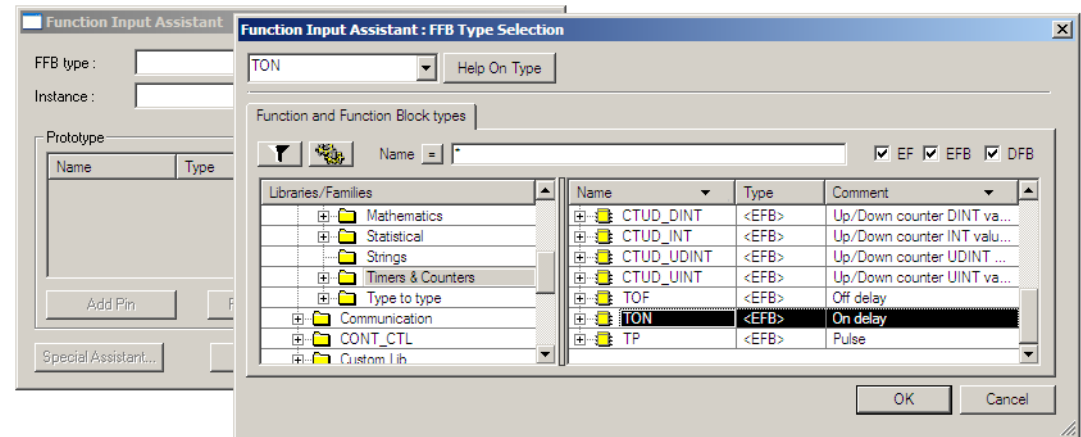
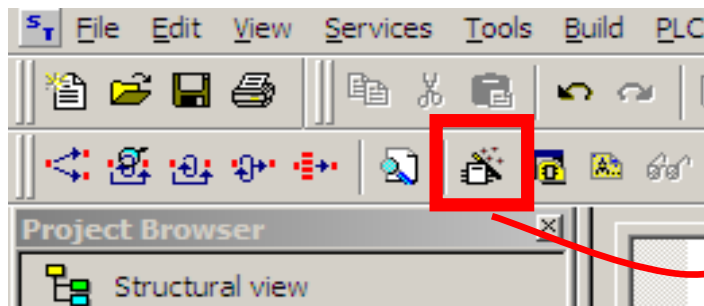
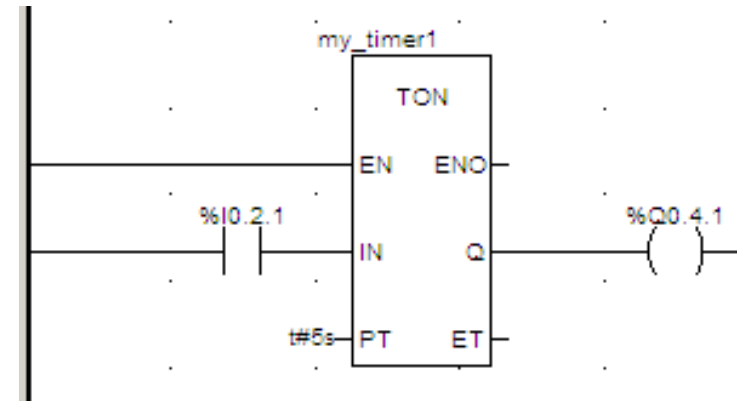
(b)

**Fig. 7-4**

On-delay timer circuit (NCTO contact). (a) Operation. (b) Timing diagram.

# Structured Text

## *Temporized Relays or Timers*



```
my_timer1 (IN := %I0.2.1 (*BOOL*),  
          PT := t#5s (*TIME*),  
          Q => %Q0.4.1 (*BOOL*),  
          ET => my_var (*TIME*));
```

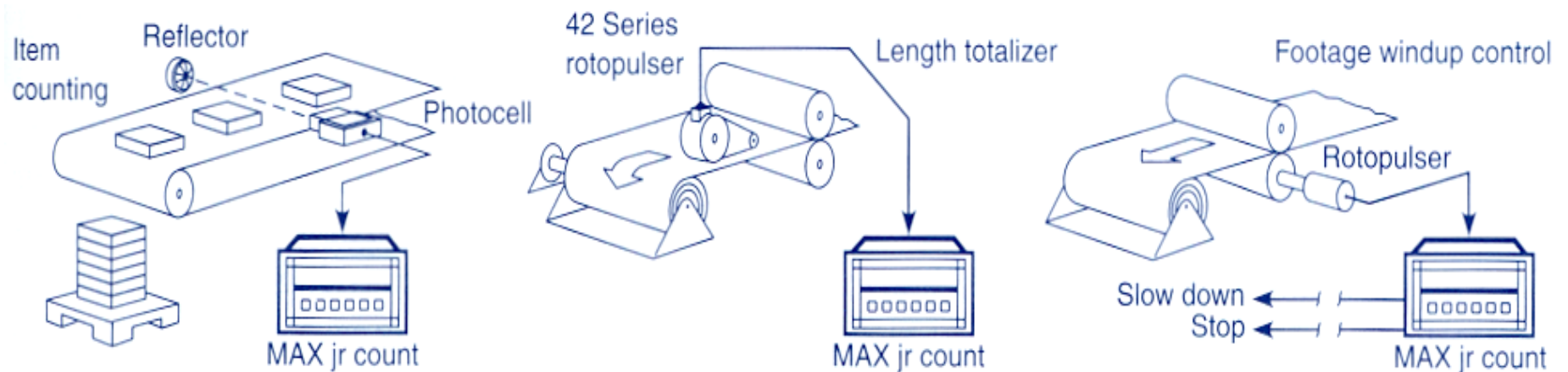
Very similar to IL, notice however the missing CAL and the required “;”.



# Structured Text

## Counters

Some applications...

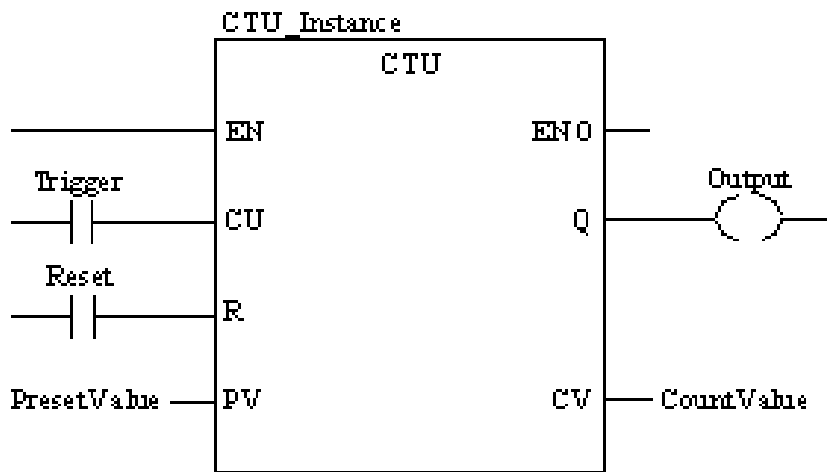


**Fig. 8-3**

Counter applications. (Courtesy of Dynapar Corporation, Gurnee, Illinois.)

# Structured Text

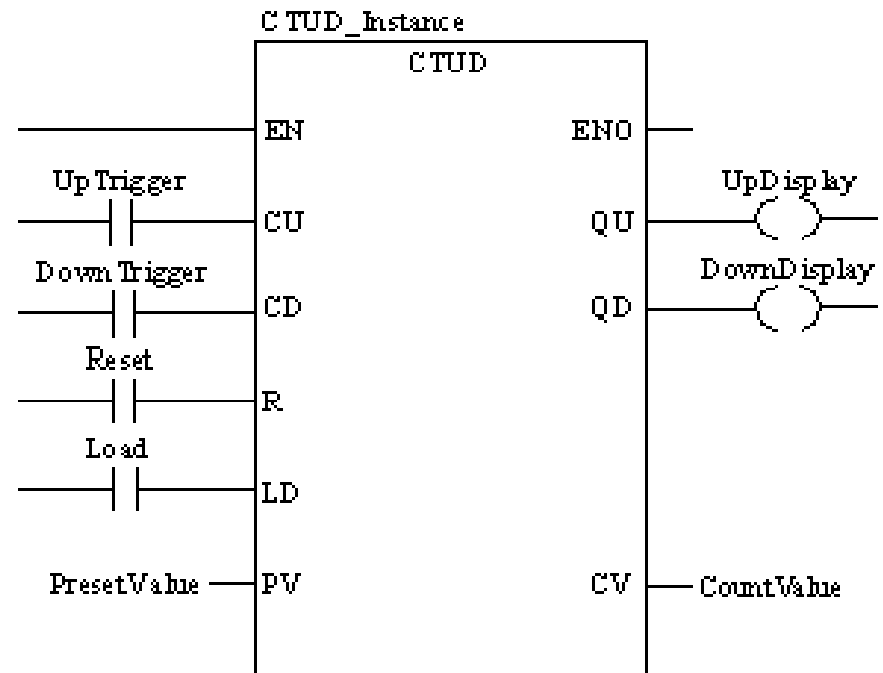
## Counters in Unity Pro



**CU "0" to "1"** => CV is incremented by 1

**CV ≥ PV** => Q:=1

**R=1** => CV:=0



**CU "0" to "1"** => CV is incremented by 1

**CD "0" to "1"** => CV is decremented by 1

**CV ≥ PV** => QU:=1

**CV ≤ 0** => QD:=1

**R=1** => CV:=0    **LD=1** => CV:=PV

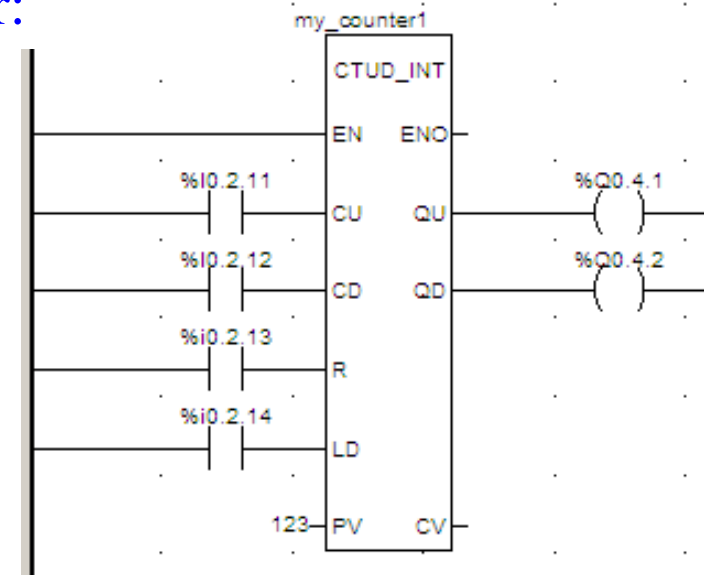
R has precedence over LD

*NOTE: counters are saturated such that no overflow occurs*

# Structured Text

## Counters in Unity Pro

Ladder:



Instruction List:

```

CAL my_counter1 (CU := %I0.2.11 (*BOOL*),
                CD := %I0.2.12 (*BOOL*),
                R  := %I0.2.13 (*BOOL*),
                LD := %I0.2.14 (*BOOL*),
                PV := 123 (*INT*),
                QU => %Q0.4.1 (*BOOL*),
                QD => %Q0.4.2 (*BOOL*),
                CV => %MW100 (*INT*));
    
```

Structured Text:

```

my_counter1 (CU := %I0.2.11 (*BOOL*),
            CD := %I0.2.12 (*BOOL*),
            R  := %I0.2.13 (*BOOL*),
            LD := %I0.2.14 (*BOOL*),
            PV := 123 (*INT*),
            QU => %Q0.4.1 (*BOOL*),
            QD => %Q0.4.2 (*BOOL*),
            CV => %MW100 (*INT*));
    
```

Again IL and ST are similar, notice however the missing CAL and the required “;”.

## Structured Text

### *Numerical Processing*

#### Algebraic and Logic Functions

```
%Q2.2 := %MW50 > 10;  
IF %I1.0 THEN  
    %MW10 := %KW0 + 10;  
END_IF;  
IF FE (%I1.2) THEN  
    INC (%MW100);  
END_IF;
```

## Structured Text

### *Numerical Processing*

#### Arithmetic Functions for Words

<b>+</b>	addition of two operands	<b>SQRT</b>	square root of an operand
<b>-</b>	subtraction of two operands	<b>INC</b>	incrementation of an operand
<b>*</b>	multiplication of two operands	<b>DEC</b>	decrementation of an operand
<b>/</b>	division of two operands	<b>ABS</b>	absolute value of an operand
<b>REM</b>	remainder from the division of 2 operands		

#### Operands

Type	Operand 1 (Op1)	Operand 2 (Op2)
Indexable words	%MW	%MW,%KW,%Xi.T
Non-indexable words	%QW,%SW,%NW,%BLK	Imm.Val.,%IW,%QW,%SW,%NW,%BLK, Num.expr.
Indexable double words	%MD	%MD,%KD
Non-indexable double words	%QD,%SD	Imm.Val.,%ID,%QD,%SD, Numeric expr.

## Structured Text

### *Numerical Processing*

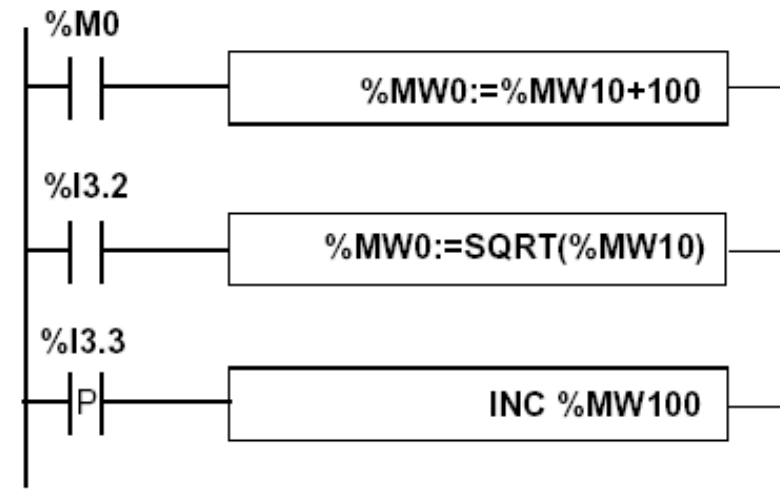
#### Example:

Arithmetic functions

```
IF %M0 THEN
    %MW0 := %MW10 + 100;
END_IF;

IF %I3.2 THEN
    %MW0 := Sqrt(%MW10);
END_IF;

IF RE(%I3.3) THEN
    INC(%MW100);
END_IF;
```



## Structured Text

### *Numerical Processing*

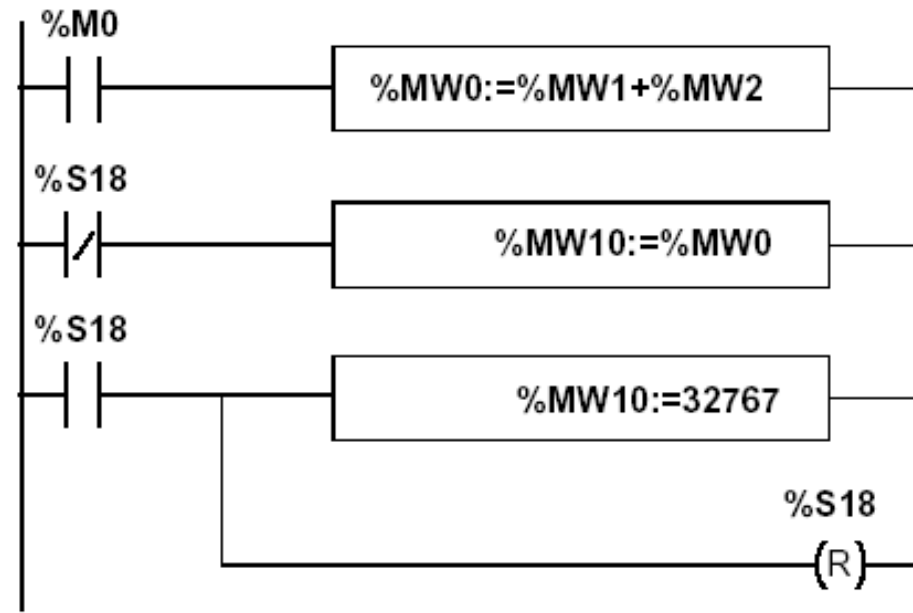
#### Example:

#### Arithmetic functions

```
IF %M0 THEN
  %MW0 := %MW1 + %MW2;
END_IF;

IF %S18 THEN
  %MW10 := 32767; RESET %S18;
ELSE
  %MW10 := %MW0;
END_IF;
```

Use of a system variable:  
%S18 – flag de overflow



## Structured Text

### Numerical Processing

#### Logic Functions

<b>AND</b>	AND (bit by bit) between two operands
<b>OR</b>	logical OR (bit by bit) between two operands
<b>XOR</b>	exclusive OR (bit by bit) between two operands
<b>NOT</b>	logical complement (bit by bit) of an operand

---

Comparison instructions are used to compare two operands.

- >: tests whether operand 1 is greater than operand 2,
  - >=: tests whether operand 1 is greater than or equal to operand 2,
  - <: tests whether operand 1 is less than operand 2,
  - <=: tests whether operand 1 is less than or equal to operand 2,
  - =: tests whether operand 1 is different from operand 2.
- 

#### Operands

Type	Operands 1 and 2 (Op1 and Op2)
Indexable words	%MW,%KW,%Xi.T
Non-indexable words	Imm.val.,%IW,%QW,%SW,%NW,%BLK, Numeric Expr.
Indexable double words	%MD,%KD
Non-indexable double words	Imm.val.,%ID,%QD,%SD,Numeric expr.

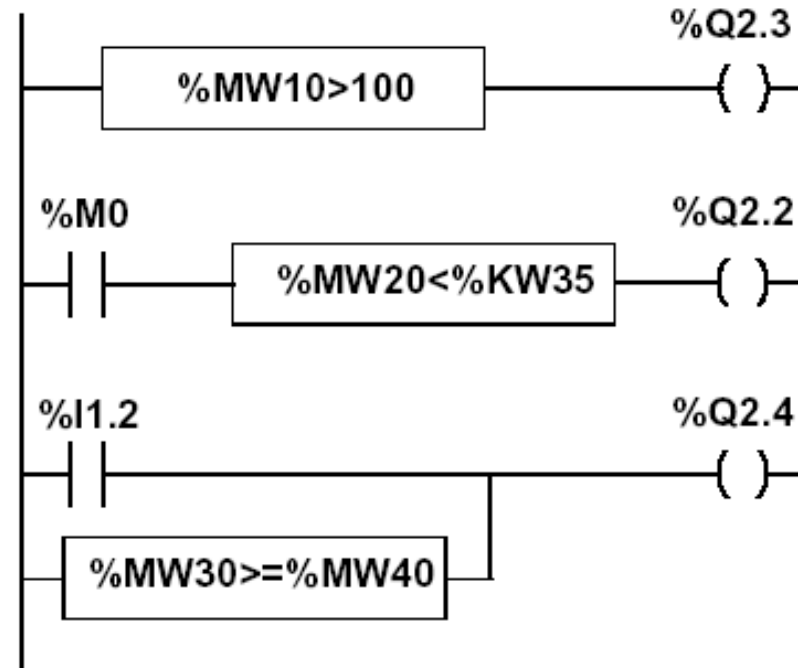


## Structured Text

### Numerical Processing

#### Example:

Logic functions



### Structured text language

```
%Q2.3 := %MW10 > 100 ;
```

```
%Q2.2 := %M0 AND (%MW20 < %KW35) ;
```

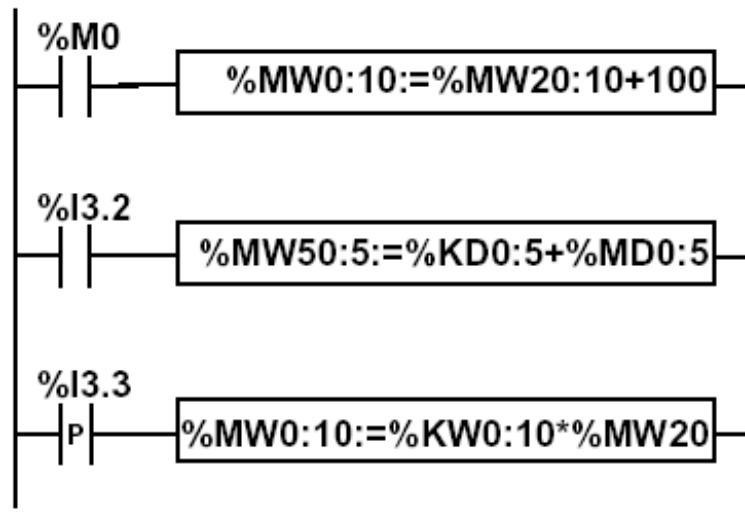
```
%Q2.4 := %I1.2 OR (%MW30 >= %MW40) ;
```

# Structured Text

## Numerical Processing

### Example:

#### Numeric Tables Manipulation



#### Structured text language

```
IF RE %I3.3 THEN  
  %MW0:10:=%KW0:10*%MW20;  
END_IF;
```

## Structured Text

### Numerical Processing

#### Priorities on the execution of the operations

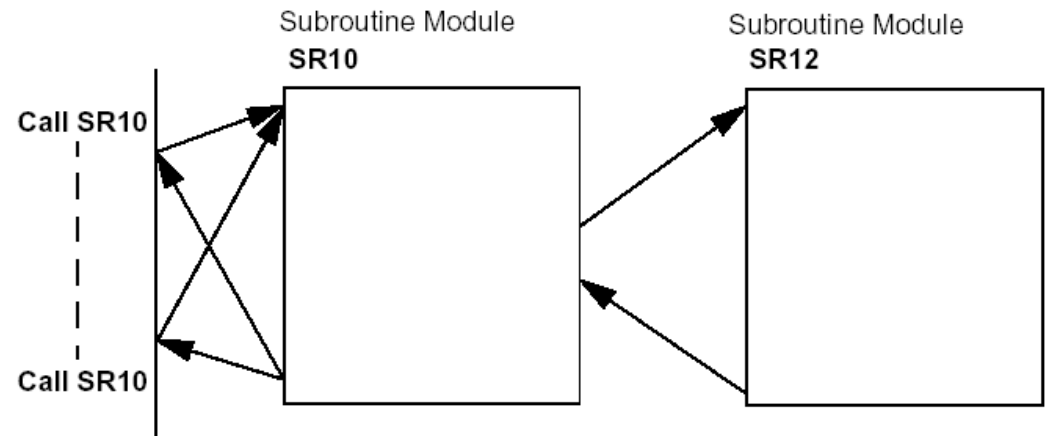
Rank	Instruction
1	Instruction to an operand
2	*,/,REM
3	+,-
4	<,>,<=,>=
5	=,<>
6	AND
7	XOR
8	OR

# Structured Text

Structures for Control of Flux

Subroutines

Call and Return



## Structured text language

```
IF %M8 THEN
    RETURN;
END_IF;
```

## Structured text language

```
IF (%M5 > 3) THEN
    RETURN;
END_IF;
IF %M8 THEN
    %MD26 := %MW4 * %KD6;
END_IF;
```

Not executed if %M5  
is larger than 3

## Structured Text

### Structures for Control of Flux

#### JUMP instructions:

##### Instruction List - conditional and unconditional jumps

Jump instructions are used to go to a programming line with an %Li label address:

- **JMP**: unconditional program jump
- **JMPC**: program jump if the instruction's Boolean result from the previous test is set at 1
- **JMPCN**: program jump if the instruction's Boolean result from the previous test is set at 0. %Li is the label of the line to which the jump has been made (address i from 1 to 999 with maximum 256 labels)

**Structured Text – just unconditional jumps** as the  
IF .. THEN .. ELSE provides the conditional clauses.

Note: by default, **jumps are disabled** in Structured Text  
(if needed, enable them in the menu Tools -> Project Settings)

# Structured Text

## Structures for Control of Flux

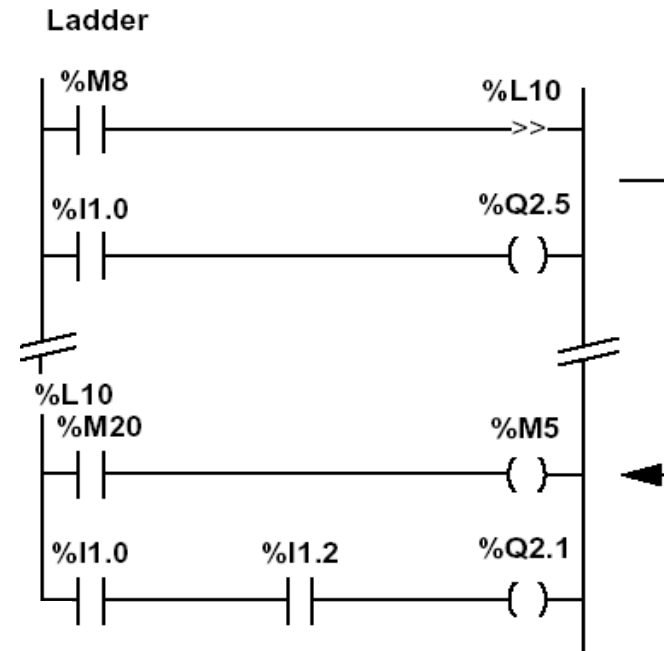
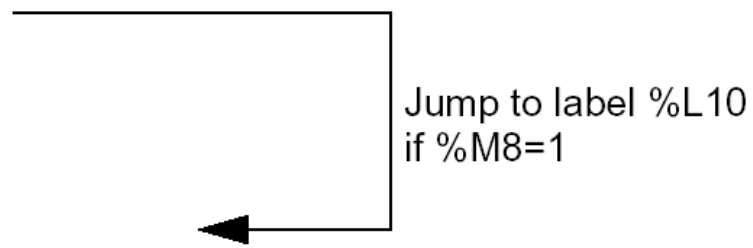
### Example:

Use of jump instructions

```

IF %M8 THEN
    JUMP %L10;
END_IF;
%Q2.5 := %I1.0;

-----
%L10:
    %M5 := %M20;
    %Q2.1 := %I1.0 AND %I1.2;
    
```



### Unity Pro:

```

IF %M8 THEN
    JMP my_label_L10;
END_IF;
%Q0.4.5 := %I0.2.0;

(* other code ... *)

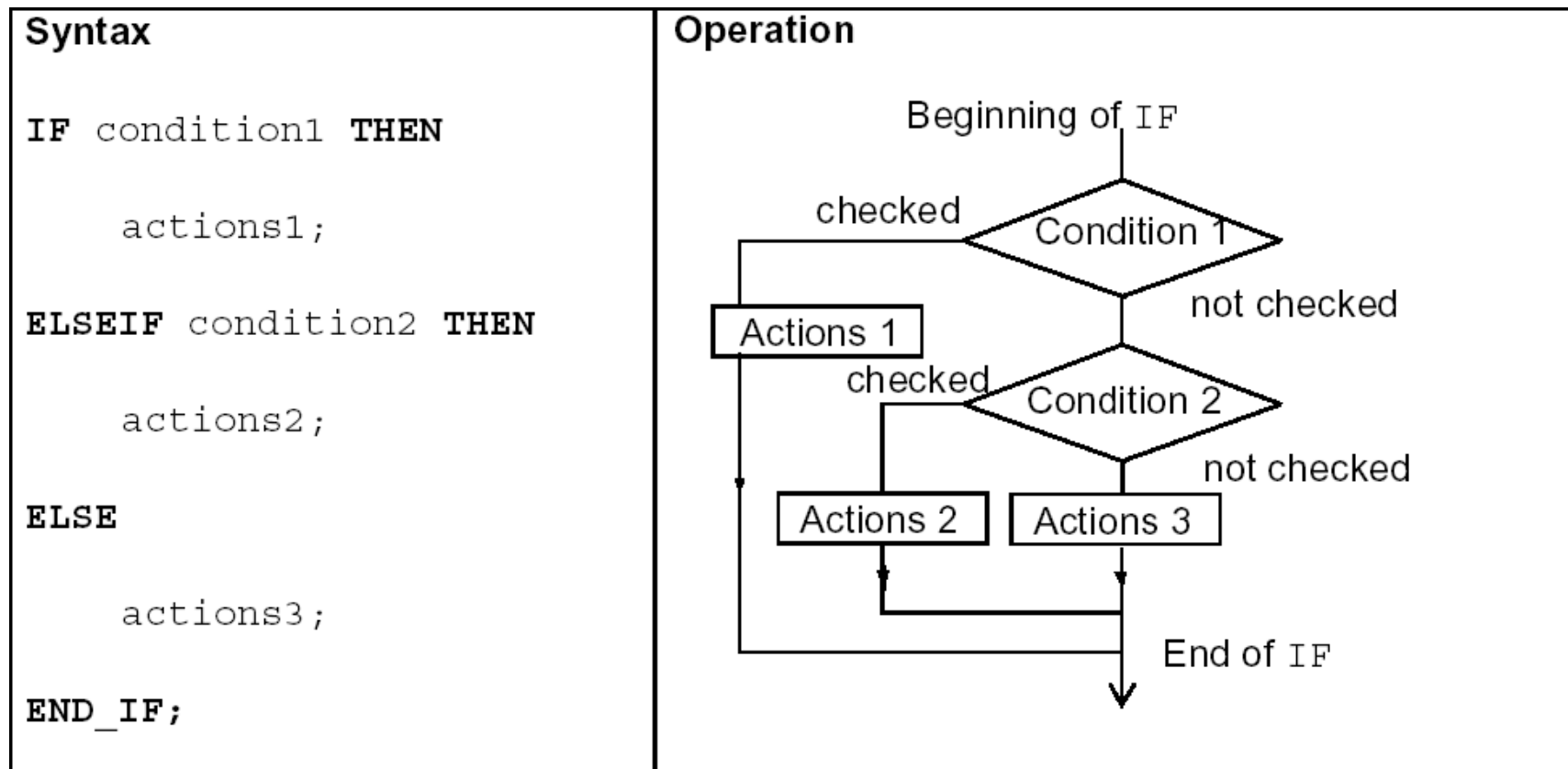
my_label_L10:
%M5 := %M20;
    
```

*Notes: It is not a good style of programming. Does not improve the legibility of the proposed solution. Attention to INFINITE LOOPS.*

## Structured Text

### Structures for Control of Flux

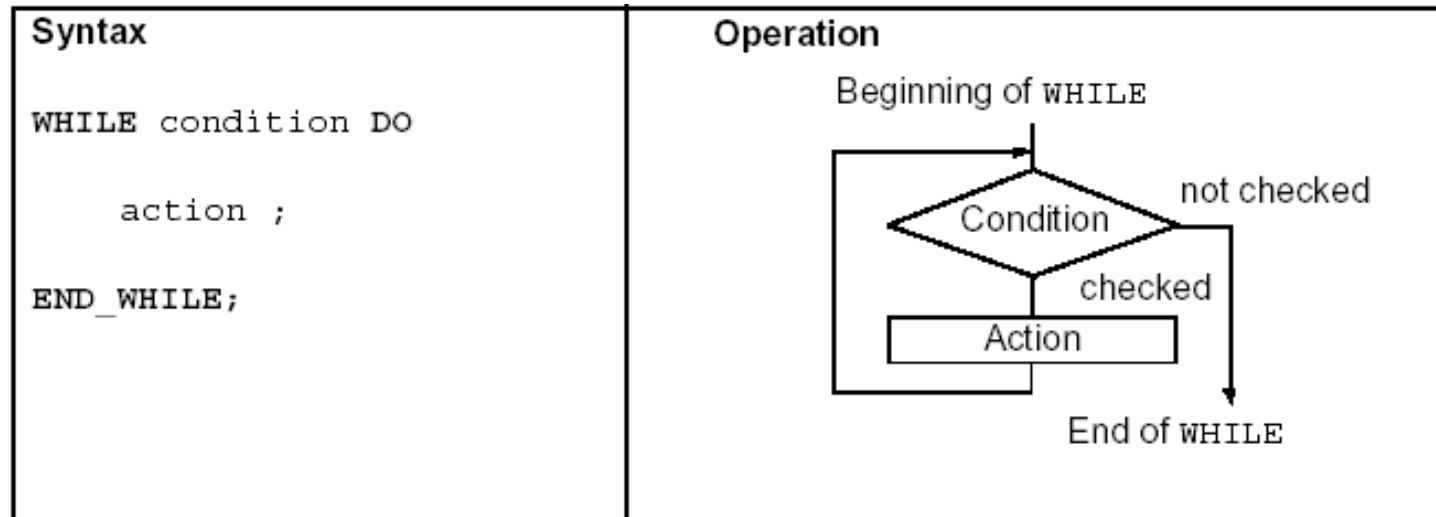
#### IF ... THEN ... ELSE ...



## Structured Text

### Structures for Control of Flux

#### WHILE



Example:

```
(*WHILE conditional repeated action*)  
WHILE %MW4<12 DO  
    INC(%MW4);  
    SET(%M25 [%MW4]);  
END_WHILE;
```



## Structured Text

### Structures for Control of Flux

**REPEAT ... UNTIL**

**FOR ... DO**

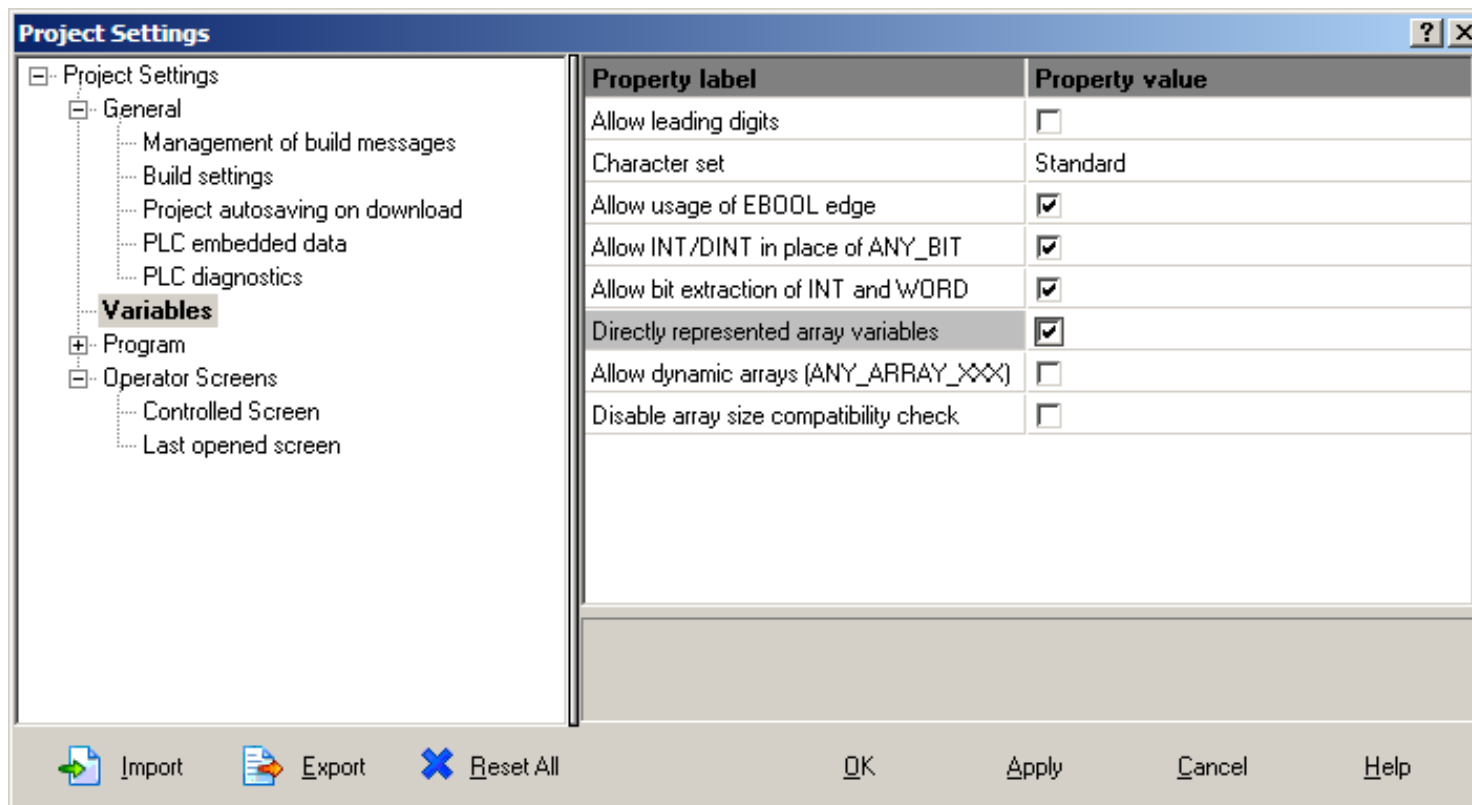
**EXIT** to abort the execution of a structured flux control instruction

Example:

```
(* using EXIT to break a loop *)
WHILE %MW1<124 DO
  %MW2 := 0;
  %MW3 := %MW100[%MW1];
  REPEAT
    %MW500[%MW2] := %MW3 + %MW500[%MW2];
    IF (%MW500[%MW2] > 32700) THEN
      EXIT;
    END_IF;
    INC(%MW2);
  UNTIL %MW2>25 END_REPEAT;
  INC(%MW1);
END_WHILE;
```

# Structured Text

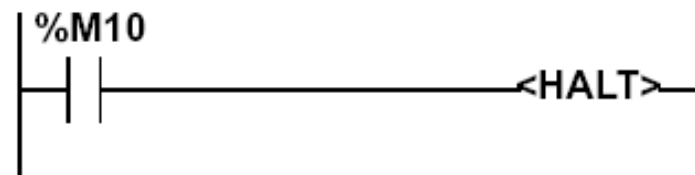
*Note: in Unity Pro, both in Structured Text and Instruction List, the conventional array indexing (e.g. %MW100[%MW1]) is **disabled by default**. To enable it, go to the project settings, menu Tools -> Project Settings. See the grayed region in the next figure:*



## Structured Text

### Structures for Control of Flux

#### Halt

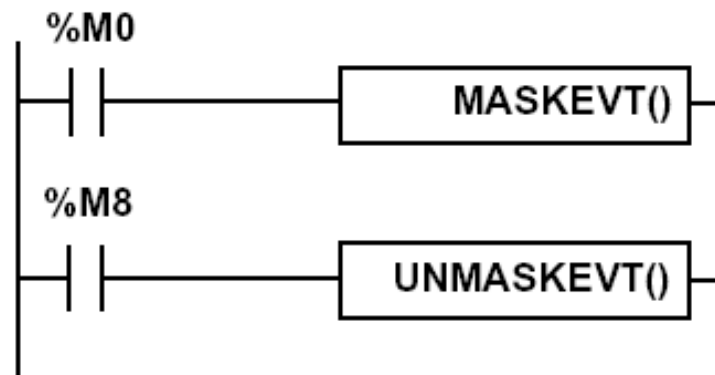


Stops all processes!

#### Structured text language

```
IF %M10 THEN  
    HALT;  
END_IF;
```

#### Events masking



#### Structured text language

```
IF %M0 THEN  
    MASKEVT ();  
END_IF;  
IF %M8 THEN  
    UNMASKEVT ();  
END_IF;
```

## Structured Text

### Data and time related instructions

Name	Function
SCHEDULE	Time function
RRTC	Reading system date
WRTC	Updating system date
PTC	Reading date and stop code
ADD_TOD	Adding a duration to a time of day
ADD_DT	Adding a duration to a date and time
DELTA_TOD	Measuring the gap between times of day
DELTA_D	Measuring the gap between dates (without time).
DELTA_DT	Measuring the gap between dates (with time).
SUB_TOD	Totaling the time to date
SUB_DT	Totaling the time to date and time
DAY_OF_WEEK	Reading the current day of the week
TRANS_TIME	Converting duration into date
DATE_TO_STRING	Converting a date to a character string
TOD_TO_STRING	Converting a time to a character string
DT_TO_STRING	Converting a whole date to a character string
TIME_TO_STRING	Converting a duration to a character string

## Structured Text

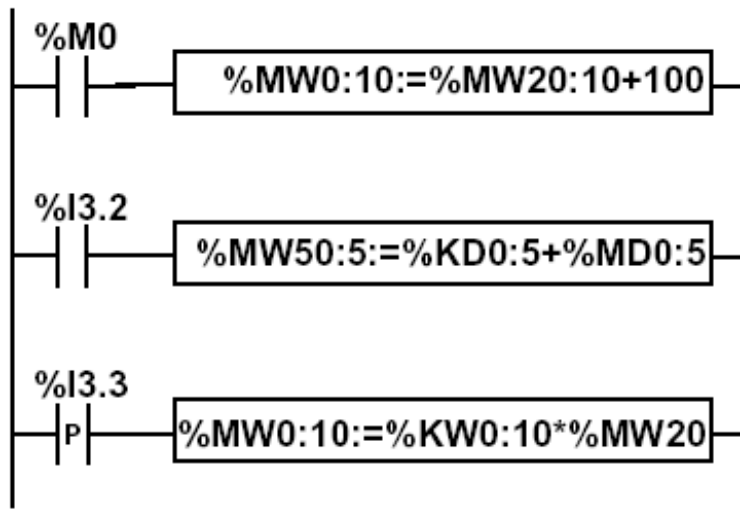
**There are other advanced instructions (see manual)**

- **Monostable**
- **Registers of 256 words (LIFO ou FIFO)**
- ***DRUMs***
- **Comparators**
- ***Shift-registers***
- **...**
- **Functions to manipulate *floats***
- **Functions to convert bases and types**

## Structured Text

### Numerical Tables

Type	Format	Maximum address	Size	Write access
Internal words	Simple length	%MWi:L	i+L<=Nmax (1)	Yes
	Double length	%MWDi:L	i+L<=Nmax-1 (1)	Yes
	Floating point	%MFi:L	i+L<=Nmax-1 (1)	Yes
Constant words	Single length	%KWi:L	i+L<=Nmax (1)	No
	Double length	%KWDi:L	i+L<=Nmax-1 (1)	No
	Floating point	%KFi:L	i+L<=Nmax-1 (1)	No
System word	Single length	%SW50:4 (2)	-	Yes



#### Instruction list language

```
LD %M0
[%MW0:10:=%MW20:10+100]

LD %I3.2
[%MD50:5:=%KD0:5+%MD0:5]
```