Industrial Automation
(Automação de Processos Industriais)

PLC Programming languages
Structured Text

http://users.isr.ist.utl.pt/~jag/courses/api1415/api1415.html

Slides 2010/2011 Prof. Paulo Jorge Oliveira
Rev. 2011-2015 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*.

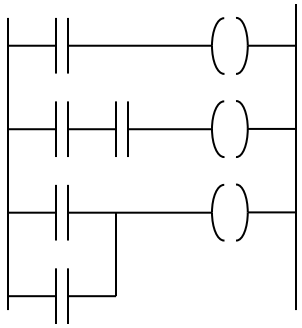
Software development resources.

...

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

PLC Programming Languages (IEC 61131-3)

Ladder Diagram



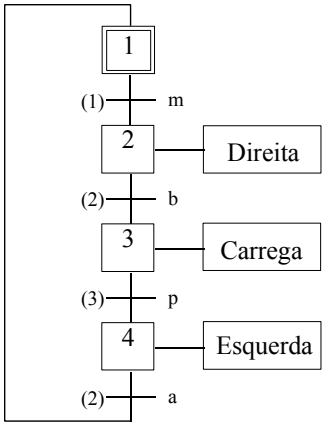
Structured Text

```
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;
```

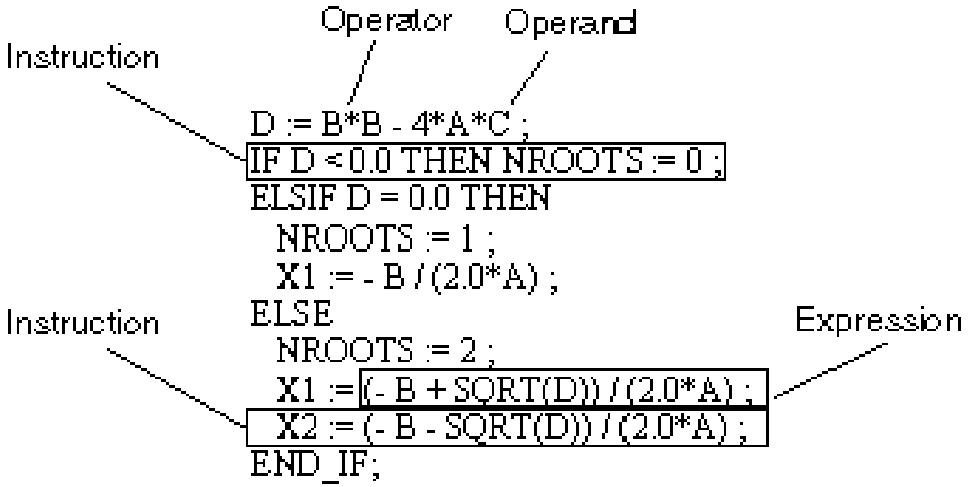
Structured Text

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:

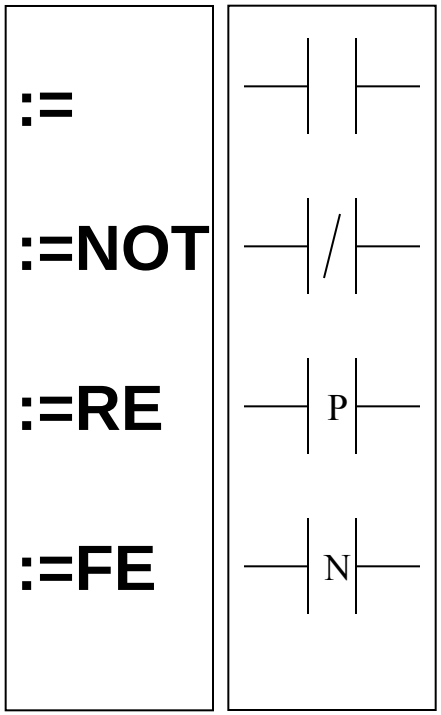


The **length of an instruction line** is limited to 300 characters. The **length of an ST section is not limited** within the programming environment. The length of an ST section is only limited by the size of the PLC memory.

Structured Text

Basic Instructions

Load



Open contact: contact is active (result is 1) while the control bit is 1.

Close contact: contact is active (result is 1) while the control bit is 0.

Contact in the rising edge: contact is active during a scan cycle where the control bit has a rising edge.

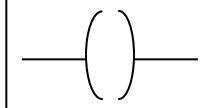
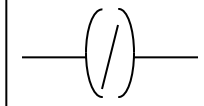
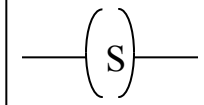
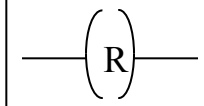
Contact in the falling edge: contact is active during a scan cycle where the control bit has a falling edge.

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

Structured Text

Basic Instructions

Store

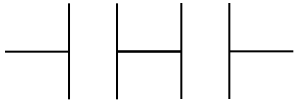
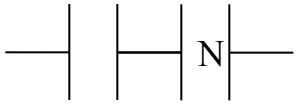
:=		The result of the logic function activates the coil.
:=NOT		The inverse result of the logic function activates the coil.
SET		The result of the logic function energizes the relay (sets the latch).
RESET		The result of the logic function de-energizes the relay (resets the latch)..

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

Structured Text

Basic Instructions

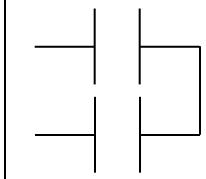
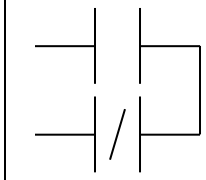
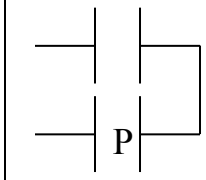
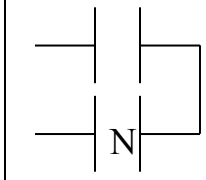
AND

AND		AND of the operand with the result of the previous logical operation.
AND(NOT...)		AND of the operand with the inverted result of the previous logical operation.
AND(RE...)		AND of the rising edge with the result of the previous logical operation.
AND(FE...)		AND of the falling edge with the result of the previous logical operation.

Structured Text

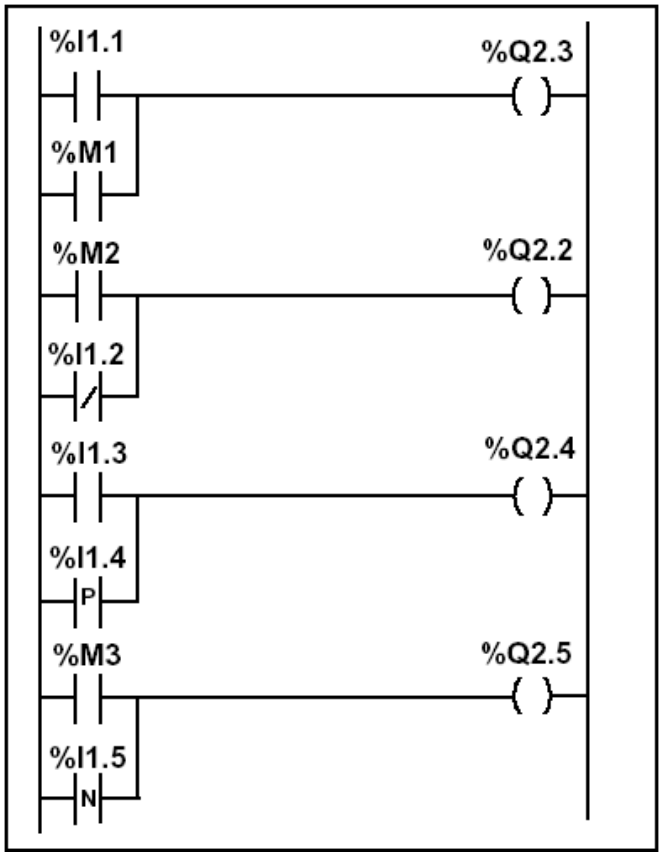
Basic Instructions

OR

OR		OR of the operand with the result of the previous logical operation.
OR(NOT...)		OR of the operand with the inverted result of the previous logical operation.
OR(RE...)		OR of the rising edge with the result of the previous logical operation.
OR(FE...)		OR of the falling edge with the result of the previous logical operation.

Structured Text

Example:



PL7 (Micro PLC):

```
%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);
```

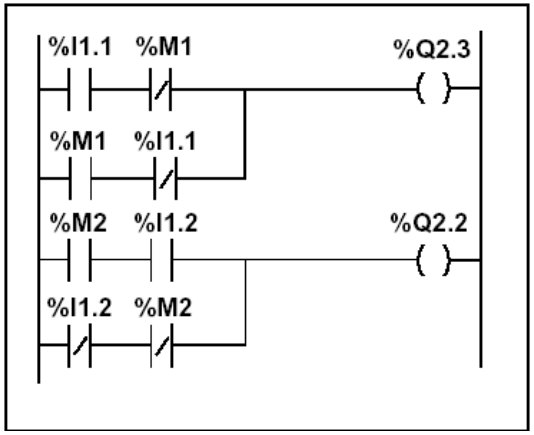
Unity Pro (Premium PLC):

```
%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);
```

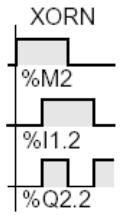
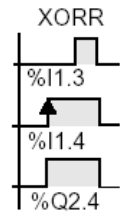
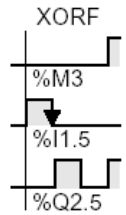
Structured Text

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);
```

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.	

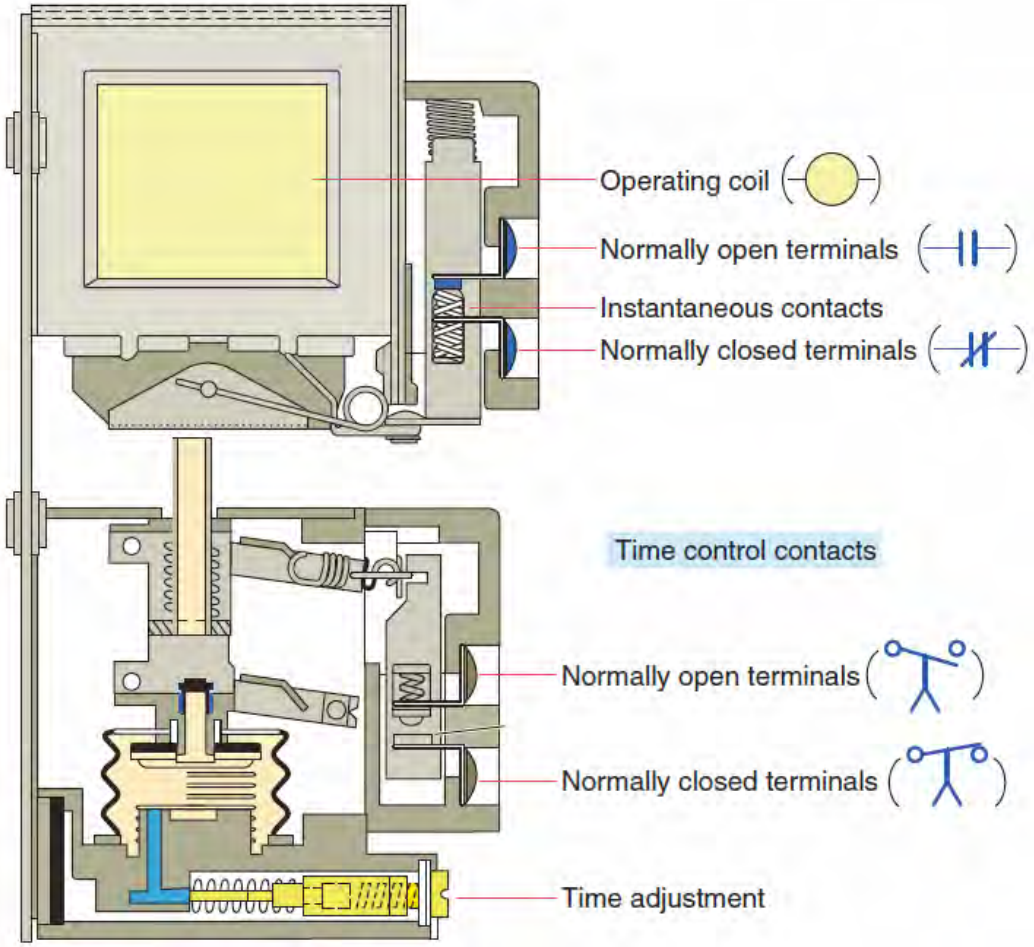
Unity Pro (Premium PLC):

```
%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);
```

Structured Text

Temporized Relays or Timers (pneumatic)

Pneumatic timing relay



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.

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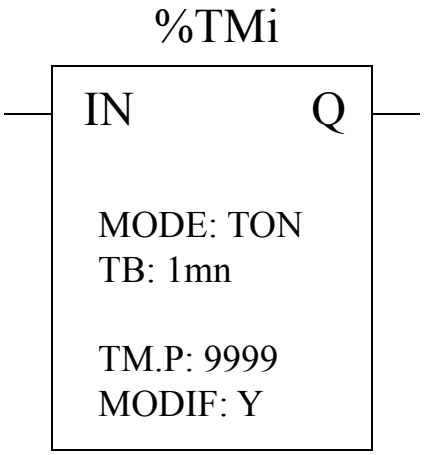
Temporized Relays or Timers



Characteristics:

Identifier:	%TMi	0..63 in the TSX37
Input:	IN	to activate
Mode:	**TON**	On delay
	TOFF	Off delay
	TP	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

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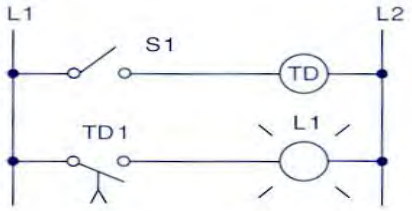
Example:



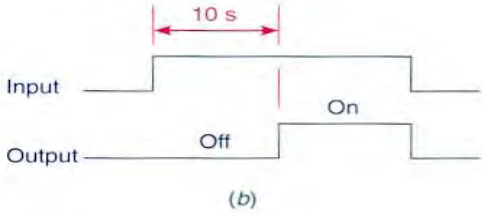
Sequence of operation:
S1 open, TD de-energized, TD1 open, L1 off.

S1 closes, TD energizes, timing period starts, TD1 is still open, L1 is still off.

After 10 s, TD1 closes, L1 is switched on.

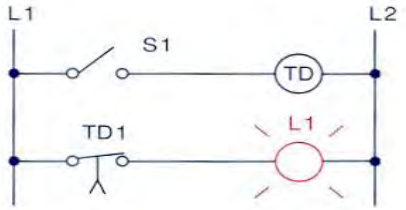
S1 is opened, TD de-energizes, TD1 opens instantly, L1 is switched off.

(*a*)



(*b*)

Fig. 7-3
On-delay timer circuit (NOTC contact). (a) Operation. (b) Timing diagram.



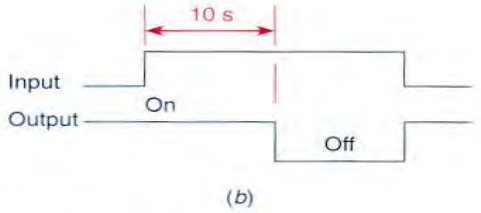
Sequence of operation:
S1 open, TD de-energized, TD1 closed, L1 on.

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*)

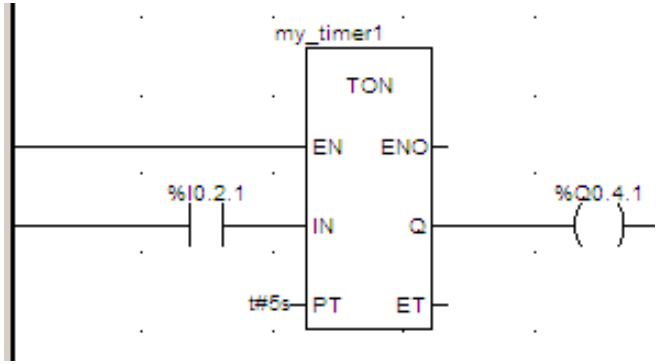


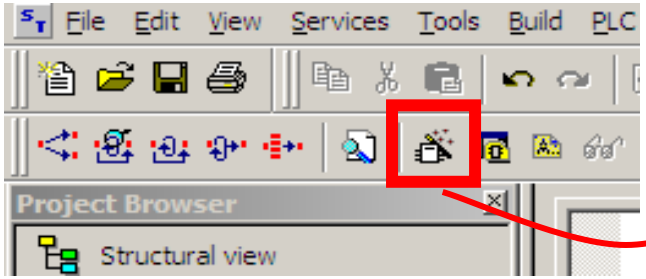
(*b*)

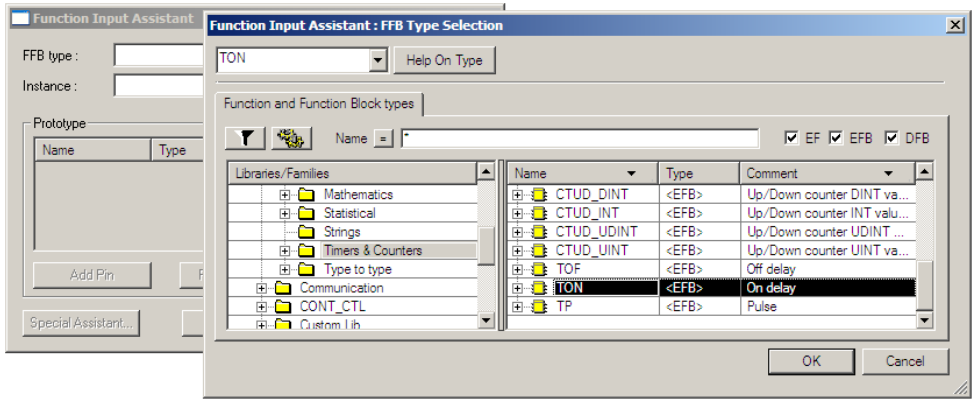
Fig. 7-4
On-delay timer circuit (NCTO contact). (a) Operation. (b) Timing diagram.

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 ";".

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Counters

Some applications...

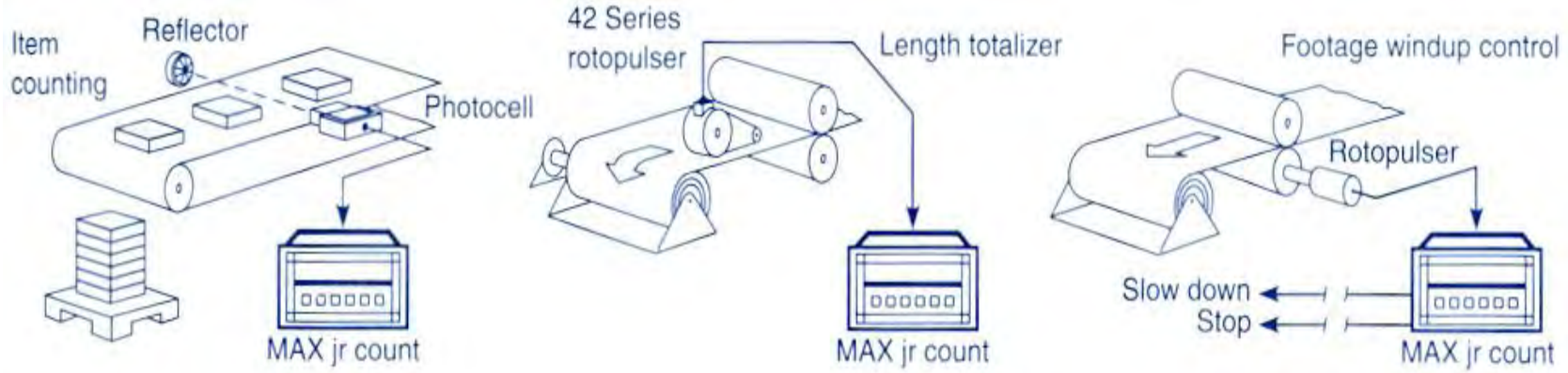

Fig. 8-3

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

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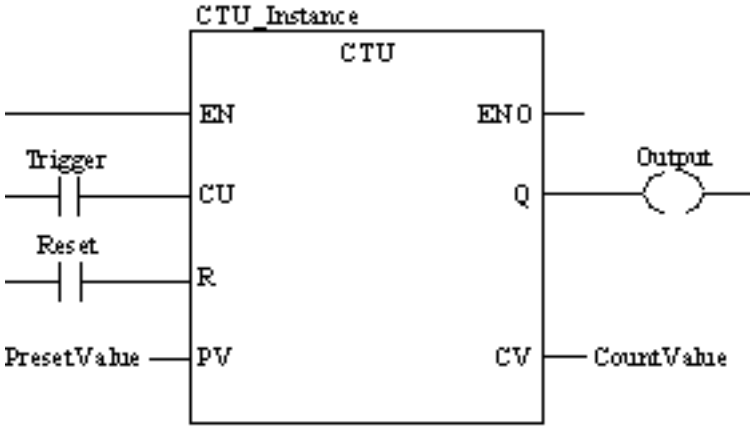
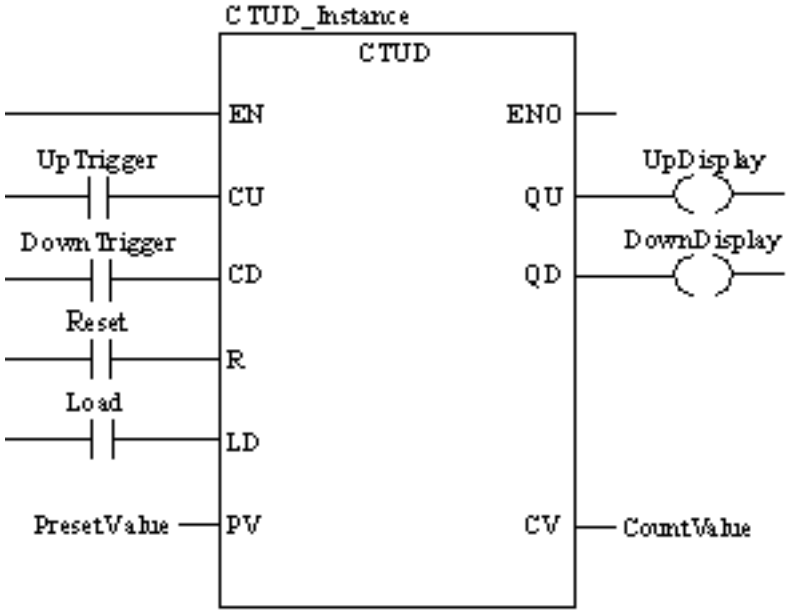
Counters in Unity Pro



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

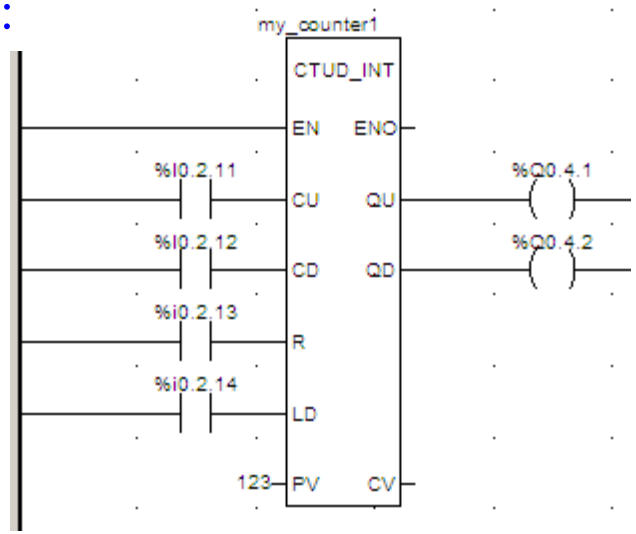
R=1 => CV:=0 **LD=1** => CV:=PV
R has precedence over LD

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

+	addition of two operands	**SQRT**	square root of an operand
-	subtraction of two operands	**INC**	incrementation of an operand
*	multiplication of two operands	**DEC**	decrementation of an operand
/	division of two operands	**ABS**	absolute value of an operand
REM	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.

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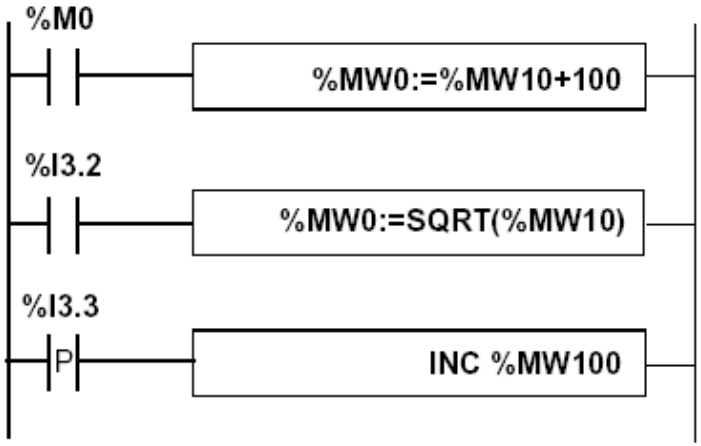
Numerical Processing

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

Logic Functions

AND	AND (bit by bit) between two operands
OR	logical OR (bit by bit) between two operands
XOR	exclusive OR (bit by bit) between two operands
NOT	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

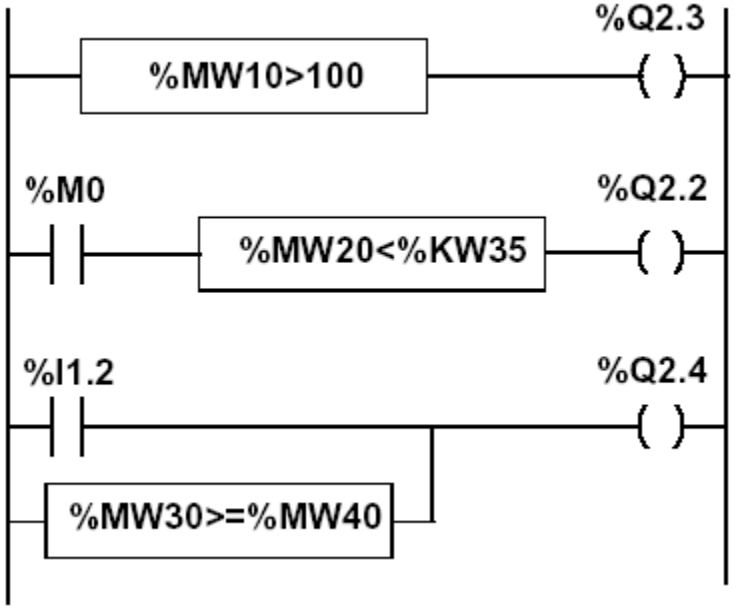
Type	**Operands 1 and 2 (Op1 and Op2)**
Indexable words	%MW,%KW,%Xi.T
Non-indexable words	Imm.val.,%IW,%QW,%SW,%NW,%BLK, Numeric Expr.
Indexable double words	%MD,%KD
Non-indexable double words	Imm.val.,%ID,%QD,%SD,Numeric expr.

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

Priorities on the execution of the operations

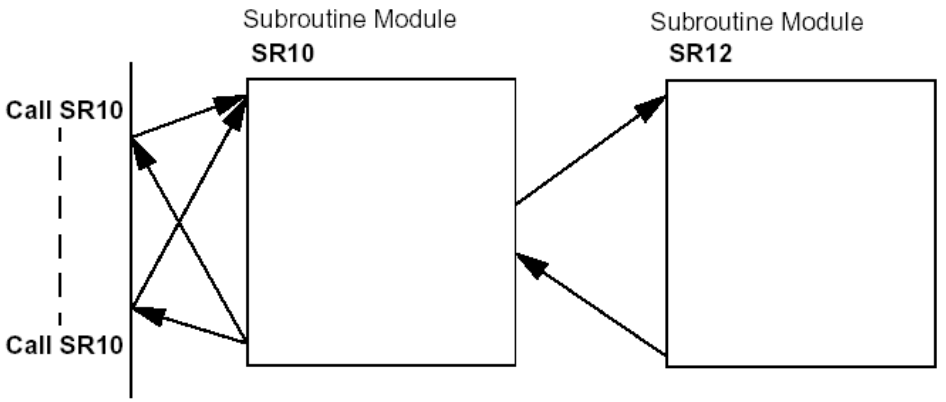
Rank	Instruction
1	Instruction to an operand
2	*,/,REM
3	+,-
4	<,>,<=,>=
5	=,<>
6	AND
7	XOR
8	OR

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)

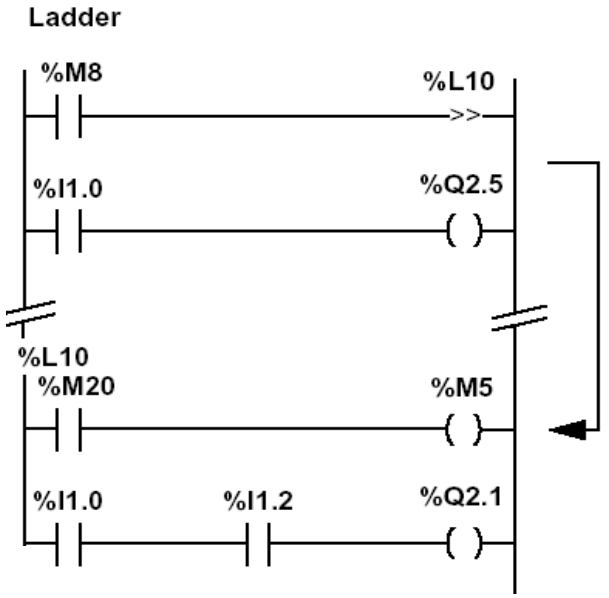
Structured Text – just unconditional jumps as the IF .. THEN .. ELSE provides the conditional clauses.

Note: by default, **jumps are disabled** in Unity Pro / 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;
```

Jump to label %L10
if %M8=1

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

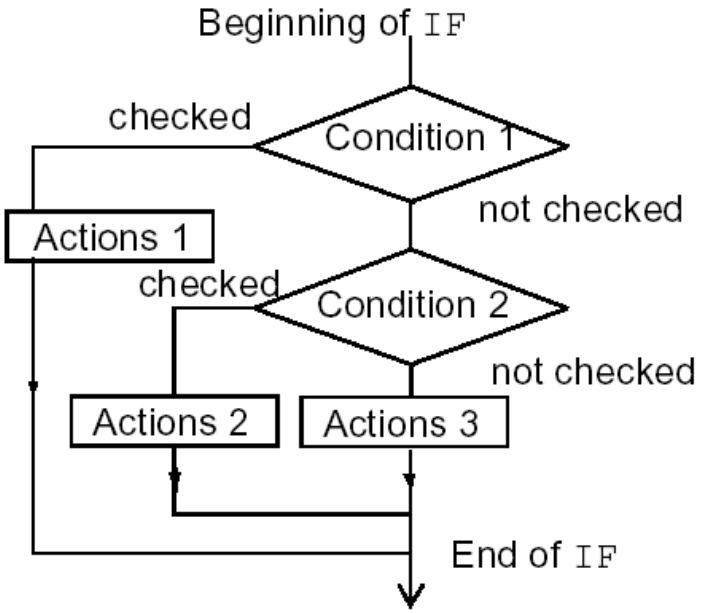
Structures for Control of Flux

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

Syntax

```
IF condition1 THEN
    actions1;
ELSEIF condition2 THEN
    actions2;
ELSE
    actions3;
END_IF;
```

Operation



Structured Text

Structures for Control of Flux

WHILE

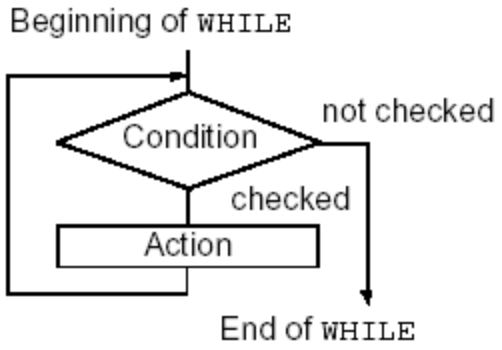
Syntax

```
WHILE condition DO

    action ;

END_WHILE;
```

Operation



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

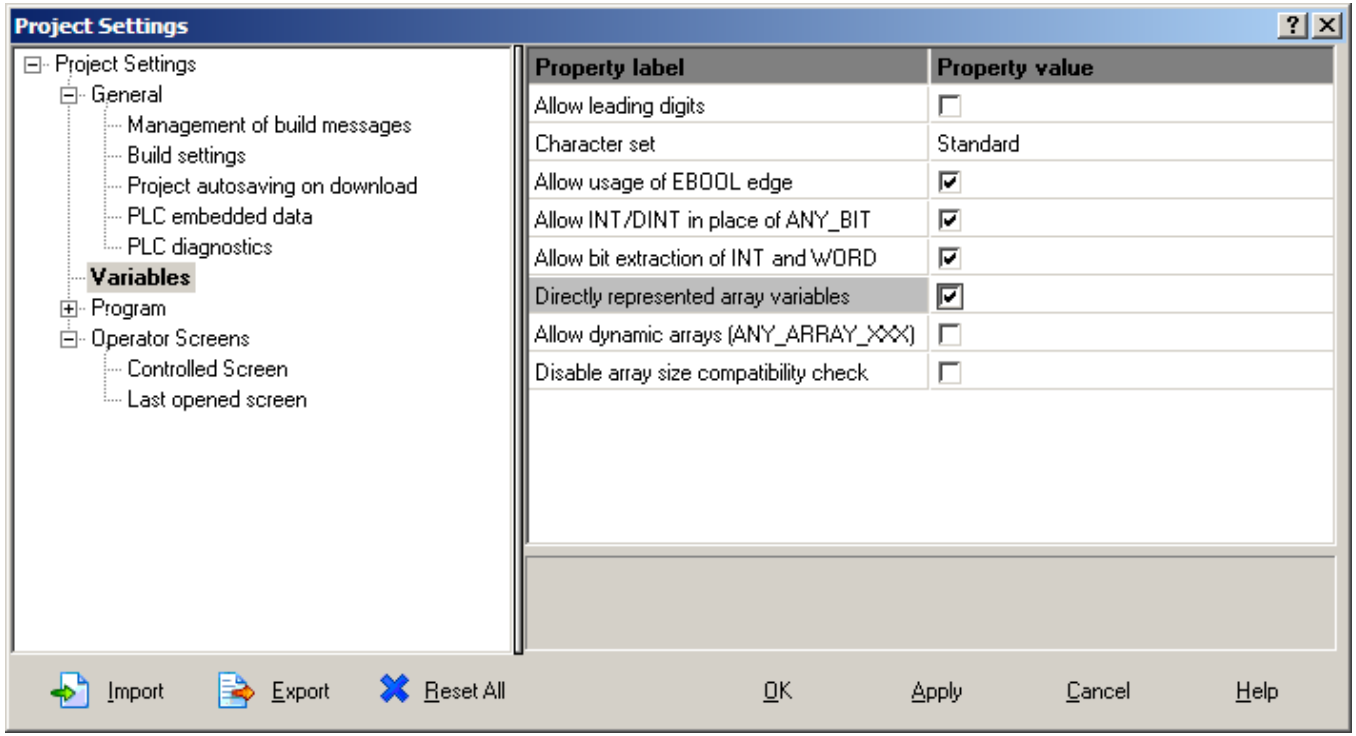
EXIT to abort the execution of a structured flux control instruction

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

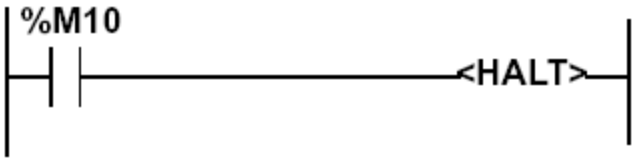
Note: in Unity Pro, both in Structured Text and Instruction List, the conventional array indexing (e.g. `%MW100[%MW1]`*) is* ***disabled by default****. To enable it, go to the project settings, menu Tools -> Project Settings. See the grayed region in the next figure:*



Structured Text

Structures for Control of Flux

Halt

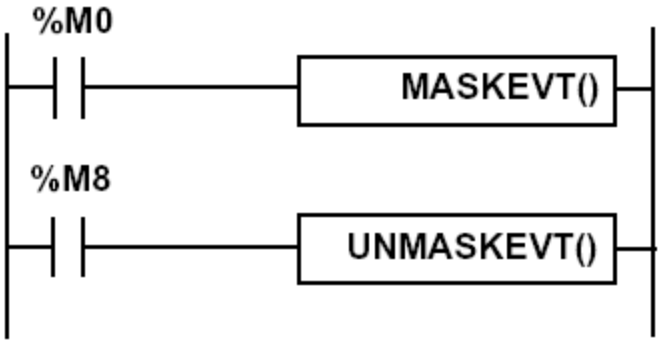


Structured text language

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

Stops all processes!

Events masking



Structured text language

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

Structured Text

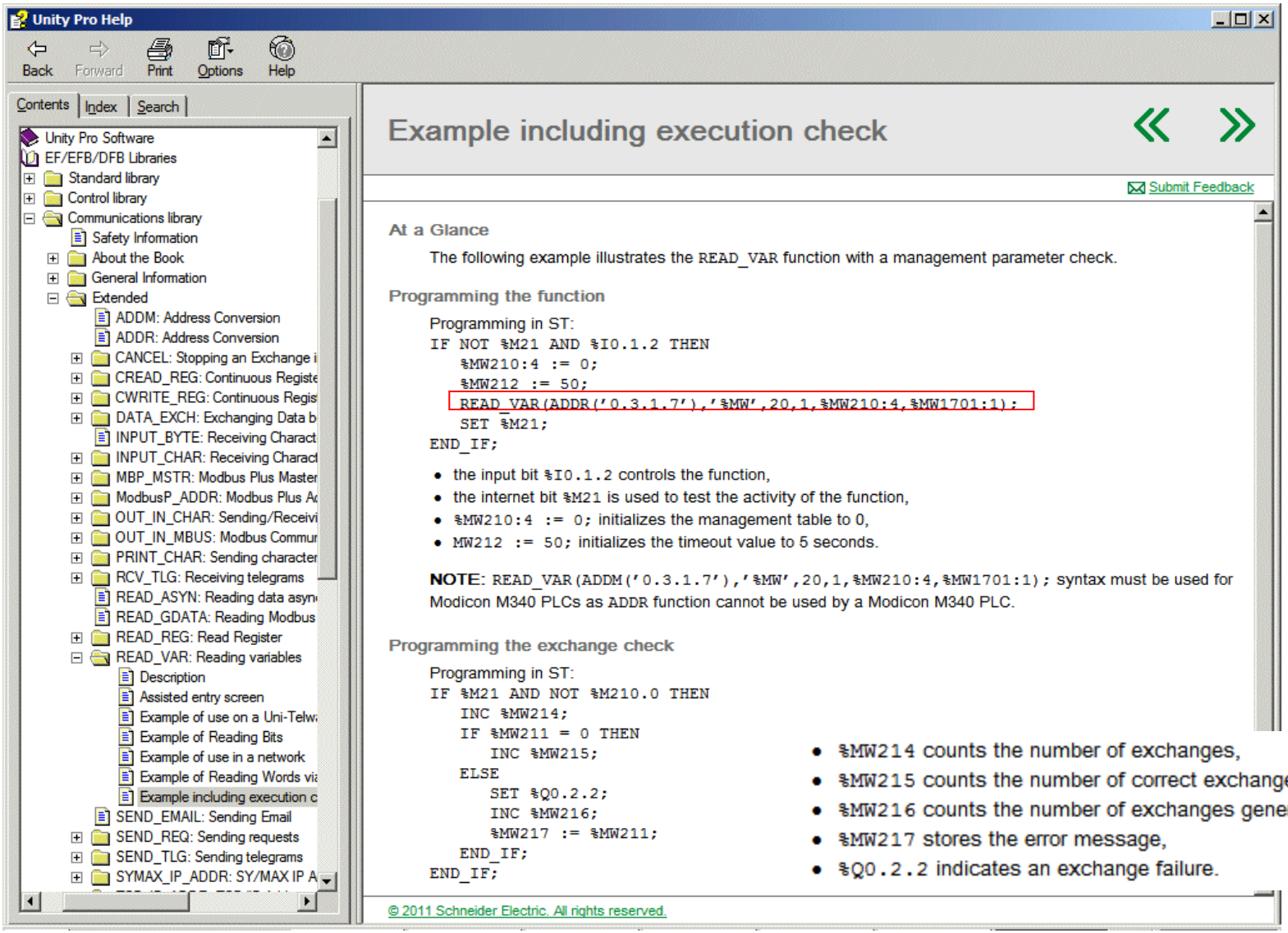
There are other advanced instructions (see manual)

- **Monostable**
- **Registers of 256 words (LIFO ou FIFO)**
- ***DRUMs***
- **Comparators**
- ***Shift-registers***

  ...
- **Functions to manipulate *floats***
- **Functions to convert bases and types**

Structured Text

Networking (in Unity Pro)



Keywords: MODBUS, READ_VAR, WRITE_VAR