PLC programming

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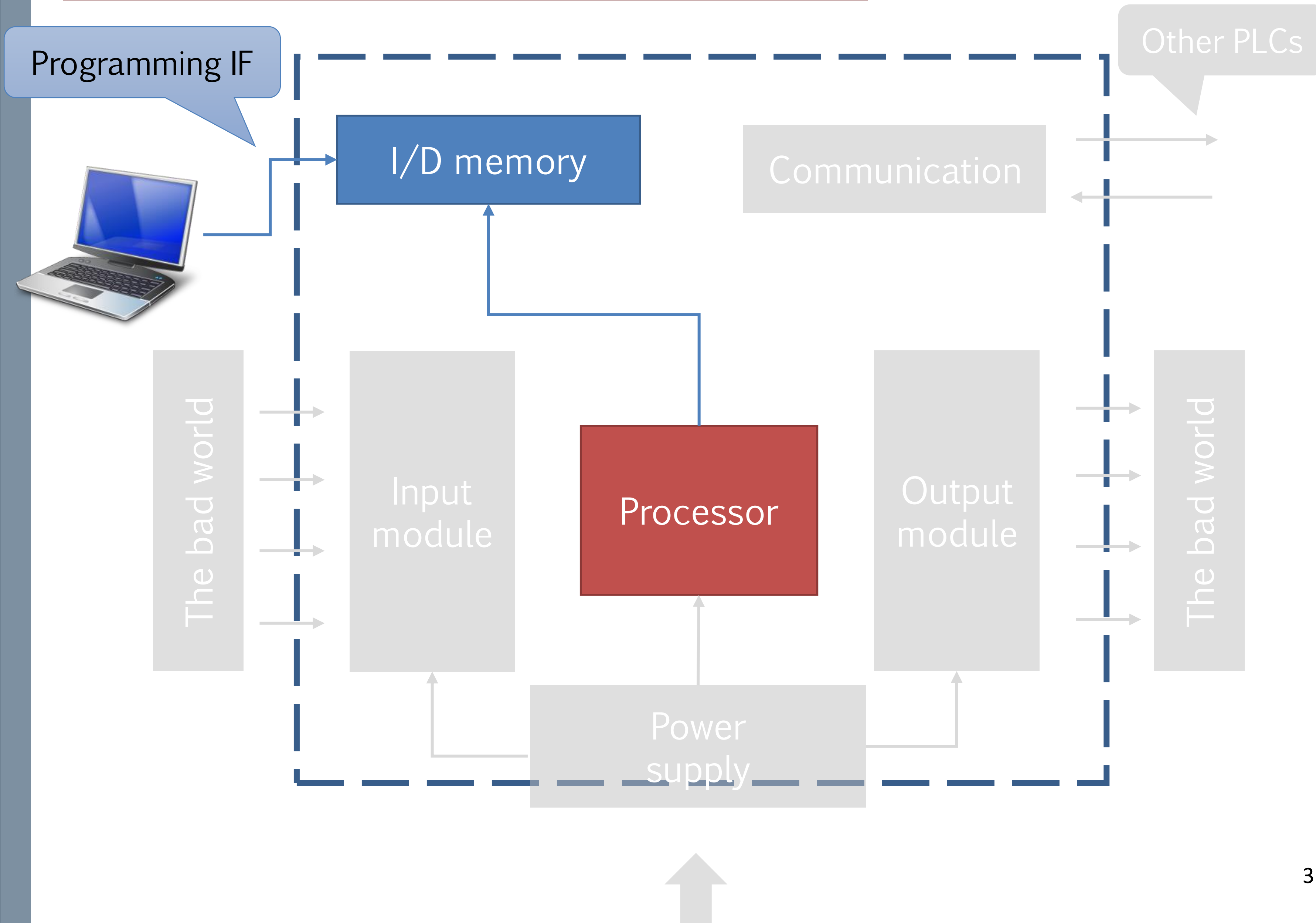
High Performance Real Time Lab


while (not edge) {
run();
}
do {
run();
} while (not edge);

Structure of a PLC



PLC programming with IEC 61131

First attempt of standardization => **IEC 61131-3 standard**

- yr 1993, latest rev 2013
- Before that, “the fish market” of languages
- Still, Ladder was a prominent one...but everyone had its own variant!!

States that there are 5 “standard” ways of programming PLCs

- **Ladder diagram**
  - Description of electrical wiring, designed for non-informatics
- **Function Block Diagram – FBD**
  - From electronics
- Sequential Functional Chart – SFC
  - Petri-net style
- Instruction List – IL
  - ASM-like
- **Structured Text – ST**
  - Similar to Pascal/VB

IEC 61131

Covers the complete lifecycle of PLC modules and ~~sw development for PLC~~ PLC programming

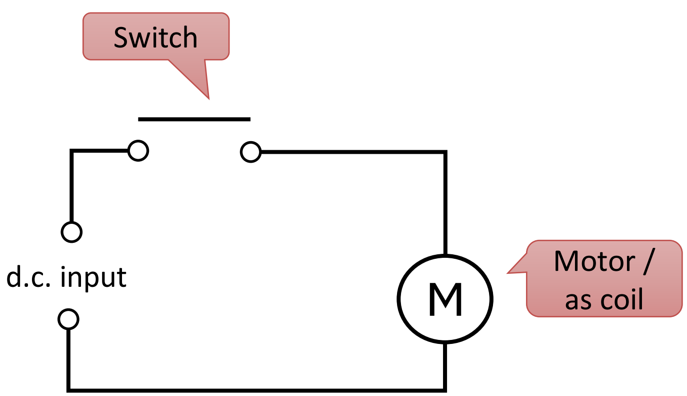
- Part 1: definition of terminology and concepts
- Part 2: electronic and mech equipment and verification/testing
- Part 3: programming languages (5 types)
- Part 4: how to choose, install and maintain
- Part 5: how to communicate (MMS – Manufacturing Messaging Specification)
- Part 6: communication via fieldbusses/other ind. standards
- Part 7: fuzzy control (won’t see this..if you don’t want)
- Part 8: sw dev guidelines

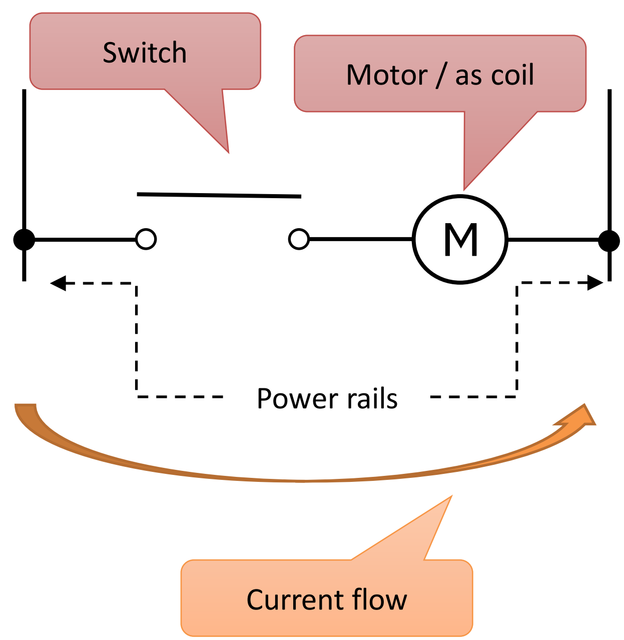
Ladder

Ladder diagrams

Possible circuit to power on a motor

- Left: electrical diagram; right: Ladder
- Does it remind of something…?

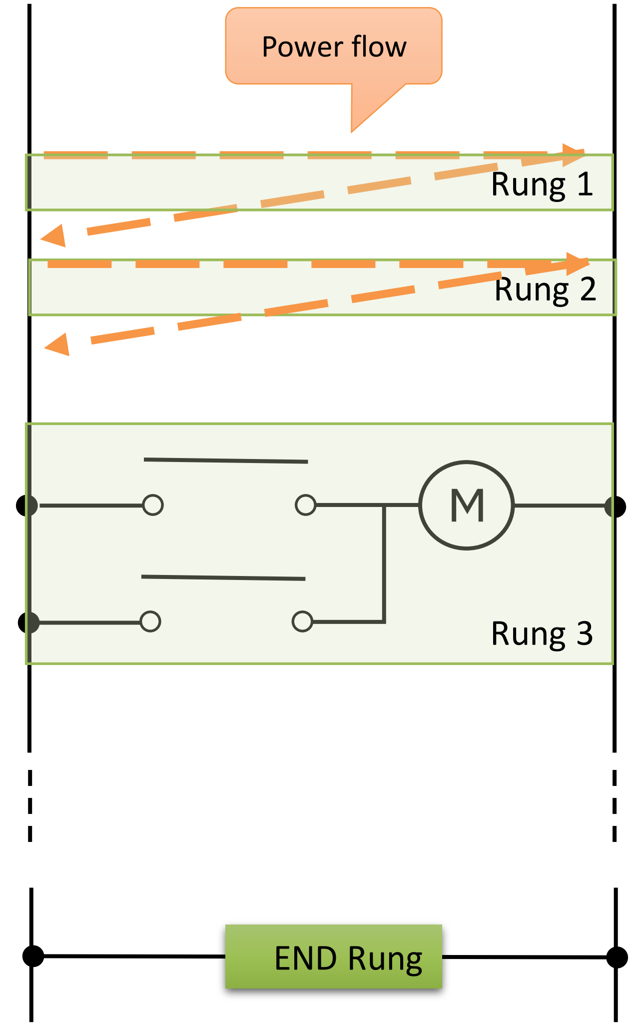




Ladder programs

Writing a program is as easy as writing a switching circuit

- Vertical lines are power rails, and power flows from top-left to bottom-right
  - So does "program flow"
- Horizontal lines (rungs) connect power rails
  - Every rung starts with one or more inputs, and ends with exactly one output
- Typical exec time: 1ms for 1k bytes of program, so usually approx 10-50ms



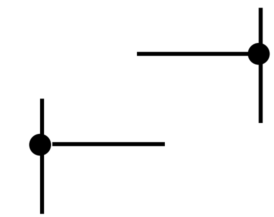
Program flow

- Store input status in mem
- Read inputs from memory, run program, store out in mem
- Update all outputs

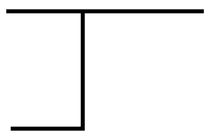
Ladder symbols

- Power rails (Vert lines)

- Rungs (Horiz lines)



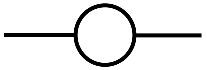
- Left/right connection between power rail and rugs
- Dual connection



- Normally open (NO) contact

- Normally closed (NC) contact

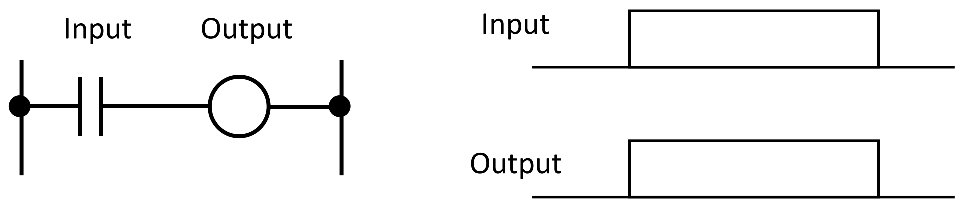
- Output coil (from a lamp, a motor…)



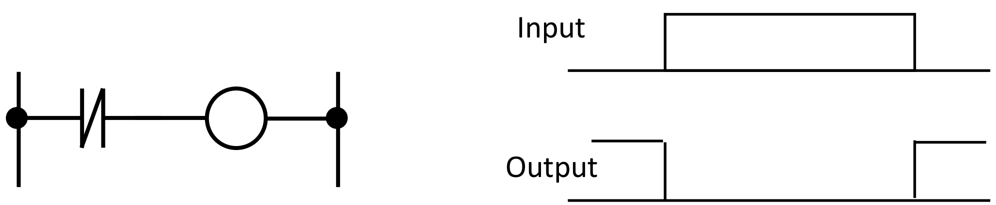
- A switch

Example: a (lamp?) switch

› When a NO contact is closed, the attached coil propagates the signal



› When a NC contact is opened, the attached coil propagates the input signal



Structured Text

Structured text

- Inspired by Pascal language, also Basic and VB programmer might find it familiar
- Procedural language (can define Functions, or Function Blocks)
- Or define a Program (and call it from within your Application MainTask)
  - Can have multiple programs…you must have one call for one program!

Can also comment code..

```
(* This is a comment! *)

(* This is a
   multi-line
   comment! *)
```

Defining variables

Can also initialize them

- Don't forget semicolon **;**

IEC 61131.3 defines several datatypes

- Few examples

```
Contact1: BOOL;

Contact2: BOOL := FALSE;
```

IEC Data Type	Format	Range
`SINT`	Short Integer	-128 … 127
`INT`	Integer	-32768 … 32767
`DINT`	Double Integer	-2^31 … 2^31-1
`UINT`	Unsigned Integer	0 … 2^16-1
`BOOL`	Boolean	1 bit
`BYTE`	Byte	8 bits
`WORD`	Word	16 bits
`STRING`	Character String	`'My string'`
`TIME`	Duration of time after an event	**T#**10d4h38m57s12ms **TIME#**10d4h38m
`DATE`	Calendar date	**D#**1989-05-22 **DATE#**1989-05-22
`REAL`	Real Numbers	±10 ^ ±38

Variables: simple operations

- Assigning immediate vals to variables

```
Contact1 := FALSE;
Input1 := 11;
Output1 := 5;
```

```
Contact1: BOOL;
Input1: INT;
Output1: BYTE;
```

- Also, with operators in R-values

```
Output1 := Input1 – Output1 / ( Input6 + 3 );
```

Structured Text Operators (and their priority)

Operators	Description
`( . . . )`	Parenthesized (brackets) expression
`Function ( . . . )`	List of parameters of a function
`**`	Power
`-, NOT`	Negation, Boolean NOT
`* , / , MOD`	Multiplication, division, modules operations
`+, -`	Add, subtract
`< , > , <= , >=`	Comparison
`=, <>`	Comparison
`AND, OR`	Boolean operator
`XOR`	Exclusive OR
`OR`	Boolean OR

Precedence

Define your own datatypes

```
(* Enum-like datatype *)
TYPE Motor:( Stopped, Running );
END_TYPE;
```

```
(* Analog value datatype *)
TYPE Pressure: REAL;
END_TYPE;
```

Variables: nomenclature

- ST is not case sensitive; in case you might want to use capital letter for clarity
- Use the `AT` keyword to fix the memory location of a variable

```
Contact1: BOOL AT %MX100; (* Internal memory Bit at address 100 *)

Input1: INT AT %IW200; (* Input memory Word at address 200 *)

Output1: BYTE AT %OB300; (* Output memory Byte at address 300 *)
```

% M X 100

Memory Address

Memory type
M - internal
I - input
O - output

Data type
X (bit) - 1 bit
B (byte) - 8 bit
W (word) - 16 bits
D (double word) - 32 bits
L (long word) - 64 bits

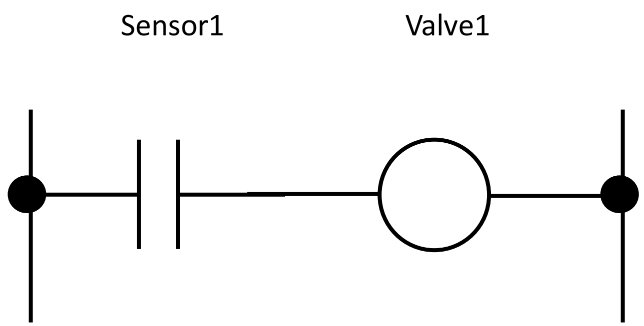
If-Then-Else

```
IF Contact1 = TRUE THEN;
  Coil1 := TRUE;
ELSE;
  Coil1 := FALSE;
END_IF;
```

```
IF NOT Contact1 = TRUE;
  Coil1 := TRUE;
END_IF;
```

```
IF Contact1 = TRUE OR Input1 = 11;
  Coil1 := TRUE;
END_IF;
```

Ladder vs. ST




```
Valve1 := Sensor1;

IF Sensor1 THEN;
  Valve1 := 1;
END_IF;
```

Switch-case

- Multiple instructions on the same line
- Default with `ELSE` keyword
- Can also use ranges

```
CASE (State) OF
  1: NextState := 2; ERROR := FALSE;
  2: NextState := 3; ERROR := FALSE;
ELSE
  NextState := 4; ERROR := TRUE;
END_CASE;
```

```
CASE (Temperature) OF
  0...40:   Furnace_switch := ON;
  40...100: Furnace_switch := OFF;
END_CASE ;
```

Loops

› For, While-Do, Repeat-Until

```
(* for (input1 = 10;
        input1 >= 0;
        input1-- *)
FOR Input1 := 10 to 0 BY -1
DO
  Output1 := Input1;
END_FOR;
```

```
(* do...
   while (input1 < 3
          && input2 == 5); *)
Output1 := 0;
REPEAT
DO
  Output1 := Output1 + 1;
UNTIL Input1 < 3 AND Input2 = 5
END_REPEAT;
```

```
(* while (input1 < 3
          && input2 == 5) *)
Output1 := 0;
WHILE Input1 < 3 AND Input2 = 5
DO
  Output1 := Output1 + 1;
END_WHILE;
```

Defining Programs

› Read (input vars) – Exec – Write (output vars) paradigm

```
(* ... *)

VAR (* Input type, and datatype,
implicit by memory *)
  Temperature AT $IW100;
END_VAR;

(* ... *)
```

```
PROGRAM Example

VAR_IN (* Input *)
  Temperature: INT;
  Humidity: REAL;
END_VAR;

VAR_IN (* Input *)
  Speed: INT = 50;
END_VAR;

VAR_OUT (* Outputs *)
  Motor_speed: REAL;
END_VAR;


(* Instructions here *)

END_PROGRAM;
```

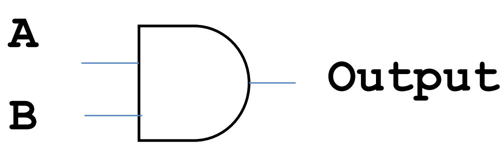
Logic blocks

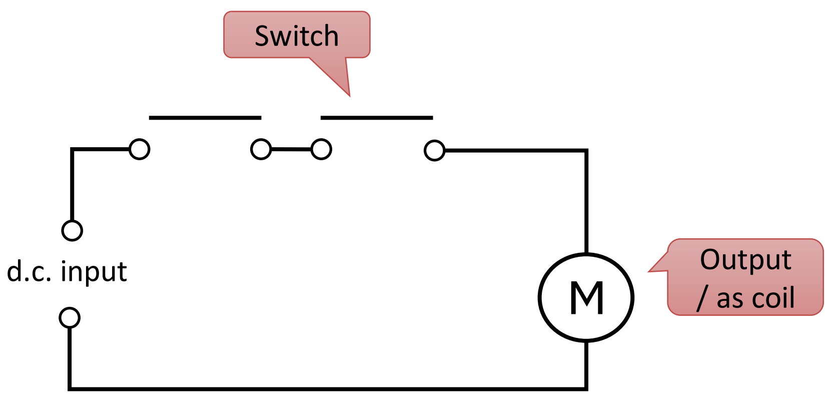
(Unnecessary) brief recap

Logic functions

- Already seen in previous courses
- Express Boolean logics, adders, latches, …

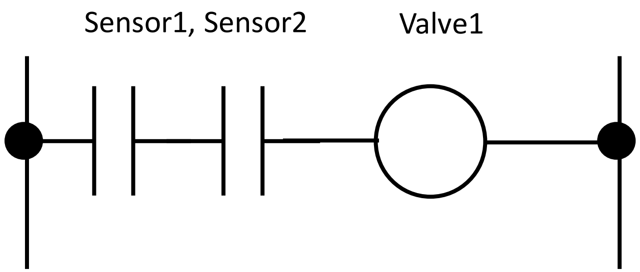
Example: Logical AND



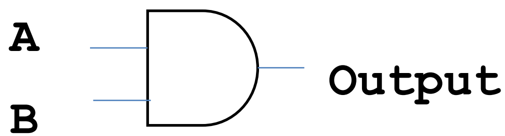


A	B	Output
0	0	0
0	1	0
1	1	1
1	0	0

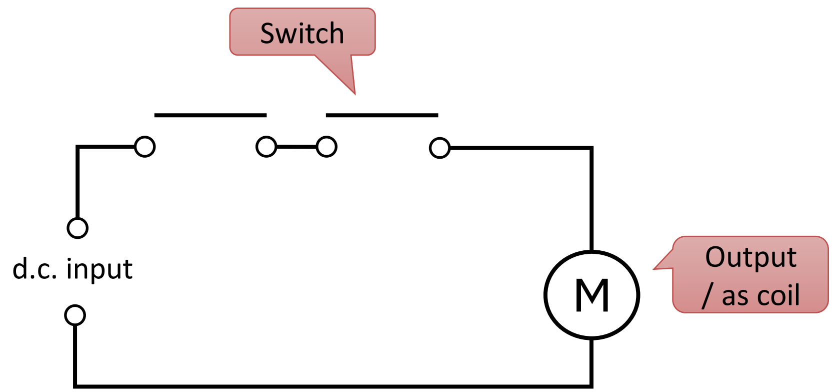
Ladder and ST AND



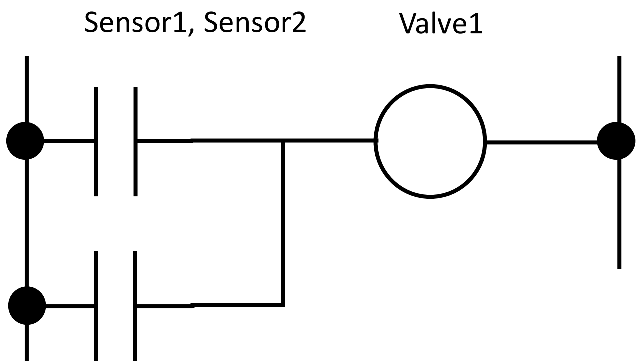

```
IF Sensor1 AND Sensor2 THEN;
  Valve1 := TRUE;
ELSE
  Valve1 := FALSE;
END_IF;
```



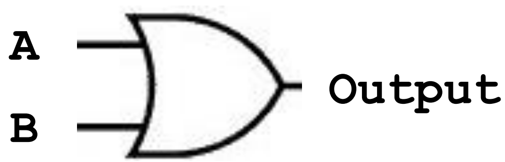
A	B	Output
0	0	0
0	1	0
1	1	1
1	0	0



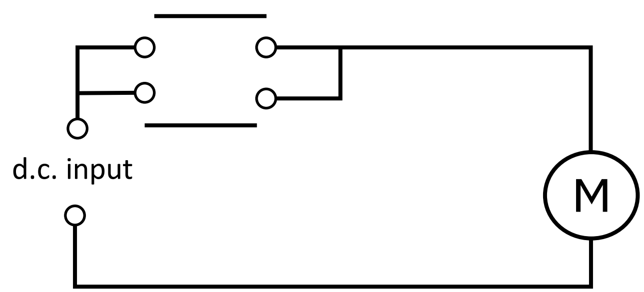
Ladder and ST OR



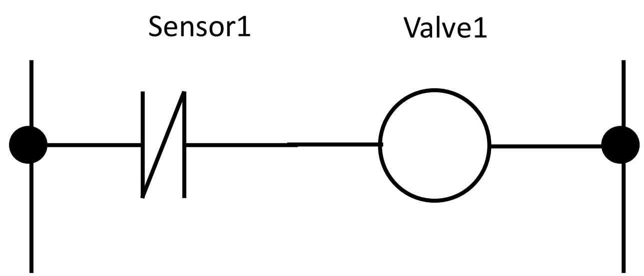

```
IF Sensor1 OR Sensor2 THEN;
  Valve1 := TRUE;
ELSE
  Valve1 := FALSE;
END_IF;
```



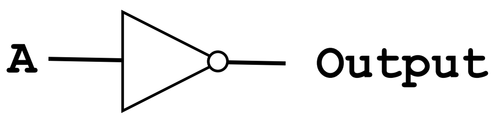
A	B	Output
0	0	0
0	1	1
1	1	1
1	0	1



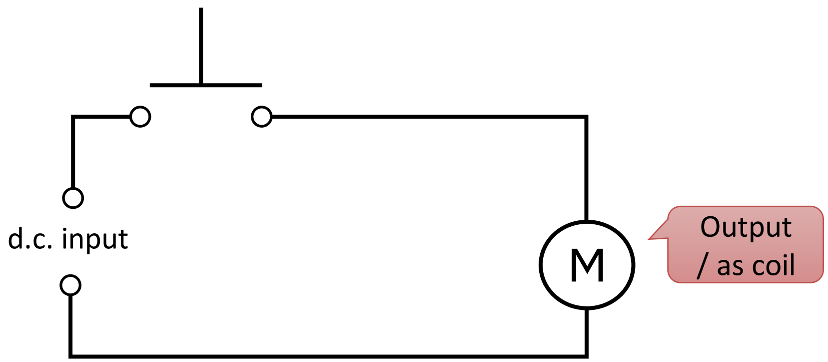
Ladder and ST NOT




```
IF NOT Sensor1 THEN;
  Valve1 := TRUE;
ELSE
  Valve1 := FALSE;
END_IF;
```

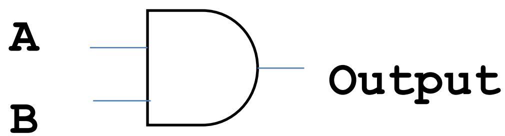


A	Output
0	1
1	0



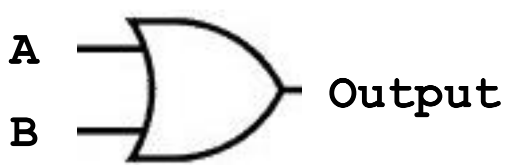
Boolean algebra

- A * B = Out

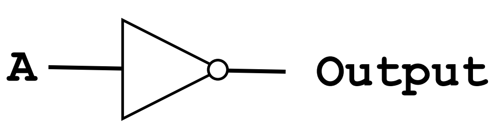


A	B	A + B
0	0	0
0	1	0
1	1	1
1	0	0

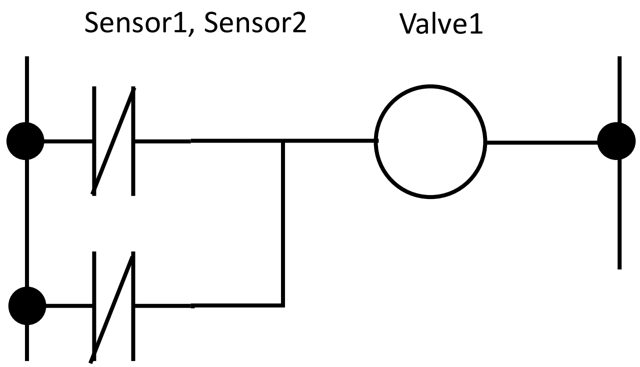
- A + B = Out



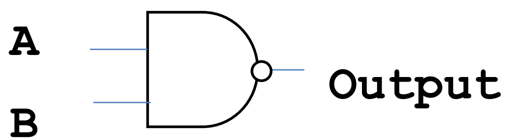
- $\overline{A}$ = Out



Ladder and ST NAND



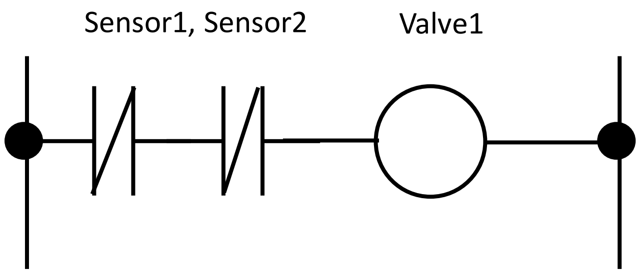

```
IF NOT Sensor1 OR NOT Sensor2 THEN;
   Valve1 := TRUE;
ELSE
   Valve1 := FALSE;
END_IF;
```



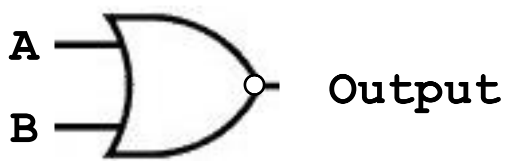
A	B	Output
0	0	1
0	1	1
1	1	0
1	0	1

```
IF Sensor1 AND Sensor2 THEN;
   Valve1 := FALSE;
ELSE
   Valve1 := TRUE;
END_IF;
```

Ladder and ST NOR



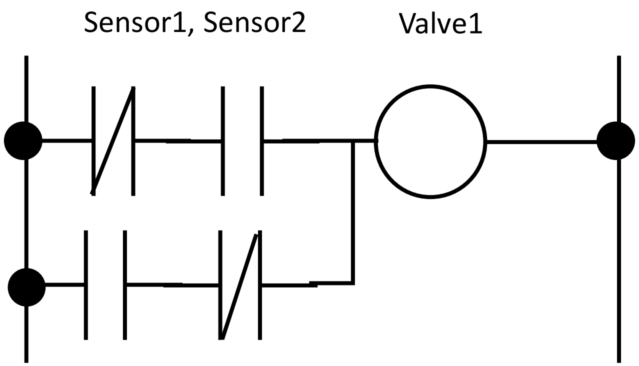

```
IF NOT Sensor1 AND NOT Sensor2 THEN;
  Valve1 := TRUE;
ELSE
  Valve1 := FALSE;
END_IF;
```



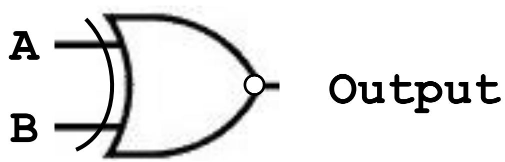
A	B	Output
0	0	1
0	1	0
1	1	0
1	0	0

```
IF Sensor1 OR Sensor2 THEN;
  Valve1 := FALSE;
ELSE
  Valve1 := TRUE;
END_IF;
```

Ladder and ST XOR




```
IF (Sensor1 AND NOT Sensor2)
   OR (NOT Sensor 1 AND Sensor2)
THEN;
  Valve1 := TRUE;
ELSE
  Valve1 := FALSE;
END_IF;
```



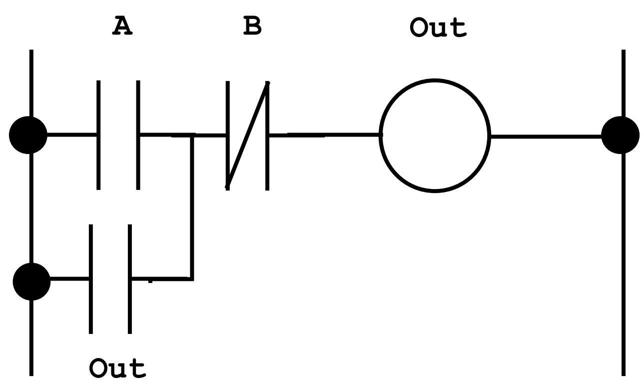
A	B	Output
0	0	0
0	1	1
1	1	0
1	0	1

Latching

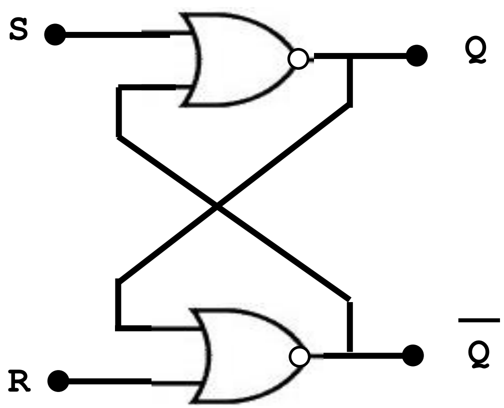
- We often need to store in memory a value (e.g. a bit)
  - I.e., to store a **state**
- Can implement it with NANDs, or NORs

SR Latch circuit

- When **`A`** closes (‘**1**’), **`Out`** coil gets energy (‘**1**’)
- Also, **`Out`** contact closes, so, even if **`A`** opens (‘**0**’), the “OR” keeps the **`Out`** coil powered (‘**1**’)
- Until the NC **`B`** contacts closes (‘**0**’). Then the **`Out`** coil becomes ‘**0**’



Latch with NOR



We also have the negate available for free!

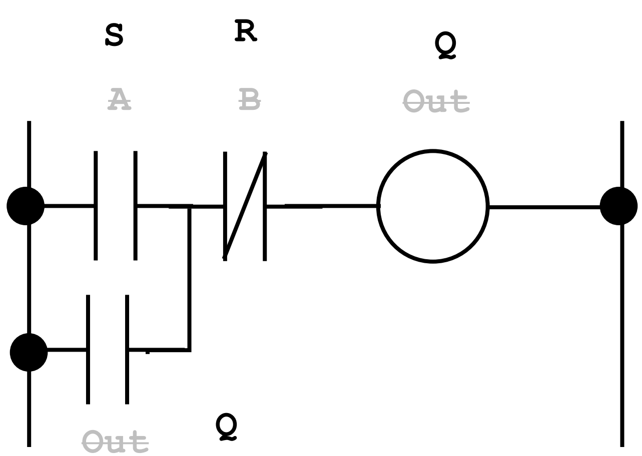
S	R	Q
0	0	LATCH
0	1	0
1	0	1
1	1	-

Memory

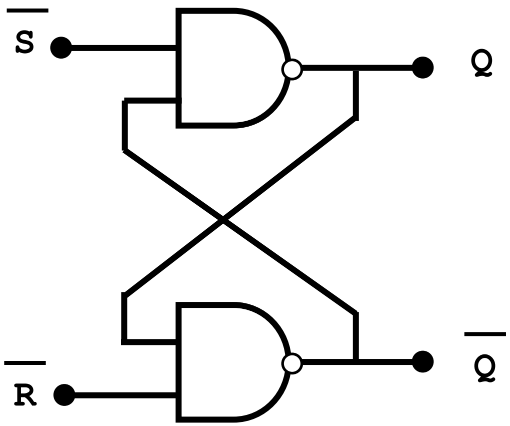
Reset

Set

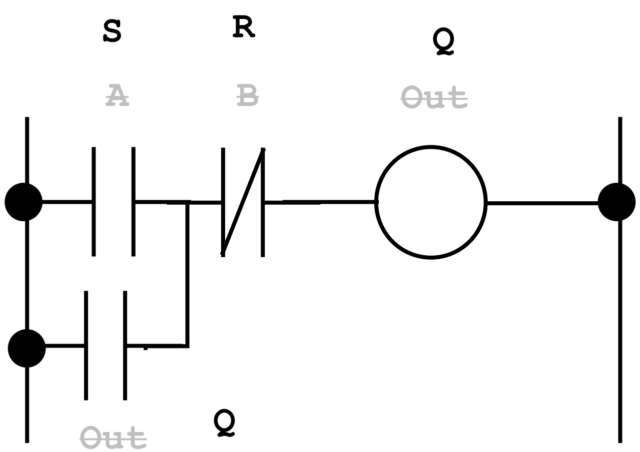
Not legal



Latch with NAND



S	R	Q
0	0	-
0	1	0
1	0	1
1	1	LATCH



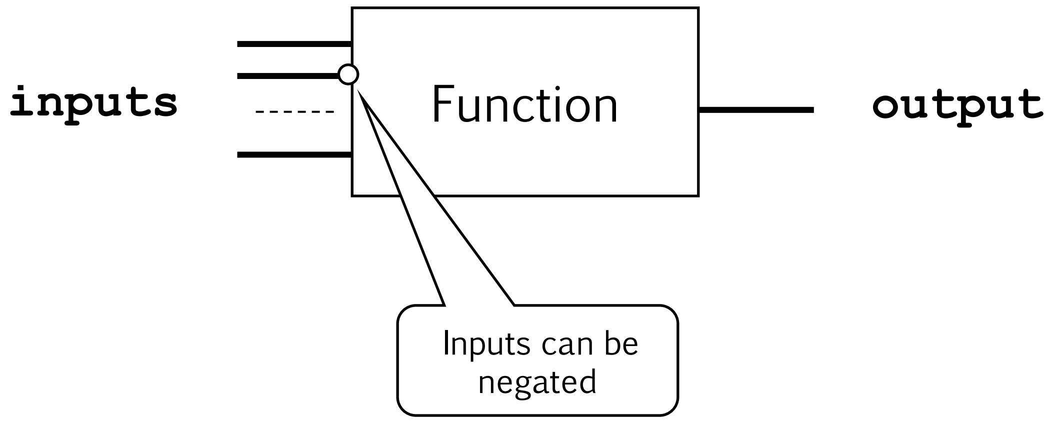
Functional Block Diagrams

Function blocks

Enable us grouping a functionality in a reusable elements

- “aka”: function ☺
- Multiple inputs, multiple outputs
- Standard-defined functions vs. user-defined functions

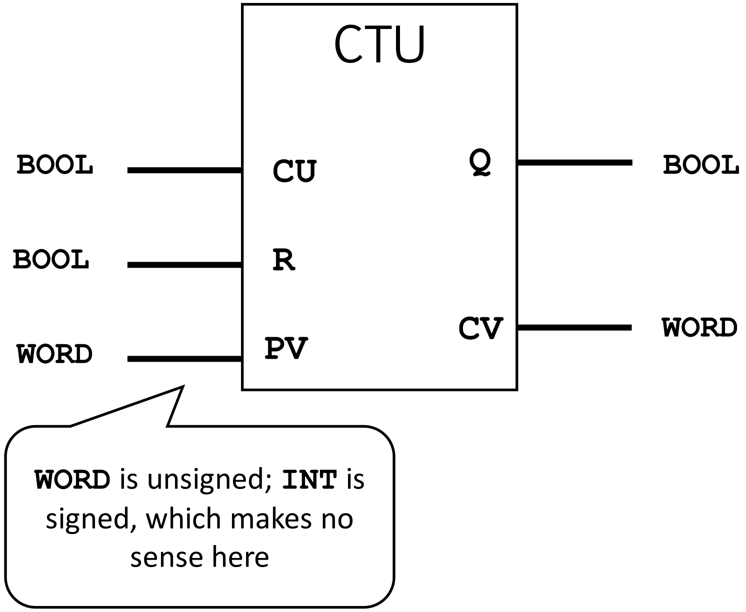
IEC 61131-3 defines them graphically as



Standard blocks: CTU

Up counter **`CTU`**

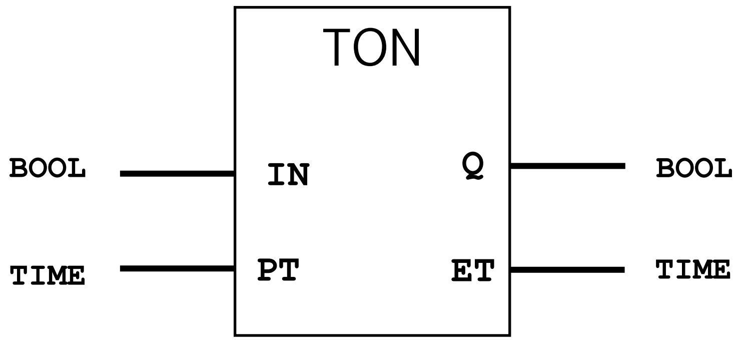
- Gives output **`Q`** when *input pulse* **`CU`** reaches the *set value* **`PV`**
- Reset input **`R`**
- Also, every time **`Q`** is set, **`CV`** is incremented



Standard blocks: TON

Timer ON **TON**

- Gives output **Q** when timer gets to time to pass **PT** has a rising edge
- Starts when **IN** has a rising edge, reset when **IN** has a falling edge
- Also, *Elapsed Time* **ET** keeps trace of time



Defining our own Function Blocks

- Here, written in ST
- Define function to reuse code
- Define in, out, internal vars


```
FUNCTION_BLOCK MyFb

VAR_INPUT (* Inputs *)
  (* ... *)
END_VAR;

VAR_OUTPUT (* Outputs *)
  (* ... *)
END_VAR;

VAR (* Internal *)
  (* ... *)
END;


 (* Instructions here *)

END_FUNCTION_BLOCK;
```

References

Course website

- http://hipert.unimore.it/people/paolob/pub/Industrial_Informatics/index.html

My contacts

- paolo.burgio@unimore.it
- http://hipert.mat.unimore.it/people/paolob/

Resources

- W. Bolton, ''Programmable Logic Controllers'', 6th edition, Newnes
- “Industrial informatics” course by Proff. Vezzani and Pazzi @UNIMORE
- A "small blog"
  - http://www.google.com