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Exercise for

Embedded Systems

Summer Term 2025

Sheet 3: Programmable Logic Controllers

Exercise 1: Running in circles

- Explain the term *cyclic execution*.

  Solution:
  There are four repeating steps:

  - Internal Checks
  - Reading Hardware Inputs
  - Proram Execution
  - Writing Hardware Outputs

- What are the two worst-case assumptions that are made when calculating the maximum reaction time?

  Solution:
  The two assumptions are that **the input changes just after the inputs are read** and the **maximum cycle time** is reached.

- How are maximum cycle time and maximum reaction time linked?

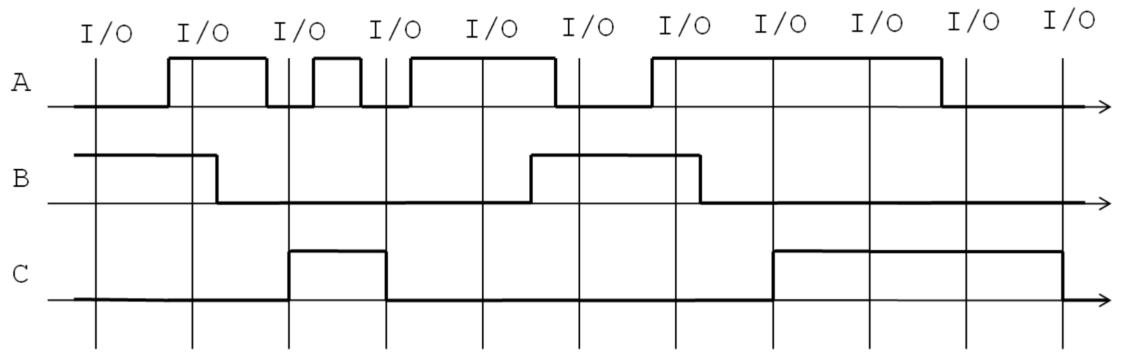
  Solution:
  Maximum reaction time $\approx 2\cdot$ Maximum Cycle time

Exercise 2: Never too late

Complete the signal diagram below for the following IL program. A and B are inputs while C is an output.

```
LD A
AND B
S C
LDN A
ANDN B
R C
```

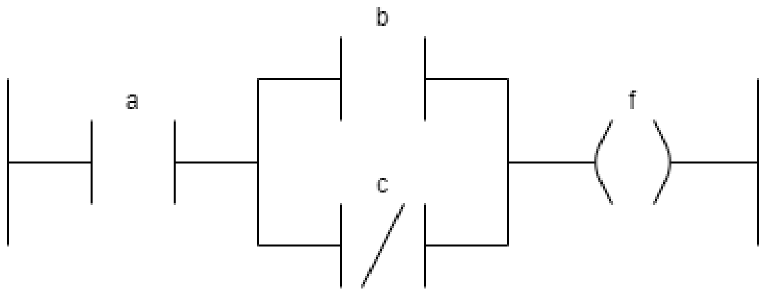
Solution:



Exercise 3: Fun with functions
Implement the function $f = a \wedge (b \vee \neg c)$ in

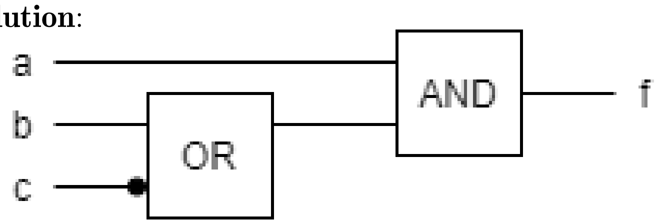
- Ladder diagram

  Solution:



- Function block

  Solution:



- Instruction list

  Solution:

```
LD A
AND (
LD B
ORN C
)
ST F
```

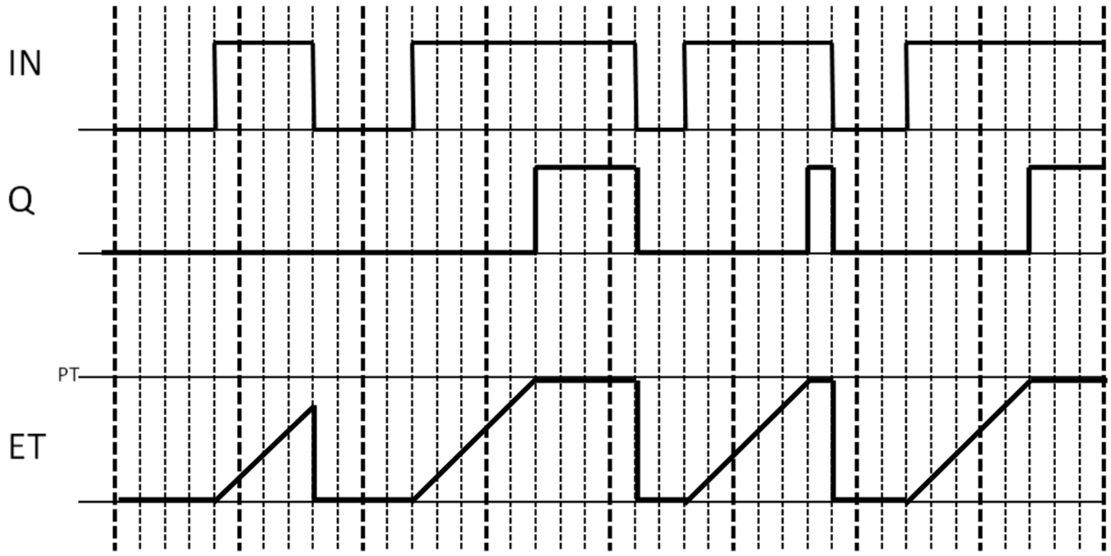
or

```
LD B
ORN C
AND A
ST F
```

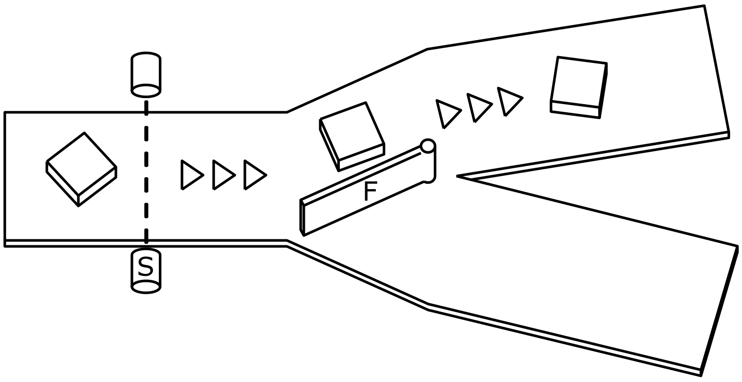
Exercise 4: Good timing

Complete the following diagram of a TON. ET needs five time units to reach PT

Solution:



Exercise 5: Choosing the right path



The sketch above shows a branch in a conveyor belt. The belt transports objects, which are directed either to the upper or to the lower branch by a separator flap (F). **Write a controller for the flap in IL code with the following behaviour and briefly explain what each line of your code does:**
The flap shall pass the first two objects to the lower branch, then five to the upper one, then two to the lower one, five to the upper, and so on. To count the objects, there is a light barrier switch (S). Assume that there can only be up to one object passing per cycle and that objects passing the light barrier also pass the flap in the same cycle. In other words: When the light barrier variable fires, the object has already passed the flap.
Use 15 instructions or less (it is possible with 6 instructions). Hint: Instead of variables, you can also use number literals as operands. For example, LD 5 sets the CR register to 5.

Use the following variables:

Name	Type	Description
S	input	Equals one for a single cycle when an object passed the light barrier, zero otherwise.
F	output	Controls flap. Directs objects to lower branch when F equals zero, otherwise to the upper branch. Initialized with zero.
C	in/out	Use this to count the objects (increment when S is true). Initialized with zero.

Useful IL instructions:

ADD X	Adds an integer X to CR.
MOD X	Computes CR modulo X (for an integer X).
RETC	If CR is true, skips the rest of the program (equivalent to jumping to the end of the program).
RETCN	Same as RETCN, but only jumps if CR is false.
GT X	Checks if CR is greater than an integer X.
LT X	Checks if CR is less than an integer X.

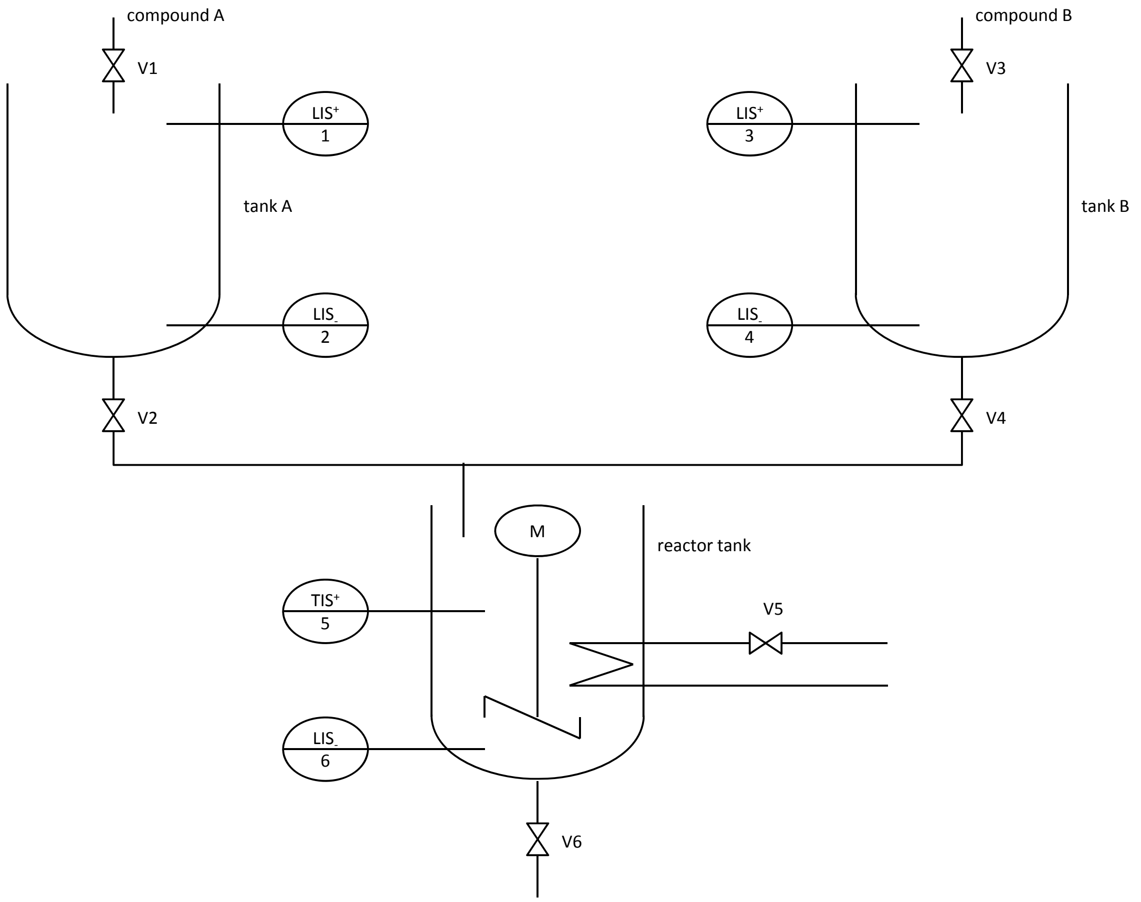
Solution:

```
LD S
RETCN
LD C
ADD 1
ST C
GT 1
S F
LD C
GT 6
R F
R C
```

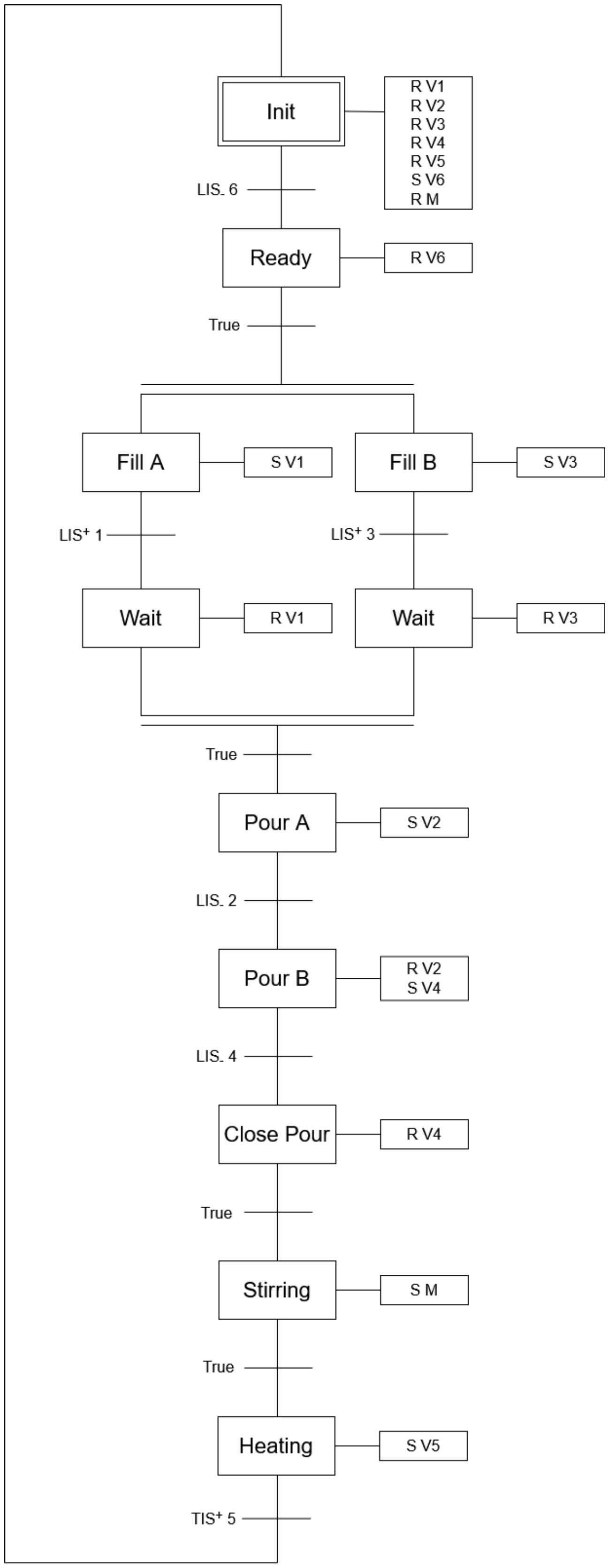
Exercise 6: Secret ingredients
Have a look at the P/ID diagram below. It shows a pipeline and instrumentation diagram of a very simple chemical plant. Two top secret compounds have to be mixed and heated to produce an even more secret compound. As everything is classified your system is completely independent of all other systems. You have been assured that there will always be enough compound A and B to fill your tanks and that you can empty your reactor at any time. You, therefore, only have to follow these important rules:

- The reactor tank can exactly hold the volumes of tank A and tank B combined. There must be no way that the reactor overflows.
- Compound A must never be poured in compound B.
- As timing is highly classified you cannot use timers.
- Tank A and tank B are at the same height. Opening V2 and V4 at the same time might force a backflow causing massive damage to the plant.
- Heating is very delicate and may only be applied when the stirrer is running.
- As soon as the reactor reaches critical temperature the product must be drained.

Create a SFC to control the plant.



Solution:


Init
R V1
R V2
R V3
R V4
R V5
S V6
R M
LIS- 6
Ready
R V6
True
Fill A
S V1
Fill B
S V3
LIS+ 1
LIS+ 3
Wait
R V1
Wait
R V3
True
Pour A
S V2
LIS- 2
Pour B
R V2
S V4
LIS- 4
Close Pour
R V4
True
Stirring
S M
True
Heating
S V5
TIS+ 5