Combinatorial and Sequencing Control

Chapter 13

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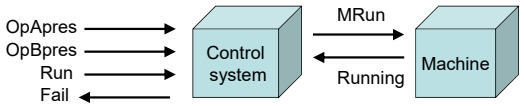
Combinatorial vs. Sequential

- Combinatorial – no memory
  - Only depends on current signals
- Sequential – contains state(s)
  - Next state is a function of:
    - Current inputs
    - Current state

Applicable for:

Machine and/or Control system

Example: Combinatorial Control



Task:

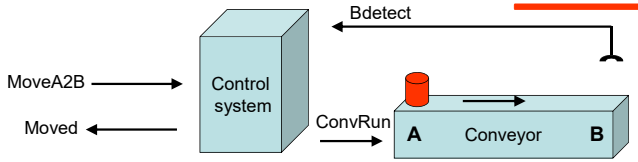
Run the machine while the "Run" signal is given if both operator A and operator B are present.

Give "Fail"-signal if machine doesn't respond.

MRUN = OpApres AND OPBpres AND Run

Fail = MRun AND NOT Running

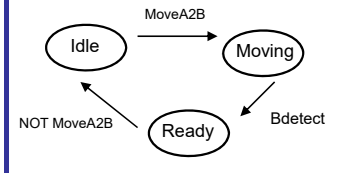
Example: Sequential Control



Task:

Move the object from A to B when the signal "MoveA2B" becomes true.

Give a true signal on "Moved" when the object has reached B.



Consequently….

- The controlled machine may contain states
- The controller may contain states
- The macro view of controller and machine contain states if any subsystem contain states

Focus on the Controller

- Most controllers are sequential
- Is this a sequential controller? :

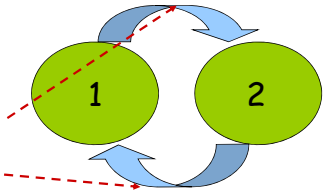
```
while (true) {
       while (NOT MoveA2B)    /* do nothing */  ;
       ConvRun := true;
       while (NOT Bdetect) /* do nothing */  ;
       ConvRun := false;
       Moved := true;
       while (MoveA2B)    /* do nothing */  ;
       Moved := false;
}
```

If yes – where is the state?

Event Driven Systems – State Concept

Sequencing circuits

- one state at a time
- state transfer
- conditions for each state transfer



Sequential Control Tools

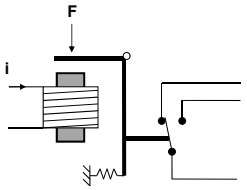
- State diagrams
- Petri nets
- Sequential Function Charts - Grafcet
- Switching theory
- PLC languages IEC61131

PLC programming

The standard IEC 61131-3 implies:

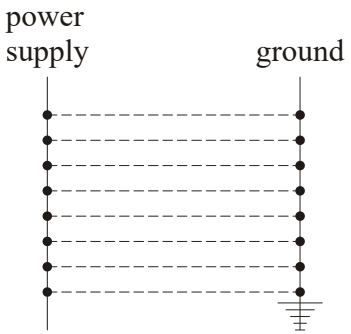
- definition of sequential function chart (SFC), and 4 language options
  - instruction list (IL)
  - function block (FBD)
  - ladder diagram (LD)
  - structured text (ST)

Automation in the Good Old Days….

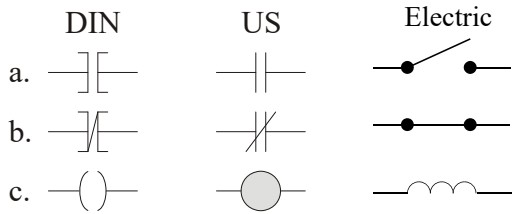


Ladder (LD) is based on this model

Ladder Framework

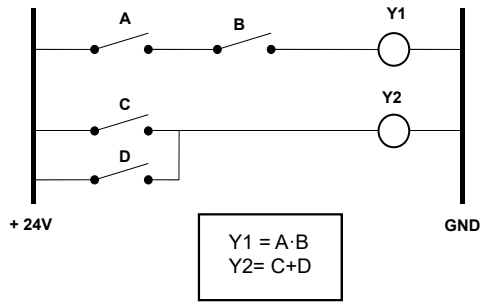


Ladder Symbols

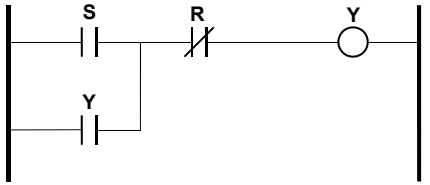


a.) Normally open (NO), make
b.) Normally closed (NC), break
c.) Output, coil

Boolean Logic in LD



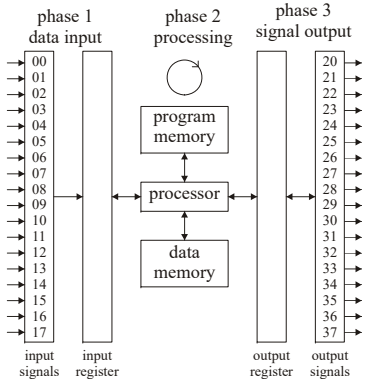
Set – Reset in LD
(State implementation)



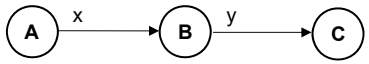
Reflections…

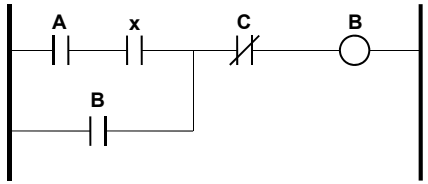
- A relay has only one coil, consequently we use only one coil symbol with the same name.
- An arbitrary number of make/break elements can be used in a ladder diagram.
- Symbols may be physical or logical in a PLC.

An elementary PLC structure

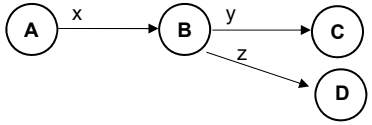


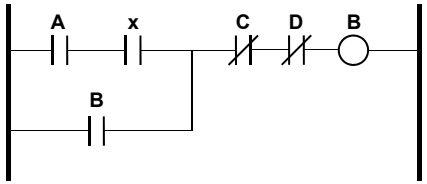
State Encoding in LD





Alternative State Transitions

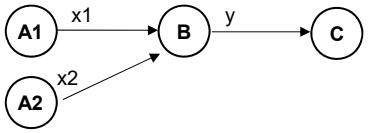


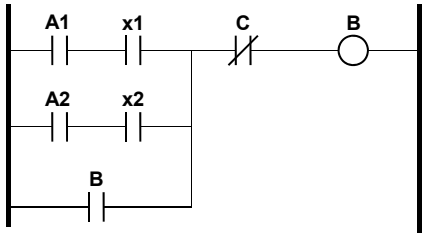


Note!

y and z have to be mutually excluding

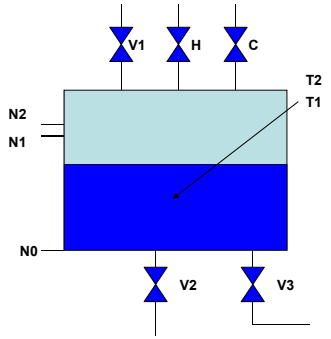
Several Ways to Enter a State



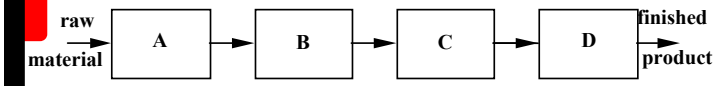


Example:

A mixing tank is used to produce process water with correct temperature (T1 true, T2 false). Supply water with approximately correct temperature is filled with V1 to level N2. If the temperature is too high or too low the water is reduced to N1 using dump valve V3. Then hot or cold water is added to level N2 using H or C. This is repeated until the temperature is correct. Then the water is delivered using V2 and a new batch of water should be produced.



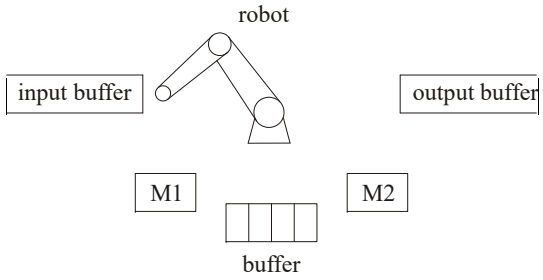
The Classical Transfer Line



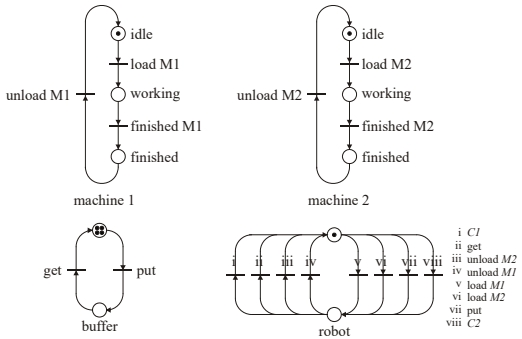
Starving - no input product

Blocking - can not deliver finished product

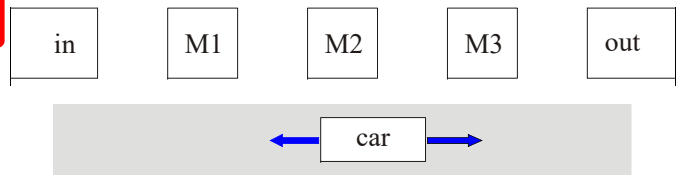
Simple Cell



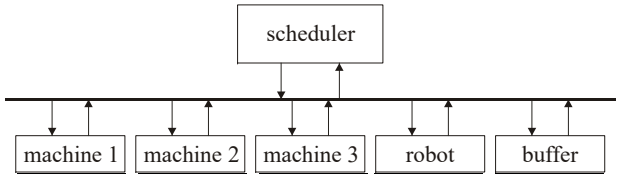
Petri Net of the simple cell



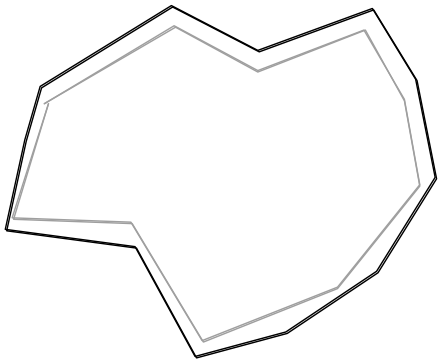
The Manufacturing Cell



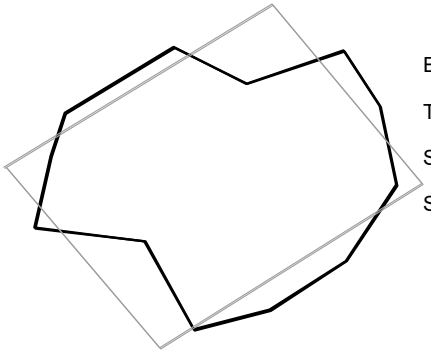
Controlling the Cell



1970s: á la carte programming



1980s: industrial packages



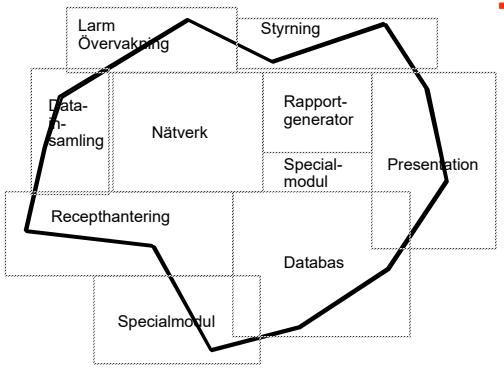
Exempel:

TDC3000

SCADA

SATT line

1990s: open protocols



The Software Problem

- Software ~2 yrs
- Hardware ~5 yrs
- Application ~15 yrs

Requires:

- Standardised interfaces (ActiveX, ODBC, DDE, OPC,...

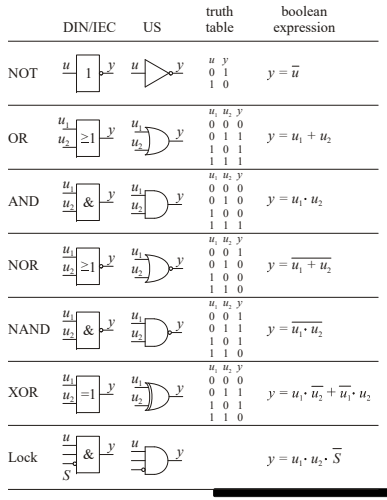
- Solutions have to survive a generation shift (planned obsolescence)
- Has to permit stepwise implementation

Two different developments

- The process industry
  - Replace the analog PID controller with a computer
  - The instrumentation people
- The manufacturing industry
  - Replace the electromechanical relays with a computer
  - The electricians

Sequential Control Tools

- State diagrams √
- Petri nets √
- Sequential Function Charts – Grafcet (SFC)
- **Switching theory**
- PLC languages IEC61131 (LD √)



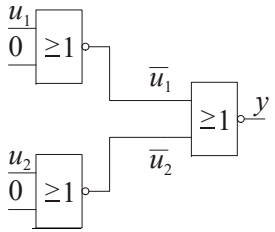
Elementary Boolean expressions

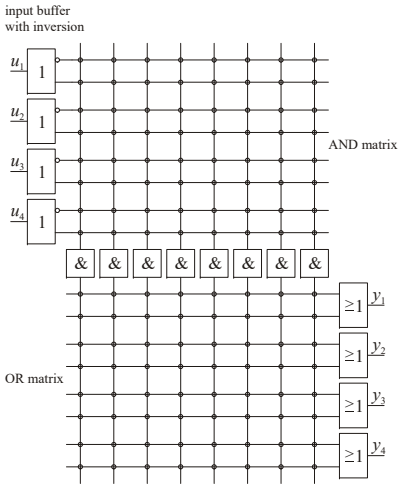
De Morgans theorem

$$\overline{(x \cdot y \cdot z \cdots)} = \bar{x} + \bar{y} + \bar{z} + \cdots$$

$$\overline{(x + y + z + \cdots)} = \bar{x} \cdot \bar{y} \cdot \bar{z} \cdots$$

Three NOR = AND





Structure of PLD, PROM

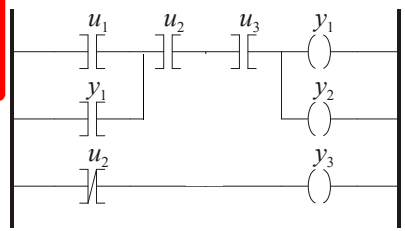
PLC programming

The standard IEC 61131-3 implies:

- definition of sequential function chart (SFC), and 4 language options
  - instruction list (IL)
  - function block (FBD)
  - ladder diagram (LD) √
  - structured text (ST)

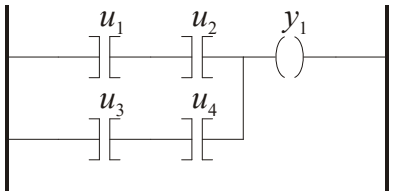
From ladder to PLC code

Instruction List (IL)



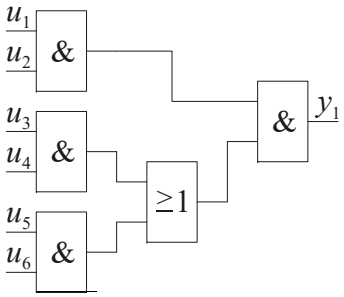

```
ld u1
or y1
and u2
and u3
out Y1
out Y2
ldi u2
out Y3
```


From ladder to PLC




```
ld u1
and u2
ld u3
and u4
orb
out Y1
```


From Boolean to PLC



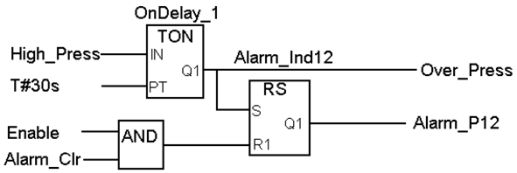

```
ld u1
and u2
ld u3
and u4
ld u5
and u6
orb
anb
out Y1
```


PLC programming

The standard IEC 61131-3 implies:

- definition of sequential function chart (SFC), and 4 language options
  - instruction list (IL) √
  - function block (FBD)
  - ladder diagram (LD) √
  - structured text (ST)

Function Block Diagram (FBD)



PLC programming

The standard IEC 61131-3 implies:

- definition of sequential function chart (SFC), and 4 language options
  - instruction list (IL) √
  - function block (FBD) √
  - ladder diagram (LD) √
  - structured text (ST)

Structured Text (ST)

```
IF SPEED1 > 100.0 THEN
    Flow_Rate := 50.0 + Offset_A1;
ELSE
    Flow_Rate := 100.0;  Steam := ON;
END_IF;
```

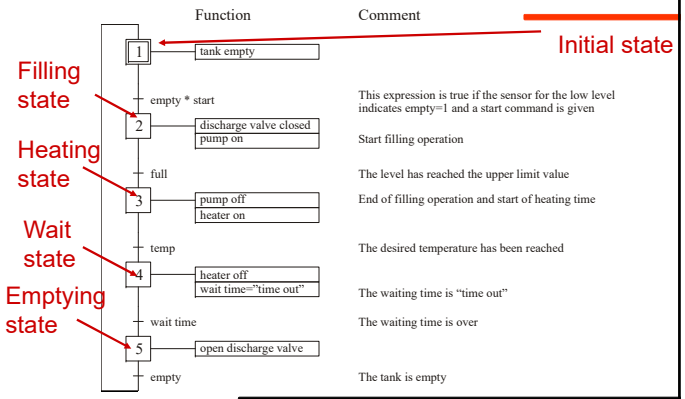
Strongly resembles Pascal

PLC programming

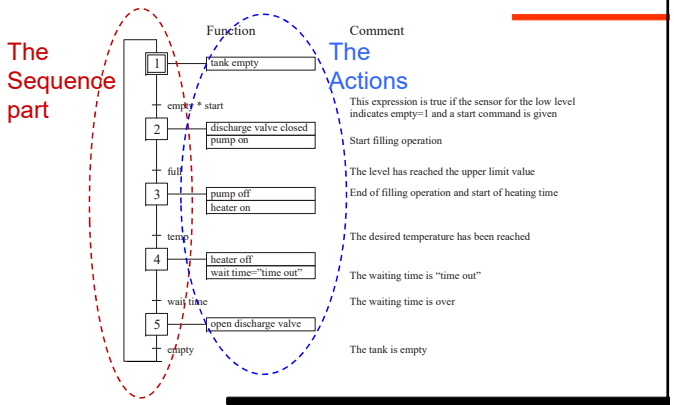
The standard IEC 61131-3 implies:

- definition of sequential function chart (SFC), and 4 language options
  - instruction list (IL) √
  - function block (FBD) √
  - ladder diagram (LD) √
  - structured text (ST) √

Controlling a simple Batch Tank



The Sequential Function Chart



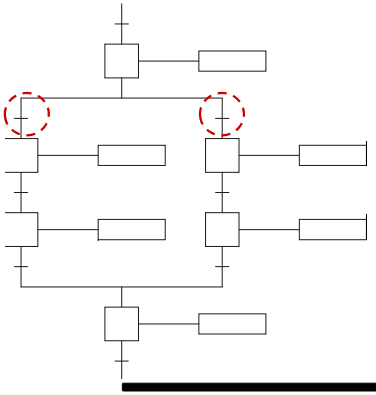
The finite state concept

- The process is represented by 5 states
- Only 1 state at a time!
- A transition signal marks the change from one state to another one
- A condition for transition (from a sensor, a timer, an operator)
- In each state there is an action

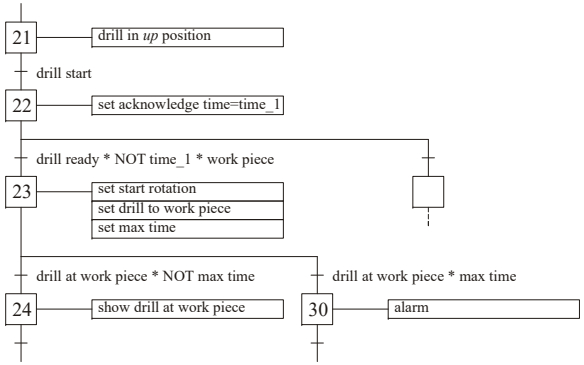
Grafcet

- Developed in France 1977
- Graf + AFCET (Association Francaise pour la Cybernetique Economique et Technique)
- French standard 1982
- IEC standard 1988 - IEC 848 (=SFC, Sequential Function Chart)
- Essential part of IEC 61131-3

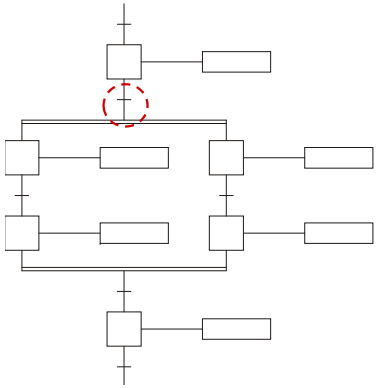
Alternating Parallel Branches

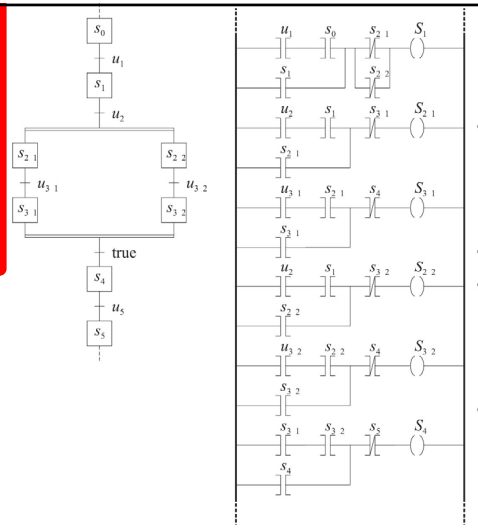


Grafcet for a Drill
(Alternating parallel branches)



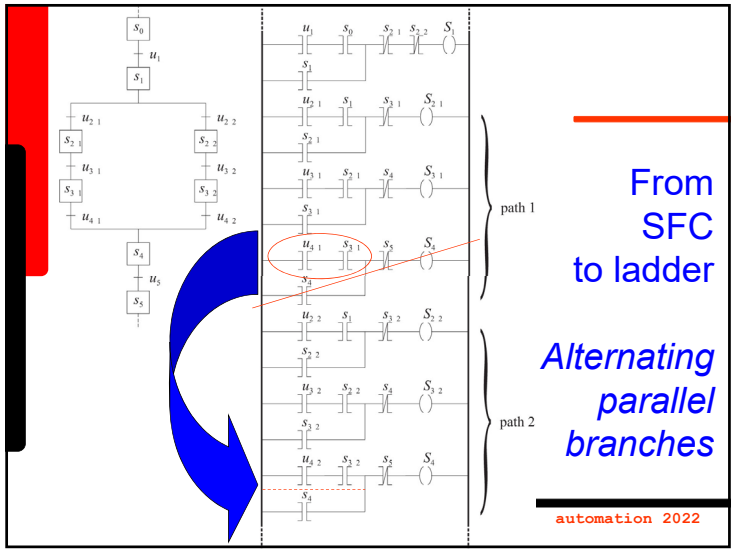
Simultaneous Parallel Branches





From SFC to ladder

Simul-taneous parallel branches



From SFC to ladder

Alternating parallel branches

PLC open

- PLC open is an organisation to support the standard 61131-3
- Manufacturer and product independent
- Members of the PLC open group are expected to deliver products that follow the 61131-3 standard

http://www.plcopen.org/

PLC Open (2)

- Open systems can be replaced with software or hardware from a third party
- Some companies call products open incorrectly
- The IEC 61131 standard encourages interchangeable systems
- Open architecture controllers replace a PLC with a standard computer

Batch Operation

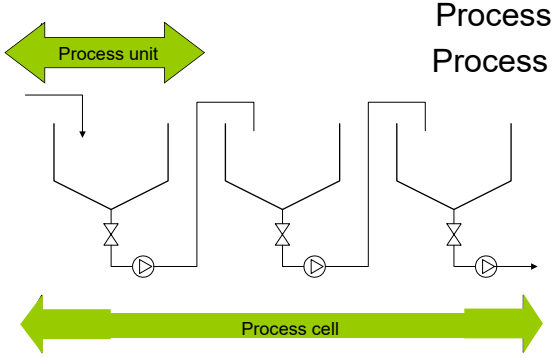
- Batch operation software is standardised in the ISA S-88 standard (ISA)
- S-88 defines models and terminology

www.isa.org/isa88

Structure of a Batch Operation

Process cell

Process unit



Important Concepts

- Process cell
- Process unit
- Batch
- General recipe
- Control recipe
- Phase

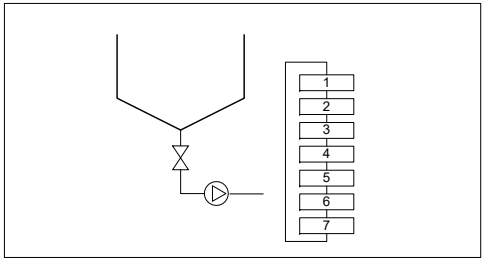
Batch – from the start

- The customer has a manufacturing procedure (recipe)
- How to structure the software ?

Add 10 l of water
Add 5 l of ethanol
Mix 3 min, 300 rpm
Add 2 l of salt
Mix 2 min, 1000 rpm
Heat until 45° C
Empty after 5 min

Batch (2)

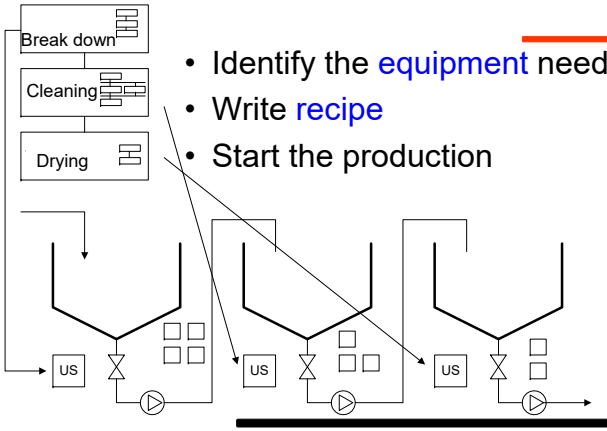
Identify a sequence of operations in the unit



Batch (3)

- Identify phases and parameters for each unit
  - Raw material (sort, volume)
  - Mixing (time, speed)
  - Temperature control (setpoint value)
  - Empty (time)
- Write the executing of the recipe

Batch (4) - several units



- Identify the equipment need
- Write recipe
- Start the production