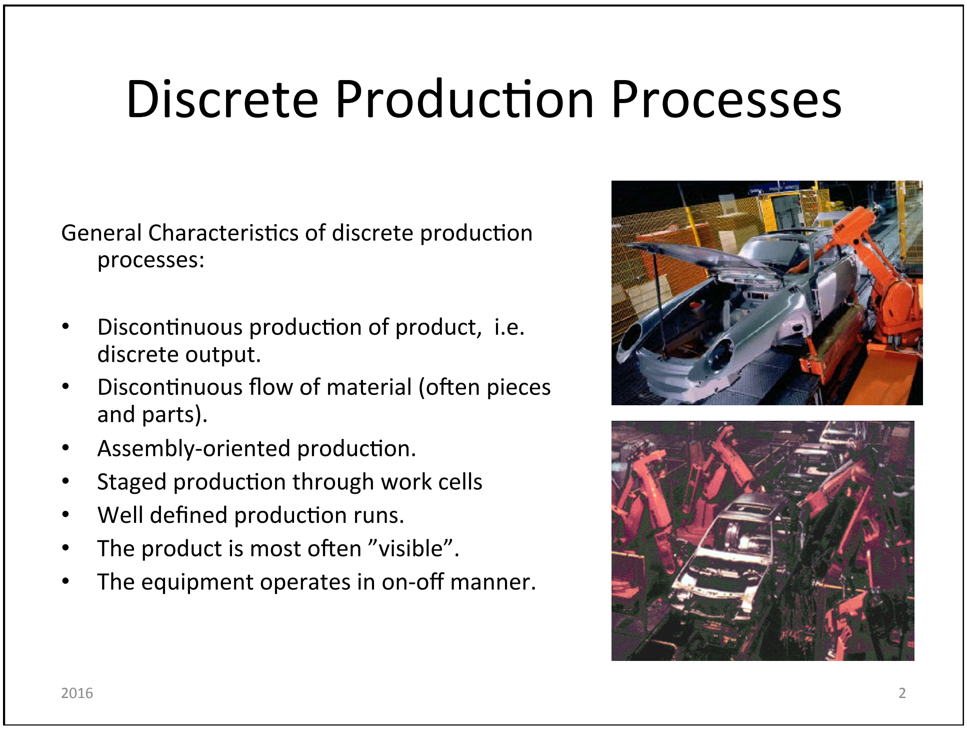
Market-Driven Systems

Marknadsstyrda System

FRTN20

Lecture 2: Discrete Production



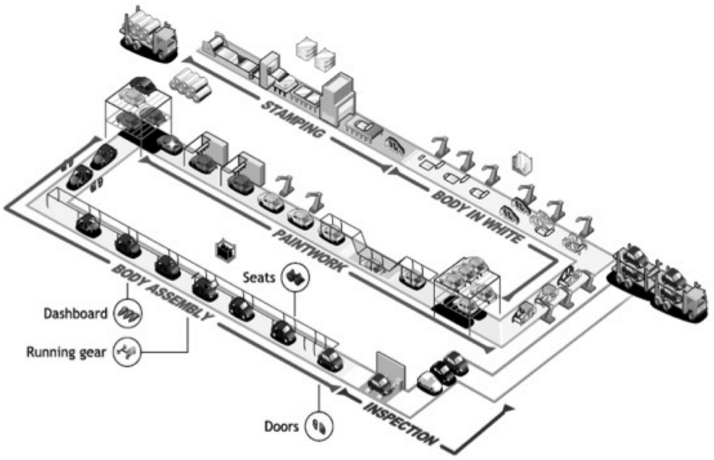
Discrete Production Processes

General Characteristics of discrete production processes:

- Discontinuous production of product, i.e. discrete output.
- Discontinuous flow of material (often pieces and parts).
- Assembly-oriented production.
- Staged production through work cells
- Well defined production runs.
- The product is most often ”visible”.
- The equipment operates in on-off manner.

Discrete Production Processes

A discrete production process is the assembly of piece parts into products. The product is a discrete entity.



Discrete Event Systems

Definition:

A *Discrete Event System (DES)* is a discrete-state, event-driven system, that is, its state evolution depends entirely on the occurrence of asynchronous discrete events over time.

Sometimes the name *Discrete Event Dynamic System (DEDS)* is used to emphasize the dynamic nature of DES.

Discrete Event Systems

1. The state space is a discrete set
2. The state transition mechanism is event-driven
3. The events can be synchronized by a clock, but they do not have to be (i.e., the system can be asynchronous)

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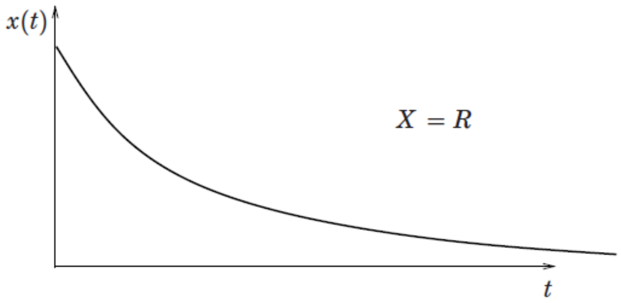
Continuous-Time Systems

State trajectory is the solution of a differential equation

$$\dot{x}(t) = f(x(t), u(t), t)$$



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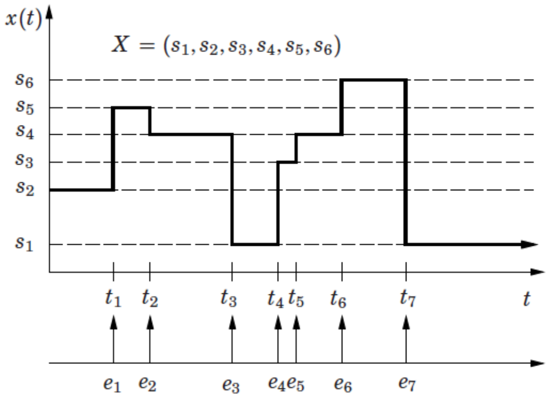
Discrete-Event Systems

State trajectory (sample path) is piecewise constant function that jumps from one value to another when an event occurs.



How do we control a machine?

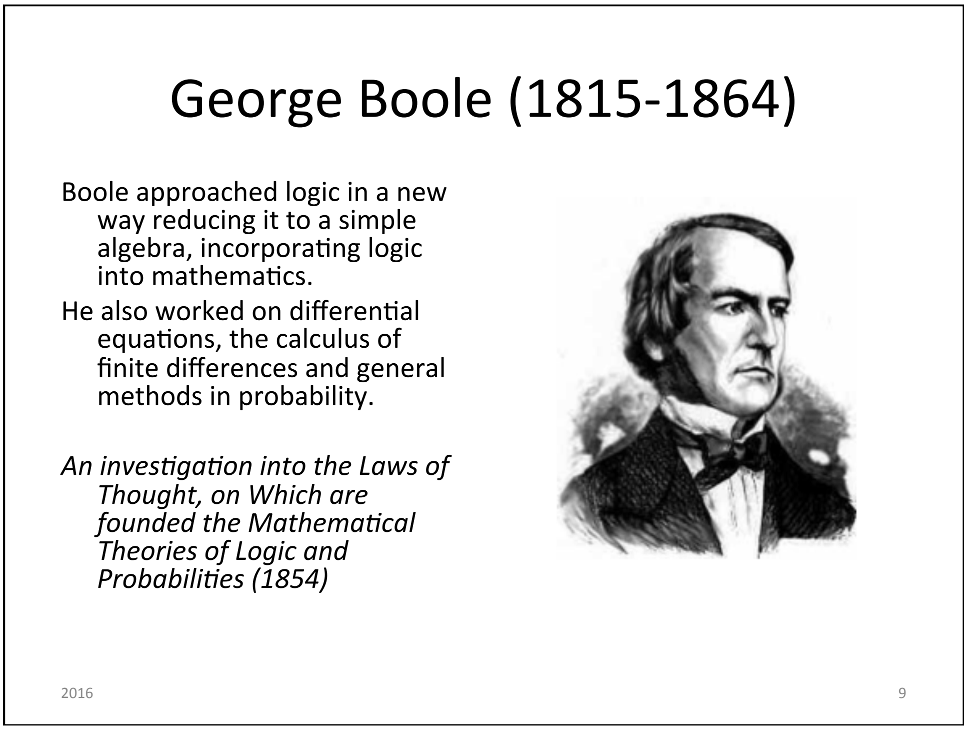
Automation of the discrete operations (on-off) is largely a matter of a series of carefully timed on-off steps. The equipment performing the operations operates in an on-off manner.

Discrete signals

- Control parameters: true or false
- Actuators: on or off

Interlocks (”förreglingar”)

- Output = function(input)
- Boolean algebra



George Boole (1815-1864)

Boole approached logic in a new way reducing it to a simple algebra, incorporating logic into mathematics.

He also worked on differential equations, the calculus of finite differences and general methods in probability.

An investigation into the Laws of Thought, on Which are founded the Mathematical Theories of Logic and Probabilities (1854)

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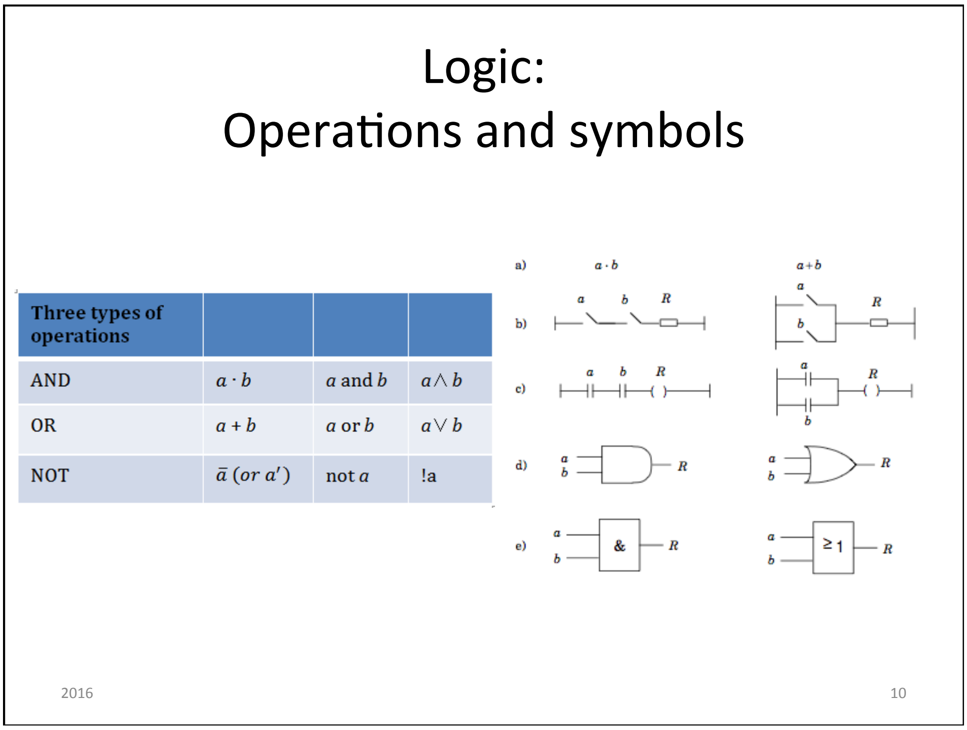

Logic:
Operations and symbols

Three types of operations			
AND	$a \cdot b$	a and b	$a \wedge b$
OR	$a + b$	a or b	$a \vee b$
NOT	$\bar{a}$ (or a')	not a	!a

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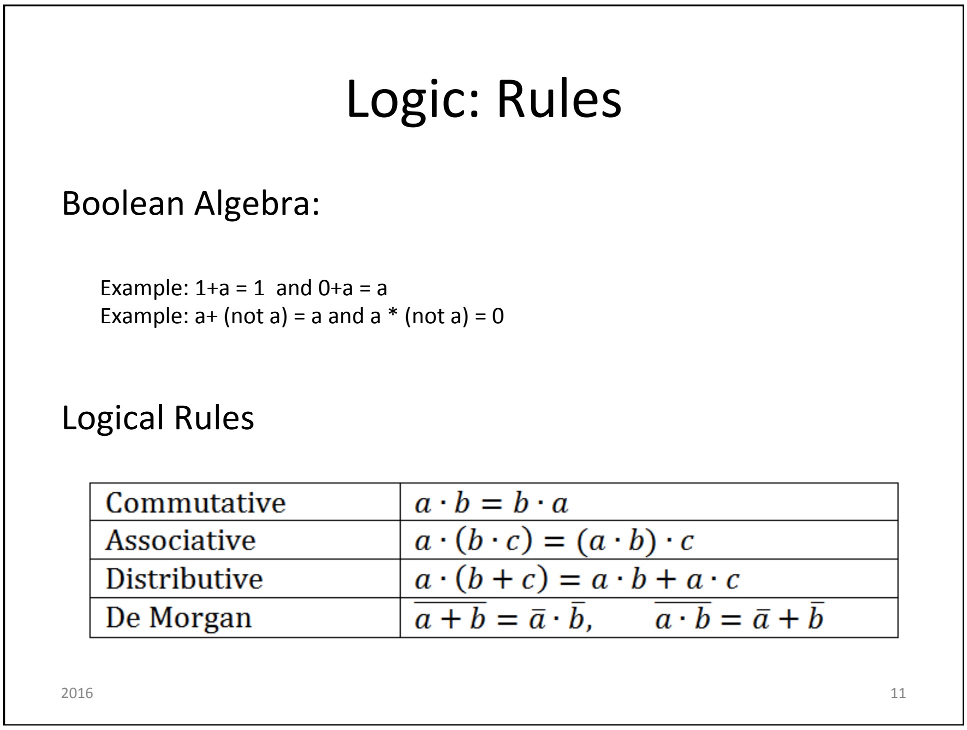


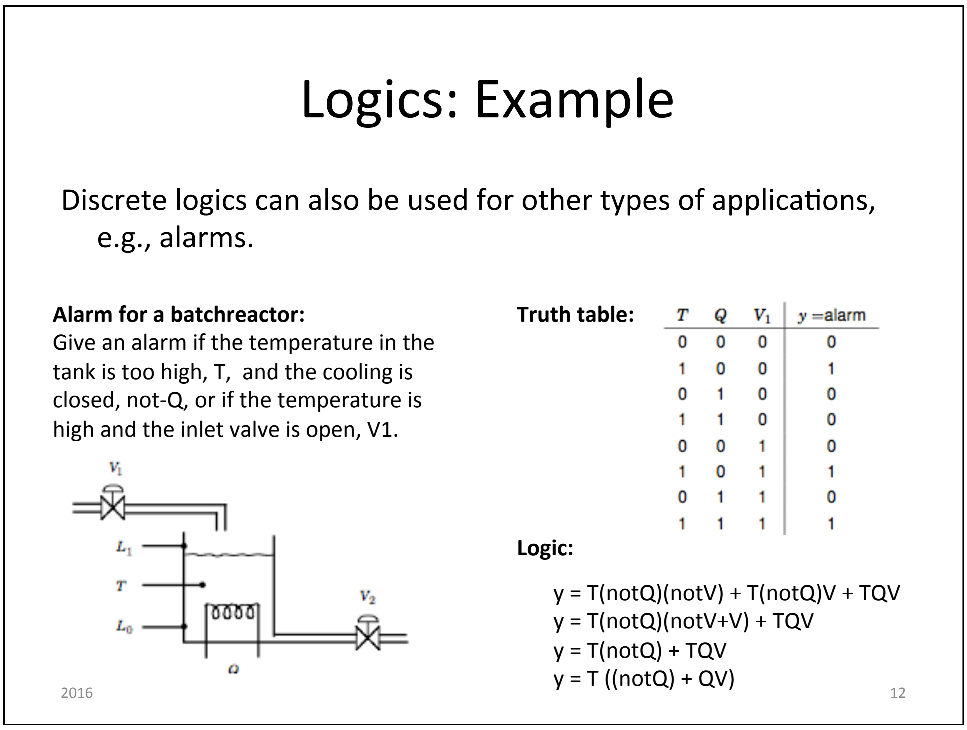
Logic: Rules

Boolean Algebra:

Example: 1+a = 1 and 0+a = a
Example: a+ (not a) = a and a * (not a) = 0

Logical Rules

Commutative	$a \cdot b = b \cdot a$
Associative	$a \cdot (b \cdot c) = (a \cdot b) \cdot c$
Distributive	$a \cdot (b + c) = a \cdot b + a \cdot c$
De Morgan	$\overline{a + b} = \bar{a} \cdot \bar{b}, \qquad \overline{a \cdot b} = \bar{a} + \bar{b}$



Logics: Example

Discrete logics can also be used for other types of applications, e.g., alarms.

Alarm for a batchreactor:
Give an alarm if the temperature in the tank is too high, T, and the cooling is closed, not-Q, or if the temperature is high and the inlet valve is open, V1.

V_1
L_1
T
L_0
V_2
Q

Truth table:

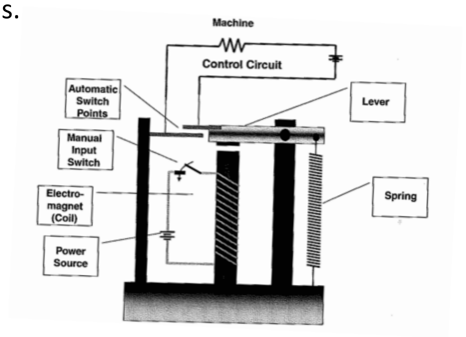
T	Q	V_1	y =alarm
0	0	0	0
1	0	0	1
0	1	0	0
1	1	0	0
0	0	1	0
1	0	1	1
0	1	1	0
1	1	1	1

Logic:

y = T(notQ)(notV) + T(notQ)V + TQV
y = T(notQ)(notV+V) + TQV
y = T(notQ) + TQV
y = T ((notQ) + QV)

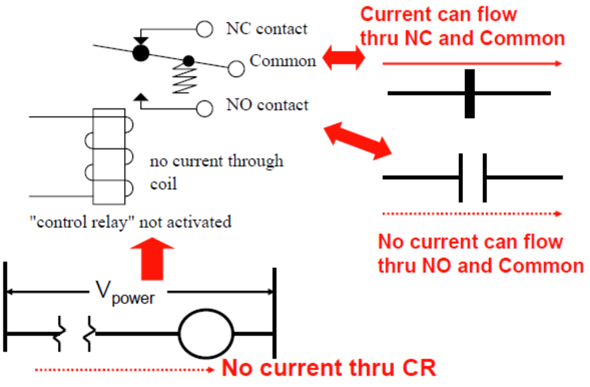
Electro-Mechanical Relays

The basic device invented for control of discrete production processes is the automatic switch and interconnected sequences of automatic switches.



Today, the automatic switches are replaced by computer programs. This technological innovation took place in the 1960s, since then discrete systems have become more automated.

Control Relay – Not Activated

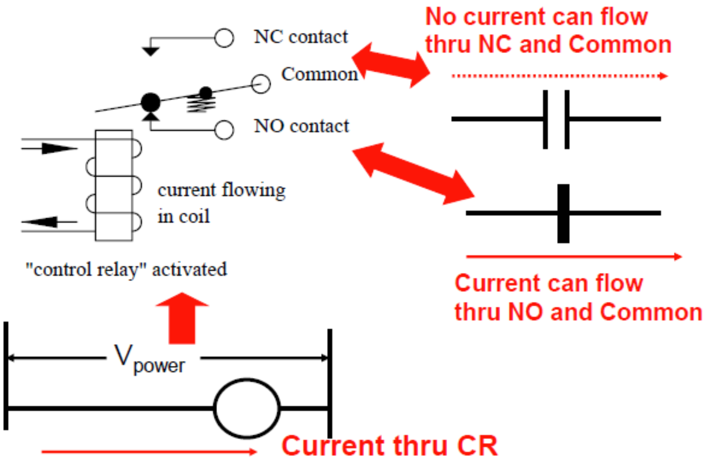


Current can flow thru NC and Common

No current can flow thru NO and Common

No current thru CR

Control Relay - Activated



No current can flow thru NC and Common

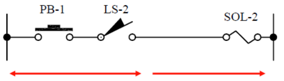
Current can flow thru NO and Common

Current thru CR

Logic Control

AND

IF (PB-1 is pressed) AND (LS-2 is activated)
THEN (SOL-2 will be turned on)

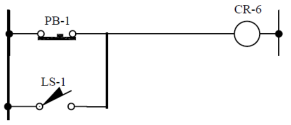


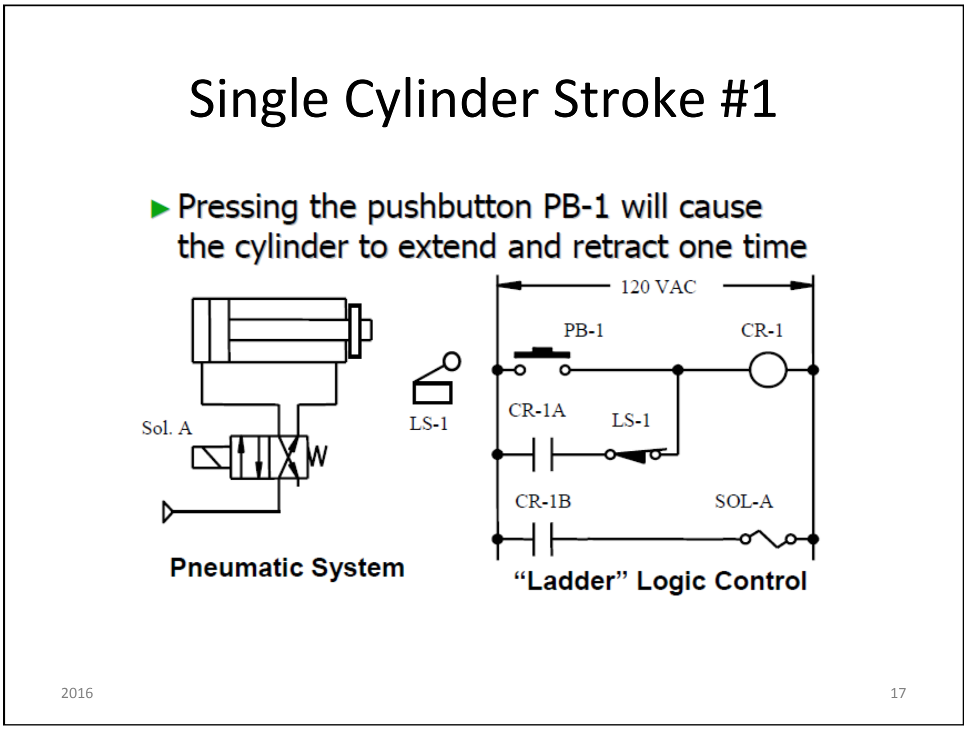
IF there is continuity across the inputs

THEN current will flow through the output

OR

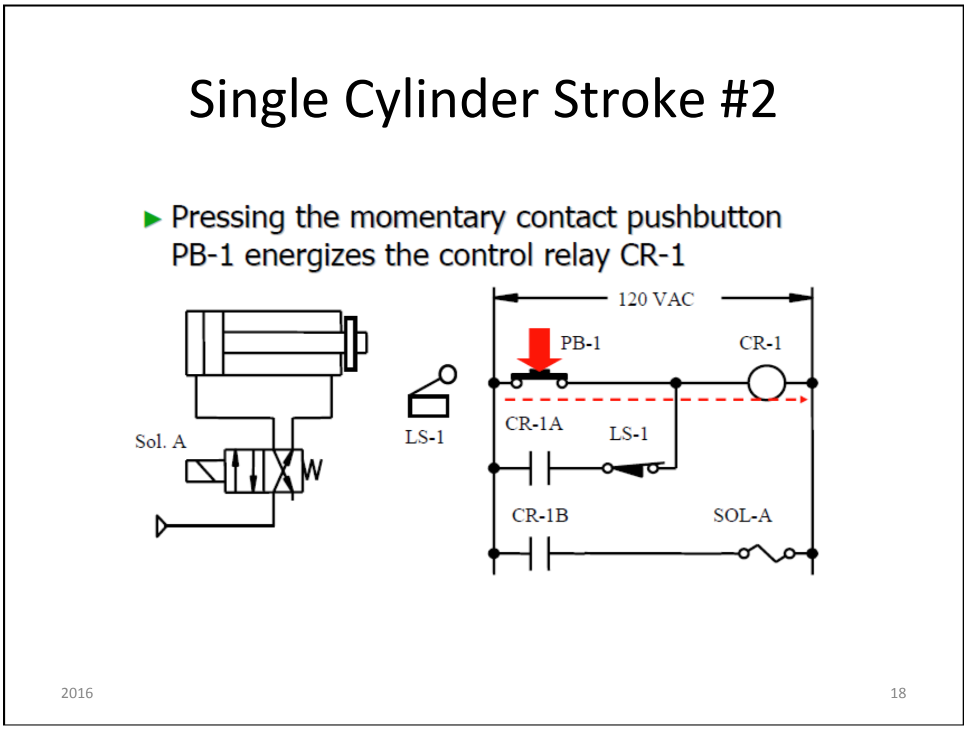
IF (PB-1 is NOT pressed) OR (LS-1 is activated)
THEN (CR-6 will be turned on)





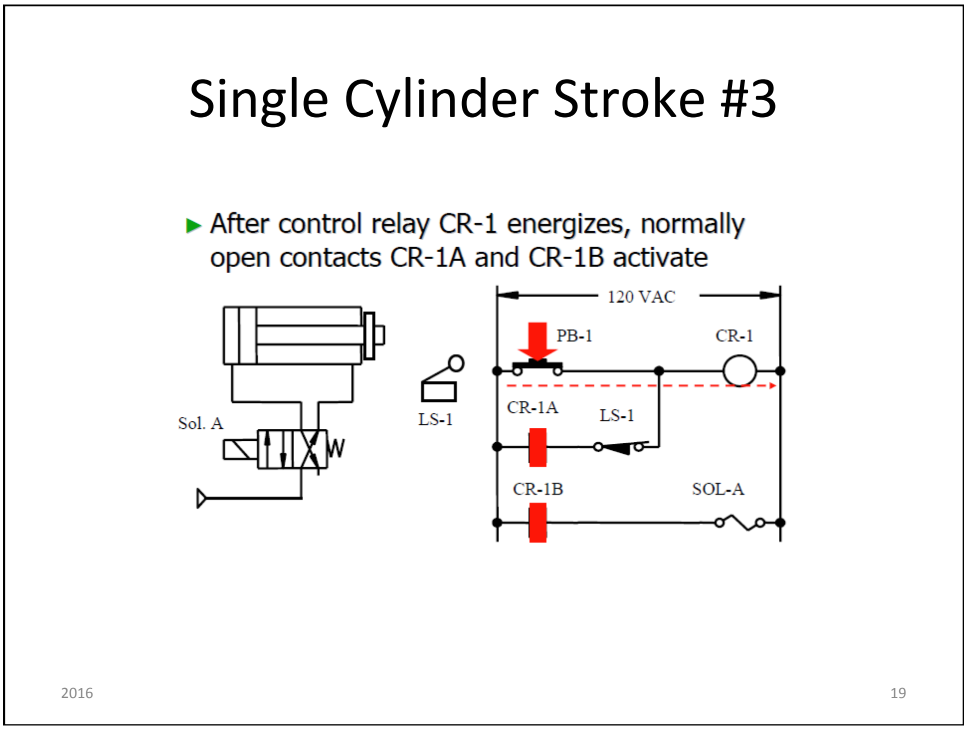
Single Cylinder Stroke #1

- Pressing the pushbutton PB-1 will cause the cylinder to extend and retract one time



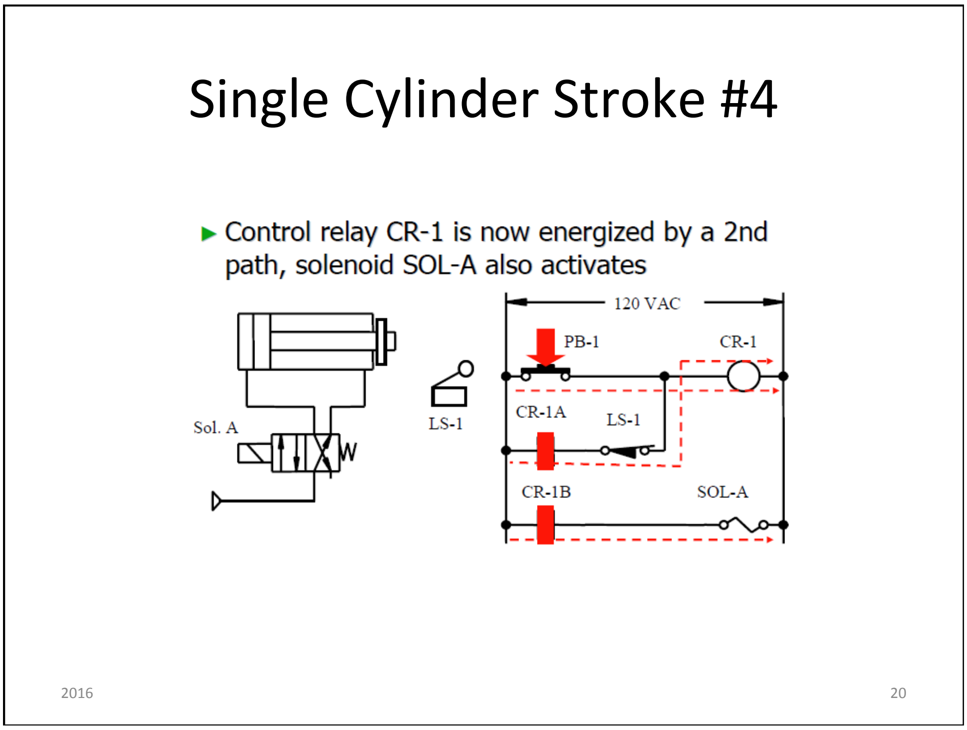
Single Cylinder Stroke #2

- Pressing the momentary contact pushbutton PB-1 energizes the control relay CR-1



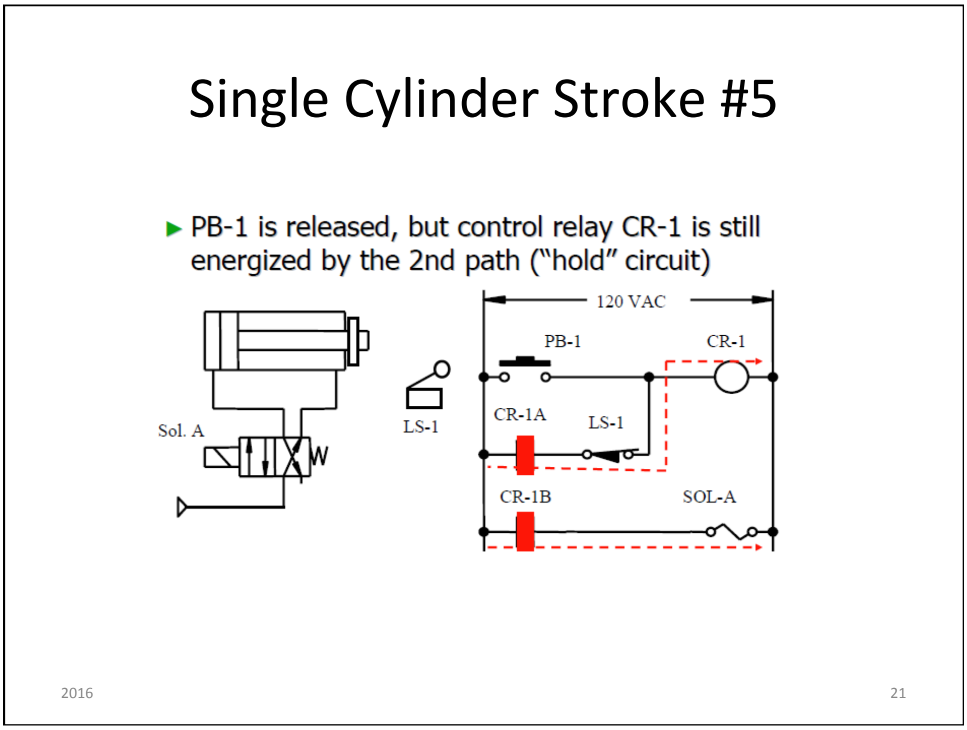
Single Cylinder Stroke #3

- After control relay CR-1 energizes, normally open contacts CR-1A and CR-1B activate



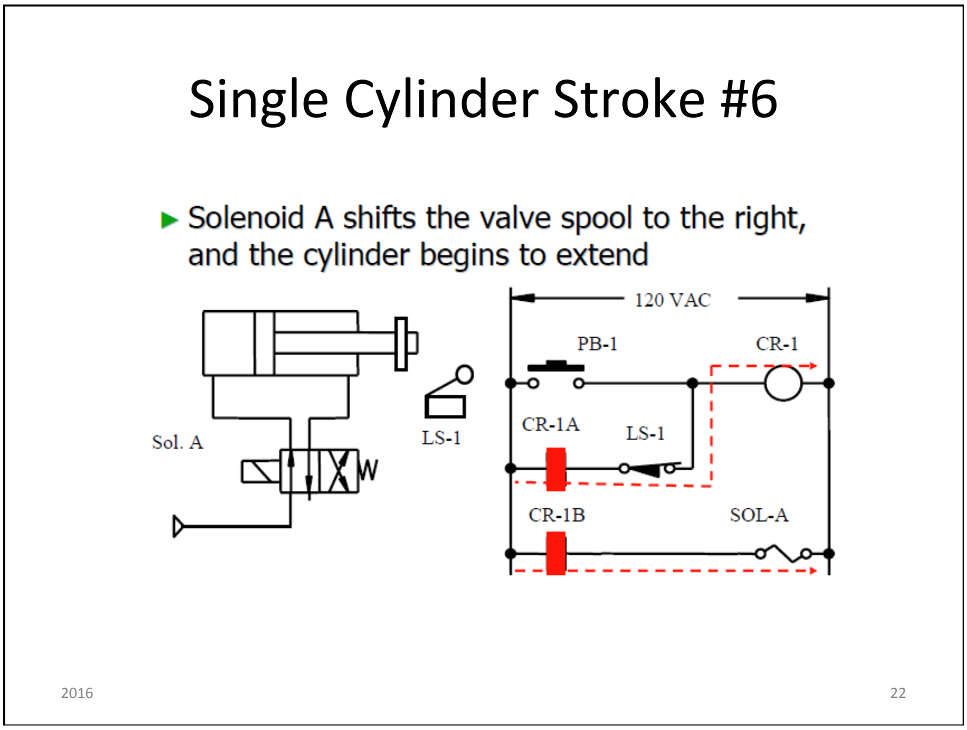
Single Cylinder Stroke #4

- Control relay CR-1 is now energized by a 2nd path, solenoid SOL-A also activates



Single Cylinder Stroke #5

- PB-1 is released, but control relay CR-1 is still energized by the 2nd path ("hold" circuit)

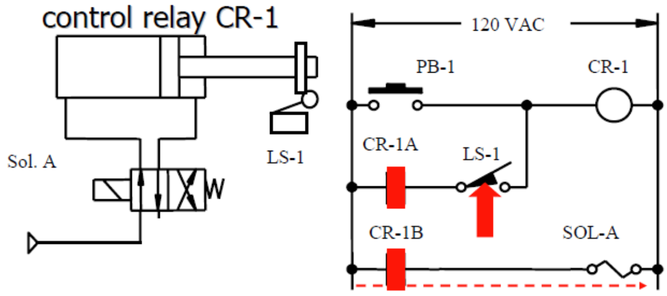


Single Cylinder Stroke #6

- Solenoid A shifts the valve spool to the right, and the cylinder begins to extend

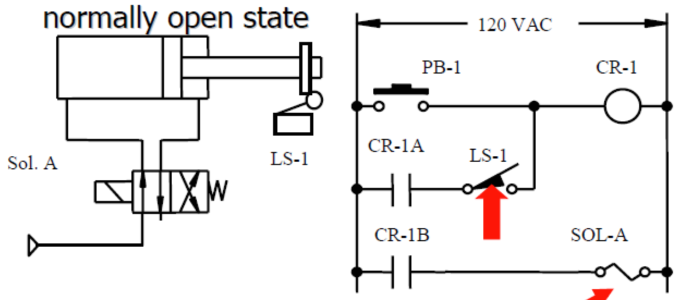
Single Cylinder Stroke #7

- Cylinder activates the normally closed limit switch LS-1, which "kills" the hold circuit for control relay CR-1



Single Cylinder Stroke #8

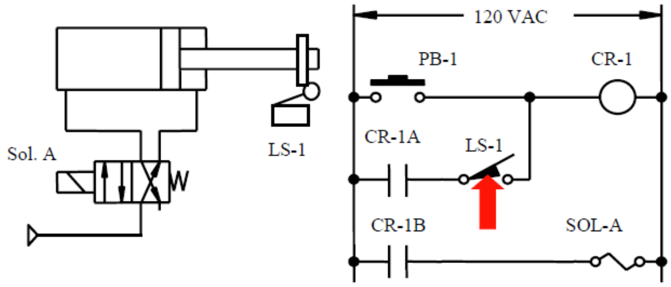
- With control relay CR-1 de-activated, the contacts CR-1A and CR-1B return to their normally open state



Solenoid SOL-A is no longer energized

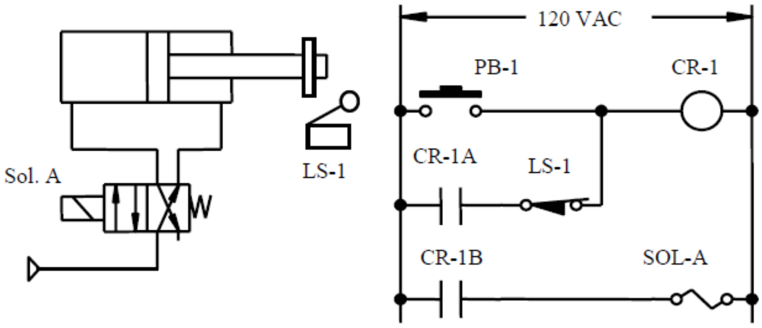
Single Cylinder Stroke #9

- CR-1B is now open, SOL-A is de-activated, spring returns valve to default state



Single Cylinder Stroke #10

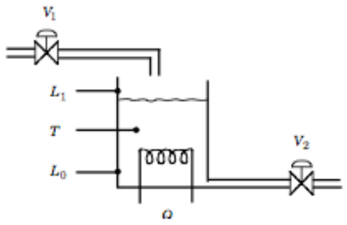
- Cylinder begins to retract, and "rolls off" of LS-1, which returns to its N.C. state

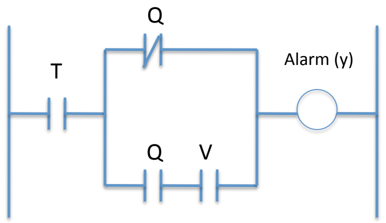


Batch Reactor Example revisited

Using ladder diagrams for simple interlocks

Alarm for a batchreactor:
Give an alarm if the temperature in the tank is too high, T, and the cooling is closed, not-Q, or if the temperature is too high, T, and the inlet valve is open,





Logic:

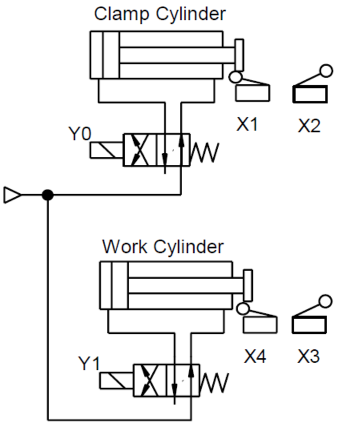
y = T(notQ)(notV) + T(notQ)V + TQV
y = T(notQ)(notV+V) + TQV
y = T(notQ) + TQV
y = T ((notQ) + QV)

Logics:
Example (discrete production process)

A common manufacturing process:

- receive an object
- position the object
- clamp the object
- “do something” to (work on) the object
- release the object

Example: Clamp/Work Layout

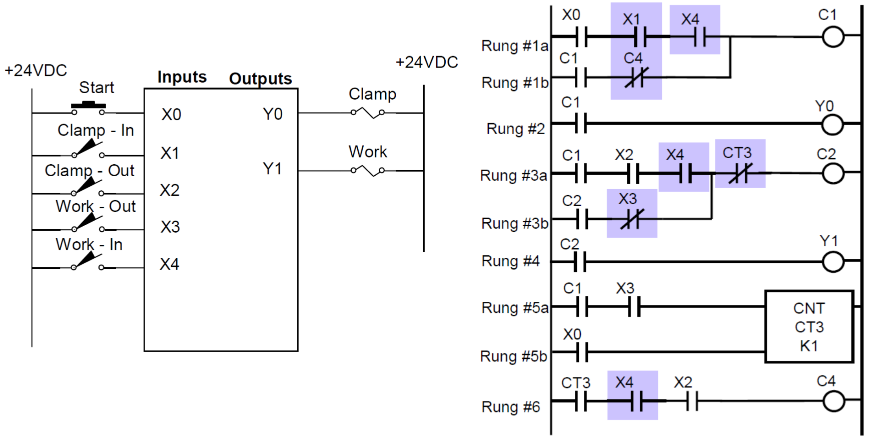


Process:

1. Press the ”START” button
2. Extend the clamp cylinder
3. When the clamp cylinder is fully engaged, start extending the work cylinder
4. When the work has finished, retract the work cylinder
5. When the work cylinder is fully retracted, retract the clamp cylinder

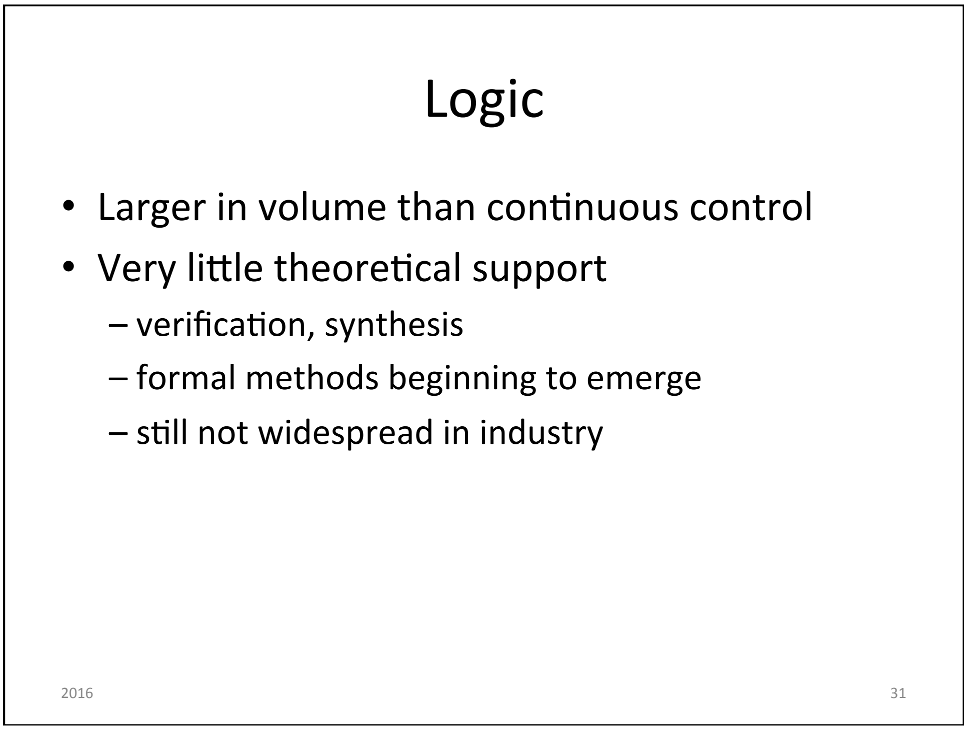
NOTE: Example from University of Alabama (www.me.au.edu)

Example: Clamp/Work Layout



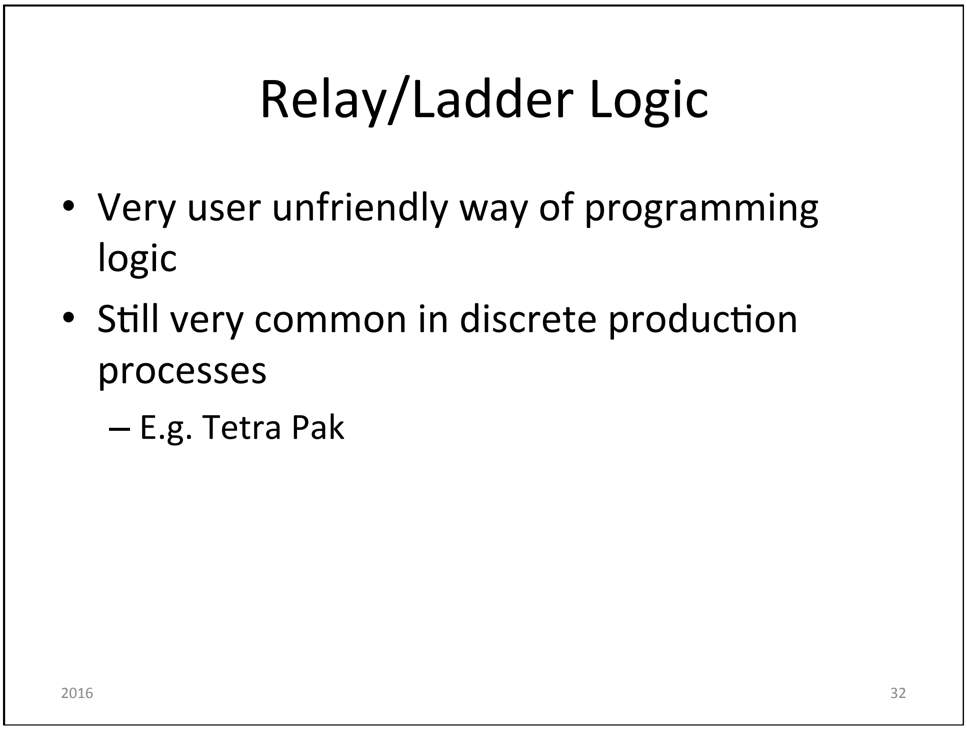
Relay Ladder Logic Notation with counter

Each relay represents a state variable



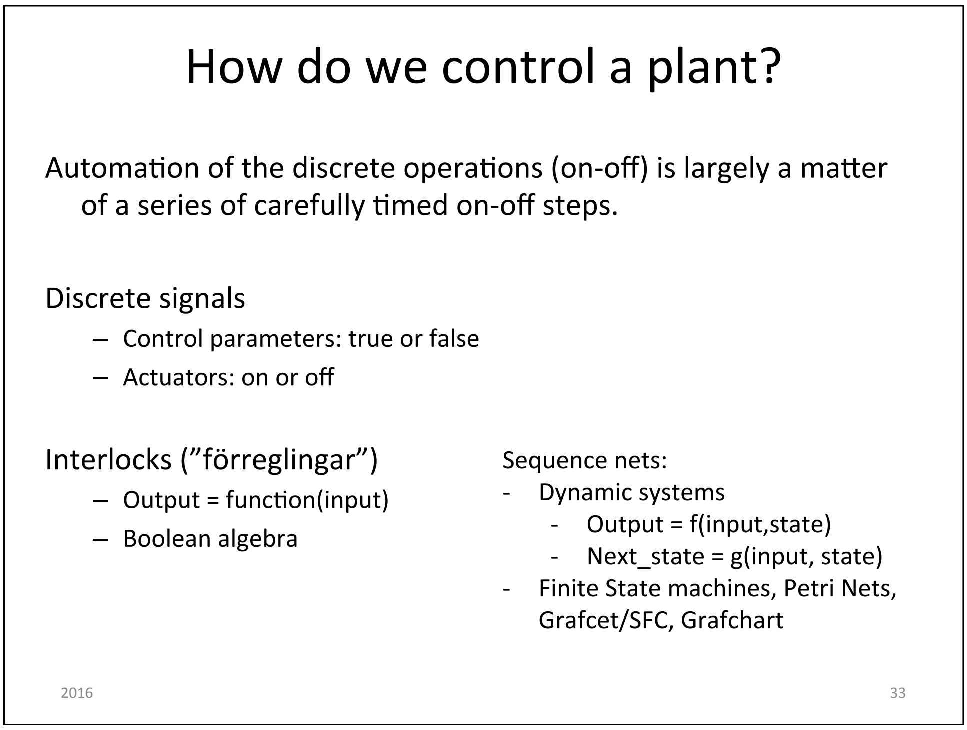
Logic

- Larger in volume than continuous control
- Very little theoretical support
  - verification, synthesis
  - formal methods beginning to emerge
  - still not widespread in industry



Relay/Ladder Logic

- Very user unfriendly way of programming logic
- Still very common in discrete production processes
  - E.g. Tetra Pak



How do we control a plant?

Automation of the discrete operations (on-off) is largely a matter of a series of carefully timed on-off steps.

Discrete signals

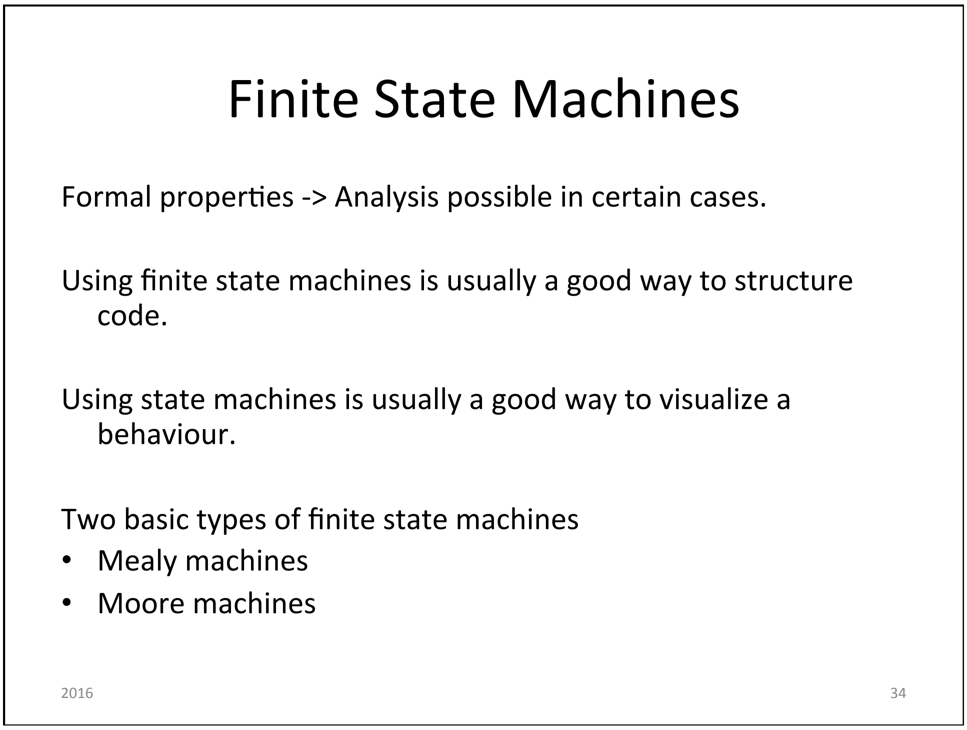
- Control parameters: true or false
- Actuators: on or off

Interlocks (”förreglingar”)

- Output = function(input)
- Boolean algebra

Sequence nets:

- Dynamic systems
    - Output = f(input,state)
    - Next_state = g(input, state)
- Finite State machines, Petri Nets, Grafcet/SFC, Grafchart



Finite State Machines

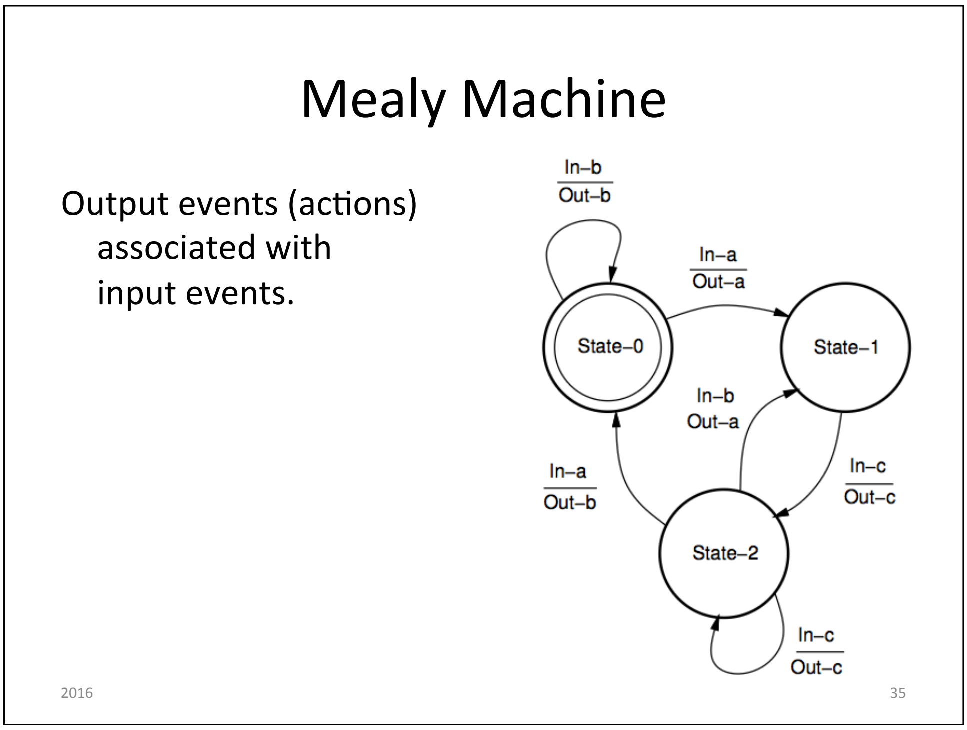
Formal properties -> Analysis possible in certain cases.

Using finite state machines is usually a good way to structure code.

Using state machines is usually a good way to visualize a behaviour.

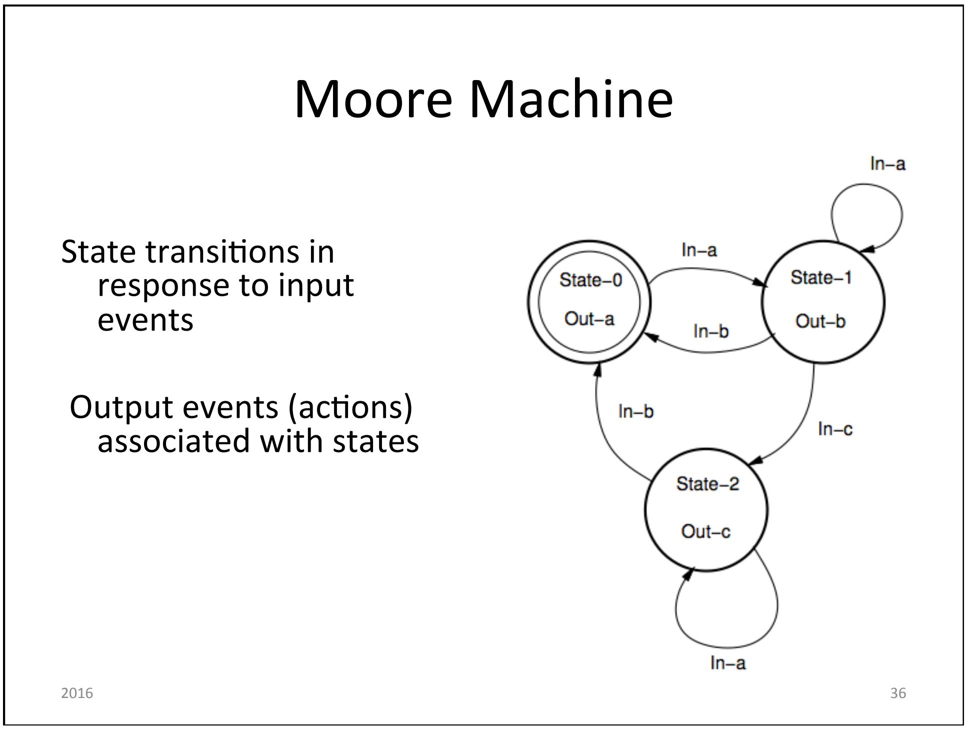
Two basic types of finite state machines

- Mealy machines
- Moore machines



Mealy Machine

Output events (actions) associated with input events.



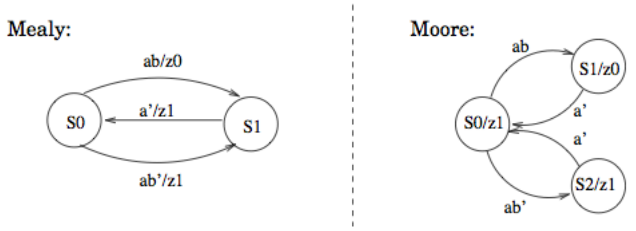
Moore Machine

State transitions in response to input events

Output events (actions) associated with states

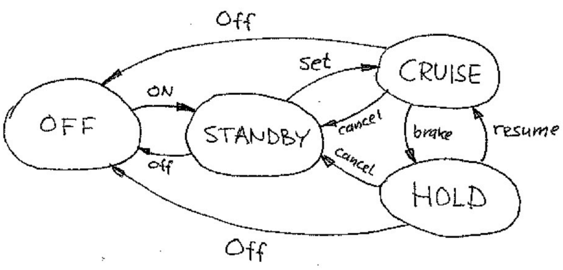
Mealy and Moore Machines

A Mealy-machine (left) and the corresponding Moore-machine (right) are shown. The two state machines have two inputs, a and b, and two outputs, z0 and z1.



Finite State machine Cruise Control

Cruise controls are common in vehicle applications.



State Machines

Ordinary state machines lack structure.

Extensions needed to make them practically useful

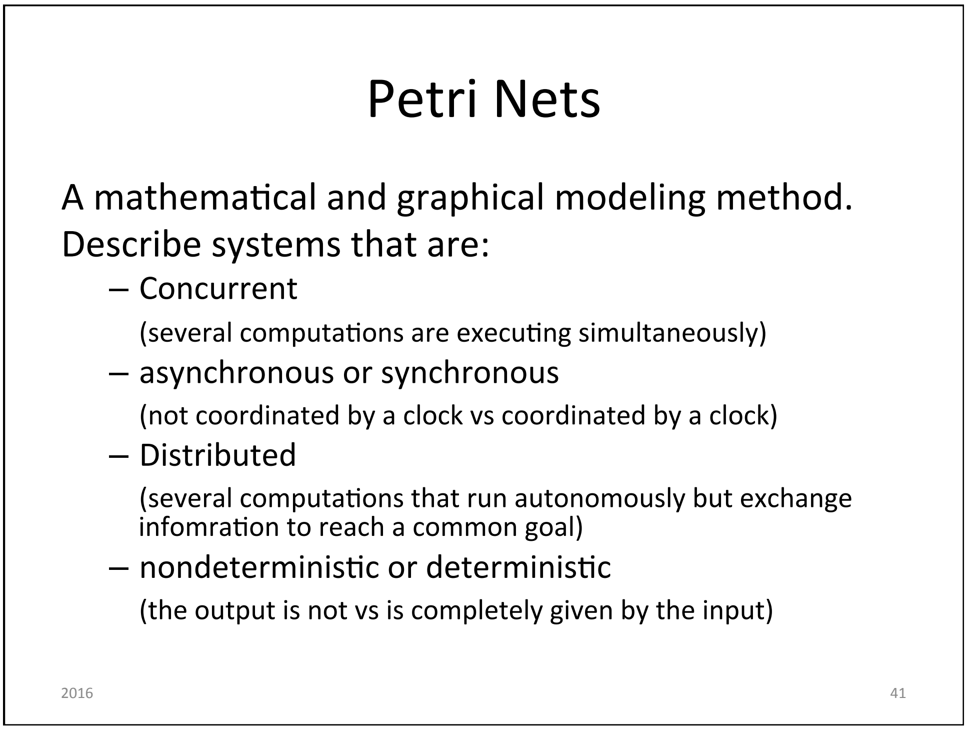
- hierarchy
- concurrency
- history (memory)

Carl Adam Petri (1926-2010)

Carl Adam Petri (born July 12, 1926) is a German mathematician and computer scientist.

Petri Nets were invented in August 1939 by Carl Adam Petri - at the age of 13. He documented the Petri net in 1962 as part of his dissertation. It significantly helped define the modern studies of complex systems and workflow management.

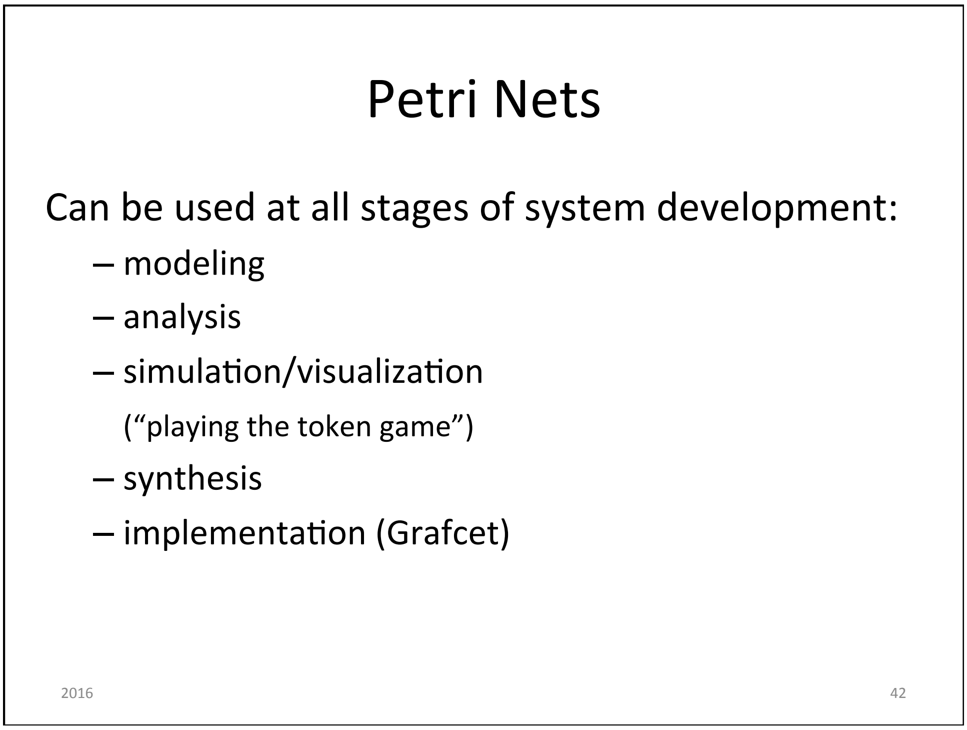
Kommunikation mit Automaten, Carl Adam Petri (1962)



Petri Nets

A mathematical and graphical modeling method.
Describe systems that are:

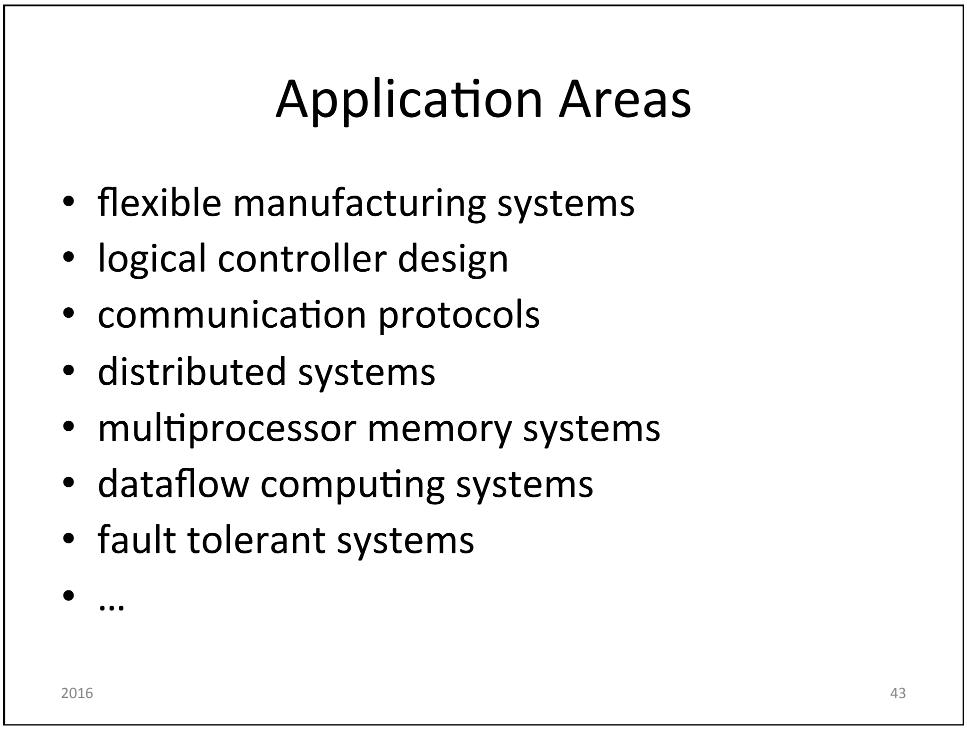
- Concurrent
  (several computations are executing simultaneously)
- asynchronous or synchronous
  (not coordinated by a clock vs coordinated by a clock)
- Distributed
  (several computations that run autonomously but exchange infomration to reach a common goal)
- nondeterministic or deterministic
  (the output is not vs is completely given by the input)



Petri Nets

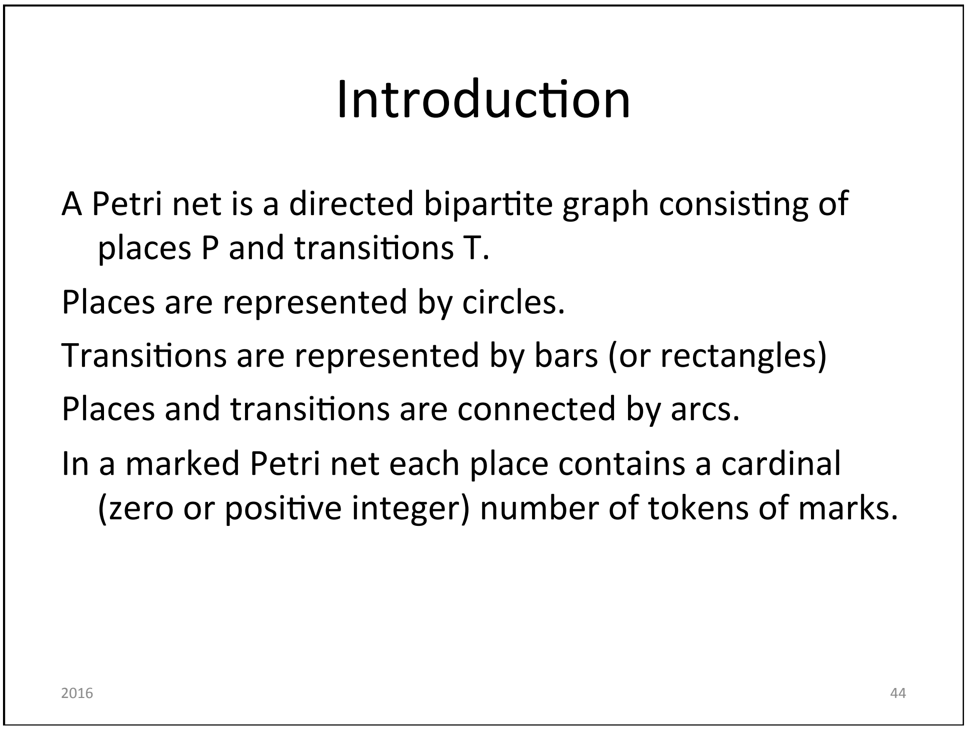
Can be used at all stages of system development:

- modeling
- analysis
- simulation/visualization
  ("playing the token game")
- synthesis
- implementation (Grafcet)



Application Areas

- flexible manufacturing systems
- logical controller design
- communication protocols
- distributed systems
- multiprocessor memory systems
- dataflow computing systems
- fault tolerant systems
- …



Introduction

A Petri net is a directed bipartite graph consisting of places P and transitions T.

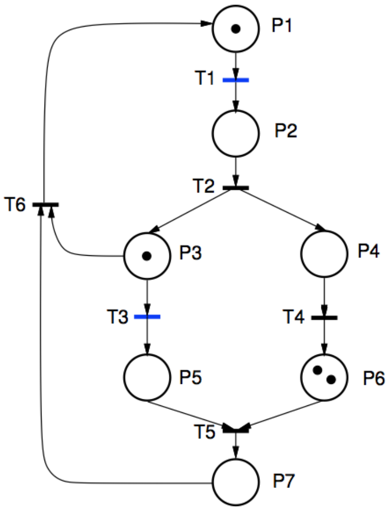
Places are represented by circles.

Transitions are represented by bars (or rectangles)

Places and transitions are connected by arcs.

In a marked Petri net each place contains a cardinal (zero or positive integer) number of tokens of marks.

Example



Firing Rules

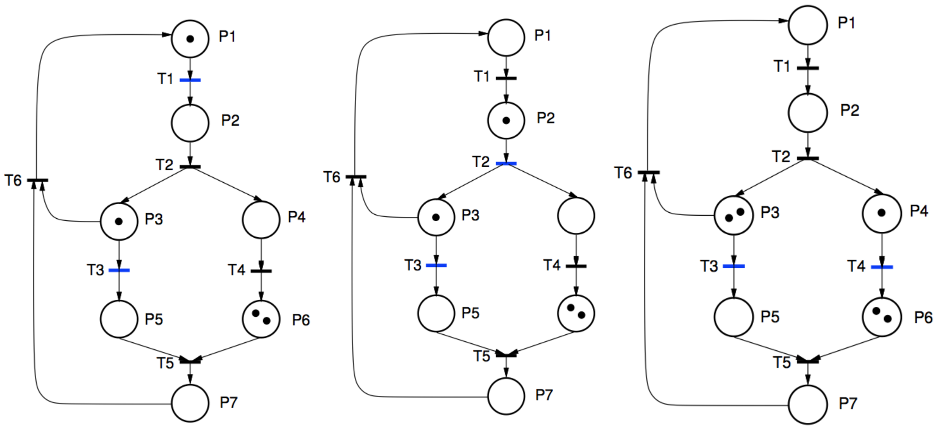
1. A transition t is enabled if each input place contains at least one token.
2. An enabled transition may or may not fire.
3. Firing an enabled transition t means removing one token from each input place of t and adding one token to each output place of t.

The firing of a transition has zero duration.

The firing of a sink transition (only input places) only consumes tokens.

The firing of a source transition (only output places) only produces tokens.

Example



Petri Net variants

Generalized Petri Nets:

Weights associated to the arcs

Times Petri Nets

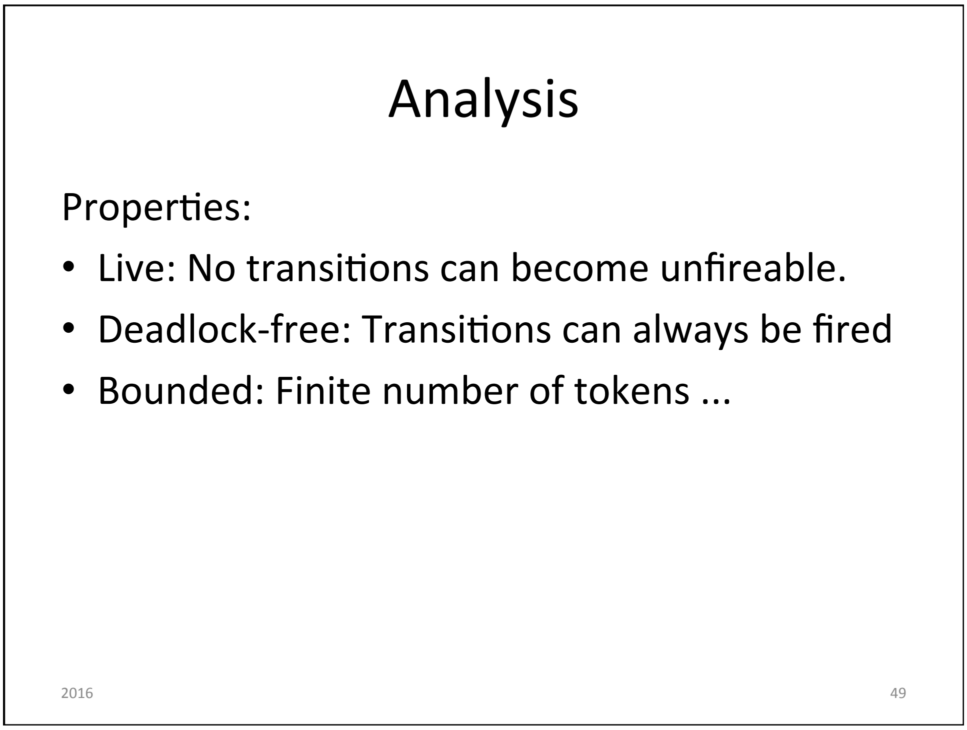
Times associated with transitions or places

High-Level Petri Nets:

Tokens are structured data types (objects)

Continuous & Hybrid Petri Nets:

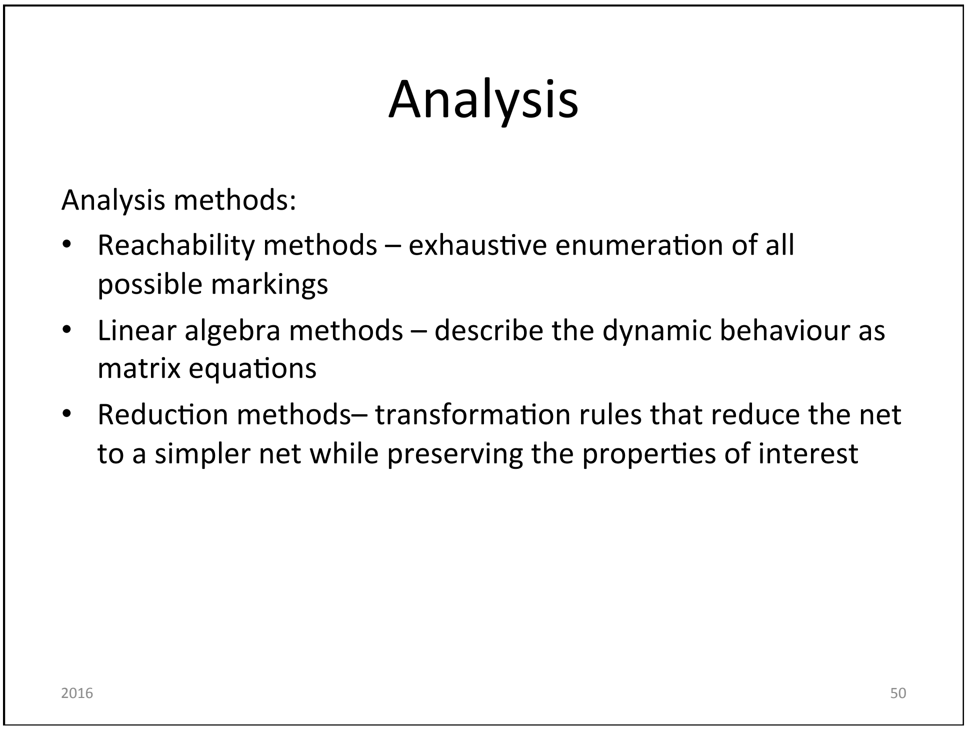
The markings are real numbers instead of integers. Mixed continuous/discrete systems



Analysis

Properties:

- Live: No transitions can become unfireable.
- Deadlock-free: Transitions can always be fired
- Bounded: Finite number of tokens ...



Analysis

Analysis methods:

- Reachability methods – exhaustive enumeration of all possible markings
- Linear algebra methods – describe the dynamic behaviour as matrix equations
- Reduction methods– transformation rules that reduce the net to a simpler net while preserving the properties of interest

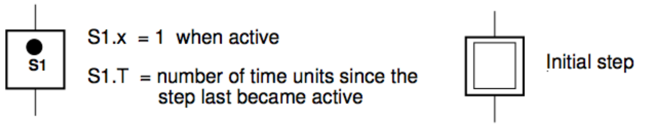
Grafcet

- Extended state machine formalism for implementation of sequence control
- Industrial name: Sequential Function Charts (SFC)
- Defined in France in 1977 as a formal specification and realization method for logical controllers
- Part of IEC 61131-3 (industry standard for PLC controllers)

Basic Elements

Steps:

- active or inactive

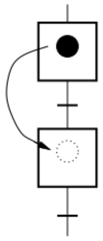


S1.x = 1 when active

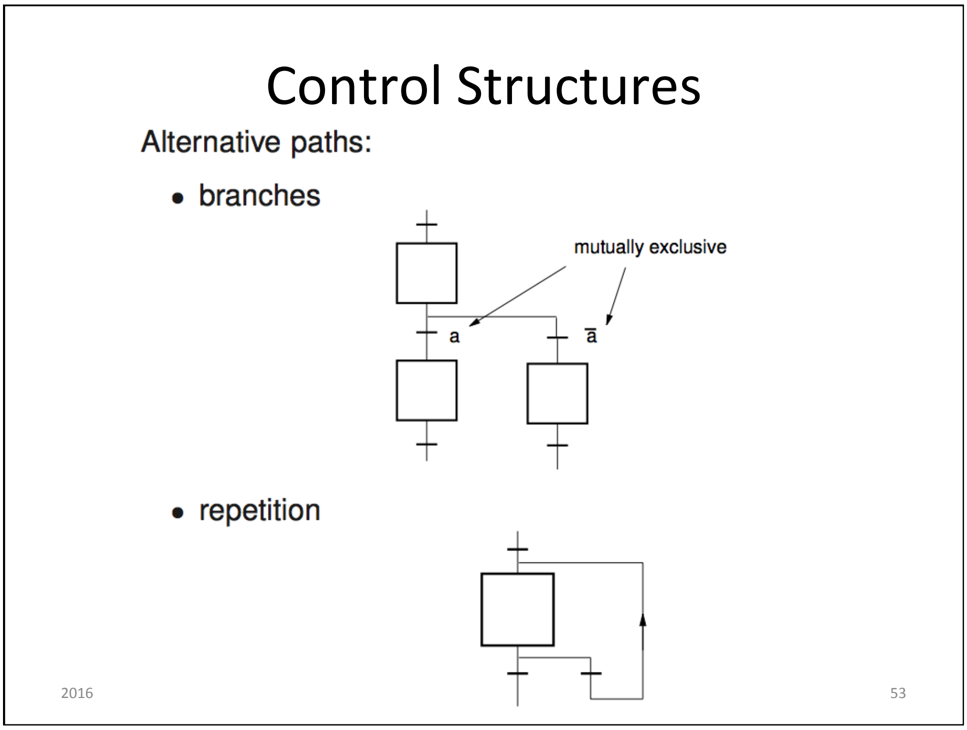
S1.T = number of time units since the step last became active

Initial step

Transitions ("övergång"):



condition true and/or event occurred + previous step active



Control Structures

Alternative paths:

- branches

mutually exclusive

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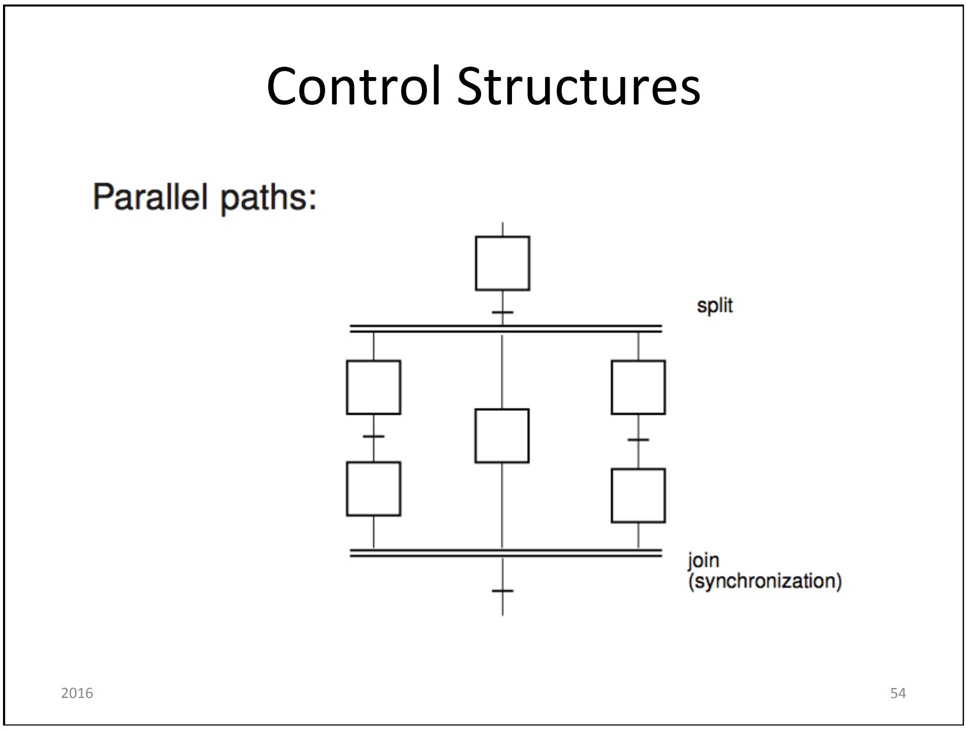
ā

- repetition

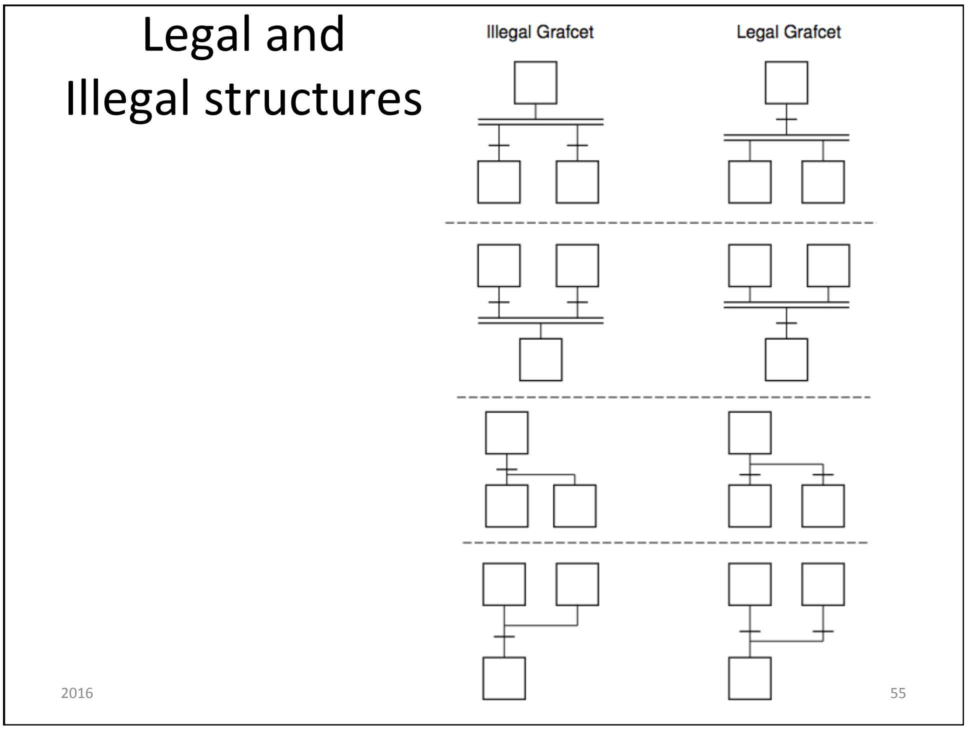


Control Structures

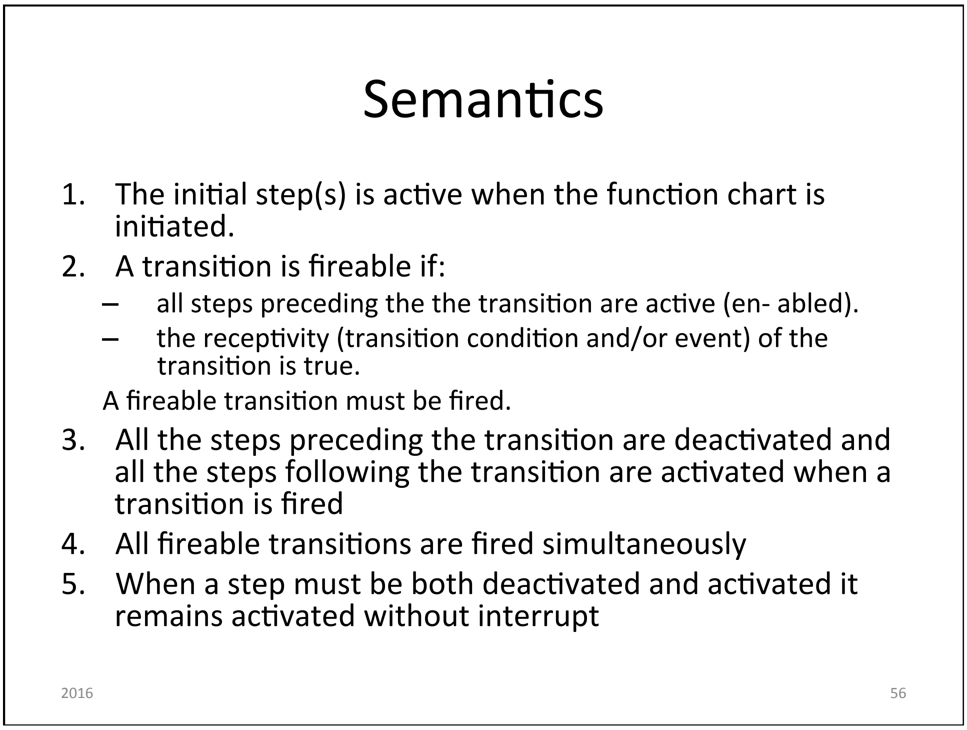
Parallel paths:

split

join
(synchronization)



Legal and Illegal structures

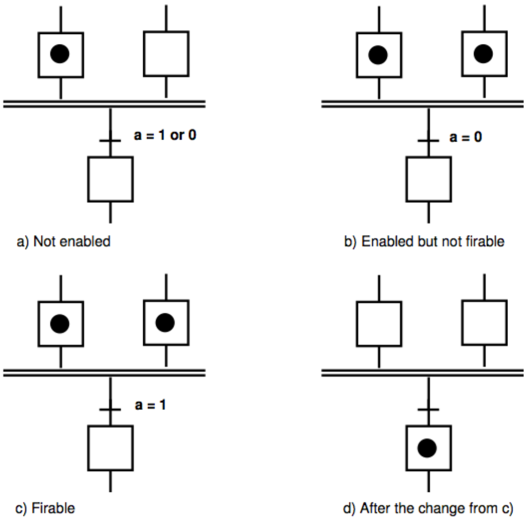


Semantics

1. The initial step(s) is active when the function chart is initiated.
2. A transition is fireable if:
   - all steps preceding the the transition are active (en- abled).
   - the receptivity (transition condition and/or event) of the transition is true.

   A fireable transition must be fired.
3. All the steps preceding the transition are deactivated and all the steps following the transition are activated when a transition is fired
4. All fireable transitions are fired simultaneously
5. When a step must be both deactivated and activated it remains activated without interrupt

Firing



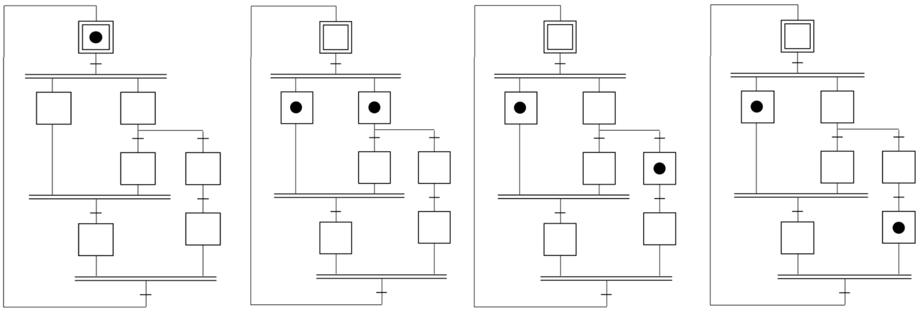
a) Not enabled

b) Enabled but not firable

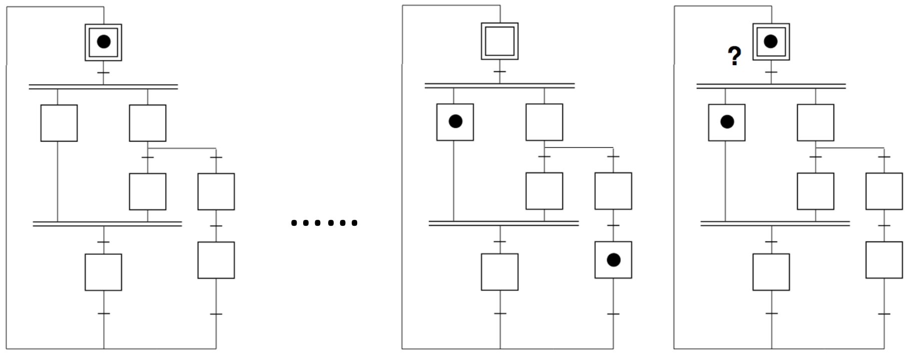
c) Firable

d) After the change from c)

Unreachable Grafcet



Unsafe Grafcet

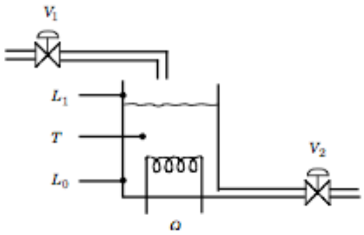


Example

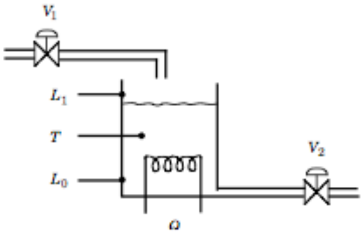
Specifikations:

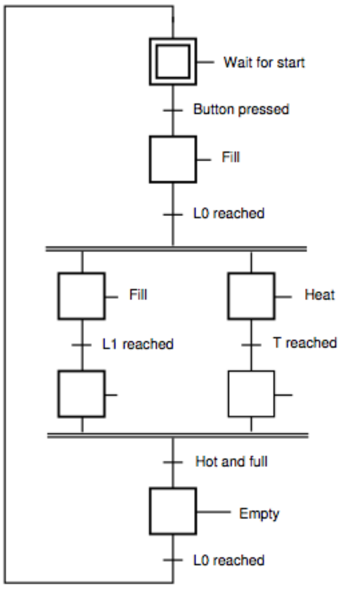
Verbal description

1. Start the sequence by pushing the button B
2. Open valve V1 in order to fill water up to level L1
3. Heat the water until the temperature hs higher than T. Heating can start as soon as there are water above level L0.
4. Empty the tank by open valve V2 until the level reaches below L0.
5. Close the valves and go to 1) and wait for a new start-command



Example





IEC 61131

- IEC standard for programmable controllers (PLCs)
- Several parts, e.g.
  - 61131-3 Programming languages
  - 61131-5 Communications
  - 61131-6 Functional safety
- Adopted by essentially all PLC vendors

IEC 61131-3

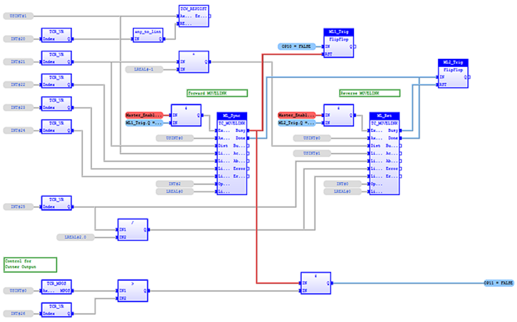
- Defines 5 PLC programming languages
  - Function block diagrams (FBD)
  - Ladder Diagrams (LD)
  - Structrured text (ST)
  - Instruction list (IL)
  - Sequential function chart (SFC), i.e. Grafcet

+ how they may interact

Currently extended with object-orientation

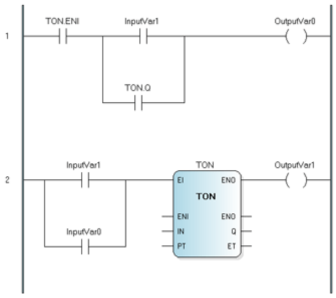
Function block diagrams (FBD)

- Graphical data-flow language
- Interconnects function blocks
- Cp. Simulink



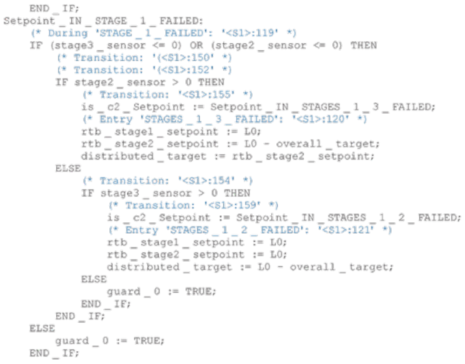
Ladder Diagrams

- Ladder logic extended with function blocks



Structured Text

- Block-structured high-level programming language inspired by Pascal
- Iteration loops (WHILE, REPEAT)
- Conditional branches (IF, CASE)
- Functions



```
    END _ IF;
Setpoint _ IN _ STAGE _ 1 _ FAILED:
    (* During 'STAGE _ 1 _ FAILED': '<S1>:119' *)
    IF (stage3 _ sensor <= 0) OR (stage2 _ sensor <= 0) THEN
        (* Transition: '(<S1>:150' *)
        (* Transition: '(<S1>:152' *)
        IF stage2 _ sensor > 0 THEN
            (* Transition: '<S1>:155' *)
            is _ c2 _ Setpoint := Setpoint _ IN _ STAGES _ 1 _ 3 _ FAILED;
            (* Entry 'STAGES _ 1 _ 3 _ FAILED': '<S1>:120' *)
            rtb _ stage1 _ setpoint := L0;
            rtb _ stage2 _ setpoint := L0 - overall _ target;
            distributed _ target := rtb _ stage2 _ setpoint;
        ELSE
            (* Transition: '<S1>:154' *)
            IF stage3 _ sensor > 0 THEN
                (* Transition: '<S1>:159' *)
                is _ c2 _ Setpoint := Setpoint _ IN _ STAGES _ 1 _ 2 _ FAILED;
                (* Entry 'STAGES _ 1 _ 2 _ FAILED': '<S1>:121' *)
                rtb _ stage1 _ setpoint := L0;
                rtb _ stage2 _ setpoint := L0;
                distributed _ target := L0 - overall _ target;
            ELSE
                guard _ 0 := TRUE;
            END _ IF;
        END _ IF;
    ELSE
        guard _ 0 := TRUE;
    END _ IF;
```

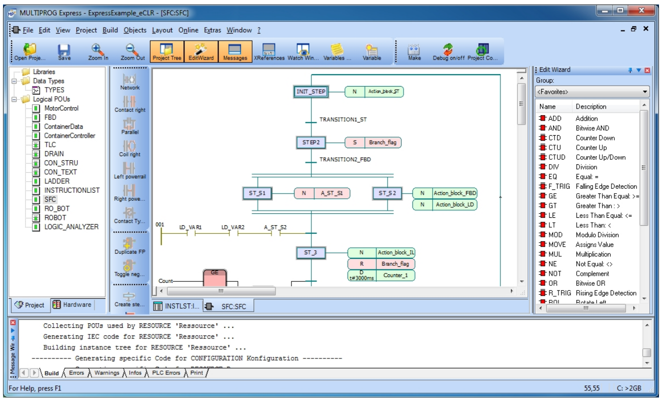
Instruction List

- Low-level textual assembly-like language
- Stack-machine oriented

```
          LD      Speed
          GT      1000
          JMPCN   VOLTS_OK
          LD      Volts
VOLTS_OK  LD      1
          ST      %Q75
```

Sequential Function Charts

- Grafcet

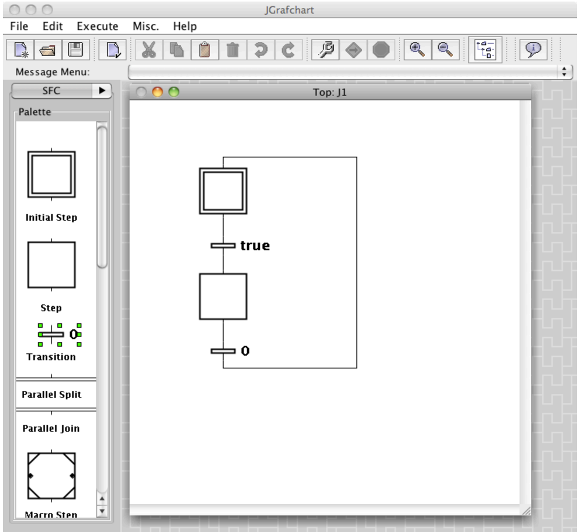


Name	Description
ADD	Addition
AND	Bitwise AND
CTD	Counter Down
CTU	Counter Up
CTUD	Counter Up/Down
DIV	Division
EQ	Equal: =
F_TRIG	Falling Edge Detection
GE	Greater Than Equal: >=
GT	Greater Than : >
LE	Less Than Equal: <=
LT	Less Than: <
MOD	Modulo Division
MOVE	Assigns Value
MUL	Multiplication
NE	Not Equal: <>
NOT	Complement
OR	Bitwise OR
R_TRIG	Rising Edge Detection
ROL	Rotate Left

```
    Collecting POUs used by RESOURCE 'Ressource' ...
    Generating IEC code for RESOURCE 'Ressource' ...
    Building instance tree for RESOURCE 'Ressource' ...
---------- Generating specific Code for CONFIGURATION Konfiguration ----------
```

JGrafchart

JGrafchart is a Grafcet/SFC editor and execution environment developed at the Department of Automatic Control, Lund Institute of Technology.



JGrafchart

JGrafchart is a Grafcet/SFC editor and execution environment developed at the Department of Automatic Control, Lund Institute of Technology.

JGrafchart supports the following language elements:

- workspace objects
- Steps
- initial steps
- transitions
- parallel splits and parallel joins
- macro steps
- exception transitions

In addition there is support for:

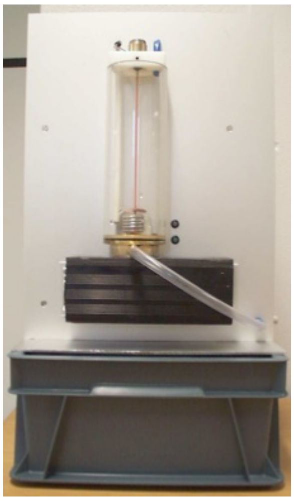
- digital inputs and digital outputs
- analog inputs and analog outputs
- socket inputs and socket outputs
- internal variables (real, boolean, string, and integer)
- action buttons and free text for comments.

JGrafchart

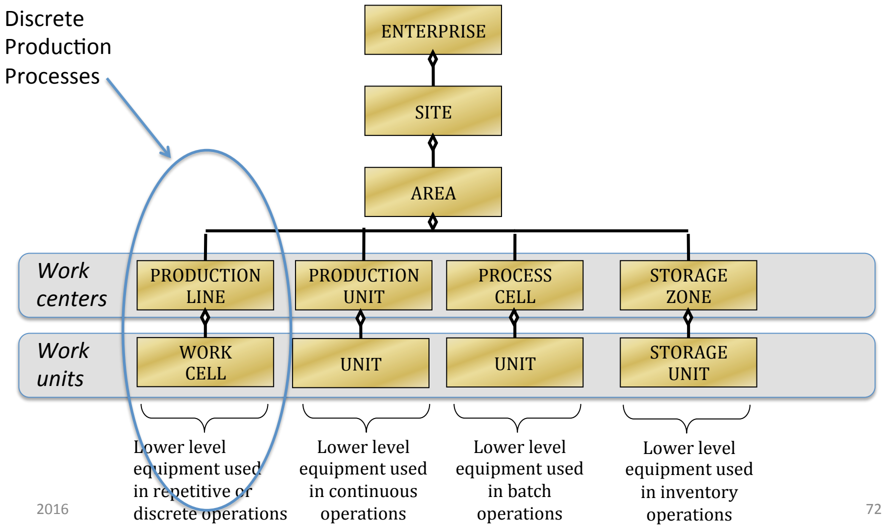
JGrafchart is a Grafcet/SFC editor and execution environment developed at the Department of Automatic Control, Lund Institute of Technology.

JGrafchart will be used in Laboratory Exercise 1.

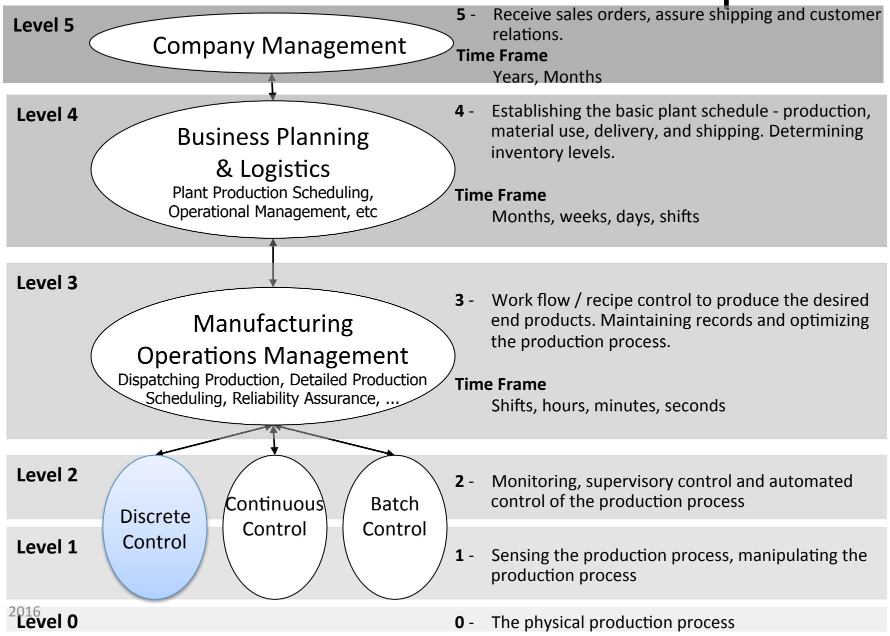
A richer description of JGrafchart is contained within Laboratory Exercise 1.



Physical Model of an Enterprise


Discrete
Production
Processes
ENTERPRISE
SITE
AREA
Work centers
PRODUCTION LINE
PRODUCTION UNIT
PROCESS CELL
STORAGE ZONE
Work units
WORK CELL
UNIT
UNIT
STORAGE UNIT
Lower level equipment used in repetitive or discrete operations
Lower level equipment used in continuous operations
Lower level equipment used in batch operations
Lower level equipment used in inventory operations

Functional Model of an Enterprise



Level 5

Company Management

5 - Receive sales orders, assure shipping and customer relations.

Time Frame

Years, Months

Level 4

Business Planning & Logistics

Plant Production Scheduling, Operational Management, etc

4 - Establishing the basic plant schedule - production, material use, delivery, and shipping. Determining inventory levels.

Time Frame

Months, weeks, days, shifts

Level 3

Manufacturing Operations Management

Dispatching Production, Detailed Production Scheduling, Reliability Assurance, ...

3 - Work flow / recipe control to produce the desired end products. Maintaining records and optimizing the production process.

Time Frame

Shifts, hours, minutes, seconds

Level 2

Level 1

Discrete Control

Continuous Control

Batch Control

2 - Monitoring, supervisory control and automated control of the production process

1 - Sensing the production process, manipulating the production process

Level 0

0 - The physical production process