# Industrial Automation

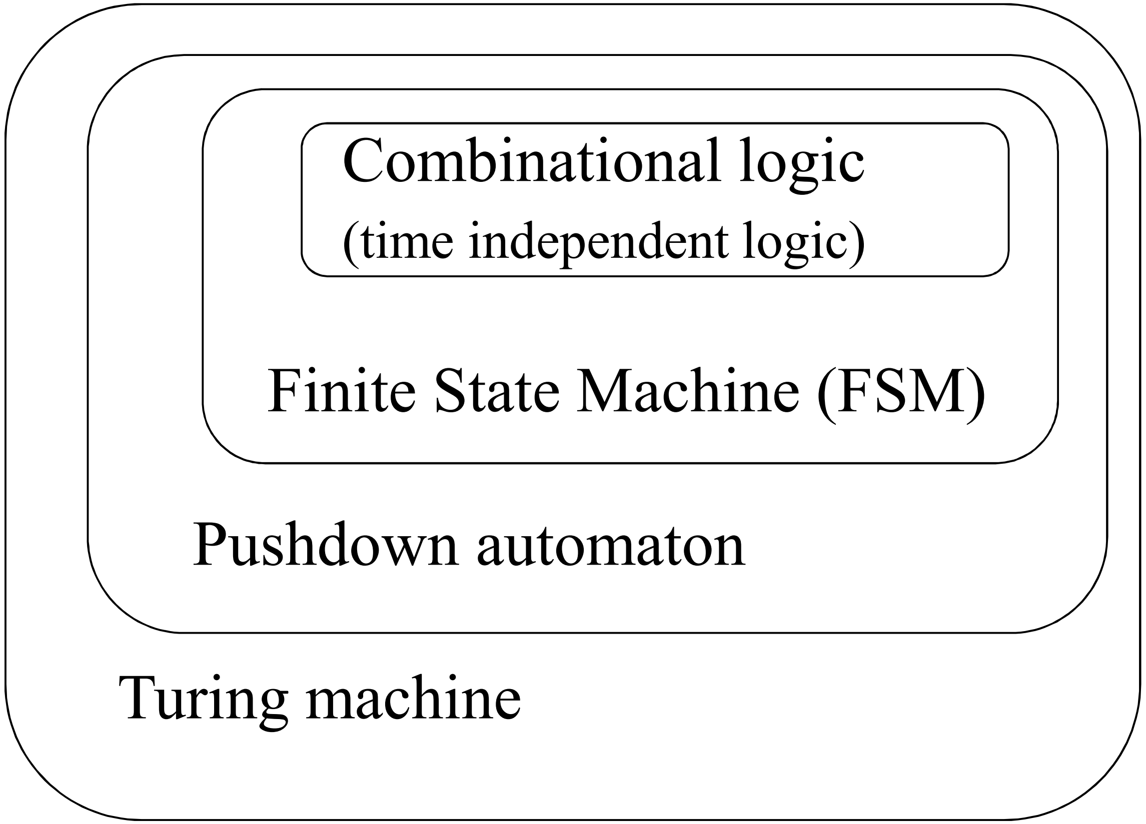
## (Automação de Processos Industriais)

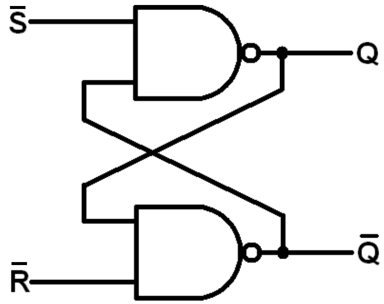
## Discrete Event Systems: Turing Machines, *Busy Beaver*

http://users.isr.ist.utl.pt/~jag/courses/api1819/api1819.html

Prof. José Gaspar, 2018/2019

# Automata theory



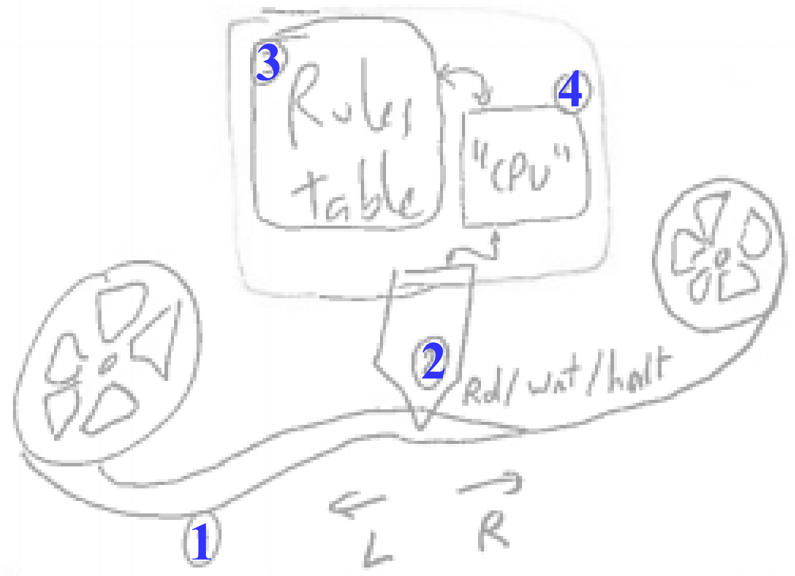

| Current state | Input SR | Next state |
|---|---|---|
| xx | 11 | 11 |
| xx | 10 | 10 |
| xx | 01 | 01 |
| xx | 00 | xx |

SR latch is a FSM example. The input *(S,R)=(0,0)* keeps the **memorized** value

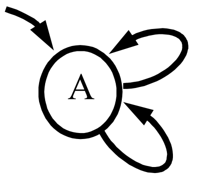
$$(Q,\overline{Q}) = (x,x)$$

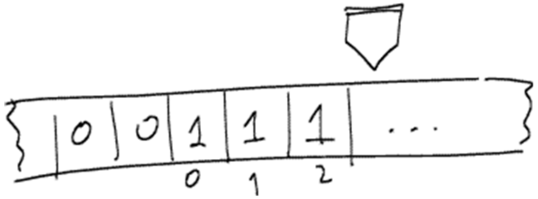
# Turing machine (TM)

Components:
(1) Infinite length magnetic **tape**
(2) Read/Write head
(3) Rules table, **FSM**
(4) State register




Example of a simple Rules table / **FSM**. Using this FSM the TM writes forever ones into the tape. Read the FSM as "if 0 or 1 is read from the tape, then write 1 to the tape, move tape to the left and continue in state A".



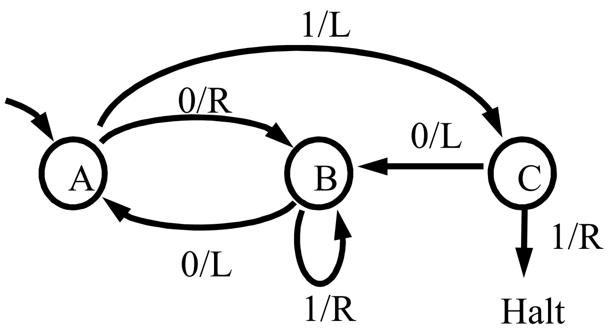




Note: a TM is not just an FSM; for example, it contains also an **infinite memory**.

# Turing machine example: *Busy Beaver*

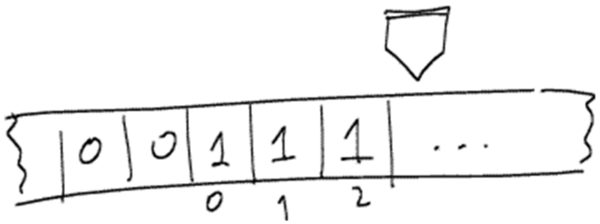
The objective is to fill the TM tape, with ones, as many as possible, using a rules table (FSM) with a minimum number of states.

One implementation of the 3-states 2-symbols Busy Beaver is:




| Current state | Input | Action R/W | Action L/R/N | Next state |
|---|---|---|---|---|
| A | 0 | write1 | right | B |
| A | 1 | write1 | left | C |
| B | 0 | write1 | left | A |
| B | 1 | write1 | right | B |
| C | 0 | write1 | left | B |
| C | 1 | write1 | null | halt |

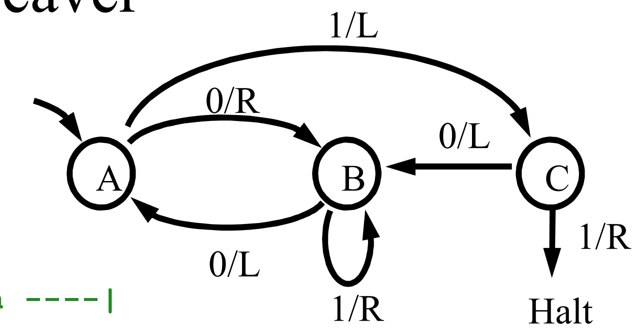
Turing machine:
(1) **tape** and
(2) read/write head




```
function TM_reset
global TMT
TMT= struct('pos',0,
            'val',[],
            'valNeg',[]);
```

```
function ret= TM_tape( op, arg1 )
% Tape for a Turing machine. Basic operations:
%   read/write and move Left/Right/None
global TMT; if isempty(TMT), TM_reset; end
switch op
    case 'reset', TM_reset;
    case 'left',  TMT.pos= TMT.pos+1;
    case 'right', TMT.pos= TMT.pos-1;
    case 'null_move' % do nothing
    case 'read`, % 1st call may need tape
        realloc_if_needed( TMT.pos );
        if TMT.pos>=0, ret= TMT.val( TMT.pos+1 );
        else           ret= TMT.valNeg( -TMT.pos );
        end
    case 'write`, % 1st call may need tape
        realloc_if_needed( TMT.pos );
        if TMT.pos>=0, TMT.val( TMT.pos+1 )= arg1;
        else           TMT.valNeg( -TMT.pos )= arg1;
        end
    otherwise, error('inv op')
end
```

# Turing machine: (3) rules table, FSM of Busy Beaver




```
function FSM= def_BusyBeaver3
% FSM has four columns:
%   curr_state, true_false_condition, actions, next_state
%           |- T/F cond -----|     |- write action and move action ----|
FSM= {
    'A',  'TM_tape("read")==0',  'TM_tape("write",1); TM_tape("right");',  'B';
    'A',  'TM_tape("read")==1',  'TM_tape("write",1); TM_tape("left");' ,  'C';
    'B',  'TM_tape("read")==0',  'TM_tape("write",1); TM_tape("left");' ,  'A';
    'B',  'TM_tape("read")==1',  'TM_tape("write",1); TM_tape("right");',  'B';
    'C',  'TM_tape("read")==0',  'TM_tape("write",1); TM_tape("left");' ,  'B';
    'C',  'TM_tape("read")==1',  'TM_tape("write",1); TM_tape("null_move");', 'halt';
    };
```

| Current state | Input | Action R/W | Action L/R/N | Next state |
|---|---|---|---|---|
| A | 0 | write1 | right | B |
| A | 1 | write1 | left | C |
| B | 0 | write1 | left | A |
| B | 1 | write1 | right | B |
| C | 0 | write1 | left | B |
| C | 1 | write1 | null | halt |

Alternative, more compact, representation:

```
function FSM= def_BusyBeaver3
tbl= {'A01RB', 'A11LC', ...
      'B01LA', 'B11RB', ...
      'C01LB', 'C11NH'};
FSM= convert_table_to_list( tbl );
```

Turing machine:
(4) state register, `curr_state`
for **running** the machine

Recall the first line of the table:

```
FSM{1,:} =
'A'
'TM_tape("read")==0'
'TM_tape("write",1); TM_tape("right");'
'B'
```

and read it as "if current state is A and tape read is zero, then write 1 to the tape, move tape right, and the next state is B".

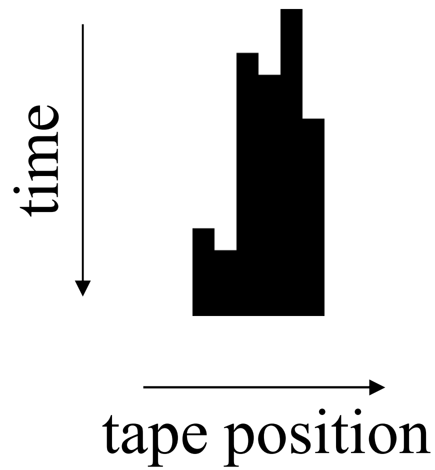
```
function TM_run
TM_tape( 'reset' );
FSM= TM_ini( 'BusyBeaver3' );
curr_state= FSM{1,1};
while ~strcmpi(curr_state, 'halt')
    for i=1:size(FSM,1)
        if strcmpi(FSM{i,1}, curr_state) ...
                && eval( FSM{i,2} )
            % found state and true condition
            eval( FSM{i,3} );
            % curr_state <- next state
            curr_state= FSM{i,4};
            break;
        end
    end
end
```

Download the complete implementation from:
http://isr.tecnico.ulisboa.pt/~jag/course_utils/Turing_Machines_sim/Turing_Machines_sim.html

# Turing Machine Busy Beaver: simulation results

**3-state** Busy Beaver:
a0 -> b1r   a1 -> h1r
b0 -> c0r   b1 -> b1r
c0 -> c1l   c1 -> a1l

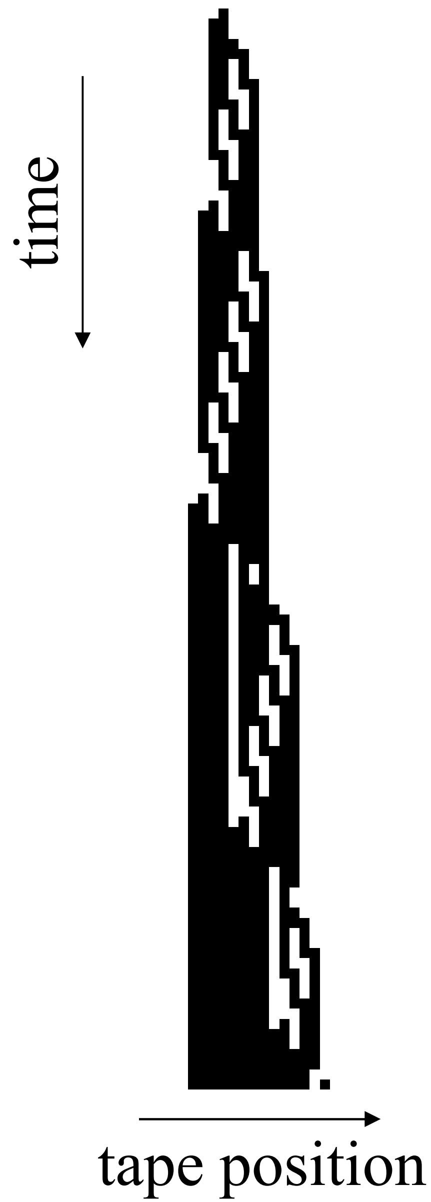
halts after **21 time steps**
fills **6 ones**




**4-state** Busy Beaver:
a0 -> b1r   a1 -> b1l
b0 -> a1l   b1 -> c0l
c0 -> h1r   c1 -> d1l
d0 -> d1r   d1 -> a0r

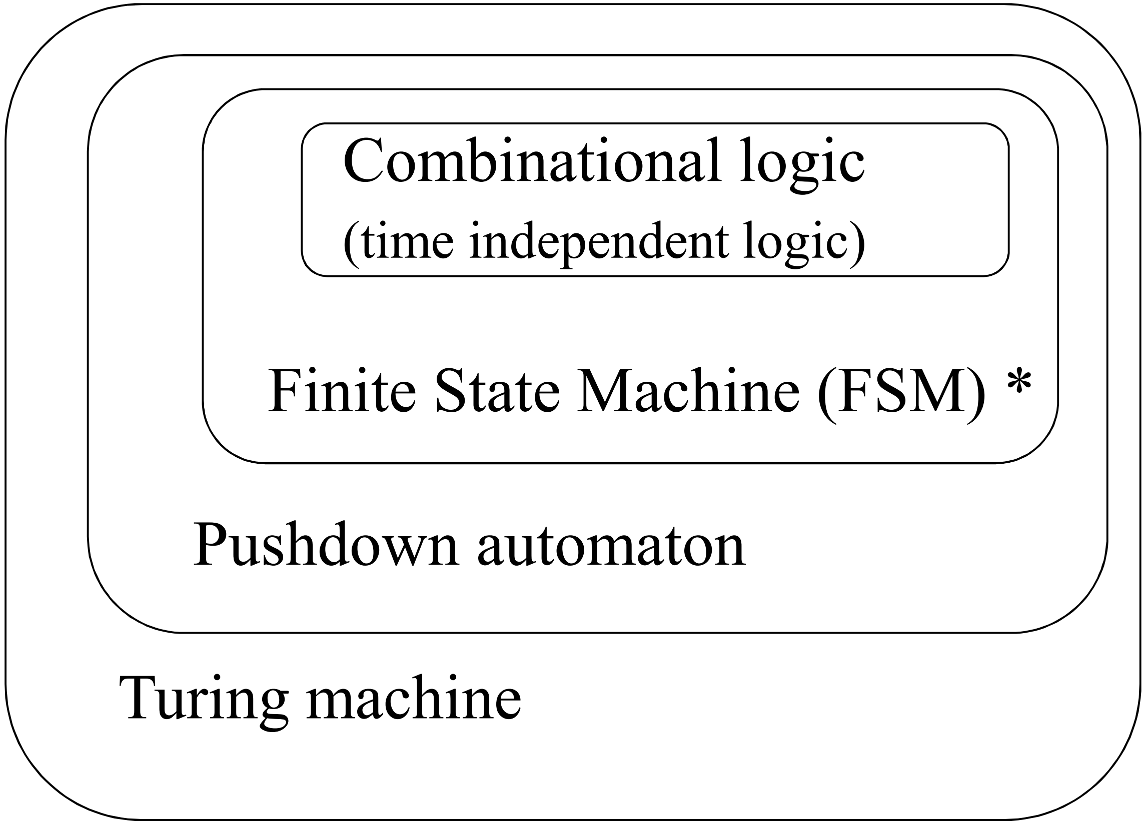
halts after **107 time steps**
fills **13 ones**

| *States* | *Halts after n time steps* | *Fills m ones in the tape* |
|---|---|---|
| *2* | **6** | **4** |
| *3* | **21** | **6** |
| *4* | **107** | **13** |
| *5* | **47,176,870 ?** | **4098 ?** |
| *6* | **$> 7.4 \times 10^{36534}$** | **$> 3.5 \times 10^{18267}$** |




http://www.catonmat.net/blog/busy-beaver/
http://www.logique.jussieu.fr/~michel/bbc.html
(competition results visited Nov 2016)

# Automata theory




* *Time dependency, **memory**, is an essential component for automata.*
*Petri nets will introduce another essential component: **parallelization**.*