Parallel Automata and their implementation

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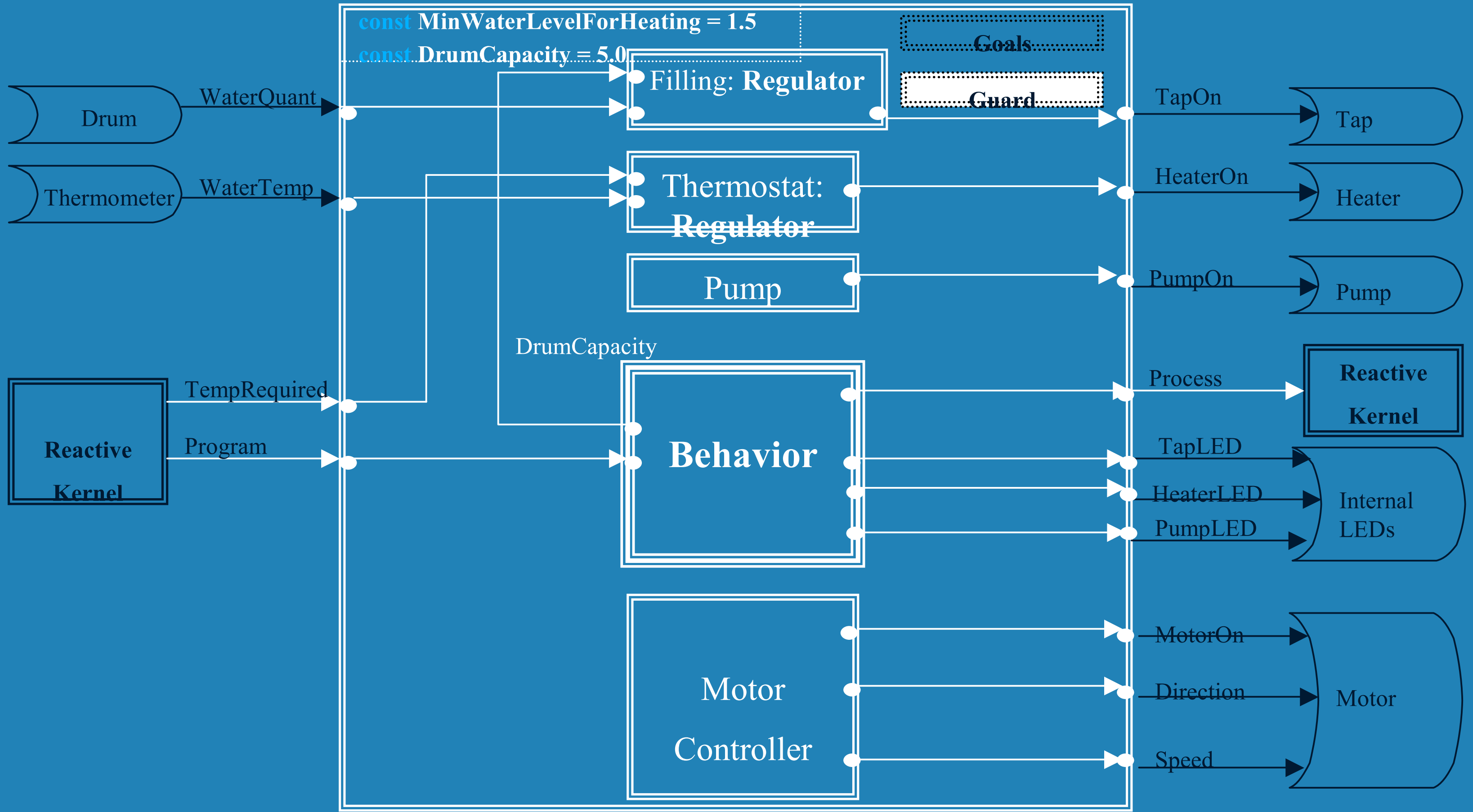
Example of DesCARTES design (washing Machine) (with Teitelbaum - JCT)



TCOM : Temporal Components (with Vidal-Naquet, SupElec)

- Var , signals , flags , clocks
- Operations : I / O , functions
- Behavior (Manager) : APA $\vee$ PTL

- Goals : PTL
- Assertion Guards : APA $\vee$ PTL

TCOM : PTL engineering dialect for validation (with Vidal-Naquet, SupElec)

GOALS/GUARDS in TCOM dialect
for the Fill-regulator component

when (Prog4 and Start) *then*
(***Eventually***((Full *and* tap_closed)
imply *Fill_Goal*));

Translation in PTL

(Prog4 Λ Start ==> <> (Full Λ closed→Fill_Goal))

Validation by Prover and Description of Behavior (with Vidal-Naquet, SupElec)

<u>Goal</u> Validation (e.g. '*STEP*' Prover)

(Fill_Goal ∧ Thermo_Goal ∧ Pump_Goal ∧ Motor_goal ∧ Main_Behavior)

==> Main_Goal

How to execute the behavior element

Direct PTL execution
(as Fisher- UK)

Or

Execution through a bridge-model between
"Extended FSM" and PTL

Parallelism, explosion of states and Mealy model

- For the representation of R-T control, we need :
  - Parallel tests on variables, timers or Parallel receiving of events or inputs
  - Run Parallel actions and outputs
- We need to differentiate the same elements in various situations,
- this leads to an

  explosion of number of states

Main trends in Extended FSM for component behavior execution

- **Adding Conditions to the global state**
  - $E_m , s_k , c_n , !c_{p\ldots} \rightarrow \quad a_i , s_r , !c_q , c_t$
- **Adding variables to the global state**
  - $E_m , s_k , d_n \ldots \rightarrow \quad a_i , s_r , d_t \ldots$
- **Adding clocks to the global state**
  - $E_q , s_p , cond_n(clock_m) \rightarrow$
    $a_k , s_j , reset(clock_i)$

Extended FSM : (2) for component behavior execution

- Automata with multiple states
  - E_i , $\{n_2$, n_5 ....$\}$ $\rightarrow$ $\{n_4$, n_6 .... $\}$

- Automata with several events and multiple actions (I/O automata) and global state
  - E_r , E_h , st_j $\rightarrow$ act_i , out_k , st_k

Seeking
a general bridging-model "TCOM-PTL" – "Extended-FSM"

- <u>In PTL</u> : no specific "states"
- <u>In EFSM</u> : various extensions to states : conditions on var, time, …

  with specific semantic meaning
- <u>formally</u> : states, events, inputs, flags, timers, actions, outputs, ...

  can be <u>variables</u> to test or to assign

  $Cond_n (V) \rightarrow Assign_i (V, N)$

Representation of time control (discrete or continuous time ?)

- The controller needs only to know
  dates and **interval of times**
- It needs only to <u>read</u> (input) or <u>reset</u> **time variables** (timers).
- These **time variables** are updated by an external mechanism which does not interest the controller, so the notion of time can be viewed as an abstract notion external to control

APA: Abstract Parallel Automata for behavior execution

- Abstract forms

conjunction form	π_j / cond $_j$ / $\rightarrow$ π_k / assign$_k$ /
General form	compound cond $\rightarrow$ π_k /assign$_k$/

cond$_j$ are boolean relation tests :

- event, input signal or flag arrived
- state or variable or time condition

assign$_k$ are setting of values to variables :

- setting a state , a variable or a clock
- execution of actions or functions
- output of flags , Sending of Events

More formal definition of APA: Abstract Parallel Automata

(with Yehezkael, T. Hirst – JCT)

APA = (I, V, O, K, R)

I = $\{x_1,\ldots,x_r\}$ a finite set of input variables.

V = $\{y_1,\ldots,y_s\}$ a finite set of internal variables.

O = $\{z_1,\ldots,z_t\}$ a finite set of output variables.

K = the finite range of values of each variable

R = a finite number of rules:

test the values of variables --➔

make assignments to variables

definition of the APA execution / synchronous hypothesis

- The execution of automata rules takes place in a **succession of cycles**:
  - In each **cycle**,
    each automata rule is scanned once only
  - During each **cycle**,
    variables are tested and assigned
  - The new **value** of a variable
    $I \cup V \cup O \rightarrow \{0,1,2,\ldots, K\}$
    becomes available in the **following cycle**

Example of Behavior (in APA) :
double parallelism : horizontal / vertical
(with Bloch – Reims)

[1] /prog4=1/ /start=1/ /full=0/ ➔ /fill:=1/ /LED:=2/

[2] /fill=1/ /full=1/ ➔ /fill:=0/ /thermo:=1/
/motor:=1//timer0:=0/

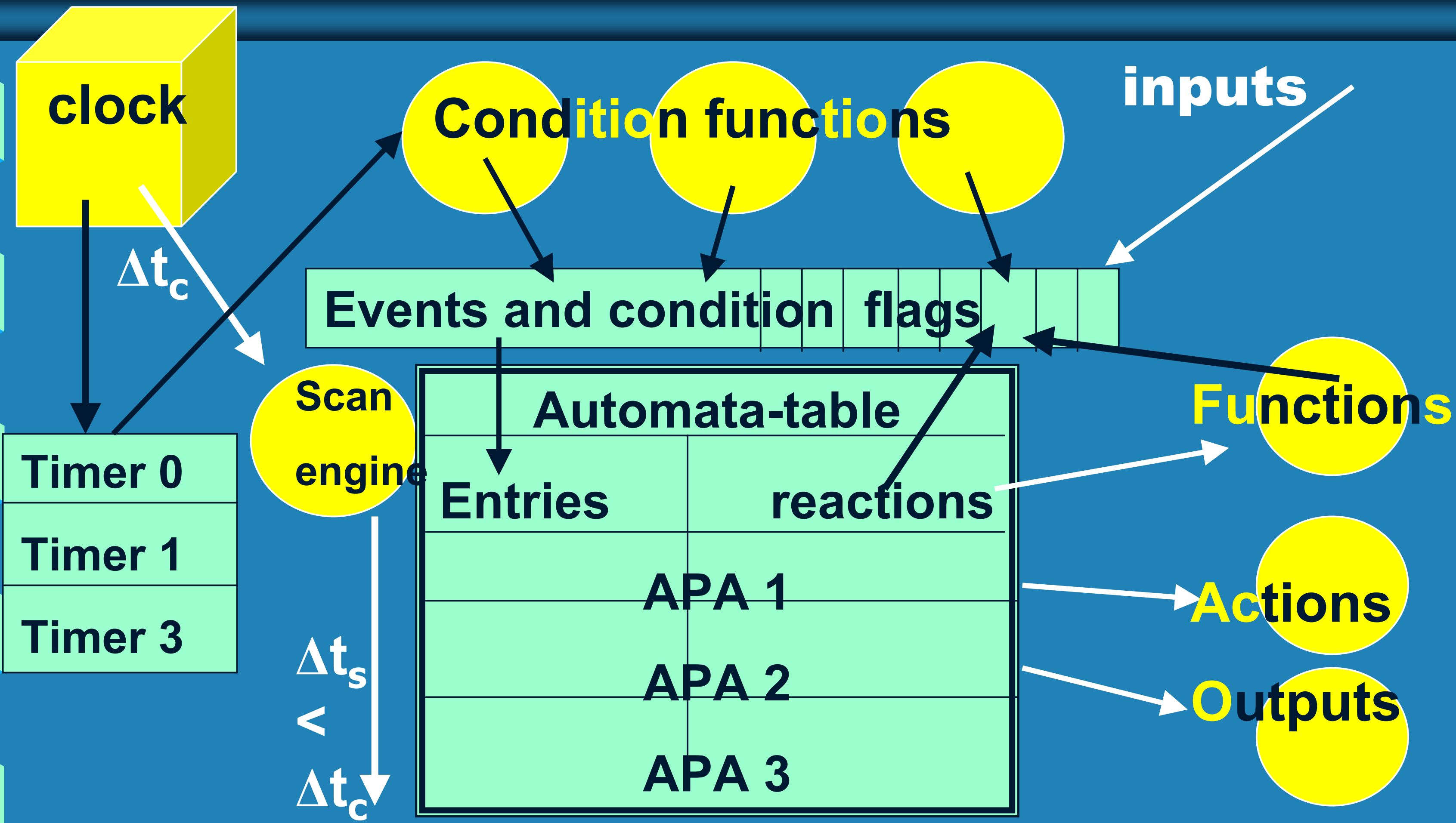
[3] /motor=1//timer0=5/ ➔ / LED :=3/ /soap:=1/

[4] /motor=1//timer0=30/➔ /thermo:=0//pump:=1/
/motor:=0/ / LED :=4/

[5] /thermo=1//temp<45/ ➔ /heat:=1/ /LED:=5/

[6] /thermo=1//temp>=45/ ➔ /heat:=0/ /LED:=6/

Architecture of a APA operating system (with Teitelbaum - JCT)



Problems of WW conflicts in APA

- (i) A <u>strong</u> conflict occurs when two or more assignments of ***<u>different</u> <u>values</u>*** are made pseudo-simultaneously to the same location.
- (ii) A <u>weak</u> conflict occurs when two or more assignments of the ***<u>same</u> <u>value</u>*** are made pseudo-simultaneously to the same location .

These conflicts can be

ACTUAL or POTENTIAL

A-priori detection of (actual or potential) conflicts (with Yehezkael, T. Hirst – JCT)

- A-priori Actual conflicts detection for *general* parallel automata is P-space complete
- And Potential conflicts detection is NP complete
- but for ***simple conjunctions***, Potential conflict detection is possible in polynomial size

Detecting potential conflicts is possible in polynomial time when all conditions are conjunctions (Yehezkael, T. Hirst, JCT)

```
potential_conflict:=false;
for every pair of rules
loop
if there exist values for making the left hand sides of
   the pair of rules true and the same variable is
   assigned (different values) on the right hand sides of
   the pair of rules
then potential_conflict:=true; exit for loop;
end if;
end for;
```

- *Checking pairs of conditions contributes a quadratic term to the complexity, and then we need to determine whether the conjunction of a pair of conditions is **satisfiable**.*

Satisfiability (Yehezkael, T. Hirst, JCT)

- *As all the conditions are conjunctions of primitive conditions, then so too is the conjunction of pairs of such conditions. Fortunately, determining the satisfiability of a conjunction of primitive conditions is easily done in polynomial time as follows.*

for each variable in the condition

loop Form the intersection of the ranges of values this variable takes.

end for;

if all these intersections of are not empty

then the condition is **satisfiable**

else the condition is **unsatisfiable**

end if;

A-priori detection of conflicts Other results (2)

(Yehezkael, T. Hirst, JCT)

- ***any parallel automaton can be converted in polynomial time into a nearly equivalent automaton which detects potential conflicts, with size proportional to the size of the original automaton.***
- ***The new automaton is equivalent to the original automaton, when the original automaton is free of conflicts.***

Conversion to a form which detects potential conflicts (Yehezkael, T. Hirst, JCT)

(a) Ensure that there is only one assignment on the right hand side of a rule:

A rule such as "Condition" → /a:=1//b:=2//c:=3/

would be replaced by the following three equivalent rules.

"Condition" → /a:=1/

"Condition" → /b:=2/

"Condition" → /c:=3/

(b) **Group rules:** For each variable there is a group consisting of all the rules which assign to it. Between groups there is not even potential conflict. A conflict may only occur in a group.

(c) Ensure no potential conflict in a group:

Consider a typical group which assigns on the variable x.

"Cond. 1" → /x:=1/
"Cond. 2" → /x:=2/
"Cond. 3" → /x:=2/

This would be replaced by the detecting rule:

"Cond. 1" and ("Cond. 2" or "Cond. 3") → /!conflict:_x:=1/

NOTE: Weak conflict not treated as an error in the above.

conflicts A-priori detection of Other results (3)

(Yehezkael, T. Hirst, JCT)

- **conversion** of a general parallel automaton into a form where all conditions are **conjunctions** of primitive conditions is possible in **polynomial size**, providing that computation rules are given priority over I/O rules.

A-posteriori on-line detection of conflicts (with Teitelbaum-JCT)

- Instead of changing the automaton, the execution mechanism can test for conflicts

  a-posteriori at run time, and not perform the assignments involved in conflicts.
- The a-priori converted automaton has no conflicts because its rules test for assignments causing conflicts at run time, and so would require more memory for storing the modified automaton rules.
- The a-posteriori approach requires that the execution mechanism tests for conflicts at run time, which would make the execution mechanism more complex..