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ABSTRACT

ALCMEN, i.e. Automaticians Language for Causal Modelisation for Expert Knowledge is an attempt to build a language able to handle simultaneously imprecision and uncertainty, and precise equations, in order to solve the communication problem between Process Experts and Control Engineers. ALCMEN appears as a network of interconnected blocks and a list of structured variables. A simple illustrative example has been used to concretize the ideas stated in this paper. ALCMEN captures the causal influence of a cause on an effect and provides the possibility of parametrizing that relation by one or many conditions. Each causal relation, is described according to the most explicit available knowledge, either using equations or natural language. Specification methodology is also provided using real time expert system development language G2.

Key words: Qualitative simulation, Numeric-symbolic interface, Language specification

1 - INTRODUCTION:

Computer systems unfortunately (or maybe fortunately) do not share the wide possibilities of imprecision and uncertainty of natural conversation between human beings. Therefore all words used in a program must have a definite meaning in the functional and material part of the computer, otherwise nothing can be implemented. The principal criticisms for expert descriptions are related to the lack of precise meaning of words and the role of the variables. ALCMEN, i.e. Automaticians Language for Causal Modelisation for Expert Knowledge is an attempt to build a language able to handle some imprecision and uncertainty, but in a precise manner, and then to solve the communication problem between Process Experts and Control Engineers. The purpose of ALCMEN is to give a sound foundament for the description of processes enhancing the modelization of causal relations, as well as to develop a practical computer tool for representing processes from qualitative and quantitative descriptions by experts. It takes advantage of the features of an object-oriented computer language as OPS or G2. The elementary objects are variables, causal relations, connections, and delays; those elements are connected into blocks,
and a Process described by ALCMEN must appear as
1) a network of interconnected blocks
2) a list of variables (structured variables)

2 - EXAMPLE:

A simple illustrative example will be used to concretize the ideas stated in this paper. Let us consider two basins connected by a sluice, as shown in fig 1, and yielding water through spillway. The simulation of this system may be required for the control of the down stream $f_2$ acting on the sluice opening $w$ for a given upstream flow $f_0$. Heights of water in each basin, $h_1$ and $h_2$ can be conveniently measured, and geometrical parameters, surfaces $S_1$, $S_2$ and spillway height $d$ are known.

$$
\frac{dh_1}{dt} = \frac{f_{i-1} - f_i}{S_i}
$$

The static relations representing the sluice and the spillway are essentially non linear and depend on scale parameters $K_1$ and $K_2$:

$$f_1 = K_1 w (h_1 - h_2)^{1/2} \quad f_2 = K_2 (h_2 - d)^{3/2}$$

These relations may be replaced by qualitative relations and rules as follows:

Sluice rules:
- if $h_1 > h_2$ then $f_1$ is an increasing function of $w$ and of $(h_1 - h_2)$
- if $h_1 < h_2$ then $f_1 = 0$

Spillway rules:
- if $h_2 > d$ then $f_2$ is an increasing function of $h_2$ [or of $(h_2 - d)$]
- if $h_2 < d$ then $f_2 = 0$

Obviously the simulation of such a system with traditional methods needs the specification of the "increasing functions" introduced.

A refinement of this qualitative description could be done by defining an intermediate variable $\Delta h = h_1 - h_2$ and adding to the sluice rules the following:

- if $\Delta h$ is positive small then $f_1$ is a linearly increasing function of $w$ and of $\Delta h$
- if $\Delta h$ is positive very large then $f_1$ is a linearly increasing function of $w$ only.

3 - VARIABLES:

A variable is a structured object as shown in figure 2. Variables are defined with respect to a sub-process called Block, they have also a function for the interconnection between blocks.

Three main fields define a variable:

- List of BLOCKs where it
appears and its ROLE (input, output, parameter)

DOMAIN split into ZONES that can be defined differently for each BLOCK but if it is used for interconnection a translation must be provided. The domain is a structured object.

1) if the variable is evaluated as a quantity, i.e. represented by a number, its range is an interval with obviously the limit values expressed in units ad-hoc. It is suitable to know the "nominal" sub-interval corresponding to the preferred or desired value (or values), as well as the "critical" sub-intervals.

2) if the variable is evaluated linguistically, i.e. represented by a word, its range is a set of words or "modalities" expressed in a vocabulary ad-hoc. It is also suitable to know the "nominal" subset corresponding to the preferred or desired value (or values), as well as the "critical" subsets. The following frame represents the object variable in the particular case of $f_1$.

### Variable

<table>
<thead>
<tr>
<th>Domain</th>
<th>Variable</th>
<th>$f_1$ communication flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>real</td>
<td>nature</td>
<td>units</td>
</tr>
<tr>
<td></td>
<td>quantity</td>
<td>m/s</td>
</tr>
<tr>
<td></td>
<td>range</td>
<td>[-10, 100]</td>
</tr>
<tr>
<td>Zones</td>
<td>target</td>
<td>constraints</td>
</tr>
<tr>
<td></td>
<td>[15, 25]</td>
<td>[10, 50]</td>
</tr>
<tr>
<td>Blocks</td>
<td>SLUICE (qual)</td>
<td>BASIN1 &amp; 2 (num)</td>
</tr>
<tr>
<td>Events</td>
<td>zero crossing</td>
<td></td>
</tr>
<tr>
<td>Interface N/S</td>
<td>parameters</td>
<td></td>
</tr>
<tr>
<td>segmentation</td>
<td>inverted</td>
<td>small</td>
</tr>
<tr>
<td></td>
<td>-10</td>
<td>0</td>
</tr>
</tbody>
</table>

Symbols:
- input (cause)
- output (effect)

**4 - CAUSAL RELATIONS:**

ALCMEN captures the causal influence of a CAUSE on an EFFECT and provides the possibility of parametrizing that relation by one or many CONDITIONS. The exact representation and function of CONDITION variables is left to be actualized for each causal relation, according to the most explicit available knowledge, its description may either use natural language (French, English, ...) or mathematical language (formulae, boolean, ...).

RELATIONS may be defined as mathematical formulae if possible, nevertheless as ALCMEN pretends to complete classical simulation languages by representing uncertainties or undeterministic knowledge by mixing Qualitative and Quantitative knowledge, it is proposed, of course, that the Qualitative features are to be used only if mathematical relations are not available.

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Figure 2
The four basic causal relations are:

1) increasing function: when \( x \) increases \( y \) increases
2) decreasing function: when \( x \) decreases \( y \) decreases
3) maximum de-tuning function: when \( x \) moves off its nominal value, \( y \) decreases
4) minimum de-tuning function: when \( x \) moves off its nominal value, \( y \) increases.

For the de-tuning function the nominal or extremal value must be given, and CONDITION may act on this extremal value.

It may be noticed that this 4 relations could be mathematically reduced to 2: monotonous and extremal.

\[
\begin{align*}
\text{variable } x & \quad \rightarrow \quad \text{variable } y \\
\text{MONOTONOUS} \\
\text{variable } x & \quad \rightarrow \quad \text{variable } y \\
\text{EXTREMAL} \\
\end{align*}
\]

5 - BLOCKS:

The BLOCK is the basic description unit, a Block is composed, as shown in figure 3 by:

1) 3 lists of variables: CAUSES, EFFECTS and CONDITIONS

2) all the CAUSAL RELATIONS between CAUSES and EFFECTS,
   all CAUSES must have at least 1 RELATION with an EFFECT
   all EFFECTS must have at least 1 RELATION with a CAUSE
   all CONDITIONS must have at least 1 link with a RELATION

6 - SPECIFICATION:

The first version of ALCMEN is being implemented using G2, one of the most technically advanced real-time expert system tool available on the market.
This tool is currently used for developing and running real-time expert systems for complex applications that require continuous and intelligent monitoring, diagnosis, and control.

G2 uses a rule and model-based approach which may result on a structure which is easy to survey and maintain.

The first step in developing an application with G2 is to define each class of object in the application. We must describe for each class, what its attributes are.

The specification of ALCMEN is based on two main kinds of classes of objects:
- blocks, with a list of variables used with relations, which are mathematic formula, or qualitative formula or simple rules.
- variables, with nature of variable, unit, range, some values, some constraints, ...

The hierarchy of those classes is on figure 6, with some attributes for each class.

```
+----------------+----------------+
| STATIC         | DYNAMIC        |
+----------------+----------------+
| BLOCK ----------| DEFINITION ----|
| state          | name formulas  |
| code           | list_var initial values |
|                | step, ...      |
|                | QUA LIT A T I V E |
|                | "good" values  |
|                | constraint     |
| VARIABLE ------|               |
| name           |               |
| nature         |               |
| unit           | QUANTITATIVE  |
```

Figure 6

The user must describe every block. He uses the following procedure:

```
begin creation_block
  write nature (static or dynamic)
  write full name
  write code
  while end-of-variables_list = false
    add variable_name on list
    write nature of variable (input, output, parameter) for this block
    write code
    if a description of this variable exists
      then write existing description
    else create a description frame
      add eventually informations on the description's variable
    end
    write the relations using the variables of list:
      - mathematic formula
      - qualitative or symbolic formula
      - rules
  end
end creation_block
```

When all blocks are described, the system creates a dictionary with all variables, and for each variable the list of blocks where it appears as input, output or parameter.

All these informations allow building an oriented matrix of blocks connections. In this matrix, we have on row $B_i$, and line $B_j$ the list of the output variables of block $B_i$ which are also the input variables of block $B_j$.

For each variable of the list, the system uses the following rules:

if $X_{numeric}$ is an output (resp input) of block $B_j$ and $X_{symbolic}$ is an input (resp output) of block $B_j$

then verify the item "numeric/symbolic conversion" for $X$ exists.

When this matrix is completed, and all necessary conversions have been defined, the connections between blocks appear as a graph and will later be
visualized. The model so constructed may then be simulated.

7 - ILLUSTRATIVE EXAMPLE:

The system of as two connected basins is used to illustrate the features described here. The system consists on instances of the numerical dynamical block BASIN, and two static qualitative blocks: SLUICE and SPILLWAY, connected as shown in figure 9.

This interconnected structure is obtained list of variables shown, and the BLOCKS of ALCMEN can then be represented in object form as represented here.

8 - FURTHER RESEARCH:

The above description corresponds to the present state of the implementation of ALCMEN, several points need to be completed, most of them are connected with the computer implementation and interfacing with graphical packages, nevertheless it must be observed that some fundamental features of ALCMEN are not developed in a generic way yet. They concern connections between causal variables and temporal features. These two topics are the object of present research.

- a) connections: The simultaneous effect of two or more causes is a situation clearly solved for analytical relations but not for qualitative environments. Similarly to the Causal Relations, it is attempted to give a typology of such connection relations. The present state of ALCMEN uses as a basis for connections the connective functions of fuzzy logic called t-norms, applied to multi-valued symbolic variables, their development is one of the prospective research subjects.

- b) time:

ALCMEN enables cinematic (or quasi-static) synchronous simulation of a given block by considering given a dated sequence of all causes and conditions, there is no apparent delay between a cause and an effect. A time base will be added, based on the shortest sampling period to consider variables; therefore another element called delay and expressed in basic sampling periods, will be adjoined to each causal relation so that the dynamic (or inertial) behaviour of the system may be simulated. The particular problems arising from this dynamic simulation have not been fully analyzed yet in ALCMEN, they refer to classical features of closed loop systems as stability, controllability, etc....
### List of variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Block</th>
</tr>
</thead>
<tbody>
<tr>
<td>( f_0 )</td>
<td>input flow</td>
<td>BASIN1</td>
</tr>
<tr>
<td>( f_1 )</td>
<td>communication flow</td>
<td>SLUICE, BASIN1&amp;2</td>
</tr>
<tr>
<td>( f_2 )</td>
<td>output flow</td>
<td>SPILLWAY, BASIN2</td>
</tr>
<tr>
<td>( h_1 )</td>
<td>water level basin 1</td>
<td>BASIN1, SLUICE</td>
</tr>
<tr>
<td>( h_2 )</td>
<td>water level basin 2</td>
<td>BASIN2, SPILLWAY</td>
</tr>
<tr>
<td>( d )</td>
<td>height of spillway</td>
<td>SPILLWAY</td>
</tr>
<tr>
<td>( w )</td>
<td>valve opening</td>
<td>SLUICE</td>
</tr>
<tr>
<td>( S_1 )</td>
<td>Surface basin 1</td>
<td>BASIN1</td>
</tr>
<tr>
<td>( S_2 )</td>
<td>Surface basin 2</td>
<td>BASIN2</td>
</tr>
</tbody>
</table>

### Dynamic

<table>
<thead>
<tr>
<th>( f_i )</th>
<th>( h_i )</th>
<th>( S_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( f_{i-1} )</td>
<td>( f_i )</td>
<td>( f_i )</td>
</tr>
<tr>
<td>( f_i )</td>
<td>( h_i )</td>
<td>( S_i )</td>
</tr>
</tbody>
</table>

\[
\frac{dh_i}{dt} = \frac{f_{i-1} f_i}{S_i}
\]

### Static

#### SLUICE

<table>
<thead>
<tr>
<th>( h_1 )</th>
<th>( h_2 )</th>
<th>( w )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( h_1 )</td>
<td>( h_2 )</td>
<td>( h_1 )</td>
</tr>
<tr>
<td>( h_1 )</td>
<td>( h_2 )</td>
<td>( f_1 )</td>
</tr>
</tbody>
</table>

if \( h_1 < h_2 \) then \( f = 0 \)

#### SPILLWAY

<table>
<thead>
<tr>
<th>( h_2 )</th>
<th>( d )</th>
<th>( f_2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( h_2 )</td>
<td>( d )</td>
<td>( f_2 )</td>
</tr>
<tr>
<td>( h_2 )</td>
<td>( d )</td>
<td>( f_2 )</td>
</tr>
</tbody>
</table>

if \( h_2 < d \) then \( f_2 = 0 \)
9 - CONCLUSION

A first version of ALCMEN is being used for the qualitative/quantitative representation and simulation of an industrial process in the framework of the ESPRIT project called IPCES (Intelligent Process Control by means of Expert Systems). It consists on the flow-coating process in TV screens manufacturing. A linguistic and logic description of the chain was first described by Petri nets where it appeared that most of the known relations could not be represented due to a lack of quantitative knowledge; therefore the tool for real time expert systems development G2 was introduced and its object oriented characteristics enabled the first implementation of the ALCMEN philosophy.

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