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MODEL BUILDING FOR FUZZY SYSTEMS BY MEANS OF FUZZSIM

Abstract. Problems encountered in modelling are discussed. Possibilities for setting up a fuzzy relation are given. Some of the author's fuzzy models of real world objects are listed. The software package GUZZSIM for fuzzy models is outlined. An simple example of a fuzzy model described in the GUZZSIM language and simulation results are presented.

1. Modelling of fuzzy systems

A well-working model of a real world object is always the result of a successful cooperation between scientists working in the field of system theory and analysis on the one hand and the specialists for the real object on the other.

In general, the claim of the model to be set up will be formulated by the specialists. This claim can impact with the possibilities of the methods used in system sciences and this, in turn, will give impulses for their further development. However, the specialists are challenged by system sciences to find out hidden qualitative and quantitative relationships in their object.

Not all of the requirements are able to be fulfilled by the partners. Nevertheless, the model established can be regarded as the best compromise that could be achieved at the moment.

In most cases, the aim consists in finding a model that captures the behavioural aspects of the real object under investigation. Many important problems such as prediction, control, classification, pattern recognition, diagnosis, decisions-making, safety analysis, etc. can be described as behavioural models.

The following items have to be considered during the process of modelling.

- Which claims and tasks are to be fulfilled with the help of the model where a certain cost-effect-relation and a necessary quality of the responses of the model are taken into account?
- Which of the quantities acting upon the system are relevant with regard to the intended task of the model?
- What are the structural relationships between the relevant variables?
- What are the types of scales of the available data?
- What methods, techniques, theories, etc. are adequate concerning the problems mentioned before?

The three questions listed at first consider qualitative features of the process of modelling mainly. The last question should not be taken into consideration too early. For instance, applying a certain method will cause in restrictions of the selection of the relevant variables before treating this point.

In general, the treatment of each of the above items will result in starting a new modelling process on this level of abstraction. In answering one of the questions there might be an effect onto those ones that have already been treated.

Hence, model building is both a hierarchical and 'iterative' process.

As already mentioned, in modelling two aspects have to be considered [6]

- the qualitative or structural aspect
- and
- the quantitative or relational (functional) one.

The qualitative interactions between the relevant variable can be described by structural relations. In complex systems it should always be possible to find out internal connections. This leads to a structured model. The complete model is regarded to be an interconnection of submodels. Each of the submodels can have a structure again. Hierarchical models have special kinds of structures.

In finding out a structure important and additional information is obtained about the system and, moreover, for the process of modelling.

A structural relation can also be a fuzzy one. In this case, care should be taken in interpreting the grades of membership.

As soon as a structure has been found each of the submodels can be identified by an appropriate method. Some of the submodels are derived from a phenomenological point of view, others from experimental process analysis and others, in turn, from a theoretical one. This will yield in an interaction of deterministic, stochastic, and fuzzy submodels.

Thus, an important claim of model building has been paid attention, namely, to bring in as much knowledge about the object as possible.

Quantitative interrelations are described by relations of functions. There exist different representations of them: an explicitly given computational instruction, an algorithm, a table of corresponding values or sets, a system of equations, etc.

Behavioural models are mostly represented by input-output models. Special input and output variables have to be derived from the relevant variables of the (sub-) model under investigation. A successful way is the consideration of the classification property of an input-output model. Then, the input variables are referred to as the features and the values of the output variable as classes.

Therefore, there is no methodological difference between classification, pattern recognition, situations recognition, diagnosis, decision making, etc. All of these stress only certain aspects.

The 'right' choice of the features is a crucial point. It has to be kept in mind that the feature extraction depends on the relevant information to be filtered.

For fuzzy models fuzzy relations are used. Here, a few possibilities for setting up a fuzzy relation are listed.

- Cause-effect relationships are often formulated as a set of 'IF...THEN'-statements. If the causes and effects are expressed by fuzzy sets (e.g. 'large', 'small', 'slightly increasing',...) it can be described by fuzzy implications. There are different definitions of fuzzy implications. A fuzzy 'IF...THEN' statement or fuzzy conditional statement is regarded as fuzzy subrelation. Their fuzzy union constitutes an estimation of the complete fuzzy relation required. Such a set of fuzzy conditional statements could also be regarded as a function that is described by means of the corresponding sets.
- Given the corresponding fuzzy inputs and fuzzy outputs the fuzzy relation is determined by solving fuzzy relational equations [3].
- Given measured input-output pairs that are regarded as typical input-output situations of the process under investigation. It is assumed that the process behaves similarly in the neighbourhood of a measured point. Then, this similarity is expressed by an unimodal fuzzy set, that is regarded as a fuzzy subrelation again. Their fuzzy union forms the required relation.
- The assumed similarity of the item listed before is used for a cluster analysis of the set of measured input-output pairs. Basing on the clusters a classifier can be derived. It is also possible to attach a parametric model to each cluster. The input-output pairs are used to estimate the parameters. Each model is defined only on its pertinent cluster.
- Sometimes, the process is given by a set of deterministic equations resulting from a theoretical process analysis. However, the parameters are fuzzy since only assumptions or some experience are available. Then, the

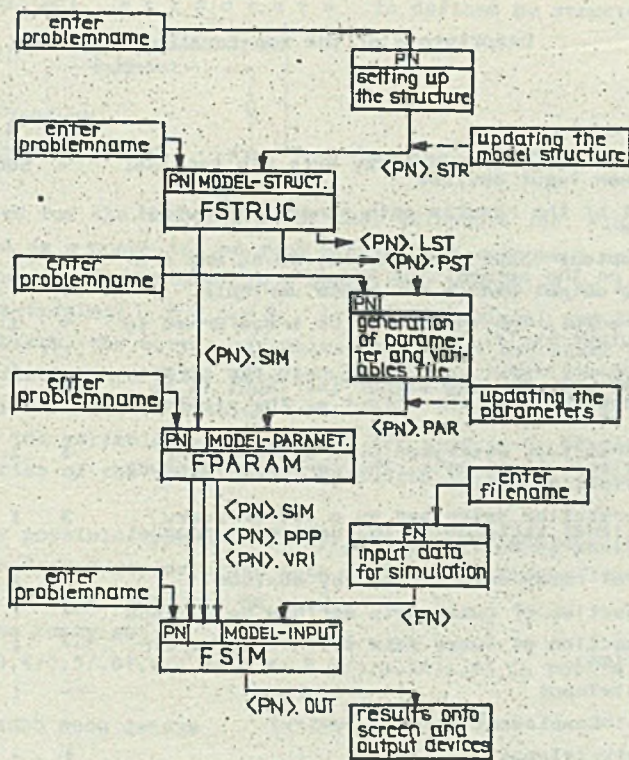


Fig. 1

$$f_c(x) = 1/(1 + \text{FACTOR} \cdot 0.016 \cdot (c-x)^2)$$

$$f(f_a \vee x[a,b] \vee f_b) - 10^{-4}$$

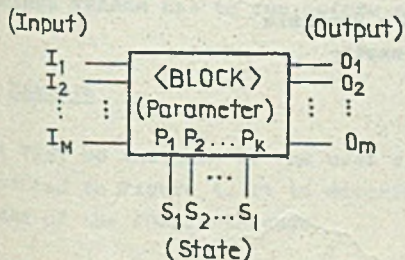
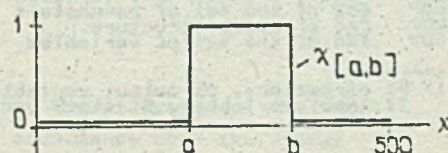
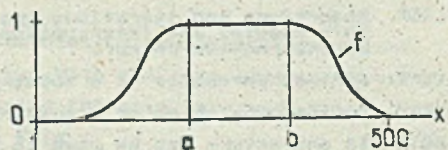


Fig. 2



$[a,b]$ full membership interval

Fig. 3

Table 1

Descriptors of the non-terminal block

symbol		maximal number of				1)
		P	O	I	S	
INPT	Input of fuzzy or non-fuzzy data via terminal or other input devices	-	500	-	-	
OUTP	Output of the results onto screen and output device	-	-	500	-	
MEMO	The topical input and the preceding one are shown on the screen. The input is transferred to the output and to the state variable	-	1	1	1	
DLAY	Delay-modul. The input will be transferred to the output at T+1	-	1	1	1	
DECN	The topical input is written onto the screen. It has to be decided either the input is to be transferred to the output or the simulation is to start again.	-	1	1	-	
RELI	Fuzzy relation described by a set of fuzzy conditional statements. The cartesian product is defined by minimum	3	1	500	-	
RELU	Fuzzy relation described by a set of fuzzy conditional statements. The cartesian product is defined by multiplication	3	1	500	-	
DISJ	Union of fuzzy sets defined by maximum	-	1	500	-	
CNJI	Intersection of fuzzy sets defined by minimum	-	1	500	-	
CNJU	Intersection of fuzzy sets defined by multiplication	-	1	500	-	
EQAL	Output:=Input	-	1	1	-	
NEGN	Output:=Complement(Input) ($y=1-x$)	-	1	1	-	
SETP	Parameter:=Input	1	-	1	-	
SETV	Output:=Parameter	1	1	-	-	
SELF	The function of this module can be coded by the user	500	500	500	500	
TIME	is used in case of dynamical system	-	-	-	-	
TMSR	reads in multivariable time-series	1	500	1	-	
SURS	designs a substructure	500	500	500	500	
LOOP	Recursions and iterations can be modelled by this module. The interruption is achieved in an interactive manner.	-	-	500	-	
DEFP	defines parameter of a substructure	500	-	-	-	
DEFV	defines variables of a substructure	-	-	500	-	
NOTE	16 characters may be used to denote a variable					
END	closes a structure, variable or parameter					
EOP	End of the set of parameters					
EOV	End of model-structure					
EOV	End of the set of variables					

1) P: parameters, O: output variables,
I: input variables, S: state variables

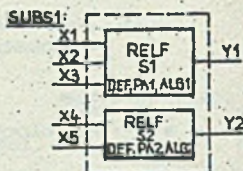
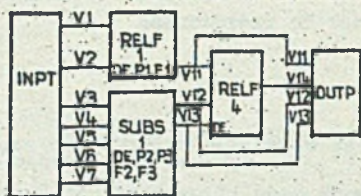


Fig. 4

The file TEST.STR containing the structure is as follows:

```

/ ILLUSTRATING EXAMPLE
/ STRUCTURE
/ PROBLEM: TEST
/ DATE: APRIL 27
/
INPT (, V1, V2, V3, V4, V5, V6, V7,;)
REL F1 (DE, P1, F1, V11, V1, V2,;)
SUBS1 (DE, P2, P3, F2, F3, V12, V13, V3, V4, V5, V6, V7,;)
REL F4 (DE, P4, F4, V14, V11, V12, V13,;)
OUTP (, V11, V12, V13, V14,;)
END

SUBS1 (DEF, PA1, PA2, ALG1, ALG2; Y1, Y2; X1, X2, X3, X4, X5,;)
REL F1 (DEF, PA1, ALG1; Y1, X1, X2, X3,;)
REL F2 (DEF, PA2, ALG2; Y2, X4, X5,;)
END

NOTEV11 (RESULT OF REL F1 )
NOTEV12 (RESULT OF REL F2 )
NOTEV13 (RESULT OF REL F3 )
NOTEV14 (RESULT OF REL F4 )
EOS

```

headline
structure
substructure
variable-
denotation
end of structure

FSTRUC creates the files TEST.SIM, TEST.LST and TEST.PST.
TEST.PST might be the basis of TEST.FAR since all the variables,
and parameters used in TEST.STR are listed.
Here is a listing of TEST.PST (shortened):

```

/ ILLUSTRATING EXAMPLE
/ STRUCTURE
/ PROBLEM: TEST
/ DATE: APRIL 27
/
V1
V2
...
V14
EDV
...
DE (TYP+, **)
END
P1 (TYP+, **)
END
F1 (TYP+, **)
END
...
P4 (TYP+, **)
END
...
F4 (TYP+, **)
END
EOP

```


The file TEST.PAR includes the specified variables and parameters of the fuzzy simulation model (shortened):

```

/ ILLUSTRATING EXAMPLE
/ PARAMETER                                     headline
/ PROBLEM: TEST
/ DATE: APRIL 27

V1(1)
V2(1)
V3(1)
...
V13(7)
V14(5)
EOV
DE(TYP2,14)                                     number of classes of
                                                variable V13
A1 425 500 1
A2 350 425 1
A3 275 350 1
A4 225 275 1
A5 150 225 1
A6 75 150 1
A7 75 75 1
B1 75 75 1
B2 75 75 1
B3 75 75 1
B4 75 75 1
B5 75 75 1
B6 75 75 1
B7 75 75 1
END
P1(TYP3,3)                                     ordering of the variables
V1 V2 V11                                     in accordance with fuzzy
END                                           algorithm F1
F1(TYP4,21,3)                                  F1 is the name of a fuzzy
A1 A1, B1;                                   algorithm with 21 state-
A1 A2, A2, B2;                               ments and 3 variables
A2 A3, A1, B2;
...
A5 A6, A7, B7;
A7, A1 A2 A3 A4, B7;
A7, A7, A5 A6, B7;
END
P2(TYP3,3)
V3 V4 V5
END
F2(TYP4,46,4)
A1 A2, A1, A1, B1;
A1, A1 A2, A2, B2;
A2, A1, A1 A2 A3, B2;
...
A5, A4 A5, A5, B5;
END
...
EOP

```


To simulate the model a file have to contain the input values.
In this example all the input values are non-fuzzy. The filename
is INPUT1.

```

V1(1)
  382
END
V2(1)
  362
END
V3(1)
  410
END
V4(1)
  390
END
V5(1)
  310
END
V6(1)
  438
END
V7(1)
  362
END
EOV

```

The file TEST.OUT contains all the results. These results are also
written onto the screen during the simulation.

```

/ ILLUSTRATING EXAMPLE
/ STRUCTURE
/ PROBLEM: TEST
/ DATE: APRIL 27
/ ILLUSTRATING EXAMPLE
/ PARAMETER
/ PROBLEM: TEST
/ DATE: APRIL 27

```

DATE: 27-APR-.. TIME: 12:31:05

FUZZY OUTPUT WITH RESPECT TO THE INPUT
OF FILE : INPUT.

V11 : RESULT OF RELF1

CLASSES
1 - 7: 1360 9999 8127 762 322 137 75

V12 : RESULT OF RELF2

CLASSES
1 - 5: 451 3378 9999 2808 451

V13 : RESULT OF RELF3

CLASSES
1 - 7: 9999 8127 7871 229 229 137 75

V14 : RESULT

CLASSES
1 - 5: 1360 9999 8127 2808 322

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MODELOWANIE SYSTEMÓW ROZMYTYCH ZA POMOCĄ FUZSIM

Streszczenie

Praca omawia problemy modelowania. Podane są możliwości tworzenia relacji rozmytych. Wymienione są niektóre z modeli rozmytych autora obiektów świata rzeczywistego. Prosty przykład modelu rozmytego opisany jest językiem FUZSIM i przedstawione są wyniki.

МОДЕЛЬНОЕ СТРОЕНИЕ СИСТЕМ FUZZY С ПОПОЩЬЮ FUZSIM

Р е з ю м е

В работе рассматриваются проблемы моделирования. Приводятся возможности образования соотношений "fuzzy". Перечисляются некоторые авторские модели fuzzy объектов действительного мира. Простой пример модели fuzzy описывается с помощью языка FUZSIM и даются также рисунки.

Recenzent: Dr inż. Ryszard Knosala

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