QUANA - AN INTERACTIVE SOFTWARE FOR QUALITATIVE ANALYSIS OF COMPLEX SYSTEMS

DARKO STIPANIČEV, ZVONIMIR TORBA

Faculty of Electrical Engineering, Machine Engineering and Naval Architecture
UNIVERSITY OF SPLIT
R.Boškovića bb, 58000 Split, Croatia, YU
tel.058/563-777 fax.058/563-877

ABSTRACT: The paper presents an interactive software QUANA developed for qualitative ANAlysis of systems modelled, either as signed digraphs , or as newly introduced fuzzy (linguistic) digraphs. QUANA was developed for different qualitative analyses of systems performances and behavior. Typical analyses are analysis of system balance, identification and characterization of system loops, stability analysis, prediction of new equilibria of systems variables after external parameter change and disturbance pulse propagation. Software was successfully used in analysis of the marine ecosystems.

1. INTRODUCTION

Conventional, quantitative, mathematical modeling techniques are quite successful in detailed characterization and description of pieces of problem, but not for solving, or even posing, broad, general problems connected with complex, not preciously known systems, as for example with ecosystems.

In coping with complexity methods of qualitative modeling are more suitable. Their main motivation is to explain and to predict the behavior of the physical world in qualitative terms. Moving from the quantitative to the qualitative descriptions all important behavioral distinctions are preserved and usually they could be easily intuitively understood.

Qualitative modeling method are designed to identify the core knowledge that underlies physical intuition. Humans appear to use a qualitative causal calculus in reasoning about the behavior of their physical environment, so with this methods we try to formalize and apply the human way of thinking. One type of qualitative modelling approach is particularly suitable for the complex systems analysis. That is weighted digraph approach which uses directed graphs (Harrare et al. 1965) for graphical visualization of interactions inside the analyzed system. Weights associated with arcs give information about kind and strength of interaction, but in qualitative models this information is qualitative and not quantitative. The most qualitative weighted digraph is signed digraph where only signs of interactions between variables are known. More sophisticated case could be when also the strength of interactions expressed by words of natural language ("positive small", "negative very big", etc.) are disposable. Using fuzzy set theory such models defined as fuzzy (linguistic) digraphs (Stipaničev and Efstathiou, 1989., Stipaničev, 1991) could be formalize and analyzed by computer.

Although qualitative weighted digraphs are not so precise as conventional mathematical models, they could be quite useful in real life applications. In this paper, after short introduction to qualitative modelling and analysis, the interactive software for qualitative analysis QUANA will be introduced and explained through an example of two competitors ecosystem

2. WEIGHTED DIGRAPHS AND QUALITATIVE ANALYSIS

Weighted directed graphs (digraphs) are used for graphical representation of interactions inside the analyzed system. The graph nodes correspond to system variables relevant to, or representative of, the analyzed system. In the case of the ecosystems variables could be species, nutrients, social groups, etc. The graph arcs correspond to interactions between variables or more preciously to interactions between variables and their grow rates. Weights associated with arcs give information about kind of interactions and sometimes about strength of interactions.

Fig 1. shows a four variable system of two competitors (A_1,A_2) and two resources (R_1,R_2). The arc between competitor A_1 and resource R_1 means that A_1 has an influence to the grow rate of R_1. Figure 1. shows two types of weights: *signs* (+,-) which give only the kind of interaction (+ means augmenting effect and - inhibiting) and *linguistic expressions* (much smaller, quite smaller, etc.) which qualitatively give the strength of interactions.

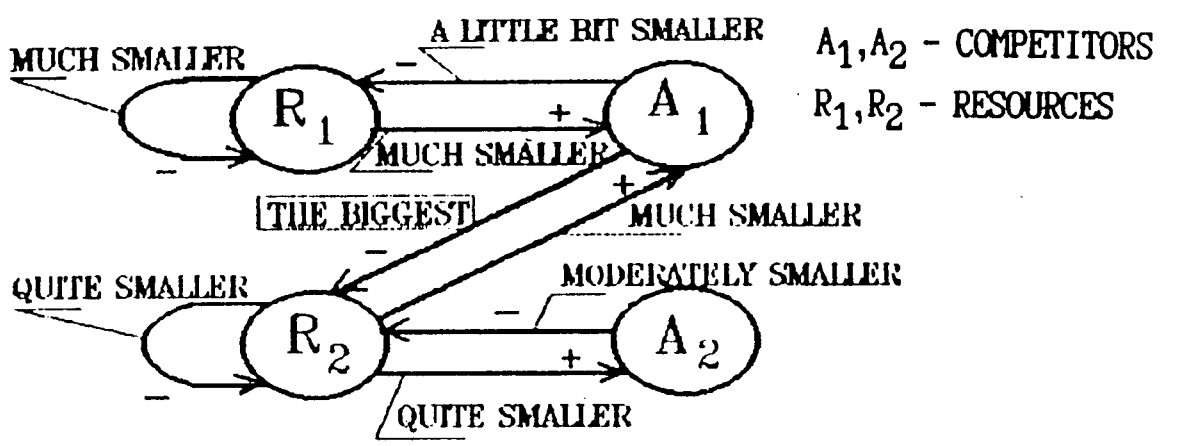

Fig. Qualitative weighted digraph of two competitors system

For simple analyzes, signed digraphs could be used but sometimes to resolve the inherent ambiguity of the sign algebra, information about strength have to be introduced. In (Stipaničev, Efstathion, 1989) and (Stipaničev, 1991) an approach based on fuzzy set theory has been developed. Both: signs and linguistic expressions are modelled with thee element fuzzy vectors, as Fig.2 and Fig.3 show. A special arithmetics with qualitative (fuzzy) values was developed and implement in QUANA.

QUANA offers several qualitative analyzes as for example:

a) *Structural analyses* which identifies important system features and properties analyzing only the structure of the digraph. Typical structural analyzes are analysis of system balance, identification of self-effect links, characterization of system loops, etc.

b) *Stability analyses.* Suppose that a community of n species is in equilibrium and one (or few) of system variables are subjected to small but sudden population increase of decrease, caused by some external, independent

parameter change (temperature increase, introduction of new protection law or similar). Some variables (species) may show changes away from equilibrium and the question is will all this variables reach new equilibria or not. Will the system be stable, at least asymptotically, or no? In lot of cases sign qualitative model is sufficient to give answers to the questions.

c) *Qualitative sensitivity analyses (prediction of equilibrium levels).* With this analysis we want to obtain more information about new equilibria, if the system is stable and if there are small and sudden perturbations. The question is will new equilibria of system variables be higher, smaller or the same as the previous one.

d) *Pulse propagation analysis.* This analysis is used when time is introduced. We are analyzing propagation of perturbation through the network. What will happened, let us say in discrete time moments (1 minute, 3 hours or maybe 1 year) if some perturbations are introduced. Of course the answers will be qualitative, typically after 1 month population of x_1 will increase and population of x_2 will decrease, after 2 months population of x_1 will be the same, but x_2 will still decrease, etc.

QUANA has all these features and it could be used in both cases: when only signs of interactions are known and when both signs and linguistic values of weights are known.

3. INTERACTIVE SOFTWARE FOR QUALITATIVE ANALYSIS

Interactive software for qualitative analysis QUANA was developed in high level language Q'NIAL. This language is a possible successor to the language LISP and APL and an alternative to PROLOG in artificial intelligence area. The language was developed at Queen's University at Kingston, Ontario, Canada. Here a short presentation of QUANA through the example of two competitors system shown in Fig.1. will be given.

Main menu of QUANA offers eight topics:

-*MAIN HELP* - A short introduction to each topic

-*NEW* - Starting level at which the system order is defined.

-*CHANGE* - Program for definition and correction of interactions between variables including their signs and weights. System balance and system determinant is automatically calculated.

-*PARAMETER* - Program for definition of external parameters changes and their influences to the variables grow rates.

-*SENSITIVITY* - Qualitative prediction of variables equilibria levels changing after external parameter change (a kind of qualitative sensitivity analysis).

-*STABILITY* - Qualitative stability analysis.

-*PULSE PROPAGATION* - Qualitative analysis of disturbance pulse propagation considering the system as a pulse process.

-EXIT - Exit to DOS.

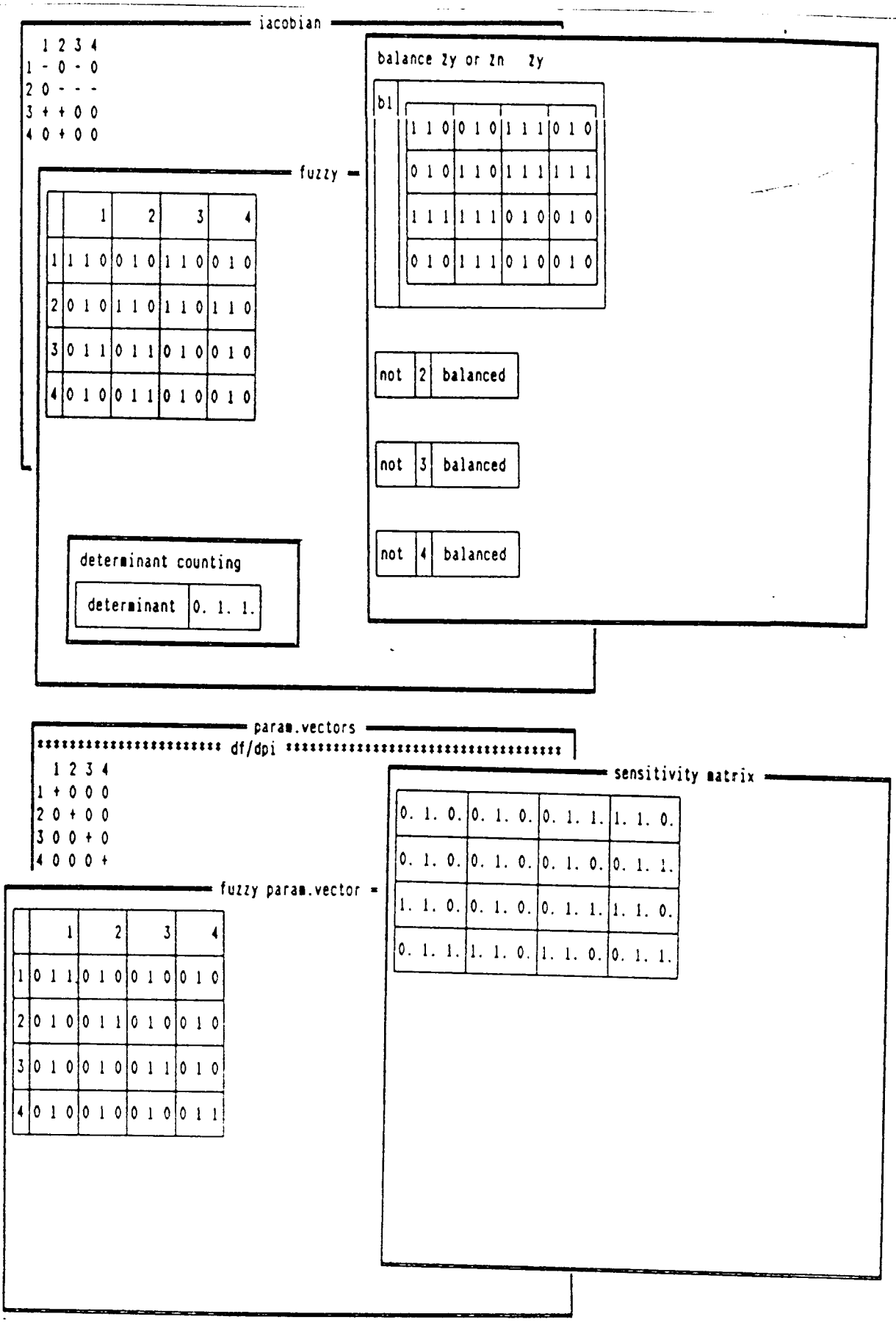

Fig. 2. Definition of system matrix of influence, analysis of system balance and qualitative sensitivity analysis for two competitors system modelled as signed digraph

Fig.2. shows windows created by CHANGE, PARAMETER and SENSITIVITY. Interactions between variables and their grow rates are given by signs. Variable 1 corresponds to resource R_1, variable 2 to resource R_2 and variables 3 and 4 to competitors A_1 and A_2. For example, from Fig.1. it could be seen that variable 3 has a negative influence on the variable 1 grow rate, so in the first row third column of the system matrix of influence (Jacobian) there is a minus (-) sign. Fuzzy version of sign Jacobian is given too. +, - and 0 are expressed with fuzzy vectors [0 1 1], [1 1 0] and [0 1 0]. Detailed explanation of this procedure could be found in (Stipaničev, Efstathiou, 1989).

The value of the system determinant is [0 1 1] what means +. Results of balance analysis is also given, but their explanation is beyond the scope of this paper. Good introduction to balance analysis is given in (Harrare et. al.,1965). The window for the external parameters changes and their influences to the system variables grow notes shows that there are four external parameters with positive influence on only one variable grow rate in a time. The sensitivity matrix gives the results of equilibria levels changing under the influences of these parameters changes. For example for positive change of 1st parameter, equilibrium levels of variables 1 and 2 will be unchanged, variable 3 will have higher and variable 4 lower equilibrium (first row of sensitivity matrix),

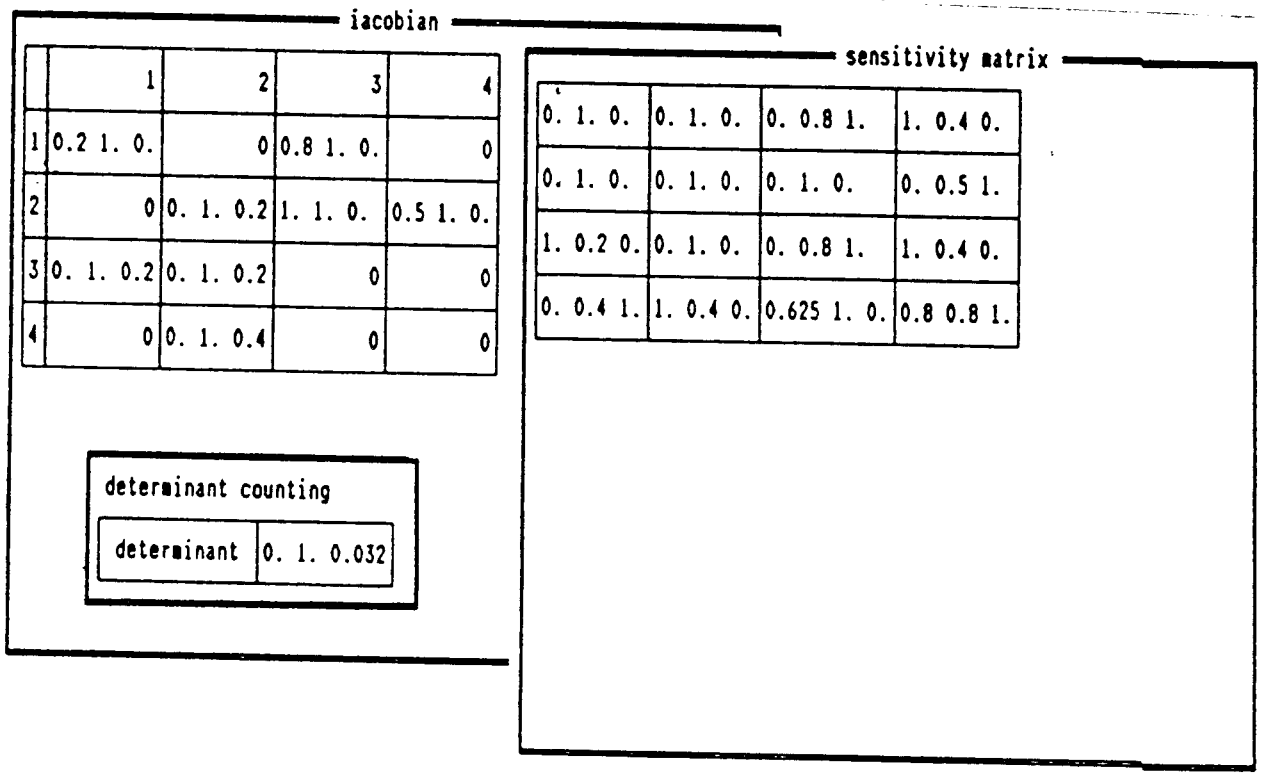

Fig.3. Definition of system matrix of influence and qualitative sensitivity analysis of two competitors system modelled as fuzzy (linguistic) digraph

QUANA also gives the possibility that the definition of the strength of influence could be expressed by the linguistic expressions.Linguistic values are also modelled with three elements fuzzy vectors. For example expression "negative much smaller" is modelled as [0.2 1 0], "negative a little bit smaller" as [0.8 1 0] and similar. The whole system matrix for two competitors system with weights according to Fig.1. is given in Fig.3.

The system determinant is [0 1 0 0,32] which represents a very small positive value. The sensitivity matrix is also shown. Interpretation is similar as before. For example the first row represents what will happened with variables steady states, if there is a positive change of the 1st parameter (which influences the variable 1 grow rate). The some as before steady states values of variables 1 and 2 will be unchanged, variable 3 will have higher and variable 4 lower new steady state value. But this time it is possible to conclude about magnitudes of steady state values changes. For example the absolute magnitude of change will be bigger for variable 4 because [1 0.4 0] represents bigger value according to its absolute magnitude than [0 0.8 1] (the first one is negative and the second one positive). More details about arithmetics with qualitative values could be found in (Stipaničev, 1991). Other possibilities of QUANA is qualitative stability analysis (Jeffries, 1974) and disturbance pulse propagation (Roberts, 1976).

QUANA was successfully used in analysis of marine ecosystems. Together with Institute of Oceanography and Fishery, Split a qualitative model of organic waste pollution and eutrophication of semi closed marine basins was developed and analyzed (Stipaničev, Marasović, Gačić, 1991).

4. CONCLUSION

An interactive software QUANA in presented. Software was developed for different kinds of qualitative analyses of systems modelled either, by signed digraphs or by fuzzy (linguistic) digraphs. Qualitative analyze of system structural properties, prediction of equilibrium levels changes after external parameter change, analysis of system stability and disturbance pulse propagation are examples of these analyzes. QUANA was successfully used in analysis of marine ecosystems.

ACKNOWLEDGMENTS

This research was supported by the Ministry of Science of Republic Croatia through the project "Intelligent system for collecting, analyzing and presentation of information about undersea environment".

REFERENCES

Harrary, F., Norman, R.Z. and Carteuright, D. (1965), *Structural Models: An Introduction to the Theory of Directed Graphs*, J.Willey and Sons, New York

Jeffries, C. (1974) "Qualitative stability and digraphs in model ecosystems", *Ecology*, Vol.55, pp.1415-1419

Roberts, F.S. (1976), *Discrete Mathematical Models*, Prentice-Hall, Inc., Englewood Cliffs

Stipaničev, D. and Efstathiou, J. (198), "Qualitative reasoning and fuzzy Set theory", *Proc. Int. AMSE Conf. "Signal and Systems"*, Brighton (UK), 12-14 July 1989, AMSE Press, Vol.1., pp.17-26

Stipaničev, D. (1991), "Arithmetics with qualitative values and fuzzy set theory" to be printed in *Proc. of 3rd Joint Workshop of IFSA-EC and EURO-WG on Fuzzy Sets*, Visegrad (Hungary), Dec. 1990. as *Annales Universitatis Scientiiiiorum Budapestiensis de Rolando Qotvos Nominatae Sectio Computatiorica* (ed. M.Kovacs) pages 8

Stipaničev, D., Marasović, J., Gačić, N. (1991) "Qualitative modelling of complex marine ecosystems", *Proc. of ETAN IN MARINE*, Zadar, June 22-24, (in Croatian)