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ON THE CONSEQUENCES OF THE COMPLEXITY OF TASKS IN MEASUREMENT*

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Abstract. This paper describes an analysis of the consequences of complex measurement tasks. The authors show that today's measurement problems open new dimensions for the interpretation of the basic measurement concepts and make the reevaluation of these concepts necessary.

In many cases, traditional methods fail to yield useful solutions, especially when measurement problems reveal considerable complexity, involve a wide spectrum of various disciplines and require a multitude of components and methods. Since traditional methods, without a proper resource management, supported at the system level, seem inappropriate to solve such problems, qualitatively new methods are needed. This paper seeks answers to these problems. It gives a brief overview of various imprecise computational methods and discusses their applicability to treat complex measurement problems. Authors propose a general modeling framework to be used as a basis for complex engineering systems, which addresses also the problem of fault tolerance at a system level.

Key words: hierarchical decomposition, soft computing, complex measurement systems, hybrid systems, independent modeling, resource management.

1. INTRODUCTION

Up to now, classical problem-solving methods have proved to be entirely sufficient in the measurement and systems engineering. Nowadays, however, measurement science tackles problems of previously unseen spatial and temporal complexity (consider, e.g., measurement problems of industrial plants, large-scale environmental systems or laboratory tests in health care). However, in numerous cases, traditional information processing methods and equipment have

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failed to handle these problems. It is obvious that new ideas are required to specify, design and implement sophisticated measurement systems.

Similar problems have appeared in many other fields of research, and therefore, it appeared natural to explore and adopt the solutions. In the field of Artificial Intelligence (AI), Soft Computing (SC), and Imprecise Computation (IC), several methods have been developed that address the problem of nonnumerical information processing and the rational control of limited resources. In AI, the so-called anytime algorithms [1,2] offer considerable control over resources, in SC and IC, the trade-off between accuracy and the use of resource is possible [3,4].

The following sections discuss problems arising from the complex nature of the problems and limited resources of the designed measurement systems.

2. PROBLEMS OF COMPLEX MEASUREMENT SYSTEMS

In the measurements, the model used serves as a basis to design information processing methods and to implement them at the equipment level. In the case of complex measurements, analytical models leading to a well-defined numerical optimal information processing are not sufficient. The complexity of the problem manifests itself not only as a hierarchy of subsystems and relations, but also as the variety of modeling approaches needed to grasp the essence of the modeled phenomena. Analytical models rarely suffice. Frequently, numerical information is missing or is uncertain. As a result, various qualitative or symbolic representation methods emerge.

This situation can still be complicated by the fact that various modeling approaches, expressing different aspects of the problem, should be used together in a well-orchestrated integrated way. Even more disturbing is that such traditional metrological concepts, like accuracy, error, scale, unit are no more applicable in their usual approved sense.

As a consequence, researchers turned to new methods and fields to tackle the problem. AI has offered means to handle nonnumerical and vague information. IC and SC have offered a novel view at the computational accuracy as a utility rather than an ultimate aim of the development. Though many methods in the fields mentioned seem applicable at the first sight, three essential problems have to be addressed.

1. The process of measurement requires much deeper analysis to decide whether and when nonnumerical, nonanalytic methods are appropriate; what the new aspects and relations are to be considered; and what kind of new problems arise.

2. It is apparent that different methods handle various modeling and processing aspects of the problem differently. Subtle but essential differences have to be identified, and their effects have to be taken into account.

3. It should be emphasized that for a complex problem, a single method will not suffice. An efficient embedding of various methods into a uniform designing framework has to be solved.

As mentioned, some of the classical concepts and goals have to be analyzed and reevaluated, and the new methods must be placed into the context of the accepted classical frame of measurement. As one of the key concepts, the meaning of accuracy has to be revised. Since individual information processing components cooperate for a global goal, results achieved by them have to be evaluated from the point of this overall goal. In consequence, a new notion of accuracy, reflecting the utility of the results, must be developed.

Using the system components, processing different forms of information, calls for a certain degree of homogeneity to hide differences and to efficiently embed and integrate them. To achieve this polymorphism, an interface is needed, simplifying the communication and information sharing and yielding a basis for a simple substitution of one method for an another.

Complex problems have to be decomposed into smaller scale problems, for which well-understood and practically applicable methods and instrumentation exist. However, decomposition results usually in a complex information processing with interacting heterogeneous components and far from trivial system integration.

This draws attention to the problem of limited resources. Since all of the methods operate in a common computational environment, they must necessarily share computational resources. Although the technology produces more and more advanced computer architectures, they cannot match the scaling up of the problems, especially when hybrid numerical and symbolic information processing is involved.

In consequence, information processing components must and will compete for resources which raises the question of how and when they will know which resources are available. Information processing in a system with finite resources must thus be organized as the interacting flows of information processing designed to solve the problem and information processing, evaluating the state of the system and managing the best distribution of the computational resources. Figure 1 shows the relation between the task and the resource levels of information processing. Information flow at the task level is implemented using certain resources. Problems appearing at the resource level (faults or insufficient resources) have decisive effect on the performance at the task level. However, this also implies that the modification of the requirements at task level leads to changes in resource allocation.

In consequence, a prospect opens for methods where the accuracy can be controlled as a function of the resource usage. This trading off between accuracy vs. resources bears immense significance in systems where resources are strictly limited, like computing systems deployed in the environment where frequent service and repair is impossible.

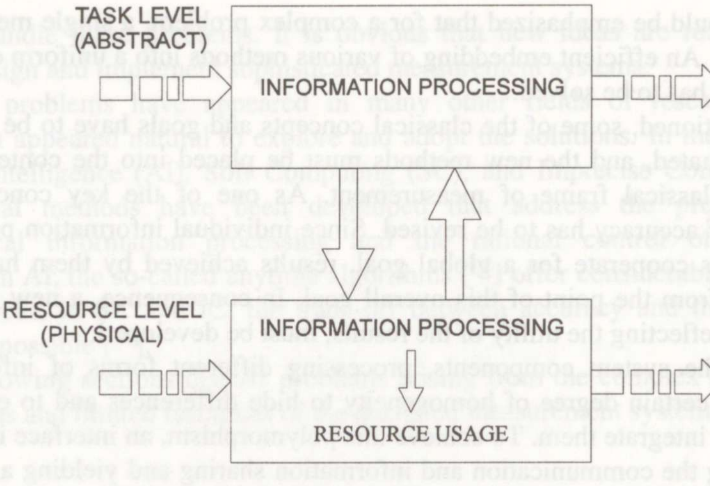

Fig. 1. The relation of task and resource levels.

Competition for resources complemented with an extended notion of accuracy (where the utility of the accuracy is evaluated with respect to a particular goal) can serve as a basis for a dynamic matching of the 'flexible' requirements of various processing components to the current available resources, seeking an optimal implementation, considering the circumstances.

The next section gives a brief overview of such methods.

3. IMPRECISE COMPUTATIONAL METHODS

The circumscription of IC [3], or SC was first proposed by Zadeh as: "In traditional hard-computing, the prime desiderata are precision, certainty, and rigor. By contrast, the point of departure in soft computing is the thesis that precision and certainty carry a cost and that computation, reasoning, and decision making should exploit – whenever possible – the tolerance for imprecision and uncertainty" [4].

Probabilistic Reasoning (PR) [5,6], Fuzzy Logic (FL) [4,7–9], Neural Networks (NN) [10], and Genetic Algorithms (GA) [11] fit this definition well, which presents a direction for research.

PR methods support problem solution in the field where the world exhibits randomness and can also be very efficient to handle rather large problem spaces, applying statistical measures to approximate the probabilities of the individual states.

FL methods can be comfortably and efficiently used to design intelligent systems on the basis of knowledge expressed in a natural language. These systems have been shown to be more successful in many applications (e.g., in control, signal processing, and decision-making) than those based on conventional approaches.

NNs are particularly interesting as the basis for the development of adaptive architectures. They can be trained or can learn, for instance, to classify, recognize patterns, understand speech, forecast, control robots, vehicles, or industrial processes.

GAs and Genetic Programming [12] can solve optimization problems efficiently. They have proved to be very useful in the optimization of non-linear multivariable systems. In addition, they have been successfully applied for problems in system identification, classification, control, robotics, optimization, and pattern recognition.

Considering the above definition of SC, a better clarification of the nature and origin of costs would lead to a more relaxed, wider spectrum of soft computing methods. In the following, different techniques will be discussed as closely related to the idea of SC.

The concept of imprecise system or computation covers a task-based, distributed computation, where each task can run at a different level of precision, naturally versus some critical resource, mainly computation time. A global intelligent (imprecise) scheduler, familiar with the actual load of the system and the required timeliness of the response, makes decisions according to the predefined or actual priorities and disposes of the accuracy level of each task to reach some global optimum in the quality of the computed results within the given resource limits. It is a very important item, for instance, in real-time systems, where the evaluation time is limited and the response time bounds the amount of possible calculations and manipulations.

The concept of monotony of computation grasps the idea of an execution where the quality of the intermediate results does not decrease as the computation continues. Fortunately, several algorithms meet this requirement (recursive methods are typical examples in measurement). The so-called any-time algorithms can be interrupted at any time-point and serve admissible results. The later such an algorithm is stopped, the better, i.e., the more accurate results it produces.

Recently we made new efforts to combine the ideas of the traditional and SC methods. One example can be the development of the so-called anytime FFT in digital signal processing [13]. The combination of fast algorithms (e.g., FFT) with simple averagers among others offers the early availability of some rough estimates of the results. This may reduce the side-effect of the delay caused by the basic (block-oriented) approach and is of real importance in applications where the response time is also specified.

Anytime algorithms, the imprecise scheduling algorithms together with various modeling techniques may lead to a completely new class of measuring systems, where the accuracy of the results is no more a strict specification item, it is rather a system resource to be traded according to the situation at hand.

In spite of the increasing interest in the new algorithms and of the large number of successful practical SC applications, fuzzy set theory and fuzzy logic, as well as the other IC methods have faced strong opposition from conventionally oriented theoreticians during the past thirty years (e.g. [[9]]). There is an aversion against these methods, on the one hand, due to the unconventional approach of handling uncertainty, on the other hand, due to some critical questions related to design and verification not solved yet. It also has become evident during the past ten or twenty years that there is no single approach for realizing all functions fundamental for intelligent systems, and therefore, it is better to integrate and fuse some of them to overcome the disadvantages of each techniques.

4. A MODELING FRAMEWORK FOR EMBEDDING COMPONENTS OF DIFFERENT NATURE

In complex measurement problems with resource limitations (time being the most precious resource in most of the cases), various SC methods can be used to balance quality versus resources. Using numerous methods of different nature (knowledge representation, information handling) draws attention to cooperation among the methods solving the subtasks. On the other hand, a subtle controlling mechanism that takes into account various properties of the applicable methods, is needed to select the most suitable one. This emphasizes the need for uniform handling of different modules (i.e., identical interfaces) and the necessity for communication between these modules.

In [[14,15]] a modeling framework was proposed for distributed diagnosis, however, it may be advanced, offering a basis for modeling complex systems – including also measurement systems – and thus may be advantageous in decreasing the problem complexity by applying hierarchical decomposition, in combining modules with different methods into a homogeneous scheme, and in building a reliable (dependable) system. Furthermore, its diagnostic components may be utilized to provide the abovementioned controlling facilities.

Let us briefly discuss the modeling approach as a possible means to help in handling some of the above detailed problems. Although we would like to emphasize that the use of this technique is not restricted to measurement systems, the idea behind it seems more general.

The model considers the system from the functional point of view, and its aim is to provide means to maintain this functionality. Since the original goal is to model complex measurement systems, the architecture offers a hierarchic decomposition scheme to divide the problem into smaller-scale subtasks. The hierarchic decomposition naturally matches the system model, for the system itself inherently posses such a structure. The model applies the abstraction of requirements and services. The overall task of the system is formulated as a top level requirement, and the active components (i.e., algorithms) of the model search for top level services to satisfy it. The hierarchic decomposition is the case, when the top level services have been found. They can be divided into requirements at a lower level. The task (and the model) is recursive in nature: a similar requirement-service substructure hides at each level (see the right side of Fig. 2).

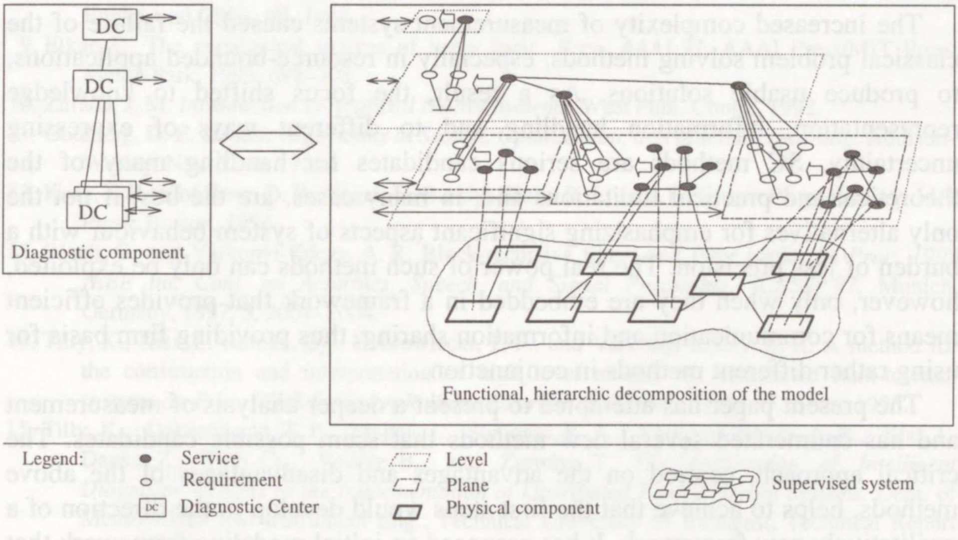

Fig. 2. The structure of the system model.

The hierarchic decomposition is also important from the practical point of view; it is necessary to cope with algorithmic and memory complexity of representing and interpreting models of complex systems.

In connection with complex measurement systems, the question of dependability, reliability comes to the front. This is amplified in the present model, since its aim is to model complex embedded systems. Though the individual components may (and very often do) show fault tolerant behaviour, means have to be provided to raise the fault tolerance to the system level. For this purpose, the model may be complemented with the so-called diagnostic centres (DC) to monitor the state of the components and to take appropriate actions in the case of faults appearing in the system. In addition to monitoring the system, DCs may be responsible for reconfiguration and planning new configurations. To maximally match the model structure, the DCs may also be organized into hierarchy similar to that of the model (see the left side of Fig. 2). The two hierarchies complement, co-operate and communicate with each other, forming information channels between components at the same levels.

Furthermore, in the case of complex measurement systems, applying SC methods, the diagnostic centres may be assigned an additional task: the control and monitoring of the applicability of various methods, and the selection of the optimal one.

5. CONCLUSIONS

The increased complexity of measurement systems caused the failure of the classical problem solving methods, especially in resource-bounded applications, to produce usable solutions. As a result, the focus shifted to knowledge representation, information handling and to different ways of expressing uncertainty. SC methods are serious candidates for handling many of the theoretical and practical limitations and, in many cases, are the best if not the only alternatives for emphasizing significant aspects of system behaviour with a burden of less precision. The real power of such methods can only be exploited, however, only when they are embedded in a framework that provides efficient means for communication and information sharing, thus providing firm basis for using rather different methods in conjunction.

The present paper has attempted to present a deeper analysis of measurement and has enumerated several new methods that seem possible candidates. The critical approach, centred on the advantages and disadvantages of the above methods, helps to achieve that the first steps would develop in the direction of a qualitatively new framework. It has proposed an initial modeling framework that can be appropriate 1) to put together the components of different nature (with different knowledge representation); 2) to allocate the system resources optimally among the competing components; and 3) to provide system level fault tolerance for the complex system.

It has also posed some open questions, which will gather momentum in the near future: 1) the generalization of concepts (stretching them to contain the new meanings); 2) the communication of the different worlds, and the interpretation of information items produced by other components.

REFERENCES

1. Zilberstein, S. and Russel, S. J. Reasoning about optimal time allocation using conditional profiles. In *Proc. AAAI-92 Workshop on Implementation of Temporal Reasoning*. San Jose, California, 1992, 191–197.
2. Zilberstein, S. and Russel, S. J. Constructing utility-driven real-time systems using anytime algorithms. In *Proc. the IEEE Workshop on Imprecise and Approximate Computation*. Phoenix, Arizona, 1992, 6–10.
3. Liu, J. W. S., Shih, W. K., Lin, K. J., Bettati, R., and Chung, J. Y. Imprecise computations, *Proc. IEEE*, 1994, **82**, 1, 83–93.

4. Zadeh, L. Fuzzy Logic, Neural Networks, and Soft Computing. *Communications of the ACM*, 1994, **37**, 3, 77–83.
5. Rich, E. and Knight, K. *Artificial Intelligence*, 2nd ed. McGrawHill, New York, 1992.
6. Russel, S. and Norvig, P. Artificial Intelligence – A Modern Approach. Prentice Hall, Englewood Cliffs, N.J., 1995.
7. Dobrowiecki, T. P., Várkonyi-Kóczy, A. R., Tilly, K., and Pataki, B. The place of fuzzy logic in the modeling of the measurement knowledge. In *Proc. Teaching Fuzzy Systems. Joint Tempus Workshop*. Budapest, Hungary, 1995, 4-2.1–4-2.5.
8. Klir, G. J. and Folger, T. A. *Fuzzy Sets, Uncertainty, and Information*. Prentice Hall, Englewood Cliffs, NJ, 1988.
9. Elkan, C. The paradoxical success of fuzzy logic. *Proc. AAAI-93*. AAAI Press/MIT Press, Menlo Park, 1993, 698–703.
10. Zurada, J. M. *Introduction to Artificial Neural Systems*. West Publ. Comp., 1992.
11. Goldberg, D. E. *Genetic Algorithms in Search, Optimization, and Machine Learning*. Addison–Wesley, New York, 1989.
12. Koza, J. R., Goldberg, D. E., Fogel, D. B., and Riolo, R. L. (eds.). *Genetic Programming*. MIT Press, Boston, 1996.
13. Péceli, G. and Várkonyi-Kóczy, A. R. Block-recursive filters and filter banks. In *Proc. 1997 IEEE Int. Conf. on Acoustics, Speech, and Signal Processing, ICASSP'97*. Munich, Germany, 1997, **3**, 2001–2004.
14. Tilly, K., Kiss, I., Román, Gy., Dobrowiecki, T. P., and Várkonyi-Kóczy, A. R. A method for the construction and interpretation of high level models for distributed fault-tolerant systems. In *Proc. IEEE Symp. on Reliable Distributed Systems, SRDS-95*. Bonn, 1995.
15. Tilly, K., Dobrowiecki, T. P., Majzik, I., Somogyi, R. A., Várkonyi-Kóczy, A. R., Kiss, I., Danko, Z., Tóth, Cs., Vadász, B., and Zsemlye, T. *The Application of Intelligent Diagnostic Centers in the Implementation of Distributed Fault-Tolerant Systems*. Dept. of Measurement and Instrument Eng., Technical University of Budapest, Technical Report TUB-TR-94-EE09, 1994.

MÕÕTEÜLESANNETE KEERUKUSTUMISE JÄRELMITEST

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Üha ulatuslikumate metroloogiliste nõuete täitmisel keerukustuvad mõõteülesanded seoses mõõtesüsteemide ruumilise hajutatusega laial maa- ja ruumalal, näiteks tehnoloogiliste protsesside jälgimise ja juhtimise korral suurtootmise tingimustes, samuti looduskeskkonna vaatluse ja meditsiinilise monitooringu puhul. Hajutatud on nii sensorsüsteemid kui ka arvutusvõimsused. Suure hulga mobiilsete allsüsteemide töö tsentraalne korraldamine traditsiooniliste meetoditega osutub võimatuks. Allsüsteemid peavad töötama kas osaliselt või täielikult iseseisvalt lõplikke tehnilisi, majanduslikke ja ajalisi ressursse ning arvutusvõimsusi ratsionaalselt kasutades ning tehisintellekti meetodeid rakendades. Erilise osakaalu omandab ajaressursside piiratus ning infotöötluse ja -esituse ajastamise probleem. Samuti on tähtis efektiivne andmeside korraldus.

Kõige olulisem on infotulvaga toimetulek – seda nii töötluse kui ka otsuste vastuvõtmise osas. Abi saab siin uusimatest infotehnoloogilistest meetoditest, nagu pehmed arvutused (*Soft Computing*), jämetöötlus (*Imprecise Computing*), tõenäosuslikud hinnangud (*Probabilistic Reasoning*) koos juba tuntumate neurovõrkude (*Neural Networks*) ja hägusloogika (*Fuzzy Logic*) meetodite kasutamisega.

Tõsiseks probleemiks kujuneb aga traditsiooniliste metroloogiliste kontseptsioonide ja mõistete, nagu täpsus, mõõteviga, skaala, ühik ja etalon erinev käsitlus tänapäevase infotehnoloogilise lähenemisega võrreldes. Kirjeldatud uusimate meetodite loominguline ühildamine vastavalt kohaldatud traditsiooniliste metroloogiliste kontseptsioonidega võiks anda uue lähenemise kogu tänapäeva metroloogiale jämemõõtmiste meetodi (*Imprecise Measurement*) väljaarendamise näol. Selle meetodi loomise probleemistikku on käsitletud siinses artiklis.