Experiences In Implementing An Expert System Supported Man-Machine-Interface For The Configuration Of The Intelligent SAR Processor

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Summary

In view of ERS-1 and X-SAR, DFVLR is establishing a high throughput Processing and Archiving Facility (PAF) for high precision SAR products. Concerning the requirements throughput and product quality, it has been realised that the SAR processing task needs a distributed and dedicated computer system to be controlled by an expert system. The solution is called ISAR, the Intelligent SAR processor.

During the first development phase, a prototype of the man-machine-interface has been implemented. It is the task of this interface to monitor, control and debug the whole processing system. Especially, there has been investigated the configuration capability of this expert system controlled man-machine-interface with relation to SAR processing.

This paper presents the experiences gathered during the development with emphasis on structuring the knowledge domains and the realisation of facts and rules applying frame based methods. Additionally it will demonstrate the use of an expert system shell for software engineering. Recommendations for future work will also be given.

Keywords:

ERS-1, X-SAR, Processing and Archiving Facility (PAF), Intelligent SAR Processing (ISAR), expert system, software engineering, man-machine-interface

1. Introduction

The upcoming new generation of spaceborne SAR sensors like ERS-1 or X-SAR has been designed to be able to acquire a huge amount of SAR scenes which is in the range of several ten thousand scenes per year. However, according to experience [1, 2] it is unrealistic to handle such a fload of data by computer systems which take care of a pure throughput optimisation only. In this case, just simple problems anywhere in the system can lead to unsolvable situations at the man-machine-interface. The term real time processing [3] could be applied and situations similar like those in the operations of a satellite ground station [4, 5] will occur at the "system console".

In the first stage of the ISAR development a top-down decomposition of the basic functional requirements has been performed. The guidelines during this process have been determined to characterise the algorithms in terms of their inherent parallelism. Henceforth, the parallelism can be found and sorted in decreasing order of granularity [6]:

- job execution,
- task execution,
- process execution,
- instruction execution,
- register transfer and
- logic device.

The decomposition order has been followed down to the level of process execution, allowing a system implementation, using high level programming languages. The result is a distributed system where the overall work has to be shared between market available computer systems connected by standard communication links. The required ISAR functions have been mapped onto the best suited architecture which is sketched in figure 1.

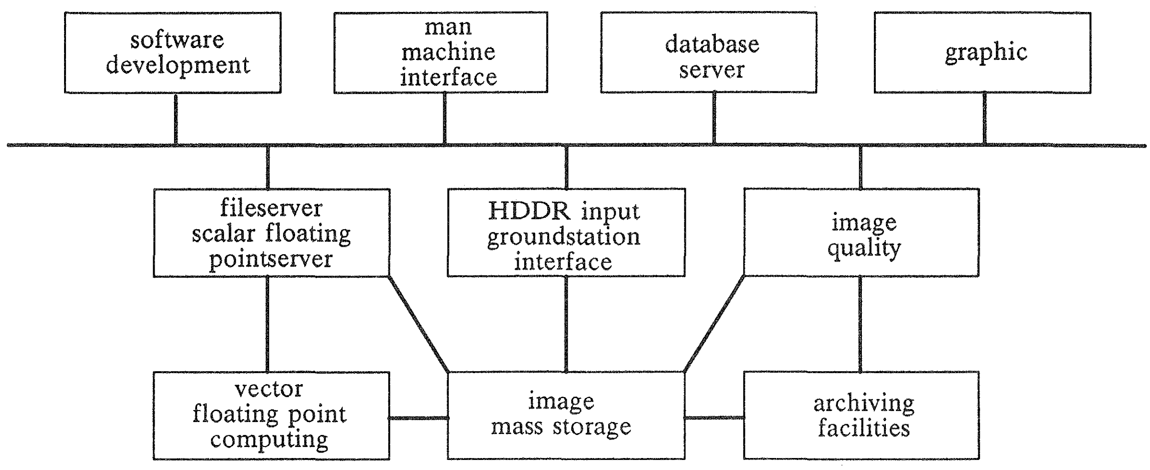

Figure 1: ISAR Functional Decomposition

Now, for each of these functions a reasonable computer system had to be selected. It is evident that the most demanding element of the distributed system is the man-machine-interface.

It has been found [2] that the realisation of the idea could best be accomplished by applying technology, developed and available in the field of knowledge based systems. From a great variety of definitions of a knowledge based system, the following one, which was given in [7], offers the necessary scope: a knowledge representation system provides a set of conventions for encoding some class of facts plus facilities for retrieving the stored facts and/or drawing some class of inferences from them. Three different issues have been distinguished:

- knowledge representation issues
  - completeness
  - expressive power
  - well-defined semantics
  - inferential validity
- programming issues
  - editing
  - debugging
  - efficiency
- human factors
  - explanation
  - robustness
  - user models

The geometry part of the SAR-processor has been intentionally chosen as the representative sub-domain. This domain contains a considerable amount of quantities and possesses a close inherent connection to SAR processing and simulation. Moreover, already before project start, a full understanding of the domain has been developed, a complete mathematical formalisation was available as well. The idea was, that a full-scale implementation of a control system for the geometry domain would reveal the techniques and problems concerned with knowledge representation, structure of knowledge base, size etc.

The geometry model describes, with respect to a set of suitable coordinate systems, a satellite-SAR in orbit, looking at a target fixed on the moving earth. A full description of the domain will be given in chapter 3. The ISAR "prototype" should henceforth prove the feasibility of the ISAR "expert system", realised as the control system equipped with a selection of (sub-) expert systems. Particularly, the possibility of the retrieval of relationships between the quantities of geometry should be demonstrated. As a side-effect the system should evaluate numerical values for them, given a set of input parameters and constraints. The results will be demonstrated in chapter 4.

2. Objectives

The root idea in the design of the ISAR processor is to improve the operation of the man-machine-interface of a computer scientific application package constrained by the requirements of high throughput, high precision and flexibility [8]. The term man-machine-interface is not being looked at as a static one, instead the whole programming of ISAR is considered an evolutionary process, which means the inclusion of operations and maintenance as the driving sources for further requirements once the development has been finished. The resulting demand of this idea comes quite close to some aspects of the intelligent man-machine-interface proposed by the Fifth Generation Computer Project [9]. At this stage especially, the separation of the man- machine- interface from the signal processing machine (and other subsystems) should be stressed.

The basic function of the ISAR expert system is that of a control system. It manages the overall processing environment, including all interfaces to other PAF-systems and allows for a far-reaching automatic and unattended processing operation [8]. Looking at the expert system as a control system, it has to make use of a series of other (sub-) expert systems, such as systems for interpretation (analysis), diagnosis, design, planning monitoring and others.

But the basis for all this is the existance of a proven SAR processor and data flow theory. This theory is expressed by a set of rigorous formulae and accompanying descriptions, modelling the behaviour of an ideal processing machine. With the occurance of any problems, the human operator is now able to detect that the behaviour of the processor is not in accordance to the requirements of the theory, by comparison to actual and ideal status.

For expert system development, it is recommended that a representative sub-domain be selected and implementation trials be performed. This phase is considered to be more an experiment than a real software phase. The results shall confirm the feasibility of the expert system with respect to knowledge representation, structure of the knowledge base, evaluating the size of that base and identifying the contraints on hardware and software.

Additionally, but no less important, the human aspects [10], [11] of the expert system development had to be experienced thoroughly. First of all new forms of teamwork and cooperation have to be explored. It is well known that the number of people comprising the team is larger than in conventional software projects. Furthermore, close attention of everyone involved over a relatively long period is required. The importance of online and up-to-date documentation has to be especially stressed. It is clear that everyone involved in the exploration of new terrain has individual expectations which can differ from the project goals. The question is, how would the human aspect influence the expenditure of time, man power and machine resources?

Moreover, the prototype shall allow the calculation of the cost for the overall ISAR expert system and establish control instruments with respect to time, goals and success. The definition of quality measures and the set-up of quality control procedures should be achieved as well.

3. Domain Description

In this chapter the problem or domain knowledge specific to the particular kind of task that the expert system was set up to solve is shortly described.

The ISAR overall system, besides the SAR processor itself, is comprised of a SAR simulator for generating raw data for arbitrary orbiting imaging radar systems. Designed as a flexible engineering test tool, such a validated simulator is to be considered an indispensable part of the ISAR system because it allows a controllable verification of all important processor subsystems during the installation and operational phase as well as a reliable performance demonstration of the overall processor characteristics.

The mathematical simulation of SAR raw data on a computer is based upon the approach to transform a fully described target into the radar space, with respect to its properties, taking into account the relative motion between SAR sensor and target, and scattering- and propagation effect as well. Complex equations describe the SAR components and their physical interactions. The result is the two-dimensional signal response, stored on a data carrier.

Within a close loop, the processor could now access this data set and process it by means of complex algorithms in such a way that the result - a final SAR image - is a measure for the scattering properties of targets at the point of time of maximal illumination. Ideally, the processor gives geolocation information for the processed targets, which is equal to the target position given as a simulator input.

The simulator needs the geolocation of a target as an input, the processor gives it as a result. Both subsystems, however, achieve their results due to the knowledge of the dynamic illumination process between sensor and target. This means, that both systems must know the complete motion of a sensor carrier (six degrees of freedom) with respect to the illumination time interval.

Therefore, regarding the geometrical aspects of SAR, different functions have to be performed by the simulator or the processor, respectively. However, they can use the same basic mathematical model. Only one flexible model has to be developed and integrated in the knowledge base - processor and simulator commonly use it, however, with a different representation and parameterisation.

For the prototype development, only a subset of the complete geometry model was chosen. Under the objective of studying how to build up a knowledge base, to establish an explain component etc., the basic SAR equations, with respect to geometry, were taken: Equations to compute slant range and Doppler frequency between target and sensor.

The expert system shall now enforce a complete and, as far as possible, error-free input of the mathematical parameters as well as the model parameters regarding orbit, earth, platform motion etc.

Furthermore, it shall support the selection of hardware and software components for computation of the equations, depending on the input data and system properties given so far. In case, a confused user should be tracked by the system.

4. Software Engineering Methods

The development of the expert system has been split into four consecutive phases. These phases are called *preliminary studies*, *mock-up phase*, *prototype phase* and *operational phase*. During the *preliminary studies* some main questions have to be answered:

- does the considered application involve knowledge, judgement and expertise of human experts?
- where are the sources for this expertise?
- who should be the user of this expert system?
- what are the expected advantages of the expert system versus the conventional approach?
- how should the expert system be tested and validated?

Two documents have been published at the end of this phase. The first one is the "Users Requirements Document" (URD). It identifies the domain of expertise and the main functions of the expert system. The second document is a draft of the "Software Requirements Document" (SRD). It classifies the sources of expertise like human experts, books etc. and defines the hardware and software environment in which the prototype is developed, tested and executed. It also explains the relationship to the operational environment.

The production of the URD and SRD is rather different. The production of the URD is straightforward but the "artificial intelligence" part of the software (knowledge base, reasoning etc.) has to be specified precisely. The draft SRD will deal mainly with those parts which can be considered as conventional software.

The main objective of the *mock-up-phase* is to consolidate the SRD. The aims of this phase are to confirm the feasibility of the system and to take decisions concerning knowledge representation and structure of the knowledge bases. This phase is like an experiment, it is performed by successive iterations, reopening issues until the objectives described earlier are met satisfactorily.

The *prototype* is the first full-scale implementation of the expert system. The objective of this phase is to evaluate its functions before developing an operational system. The prototype is developed iteratively, each iteration involving some modification of the knowledge base together with testing and evaluation.

The *operational phase* consists of the integration of the expert system in the target environment. Developing the operational system will be closer to classical software engineering than to knowledge engineering.

Any software development includes the preparation of documentation. The iterative development of the prototype and the progressive build up of the knowledge base imposes a strict software configuration control. Henceforth, additional documentation is produced for that purpose.

5. Results and Experiences

The development has been carried out in two phases. The first phase was mainly dedicated to the setting up of a knowledge base by which calculations of certain parameters could be performed. Given a situation defined by earth model, satellite movement by orbit characterisation and point target, the related SAR-relevant parameters like slant range and Doppler frequency could be calculated. The resulting values could then be compared to the ones which had been derived manually and therefore, the verification of the mathematics implemented could be performed. The formulae have been implemented by using tools from the expert system shell or LISP functions. Additionally, the first phase was used to experience an explanatory machine which allowed for an online inspection of parameters, variables and functions in the related formulae.

In phase two a reexamination of the knowledge base constructed so far has been performed. On this foundation, the knowledge base could be inlarged. Some amendments have been added. However, the most important knowledge representation concept to be studied was that of a rule system. The fundamental idea in the usage of the rule system was to make the man-machine-interface robust. Robustness shall be defined as the ability to deal with new facts not yet included within the current knowledge base. However, the fundamental prerequisites for achieving this, are to have the accessability of high level principles down to simple facts.

Three different knowledge bases have to be distinguished:

- ISAR-PRO: domain knowledge about geometry
- ISAR-IMG: images and graphics for the user interface
- DOCUMENTATION: all information needed to provide automatic technical documentation.

The structure of the knowledge base basically distinguishes between several classes. Among these are classes for

- the computational elements for the calculation of geometry related parameters
- the computing facilities used in the calculation (hardware and software)
- the models (e.g. earth, sensor, orbit...) of the object
- rules allowing for reasoning about geometry

and others. The class of the computational elements is the biggest one. As can be seen from figure 2, the mathematical structure of a formula has been used as a characteristic criterion for the objects. This led to the subclasses of parameters, transformation-matrices and vectors as the major constituents of formulae.

The prototype has been developed completely on a LISP machine. The software configuration was supported by a customary in the market available expert system shell. Some parts of the prototype have also been implemented using pure LISP code.

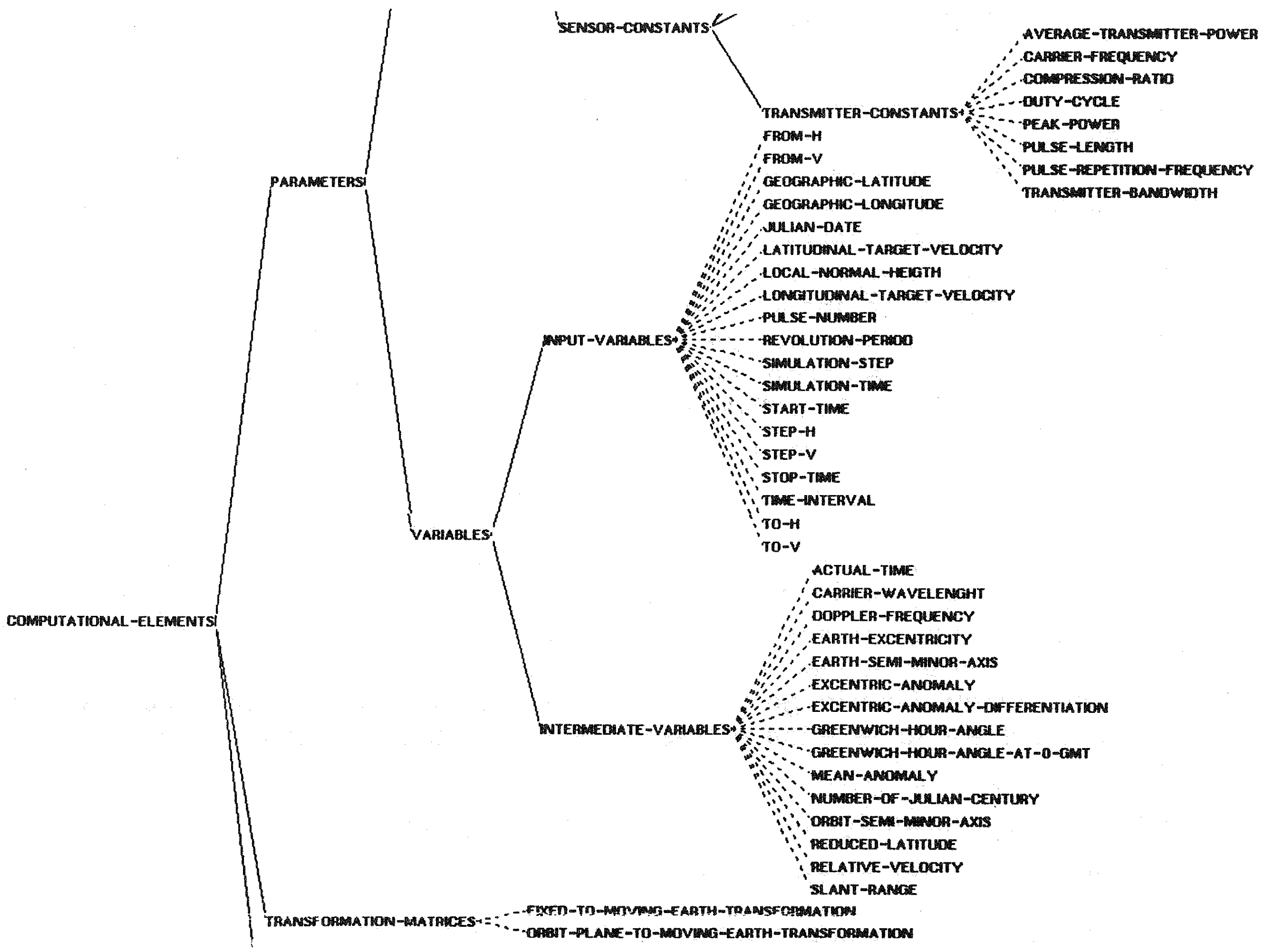

Figure 2: Formula Part of the Knowledge Base

The knowledge domain has been represented using frames. This technique allows for a standardised mapping of the object domain into its representational model. Once the object domain, and this is in our case the underlying apperatus of formulae, has been proven, regarding completeness and semantics, then other knowledge representation issues, as stated in the requirements for the expert system itself, can be investigated. Besides the two mentioned issues, the expressive power of the model as well as the inferential validity have to be considered in comparison to the theory.

The frames could easily be arranged into a meaningful hierarchy by exposing the obvious building blocks of the objects. Attributes, which can either be inherited down the hierarchy relationship or stay static at the level of definition, completed the basic level of knowledge representation. At this stage it was now possible to perform a verification of the implemented system by simply running computations for slant-range or Doppler, giving well defined start-conditions to the system.

At the following stage rules have been introduced to allow for the inference of the type of answer. A sample of a rule which works at the initialisation of a reasoning process is given in figure 3.

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IF    ((THE ITEM OF EXPLAIN-PANEL IS ?ITEM)
AND   (THE QUESTION OF EXPLAIN-PANEL IS VALUE)
AND   (CANT.FIND (THE PARAMETER.VALUE OF ?ITEM IS ?VALUE))
AND   (THE INPUT.PARAM OF ?ITEM IS ?INPUT))
THEN (ADD (THE ANCESTORS OF COMPUTATIONS IS ?INPUT)
      USING ROOT-RULES) (THE NEXT.RULE.CLASS OF COMPUTATIONS
      IS COMPUTE-VALUE-RULES))
```

Figure 3: Start Rule

The type of answer can be determined by the type of user posing the question and the type of question itself. According to the configuration task requirements, it is possible to reason about

- the definition of objects
- the defining formula
- the dimension
- relationships between objects and
- values.

Rules also make the man-machine-interface robust against false operation.

As mentioned in chapter 1 and 2, the main goal in the realisation of the expert system is to improve the operation of the man-machine-interface. Unfortunately, due to shortage of time it was not possible to experiment with different levels of operator education. It has been shown [3] that there are very valuable measures of operator work-load estimation like time-stress ratio or work-load ratio. In order to avoid the overloading of operators, the work-load must be kept at a moderate level. In the worst case, exceeding the schedule in a real time environment can lead to a loss of data.

Commonly, and this has been confirmed in [12], the objective operator work-load varies in connection with performing subtasks. By experience, in many situations false operation in subtasks most likely leads to systemwide problems. Therefore, a criterion to distinguish between superior and poor operator could be the definition of the ability to perform certain subtasks in a predefined context. This ability would then reflect the level of understanding of the model. Vice-versa, the system then had first to determine which model the user wants to apply and then derive the appropriate answer. Figure 4 shows the answer to an user, experienced in the geometry domain, to the question for a specific formula. As a result the question has been answered but the representation of the subject is not adequate. Therefore, the capabilities should be enhanced in the direction of pure mathematical formula output, that means that the system should be able to distinguish between different levels of user directed representations.

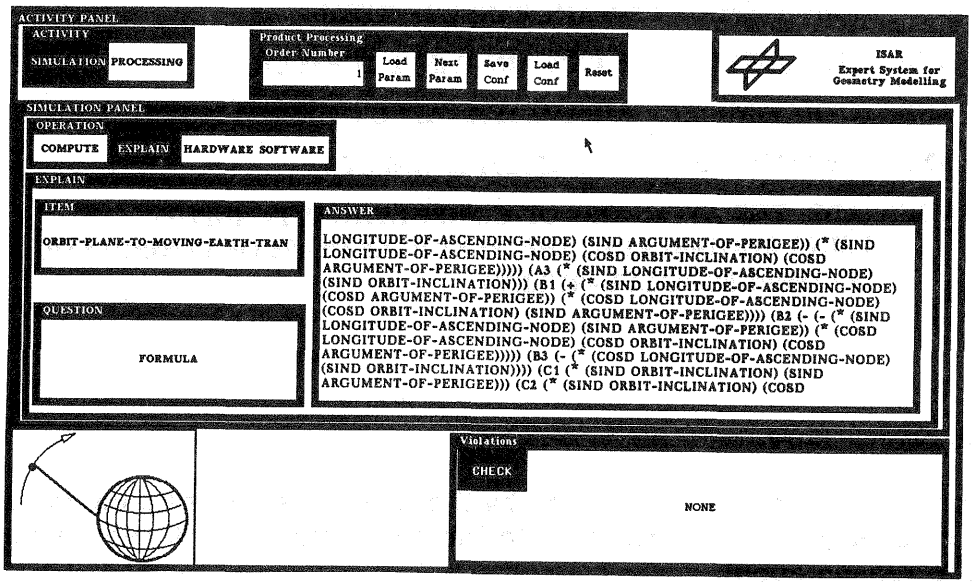

Figure 4: Reasoning about Formulae

Furtheron, the loading of a new context is in the range of minutes. It is even worse when a new start-up procedure has to be done. However, it is clear that with the processing of real time data one cannot afford any waste of time. This means that knowledge at a higher level, where subsystems communicate, has to be used to implement a reasonable system. Therefore, in order to achieve a better system performance, it is necessary to apply traditional and proven software development methods. Finally, parallel processing could help a lot if objects and their relationships could be represented physically.

The size of the system can be given to about 200 objects which have been represented as frames. It comprises less than 50 rules, several display images and additional mathematical support. The physical size is less than 1 MByte, including all additional knowledge bases. It has to be stressed that during the development the system has grown very rapidly. This caused a problem in keeping track with the documentation which has been prepared on another system.

One of the most important experiences during the prototype development phase covered the fact that at the beginning of the project, the role of the expert system user was not fully clarified. Due to that, problems occured with respect to the design of the explain component, as well as to the construction of a knowledge base (what has to be included?). To avoid all this, the classification of the final user - the person who operates the expert system - has to be done explicitly before any decision is taken regarding knowledge representation and structuring the knowledge base.

He should be included into the development process from time to time. In this way it will be possible to prepare a user-specific screen layout. Generally, other important issues to be implemented would be a formula which allows reasoning about dimensions of parameters and a data dictionary.

6. Conclusion

As a very first step in the direction of DFVLR's Intelligent SAR processor ISAR, an expert system prototype, covering a small sub-domain of the ISAR processing system has been developed. It has been found that, especially with respect to the configuration task, the formal classification of the expert system user is superior to any development of a man-machine-interface. The final user has to be involved already in the mock-up and prototype phase because his behaviour influences the development of the prototype. The explain component has to consider the user class and must allow the relation between the mathematical model (knowledge base in the AI part) and the implemented counterpart (procedural part).

The evaluation of the ISAR prototype expert system has shown that the project objectives should be achievable using the applied methods and technologies.

Bibliography

[1] Noack, W., Pich, M., Popella, A., Runge, H., Konjack, R. *Correlation of Synthetic Aperture Radar Data Using a Knowledge Based Processing System* 2nd Int. Conf. Expert Sys. London 1986, pp 221 - 228

[2] Noack, W. *Defining a Knowledge Base SAR Processor* Proceeding TROC Symp. Photogrammetric Remote Sensing Systems and Data Processing Analysis (Baltimore), pp 381 - 388, 1986

[3] Le May, M., Hird, E. *Operator Workload: When is enough enough?* Communications ACM, (29) 7 1986, pp 638 - 642

[4] O'Reilly, C.A., Cromarty, A.S. *"Fast" is not "real-time": Designing effective real-time A1 Systems* SPIE Vol. 548 Applications of Artificial Intelligence II (1985), pp 245 -257

[5] Golden, M., Siemens, R.W. *An Expert System for Automated Satellite Anomaly Resolution* priv. comm.

[6] Kleinrock, L. *Distributed Systems* Communications ACM, (28) 11 1985, pp 1200 - 1213

[7] Mostow, J. *Workshop Review - Principles of Knowledge-Based Systems* SIGART Newsletter, 92 April 1985, pp 15 - 27

[8] Noack, W., Popella, A., Schreier, G. *Knowledge-Based SAR Processing and Geocoding: The Elementary Components of the German Processing and Archiving Facility for High-Throughput and High-Precision Processing of ERS-1 SAR Data* Transactions on Geoscience and Remote Sensing, vol. GE-25, No. 6, Nov. 1987, pp 758 - 769

[9] Moto-oka, T., Kitsarega, M. *The Fifth Generation Computer - The Japanese Challenge* J. Wiley 1984

[10] Weizenbaum, Joseph *Computer Power and Human Reason from Judgement to Calculation* W.H. Freeman, 1976

[11] Good, M.D., Whiteside, J.A., Wixon, D.R., Jones, S.J. *Building a User-Derived Interface* Communications ACM, (27) 10 1984, pp 1032 - 1043

[12] Carroll, J.M., Mc Kendree, J. *Interface Design Issues for Advice-Giving Expert Systems* Communications ACM, (30) 1 1987, pp 14 - 31