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FOREIGN TRIP REPORT

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DATE: February 13, 1989

SUBJECT: Report of Foreign Travel of Judson P. Jones, Engineering Physics and Mathematics Division

TO: Alvin Trivelpiece

FROM: Judson P. Jones

Purpose: To attend the Fourth Aalborg International Symposium on Computer Vision, 1/24/89 -- 1/26/89, organized by The Aalborg University and sponsored by the Danish Research Council, and to present three invited papers on concurrent computer vision and robotics.

Sites Visited: 1/24/89 -- 1/26/89 Aalborg University, Aalborg, Denmark

Abstract: The traveler attended the Fourth Aalborg International Symposium on Computer Vision at Aalborg University, Aalborg, Denmark. The traveler presented three invited lectures entitled, "Concurrent Computer Vision on a Hypercube Multicomputer", "The Butterfly Accumulator and its Application in Concurrent Computer Vision on Hypercube Multicomputers", and "Concurrency in Mobile Robotics at ORNL", and a ten-minute editorial entitled, "Is Concurrency an Issue in Computer Vision". The traveler obtained information on current R&D efforts elsewhere in concurrent computer vision.

Symposium Report

The main purpose of this trip was to attend and deliver a series of three lectures at The Aalborg International Symposium in Computer Vision, organized annually by Aalborg University. The present Symposium is the fourth in the series. Each year two speakers from the United States are invited to present lectures covering current research in the thematic area of the Symposium. The theme this year was "concurrent computer vision". Other lectures are solicited from members of the European research community. The subject of this Symposium series, computer vision, is relevant to a number of DOE/NRC programs involving basic and applied research in autonomous robots for handling of hazardous waste and more general inspection tasks. The traveler's expenses, excluding salary, were borne in full by the Danish Research Council.

Attendance at the Symposium consists largely of representatives from various Danish research establishments and "high-tech" companies, with little representation from other countries. The Symposium was extremely well organized, with a well considered agenda and a list of abstracts available in advance.

The first two days of the Symposium consisted of 18 formal presentations, with the last day devoted to less formal discussions. Only those most relevant will be summarized here.

M. J. Manthey of Aalborg University discussed the concept of concurrency from the perspective of formal computer science. The traditional notion of hierarchy in computer systems is attacked as irrelevant (or at least of marginal utility) in the context of concurrent systems, particularly operating systems. A concurrent system is modeled as a state-transition network with formal atomic operations representing various states. Networks representing more elaborate operations are developed from the atoms, and hierarchy is reformulated in terms of resource invariants with respect to closed cycles in the network graph. This model of concurrency is rather too abstract to be of any immediate practical use, and applies more closely to systems which have an infinite closed-loop form (i.e., are not designed to calculate finite input-output relationships). In the context of mobile robotics, however, a large scale system can be thought of as having the appropriate form; it is the identity of the formal "atoms" which is unclear.

P. L. Petersen of Aalborg University presented work on integrating MULTOS, UNIX, and OS-9 based systems into the network of loosely coupled multicomputers currently in use in the image analysis laboratory at Aalborg. This system has evolved over several years, and Petersen has developed an interface based on terminal device drivers which enables concurrent processes to communicate, independent of the host operating system, in something approaching real time. The interface is easy to use since cooperating processes appear to each

other as I/O devices. This work is possibly of relevance to the CESAR mobile robotics program, since multiple-CPU OS-9 systems are incorporated into the HERMIES-III robot.

K. W. Bowyer of the University of South Florida, USA, was an invited speaker to this Symposium. Dr. Bowyer presented a series of four lectures, three of which summarized his research program in the creation and analysis of aspect graphs for computer vision.

The aspect graph system divides roughly into three parts. The first part is a system for creating a useful representation of the space surrounding an object. The space is divided according to the features (surfaces, edges) which can be viewed from any particular point. In the case of a complicated solid, the regions from which a particular constellation of features is visible may number in the thousands. The main problem is therefore finding all of the regions and representing their properties in such a way that they can be indexed by their contents. Bowyer and his students have solved the first part of this problem for single object scenes of nonconvex polyhedral objects or solids of revolution, the latter being the first instance of a solution in this domain for objects with nonplanar surfaces. The second problem, that of accessing the resulting data structure, has not seen a satisfactory conclusion. The current approach is exhaustive search, and research is currently underway on sensible methods for pruning the search space.

The second part of the system is designed to produce a description of the features of an object given an image of that object and involves more traditional methods of image analysis and description. The primary problem here is that the system requires that a perfect line drawing of the scene be produced. Despite many years of effort in the computer vision community to create a system which does this, to date systems exist which work only on synthetic images (i.e., require perfect data to produce perfect results). Thus an implicit problem in the analysis of aspect graphs is that the feature extracting system must perform reliably even in the presence of low signal to noise ratios.

The third part of the system attempts to match the representation produced by the imaging system with the representation produced by the system creating the aspect graph. Since there are many symmetries in manufactured objects, this leads to potential inefficiencies in the matching process as redundant feature constellations are processed. Therefore, this system attempts to minimize complexity by first eliminating these redundant views and matching only unique views. The matching process proceeds in two steps. First, the cardinality of the observed feature list is compared to that expected from a given node in the aspect graph. If a potential match is found, a gradient descent method is used to find the most likely view from within that region of space. The correspondence between the observed and expected views are

rated with a squared-error criterion. Once all of the potential regions have been examined, the region with the least error is chosen as the most likely view.

Although this line of inquiry seems most directly relevant to problems in automated manufacturing, it may find application to problems in less structured environments. That is, the structure of certain interesting objects in a scene (e.g., pipes, valves) may be known in advance and their appearance under certain illumination conditions predicted. In such cases knowledge-driven scene interpretation would be appropriate for finding these objects. This research has much development ahead before it becomes practical. In particular, methods for pruning the search space must be developed before the search process requires a feasible amount of computation for consideration in real-time systems.

Dr. Bowyer's fourth talk described recent results in the computation of the Hough transform on distributed and shared memory MIMD multiprocessors. The problem of computing the Hough transform on such machines is described with respect to a space of possible alternatives for the representation of the input and output data structures, which can be either located in the memory of a single processor, replicated in the memory of all processors, or distributed over the memory of each processor. For each machine, therefore, there are nine possible strategies, only one of which will be the most efficient. Dr. Bowyer examined these options from a theoretical perspective for a shared memory machine with a preferred page per processor, and a message-passing distributed memory machine. Benchmark timing results were presented only for the first machine, so it is impossible to draw firm conclusions concerning the relative merits of the competing architectures. However, the division of the possible options into nine categories was illuminating. Since the work at CESAR has to date concentrated on distributed memory machines, these options will be more relevant as common-resource machines are deployed in the mobile robotics program.

H. I. Christensen of Aalborg University discussed an approach to model based motion detection which exploits concurrency in distributed memory machines. Three possibilities were examined, pipelined, MISD, and SPMD. The SPMD approach was adopted due to inherent imbalances in the other approaches. Low-level image processing gives rise to a number of features associated with each object which are tracked as a function of time using low-order Kalman filters and relaxation labeling. Unfortunately, no efficient method for balancing the relaxation process was discovered and was left open as a topic for further research. Otherwise, it was observed that essentially real-time performance (4-5 Hz) could be obtained from a modestly sized (64 node) multicomputer if the preprocessing were done in dedicated hardware. This conclusion corroborates observations made at ORNL with respect to real-time image analysis for mobile robotics.

K. Windfeld of the Danish Technical University presented a paper on the application of nonparameteric methods in image analysis for mineral exploration. Data acquired from mineral samples taken from a particular region in France were converted to a spatial relational graph and used for making predictions on the existence of certain minerals in unexplored regions of the map. Although no independent evidence for the validity of the method was presented, the preliminary results are encouraging. In general, the nonparametric methods presented here make fewer assumptions about the distribution of parameter values than do classical parametric method. Thus, these methods, and in particular this application, may be of interest to DOE programs in mineral exploration.

The traveler was the principal invited speaker at the Symposium, and delivered a series of three lectures covering the research performed on concurrent computer vision at the Center for Engineering Systems Advanced Research. These lectures were titled, "Concurrent Computer Vision on a Hypercube Multicomputer", "The Butterfly Accumulator and its Application in Concurrent Computer Vision on Hypercube Multicomputers", and "Concurrency in Mobile Robotics at ORNL". The traveler also presented a five-minute editorial commentary entitled, "Is Concurrency an Issue in Computer Vision?", and participated in a panel discussion on the same topic.

In the first talk the development at ORNL of a multi-purpose high-performance concurrent computer vision system was detailed, and its application as a development environment for research in computer vision problems relevant to mobile and manipulative robots and as a platform for research in image processing and analysis algorithms for concurrent computers was described.

The second talk focused upon the application of a single communication algorithm of broad applicability to problems in image analysis. Concurrent solutions were given for image scaling, histogramming, component labeling, relaxation labeling, simple load balancing, and some selected neural networks.

The third talk presented in broad perspective the application of concurrent computers in the mobile robotics program at ORNL. The physical arrangement of computers in the mobile robots HERMIES-IIB and HERMIES-III was presented, along with a discussion of appropriate programming models, the organization of tasks, and suggestions for further improve ments to the architectures.

These talks were well received since concurrent computers are rare in Denmark (there is one Intel iPSC hypercube in Copenhagen and it is not used for image analysis) and in particular, there is a lack of practical experience with large scale multicomputer architectures. The discussions following these presentations concerned, in essence,

challenges to the development of appropriate programming models, since the assertions made by the traveler on this topic were not universally accepted.

In the editorial panel discussion, the traveler adopted a "devil's advocate" position, arguing that concurrency was an issue in computer vision only when performance was an issue, that is, only in applied as opposed to theoretical work. This position was largely rejected by the panel and by the audience at large, which adopted the more radical position that concurrency was an issue at all levels of research and development of intelligent sensor systems, indeed, of intelligent systems in general. This latter position was based upon the observation (made many times) that human intelligence is implemented by a concurrent system, and that intelligence is most profitably thought of as the interaction between cooperating and competing processes. This concurrency is most manifest in sensor systems, which compute descriptions of the environment based upon arrays of sensory data. Thus, the traveler "lost" this manufactured debate and was forced to concede that concurrency can be an issue at theoretical levels as well as applied levels.

The University of Aalborg is primarily an institute for engineering education and features a Master's program which is divided evenly into theoretical and laboratory work. Students are divided into groups of five or six at the beginning of the program, and in addition to taking regular courses together, each group executes a project of significant scope during each semester. Thus, by the time the student graduates, he or she possesses a significant corpus of practical knowledge as well as "book-learning". This program stands in contrast to typical programs at U.S. Universities, which are dominated by classroom instruction at the expense of laboratory work.

During the informal discussions which followed the main Symposium, student groups made presentations of semester-long projects in image analysis. Of particular interest was a project designed to monitor traffic flow based on images of a busy intersection in downtown Aalborg. The students used a multi-CPU (68020) OS-9/VME based system for image analysis and object tracking. The system came very close to performing the desired analysis. Although it did not work completely, the demonstration was impressive because of the level of sophistication required to accomplish what it did.

The Center for Engineering Systems Advanced Research hosted Henrik Christensen, a Ph.D. candidate from Aalborg University under sponsorship of the Danish Research Council for six months from 6/88 to 12/88. This visit was very productive and should result in the publication of two ORNL Technical Memorandums. ("A Concurrent Approach to Model Based Motion Detection", ORNL/TM-11051, has already been published), as well as two or more submissions to research conferences.

The results of this visit, in terms of benefits to the image analysis program at Aalborg University and benefits to the Advanced Computers and Integrated Sensor Systems Group at Oak Ridge National Laboratory, were the topic of informal discussions between the traveler and Dr. Erik Granum, head of the Image Analysis Program at Aalborg. Dr. Granum is enthusiastic about these results. The unique facilities at Oak Ridge (e.g., mobile robots, concurrent computers, and advanced sensing devices) as well as the expertise of the staff in the use of this equipment, is perceived as of potential benefit to the education of the students and to the technical direction of the research program at Aalborg.

In consequence, there is a possibility that Aalborg University could send additional students, under Danish sponsorship, for relatively short (3-6 months) visits to ORNL. In the opinion of the traveler, these visits should be encouraged. The skill of the students, as observed in the student demonstrations, is very high.

The potential benefit to Oak Ridge National Laboratory resulting from such visits, in addition to interaction with well-prepared students, are closer ties to the European vision research community. The image analysis program at Aalborg is very active. Currently there are five faculty members and more than 10 graduate students, mostly master degree candidates, exclusively concerned with image analysis. Beginning in June 1989, Aalborg University will lead a multi-year, multi-million dollar international research program on "Vision as Process", involving five European universities and funded by ESPRIT, the international research funding agency of the EEC. This program will likely result in the development of new hardware and software systems for image analysis. Thus, Aalborg University is likely to be at the forefront of the European community in image analysis for approximately the next five years.

Itinerary

1/22/89 - 1/23/89	Travel from Knoxville to Hamburg, FRG
1/24/89	Travel from Hamburg, FRG to Aalborg, Denmark
1/25/89 - 1/27/89	Attended Symposium
1/27/89	Travel from Aalborg, Denmark to Hamburg, FRG
1/28/89	Travel from Hamburg, FRG to Knoxville

Literature Acquired

P. L. Peterson, "Real-time multiprocessing under UNIX" (1988).

J. Arnspang, "Moving towards the horizon of a planar curve", DIKU TM-88/15, University of Copenhagen.

K. Henrikssen, J. Arnspang, "Director determination of the orientation of a translating 3D straight line", DIKU TM-88/23, University of Copenhagen (1988).

J. Arnspang, "Shape from hypertextel virtual motion", DIKU TM-88/10, University of Copenhagen (1988).

Individuals Contacted

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