STANFORD RESEARCH INSTITUTE
MENLO PARK, CALIFORNIA

24 March 1967

Proposal for Research
SRI No. ESU 67-24

ADVANCED PATTERN RECOGNITION TECHNIQUES

Prepared for:

U. S. Government

Prepared by:

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Charles A. Rosen, Manager
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Development

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Proposal for Research
SRI No. ESU 67-24

COMPUTER-AIDED RECOGNITION OF HUMAN FACES

Stanford Research Institute herewith proposes a research study and experimental investigation of computer-aided methods for the recognition of human faces from photographs.

I PLAN OF THE STUDY

The ultimate goal of the proposed work is the development of a computer-based system capable of recognizing human faces from photographs. The immediate goal is to determine the conditions under which this is possible. Bledsoe[1*], working on what might be termed "unconstrained" data, has obtained tradeoff curves giving the probability of recognition as a function of the fraction of the entire file that a human must search. Whether his tradeoff curves can be materially improved without a concomitant improvement in the data set is an open question. Accordingly, the study will be divided into two phases. During Phase A we will review, refine, and extend the techniques developed by Bledsoe and determine what constraints, if any, must be placed on the data set in order to achieve useful levels of performance. Phase B will be undertaken only if preliminary results during Phase A appear to warrant it. During Phase B we would expect to continue the investigation and sharpen those techniques identified during Phase A as having the greatest promise.

The following section describes in some detail possible Phase A tasks. Work to be performed during Phase B will be decided by mutual agreement.

II PROPOSED PHASE A TASKS

This section contains descriptions of a variety of possible tasks to be completed during Phase A. Some methods to be investigated are simple modifications of Bledsoe's work, while others are new departures representing fundamentally different approaches to the problem. Since it is by no means certain that any of the methods will perform satisfactorily on unconstrained data, we intend to sort the photograph-pairs into categories of varying difficulty and test candidate methods on problems from several categories. Bledsoe has indicated in discussion that there appeared to be three primary causes of failure to match photographs in the work performed to date. These causes were (1) one or both pictures showed the head in rotated position, (2) one or both pictures showed the face with a non-neutral expression, and (3) the pictures

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* References are given at the end of this proposal.

showed the individual at different ages. We therefore expect to have a human classify each photograph-pair according to whether both photos are (1) unrotated, (2) expressionless, and (3) showed the individual at approximately the same age. In addition, we would also have the human decide, subjectively, if (4) the two photographs were generally recognizable as showing the same individual. It would then be easy to test any candidate method on a classification problem ranging from the simplest (highly constrained) to the general (unconstrained) problem in controlled steps. This experimental procedure should enable us to expose the specific weaknesses of a given candidate technique quickly, and direct further efforts accordingly.

Specific Candidate Techniques

1. Investigation of Component Differences

Bledsoe has indicated in discussion that failure of his pseudo-distance classification method was often due to the large contribution of a very few measurements. A closer examination of such cases therefore appears to be warranted. For example, if the experimental data set included photographs taken at different ages, and some large component-wise differences were due to measurements taken on the hairline, it would be reasonable to disregard the contribution to the pseudo-distance made by those components. A systematic investigation might begin by deciding, a priori, which components of the 22-dimensional vector were reliable and which were not. Large contributions by unreliable components might then be ignored.

A modification and extension of this scheme, which could be tried if initial results were encouraging, would require that the operator give an associated confidence measure each time he indicated a point on the face. Thus, for example, if the outline of the nose was fuzzy, the associated confidences would indicate to the classifier that low weight should be placed upon all measurements involving such points.

2. Alternative Normalizations of Rotation

If initial experiments indicate that head rotation is a frequent cause of failure (which may very well be the case), then alternative methods of "unrotating" the head should be considered. One alternative is to normalize vertical and horizontal distances independently. At the present time all distances measured are normalized by the interpupillary distance, so no distortion of horizontal distances results even if head rotation is ignored. One could simultaneously normalize vertical distances, although nothing quite as convenient as the interpupillary distance is available, and obtain an invariance of vertical measurements under rotation.

Another possible solution to the rotation problem would make use of three-dimensional cues or bona fide stereo pairs. The latter is regarded as outside of the scope of the proposed project.

3. Contour Correlation

A contour correlation algorithm recently proposed by Feder and Freeman[2] provides another tool that might be useful in the face recognition problem. It enables one to fit a given curve to a similarly shaped section of another curve drawn to the same scale, provided such a section exists. It should be possible, with minor modification, to use this algorithm to measure the similarity between two given curves. A human operator could trace out, for example, an outline of the face or some part thereof, and the similarity measure could be used to supplement the distance measurements currently being used. Feder and Freeman point out, however, that the algorithm is applicable only when the scale and orientation of the two curves are known. If rotation proves not to be a severe problem, the algorithm deserves serious consideration.

4. Supplementary Photographs

It may transpire that the face recognition problem is beyond solution unless totally unrealistic constraints were placed on the photographs. In this eventuality it may be wise to consider the possibility of using supplementary photographs. One could speculate, for example, that a picture of the ear provides reliable clues to identify which, when used in conjunction with another picture of the entire face, vastly simplifies the problem. For some applications it may be more realistic to assume the existence of two poor-quality photographs than one high-quality picture. If this is true, and if the problem appears to be otherwise intractable, then some attention ought to be devoted during Phase A to the selection and utilization of supplementary photographs.

5. Clustering

Clustering is a data analysis technique used to group experimentally derived points, i.e. vectors, into clumps or clusters. While a human can do this easily if the points lie in a two-dimensional space, and without excessive difficulty in a three-dimensional space, other methods must be appealed to in higher dimensional spaces. Fortunately, computer programs accomplishing this have been written[3], and it would be a simple matter to subject a set of "feature" vectors to a clustering algorithm. If the vectors turn out to be approximately uniformly distributed throughout the space, or distributed in a few large clusters, then this method would not provide a solution to the problem. If, on the other hand, the vectors were distributed in many small clusters and, furthermore, the two vectors representing the two pictures of one individual were in the same cluster, then this technique could reduce computer search time by reducing the number of pseudo-distances computed.

III COMPUTING FACILITIES

A. SDS 940

The primary computing facility of the SRI Artificial Intelligence Group is an SDS 940 time-shared computer. The 32K-word core memory of this machine has a basic cycle time of 1.75 microseconds and is arranged in two separate 16K banks of 24-bit words. Important peripheral units are two magnetic tape drives, a rapid access data file (auxiliary drum storage), and an on-line graphical input-output device consisting of a CRT display and light-pen. It is anticipated that the major part of the proposed work will be performed on this machine.

B. SDS 910

The SDS 910, a 12K-word, 8 microsecond computer, is a smaller machine available within the Artificial Intelligence Group. It may be convenient and economical to use this machine to convert the raw output of larger computers into appropriate tradeoff curves.

C. B-5500

The B-5500 is the primary facility of the SRI Computation Center. This machine has a 32K core memory, 2.5 million words of disc storage, and the equivalent of a 4 microsecond (approximately) cycle time. The B-5500 will be used only to run programs (primarily clustering routines) already in existence.

D. CDC 3800

The CDC 3800 is a large, high-speed machine available out-of-house at the Control Data Corporation's Data Centers Division. Because of the high cost of this machine (about $800/hour) and the inconvenience of using an out-of-house facility, the CDC 3800 will be used only to run existing programs which would require extensive reprogramming if run on the SDS 940.

IV PERSONNEL

It is planned that the following key personnel will be involved on this program.

Rosen, Charles A. - Manager, Applied Physics Laboratory

Dr. Rosen received a B.E.E. degree from the Cooper Union Institute of Technology in 1940. He received an M.Eng. in communications from McGill University in 1950, and a Ph.D. degree in Electrical Engineering (minor, Solid-State Physics) from Syracuse University in 1956.

Since December 1959 Dr. Rosen, as Manager of the Applied Physics Laboratory, has been engaged in directing a program including major projects in microelectronics, learning machines, and artificial intelligence.

In 1940-1943 he served with the British Air Commission dealing with inspection, and technical investigations of aircraft radio systems, components, and instrumentation. From 1943 to 1946, he was successively in charge of the Radio Department, Spot-Weld Engineering, and Aircraft

Electrical and Radio Design at Fairchild Aircraft, Ltd., Longueuil, Quebec, Canada. From 1946 to 1950 he was a co-partner in Electrolabs Reg'd., Montreal, engaged in the development of intercommunication and electronic control systems. From 1950 to 1957 he was employed at the Electronics Laboratory, General Electric Co., Syracuse, New York, and was successively Assistant Head of the Transistor Circuit Group, Head of the Dielectric Devices Group, and Consulting Engineer, Dielectric and Magnetic Devices Subsection. In August 1957 Dr. Rosen joined the staff of Stanford Research Institute, where he was shortly given responsibility for developing the Applied Physics Laboratory.

His fields of specialization include learning machines, dielectric and piezoelectric devices, electro-mechanical filters, and a general acquaintance with the solid-state device field.

He has contributed substantially as co-author to two books, Principles of Transistor Circuits, R. F. Shea, editor (John Wiley and Sons, Inc., 1953) and Solid State Dielectric and Magnetic Devices, H. Katz, editor (John Wiley and Sons, Inc., 1959).

Dr. Rosen is a Senior Member of the Institute of Electrical and Electronics Engineers, a member of the American Physical Society, and the Scientific Research Society of America.

Nilsson, Nils J. - Head, Artificial Intelligence Group
Applied Physics Laboratory

Dr. Nilsson has been on the staff of Stanford Research Institute since August 1961 where he has participated in and led research in pattern recognition, learning machines, and artificial intelligence. He has taught courses on learning machines at Stanford University and at the University of California, Berkeley. McGraw-Hill published, in March 1965, a monograph by Dr. Nilsson describing recent theoretical work in learning machines.

Dr. Nilsson received an M.S. degree in Electrical Engineering in 1956 and a Ph.D. degree in 1958, both from Stanford University. While a graduate student at Stanford, he held a National Science Foundation Fellowship. His field of graduate study was the application of statistical techniques to radar and communication problems.

Before coming to SRI, Dr. Nilsson completed a three-year term of active duty in the U. S. Air Force. He was stationed at the Rome Air Development Center, Griffiss Air Force Base, New York. His duties entailed research in advanced radar techniques, signal analysis, and the application of statistical techniques to radar problems. He has written several papers on various aspects of radar signal processing. While stationed at the Rome Air Development Center, Dr. Nilsson held an appointment as Lecturer in the Electrical Engineering Department of Syracuse University.

Dr. Nilsson is a member of Sigma Xi, Tau Beta Pi, the Institute of Electrical and Electronics Engineers, and the Association for Computing Machinery.

Duda, Richard O. - Research Engineer, Applied Physics Laboratory

Dr. Duda received a B.S. degree in 1958 and an M.S. degree in 1959, both in Electrical Engineering, from the University of California at Los Angeles. In 1962 he received a Ph.D. degree from the Massachusetts Institute of Technology, where he specialized in network theory and communication theory.

Between 1955 and 1958 he was engaged in electronic component and equipment testing and design at Lockheed and ITT Laboratories. From 1959 to 1961 he concentrated on control system analysis and analog simulation, including adaptive control studies for Titan II and Saturn C-1 boosters, at Space Technology Laboratories.

In September 1962, Dr. Duda joined the staff of Stanford Research Institute, where he has been working on problems of preprocessing for pattern recognition and on the theory and applications of learning machines.

Dr. Duda is a member of Phi Beta Kappa, Tau Beta Pi, Sigma Xi, the Institute of Electrical and Electronics Engineers, and the Association for Computing Machinery.

Hart, Peter E. - Research Engineering, Applied Physics Laboratory

Dr. Hart received a B.E.E. degree in 1962 from the Rensselaer Polytechnic Institute, Troy, New York. He received the M.S. and Ph.D. degrees in Electrical Engineering from Stanford University in 1963 and 1966, respectively.

His doctoral work was on the application of nonparametric statistics to the pattern-recognition problem. During the course of his graduate studies he was a Hughes Master Fellow, a participant in the Philco Honors Co-op program, and a Research Assistant at Stanford University.

Dr. Hart is a member of Eta Kappa Nu, Tau Beta Pi, Sigma Xi, the Institute of Electrical and Electronics Engineers, and the Association for Computing Machinery.

Chan, Helen - Mathematician, Applied Physics Laboratory

Miss Chan received an A.A. degree from Monterey Peninsula College in 1955 and an A.B. degree in Mathematics from the University of California at Berkeley in 1958.

From 1958 to 1961 she worked on data-processing problems and war-game simulations for Technical Operations Inc. and for Stanford Research Institute at Monterey, California. Work was programmed for the Burroughs 220, Recomp II, and IBM 650.

From 1961 to 1965, at Panoramic Research Inc., Palo Alto, California, she wrote programs that applied evolution techniques to various simulations and mathematical problems. The latter half of this period was spent in pattern-recognition work. Feasibility studies were made on techniques, and experimental work in the digital processing of information from several optical scanners was required. The computers used on these projects were the CDC 1604A and 160A, the PDP-1, the IBM 7090, and the Philco 2000.

V REFERENCES

1. W. W. Bledsoe, "Man-Machine Facial Recognition," Panoramic Research, Inc. (1 August 1966).

2. J. Feder and H. Freeman, "Digital Curve Matching Using a Contour Correlation Algorithm," IEEE International Convention Record, Part 3 (March 1966).

3. G. H. Ball and D. J. Hall, "ISODATA, a Novel Method of Data Analysis and Pattern Classification," Stanford Research Institute.

Proposal for Research
SRI No. ESU 67-24

24 March 1967

COST ESTIMATE

Personnel Costs

Project Supervision,	1 man-month @ $[redacted]	$ [redacted]	
Research Engineer,	7 man-months @ [redacted]	[redacted]	
Mathematician,	5 man-months @ [redacted]	[redacted]	
Programmer,	2 man-months @ [redacted]	[redacted]	
Technician,	6 man-months @ [redacted]	[redacted]	
Secretary	1 man-month @ [redacted]	[redacted]	
Total Direct Labor			$ [redacted]
Payroll Burden @ 18.5%*			[redacted]
Total Salaries & Wages			$ [redacted]
Overhead @ 90% of Salaries & Wages*			[redacted]
TOTAL PERSONNEL COSTS			$ [redacted]

Direct Costs

Computer Charges:		
SDS-940, 300 hours @ $[redacted]hr.	[redacted]	
CDC-3800, 2½ hours @ [redacted]/hr.	[redacted]	
B-5500, 4 hours @ $[redacted]hr.	[redacted]	
Rand Tablet (or equivalent)	[redacted]	
Storage Cabinet	[redacted]	
Travel	[redacted]	
Car Rental	[redacted]	
Reports	[redacted]	
Consultant, 6 days @ $[redacted]day	[redacted]	
2 round trip air fares, Texas to SRI	[redacted]	
Subsistence, 6 days @ [redacted]day	[redacted]	
Total Direct Costs		[redacted]
Total Estimated Costs		[redacted]
Fixed Fee		[redacted]
TOTAL ESTIMATED COST PLUS FIXED FEE		[redacted]

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*The rates quoted are those currently approved for billing and estimating purposes. It is requested that contracts provide for provisional reimbursement at rates acceptable to the Contracting Officer subject to retroactive adjustment to fixed rates negotiated on the basis of historical cost data. Included in payroll burden are such costs as vacation and sick leave pay, social security taxes, and contributions to employee benefit plans.

10 March 1967

COST ESTIMATE

Personnel Costs

Project Supervision,	1	man-month	@ $[redacted]	$ [redacted]
Research Engineer,	5	man-months	@ [redacted]	[redacted]
Mathematician,	5	man-months	@ [redacted]	[redacted]
Research Engineer,	2	man-months	@ [redacted]	[redacted]
Programmer,	2	man-months	@ [redacted]	[redacted]
Technician,	6	man-months	@ [redacted]	[redacted]
Secretary	1	man-month	@ [redacted]	[redacted]

Total Direct Labor	$ [redacted]
Payroll Burden @ 18.5%*	[redacted]
Total Salaries & Wages	[redacted]
Overhead @ 90% of Salaries and Wages*	[redacted]
TOTAL PERSONNEL COSTS	$ [redacted]

Direct Costs

Computer Charges:		
SDS-940, 300 hours @ [redacted]/hr.	[redacted]	
CDC-3800, 2½ hours @ [redacted]/hr.	[redacted]	
B-5500, 4 hours @ [redacted]/hr.	[redacted]	
Rand Tablet (or equivalent)	[redacted]	
Travel	[redacted]	
Reports	[redacted]	
Consultant, 6 days @ [redacted]/day	[redacted]	
2 round trip air fares, Texas to SRI	[redacted]	
Subsistence, 6 days @ [redacted]ay	[redacted]	
Total Direct Costs		$[redacted]
Total Estimated Costs		[redacted]
Fixed Fee		[redacted]
TOTAL ESTIMATED COST PLUS FIXED FEE		[redacted]

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*The rates quoted are those currently approved for billing and estimating purposes. It is requested that contracts provide for provisional reimbursement at rates acceptable to the Contracting Officer subject to retroactive adjustment to fixed rates negotiated on the basis of historical cost data. Included in payroll burden are such costs as vacation and sick leave pay, social security taxes, and contributions to employee benefit plans.

9 March 1967

COST ESTIMATE

Personnel Costs

Project Supervision,	$\frac{1}{2}$ man-month @	$[redacted]	$ [redacted]	
Research Engineer,	5 man-months @	[redacted]	[redacted]	
Mathematician,	5 man-months @	[redacted]	[redacted]	
Research Engineer,	2 man-months @	[redacted]	[redacted]	
Programmer,	2 man-months @	[redacted]	[redacted]	
Technician,	6 man-months @	[redacted]	[redacted]	
Secretary,	1 man-month @	[redacted]	[redacted]	
Editor	$\frac{1}{4}$ man-month @	[redacted]	[redacted]	
Total Direct Labor				$[redacted]
Payroll Burden @ 18.5%*				[redacted]
Total Salaries & Wages				$[redacted]
Overhead @ 90% of Salaries and Wages*				[redacted]
TOTAL PERSONNEL COSTS				$[redacted]

Direct Costs

Computer time:		
SDS-940, 400 hours @ [redacted]/hr.	$[redacted]	
CDC-3800, $2\frac{1}{2}$ hours @ [redacted]/hr.	[redacted]	
B-5500, 4 hours @ [redacted]hr.	[redacted]	
Rand Tablet (or equivalent)	[redacted]	
Reports	[redacted]	
Consultant, 6 days @ [redacted]/day	[redacted]	
2 round trip air fares, Texas to SRI	[redacted]	
Subsistence, 6 days @[redacted]day	[redacted]	
Projection Equipment	[redacted]	
Total Direct Costs		[redacted]
Total Estimated Costs		$[redacted]
Fixed Fee		[redacted]
TOTAL ESTIMATED COST PLUS FIXED FEE		[redacted]

*The rates quoted are those currently approved for billing and estimating purposes. It is requested that contracts provide for provisional reimbursement at rates acceptable to the Contracting Officer subject to retroactive adjustment to fixed rates negotiated on the basis of historical cost data. Included in payroll burden are such costs as vacation and sick leave pay, social security taxes, and contributions to employee benefit plans.

February 23, 1967

Mr. Michael Kassler
c/o New York Hilton Hotel
New York, New York

Dear Michael,

Enclosed is a copy of our draft proposal, "Computer-Aided Recognition of Human Faces." Looking forward to seeing you soon.

Sincerely,

Nils J. Nilsson, Head
Artificial Intelligence Group
Applied Physics Laboratory

NJN/ces

Encl.

February 17, 1967

Professor W. W. Bledsoe
Department of Mathematics
University of Texas
Austin, Texas

Dear Woody:

Enclosed is a draft of our proposal (without boiler plate) which you were kind enough to consent to review. Since I have to send it to the sponsor in the beginning of March, I would appreciate a reasonably fast response.

Thank you.

Regards,

Peter E. Hart
Applied Physics Laboratory

PEH/ces

Encl.