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PHYSICS, COMPUTER SCIENCE AND MATHEMATICS DIVISION

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ANNUAL REPORT

1 January - 31 December 1980

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Editor

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INTRODUCTION

Research in the Physics, Computer Science, and Mathematics Division is described in this annual report for calendar year 1980. The Division's major effort remains in high energy particle physics but there is a continually growing program in computer science and applied mathematics.

Significant progress occurred this year in many areas. The Mark II Magnetic Detector and Free Quark Search experiments were installed at PEP and started taking data. The Time Projection Chamber (TPC) group was reorganized, new funding was approved, and a project engineer was assigned to take charge. The TPC suffered a set-back in August when a short circuit, due to a stray iron chip, developed in the superconducting coil necessitating a complete rebuilding of the coil.

Unusual activities in the Division included design work on a ten meter telescope (TMT) to be built by the University of California, and the finding of experimental evidence leading to a hypothesis concerning the extinction of the dinosaurs.

Activities in the Computer Science and Mathematics department cover basic research in partial differential equations, advanced computer concepts, and innovative manipulation of complex data sets. Subjects such as numerical models, distributed systems, statistical information management systems, and human /computer interactions are studied. The department is recognized nationally for its outstanding work and holds a yearly workshop on Distributed Data Management and Computer Networks attended by researchers from all over the country. The relationship among our programs and the close association of our many activities stimulate new ideas and efforts.

The vital and beneficial relationship which Lawrence Berkeley Laboratory has with the University of California at Berkeley continues to be a source of strength for the Laboratory. Our outstanding research staff includes many U.C. Berkeley faculty members and we are able to attract outstanding graduate students who, in the course of fulfilling the requirements for doctoral degrees, make important contributions to our research.

In addition, collaboration with other universities has been beneficial and fruitful. The skills of the Physics groups at LBL, together with Engineering and Technical facilities at the Laboratory, make it possible for outside groups to join us in working on the large projects necessary for today's advanced research at the frontier of particle physics.

This is my last full year as Associate Director of the Division. It has been an exciting and pleasurable experience to work in this capacity for the last 8 years with such a talented and innovative group of people.

EXPERIMENTAL PHYSICS

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EXPERIMENTAL PHYSICS

Research on e^+e^- Annihilation

The Mark II Magnetic Detector

The Mark II Detector program is a collaborative effort between scientists at LBL and the Richter and Perl groups at SLAC. The program during calendar year 1980 had two main thrusts:

1. The preparation and initial operation of the Mark II Detector at PEP;
2. The continuing analysis of data taken with the detector at SPEAR during the period March 1978 to June 1979.

We consider each of these in somewhat more detail.

Operation at PEP

The Mark II detector was moved to its location at PEP during the summer of 1979 and was reassembled during the fall of 1979. New instrumentation required for the measurements at PEP was added, and substantial improvements to the existing hardware and software were made. Some colliding beams became available in the late spring of 1980, and studies of backgrounds and of detector performance in the PEP environment were made. The backgrounds were gradually improved by addition of shielding and improvement of the vacuum in the storage ring. Unfortunately, the luminosity was rather low. Consequently, the operation in the fall of 1980 was almost totally devoted to accelerator studies aimed at luminosity improvement. In late November and early December 1980, some time was made available for physics operations, and about 500 nb^{-1} corresponding to roughly 200 hadronic events were obtained. These have been the object of study and analysis, particularly aimed at understanding detector performance and optimizing software systems. It is anticipated that substantial physics running will be taking place in 1981, principally near the maximum energies available. The detector improvements introduced for PEP operations are in satisfactory operation and have much improved the capabilities at the high energies.

One part of the LBL collaboration has been the design of mini-beta insertions to improve luminosity, taking particular responsibility for studies of shielding and background problems.

Analysis of Mark II SPEAR Data

The principal areas of data analysis have been the following:

Radiative Decays of $\psi(3097)$. In addition to the study of the inclusive prompt photon spectrum, the production of resonant states by radiative decay of the ψ has been investigated. In particular the decay mode,

$$\psi \rightarrow \gamma E\,(1420) \quad \llcorner\ K^{\pm}\pi^{\mp}K^{0}$$

has been observed with a surprisingly large branching ratio. One of the most tantalizing possible interpretations of this result is that the resonant state, E, being detected is a so-called glueball, that is, a bound state of two gluons rather than the usual quark-antiquark mesonic state. Much more data will be needed to establish such an interpretation.

Radiative Decays of ψ' (3686). The existence of what appears to be the η_c, the lowest-lying $c\bar{c}$ bound state with spin 0, first reported by the Crystal Ball Collaboration, has been confirmed by analysis of Mark II data. The η_c at mass 2980 MeV/c^2 is produced via the decay

$$\psi' \rightarrow \gamma\eta_c$$
$$\rightarrow \text{exclusive hadronic final states.}$$

Further Studies of τ Decays. The first observation of a Cabibbo-suppressed τ decay mode,

$$\tau \rightarrow K^*(892)\nu_\tau\ ,$$

has been made, and the branching ratio has been measured.

Studies of D Decays. Extensive studies of data taken at the $\psi''(3770)$ are providing the major part of the world's information on hadron decays.

Non-Radiative ψ and ψ' Decays. ψ and ψ' hadronic decays are a copious source of light quark resonances produced in states with well defined quantum numbers. Studies of these resonances are in progress.

Research Staff

Gerald S. Abrams, Dante E. Amidei, Alain P. Blondel, William Chinowsky, Mark W. Coles, Susan C. Cooper,

The Mark II Magnetic Detector. Shown are LBL physicist John Dillon and an unknown SLAC technician.(CBB 799-13458)

William E. Dieterle, John B. Dillon, Mark W. Eaton, George Gidal, Gerson Goldhaber, Laurence J. Golding, John A. Kadyk, Andrew J. Lankford, Ross E. Millikan, Mark E. Nelson, James F. Patrick, Heidi M. Schellman, Eric N. Vella, M. Ioana Videau, Yunyong Wang, Guozhe Zhao.

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The Free Quark Search

The complete FQS detector was assembled and installed in IR6 of PEP in early 1980. Cosmic ray checkout was carried out after individual components of the detector were debugged. From April to June, PEP was in operation under machine study mode, and machine related backgrounds in the FQS detector were investigated. Some sources of background were determined and the appropriate shielding installed.

During the summer shutdown, the thin front end of the detector was installed. Substantial cosmic ray data were taken with the intention of setting a better upper limit for existence of free quarks in cosmic rays.

Beginning in the fall of 1980, PEP has been running at an energy of 14.5 GeV per beam. Synchrotron radiation background was observed in the FQS detector, and it was only after substantial work on shielding that the detector survived in such a harsh environment. Trigger study was completed, and a trigger rate of 0.2 Hz was accomplished at the highest luminosity of 3×10^{30}. There were 15 days of physics run at the end of the year and approximately 1000 nb^{-1} of data were logged. Analysis of the data was in progress.

Research Staff

Denyse M. Chew, Robert P. Ely, Jr., Robert P. Hamilton, Paul B. Madden, Jr., Ting P. Pun, Vincent Vuillemin.

Publications

The PEP-14 Experiment Monitoring and Its Data Acquisition Process. V. Vuillemin, Programming Note P-266, May 1980.

The PEP-14 Data Base System. P. B. Madden, Programming Note P-267, May 1980.

PEP-14 Raw Data Tape Formats. P .B. Madden, Programming Note P-268.

The Stanford Linear Collider

During FY81, most of the LBL Mark II physicists, in collaboration with the Mark II SLAC groups, are initiating conceptual design efforts toward the construction of a detector suitable for the Stanford Linear Collider. Furthermore, several members of the group will be playing an important role in the six-month workshop effort concerned with problems of experimentation at the SLC, which is to be started at the end of March 1981.

Research Staff

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The Time Projection Chamber (PEP-4)

TPC Detector

During FY81, much progress has been made in the fabrication, testing, and assembly of components of the PEP-4 detector. Assembly of the magnet yoke, iron absorber for the 4π muon detector, cable trays, electronics house, and other elements of the main frame of the detector at PEP are essentially complete. Several of the endplane sectors for the TPC, which carry the sense wires and cathode pads, have been fabricated.

Tests of these sectors at full operating voltage and pressure indicate very satisfactory performance. Fabrication of sectors (12 are needed) will continue through May 1981.

Design of the gas system is complete, and construction is underway on the central features of the system and housing facilities for the instrumentation. Installation of the system piping has begun, and all large scale purchases have been completed. The full high voltage system for the TPC began final tests in January 1981. Since then, this system has reached its full voltage specification of 100 kV in a 10 atmosphere environment and has operated there quite stably for several weeks. Following final mechanical alignment, the high voltage system and sectors will be integrated in preparation for cosmic ray tests of the Time Projection Chamber scheduled to begin in the late spring of 1981.

The PEP-4 project suffered a serious technical setback in August 1980 when the superconducting magnet coil was damaged during an induced quench at about half the design current. Extensive analysis indicated that the most probable cause of the fault was an iron chip which caused a short between the bore tube and the ultrapure aluminum winding. The coil will be redesigned and rebuilt with better insulation. Special attention will be given to reliability and control in the fabrication process. Steps have been taken to improve insulation and the quality of the fabrication process as a whole. The magnet and its paraphernalia will be ready for testing at the end of this fiscal year. In the meantime, a conventional coil capable of providing 4kG is being constructed for use in the initial tests and running of the detector at PEP beginning in the summer of 1981.

The electronics system for the detector is approaching completion. System checkout is in progress and over 50 percent of the individual cards have been produced. About 6500 of the 8000 CCD chips have been received and tested.

The electromagnetic calorimeters which cover the pole tips inside the 10 atmosphere pressurized volume, the chambers for the 4π muon detector, and the drift chambers for triggering have been fabricated. Installation of these components into the main frame and preliminary checkout with cosmic rays is in progress.

Production of the hexagonal electromagnetic calorimeter, which is located outside of the solenoidal magnet coil, will start in April 1981. This calorimeter has 41 layers of sense wires operated in the Geiger mode sandwiched between 0.2 radiation lengths sheets of lead converter. The first of six modules should be complete in July 1981. All modules should be ready for installation by late 1981.

The bid for the lead-fiberglass laminate has been awarded, and other material including wire has been procured. The rails for support of the modules are mounted inside the magnet. The groove cutting machine is operational, and the wire winding machine is being assembled. Shop space has been reserved for assembly and testing of modules. Electronics boards are being fabricated, and patterns are being developed.

Team testing high voltage field cage for the Time Projection Chamber. Left to right are: Dale Nesbit, mechanical engineer; Donna Jones, research technician; Owen Chamberlain, physicist and Nobel Laureate; John Wirth, mechanical engineer; and William Baldock, mechanical engineer. (CBB 815-4423)

PEP-4 Software on the VAX

A strong effort in the development of computer programs for the PEP-4 experiment has continued in FY81. The "GLOBAL" Monte Carlo program is a program on the VAX that generates many kinds of events – including Bhabhas, cosmic rays, and multihadron events – and follows the tracks from these events through the detector. It can generate an output file that has, among other things, simulated PEP-4 raw data for the TPC, muon chambers, drift chambers and calorimeters. Changes were made to accommodate the PEP-9 experiment into the program.

A newly written real-time system has been implemented. It is operating as a multiprocess system with the reading of raw data from the LDB, analysis of the TPC data, CRT displays of the data from all detectors, and the writing of the results on tape. The analysis process in this system also runs as a separate program. It reads the simulated raw data and does the TPC cluster finding, pattern recognition, preliminary mass identification, track fitting and vertex finding. A flexible program has been developed to display the histogram made by the experiment.

PEP-4 Data Acquisition System

Many of the components of the data acquisition system were moved to the interaction region (IR2) at PEP during the latter part of FY80. Through FY81, work continued on the installation and testing of hardware and the development of software.

The PDP 11/70 computer system is used by up to 14 concurrent users working on hardware testing or developing new programs. This activity caused a number of difficulties. To improve system performance, we have added a new memory to the PDP 11/70, bringing the system to 1.5 megabytes. This addition will satisfy the requirements of large calibration and diagnostic programs for the foreseeable future. To allow logging of calibration data, we have added a tape drive to the system.

The Test Pulse Unit/Register Control Unit systems [TPU/RCU] were significantly modified during FY81 with the addition of a central timing system. This provides a common timing system for test functions on all detectors and significantly improves the test system.

To expedite the testing of electronics in the electronics house, a package of programs is being developed for automatic test and calibration. This program development will be completed by the end of FY81.

It is expected that the Time Projection Chamber will be tested with cosmic rays at IR2 in the latter part of FY81. The successful completion of this test with the reading out of tracks is certain to be our major milestone for the year.

To provide additional computing power for the analysis of TPC data, as well as other physics requirements, we will install a VAX 11/780 computer system at LBL in 1981. This system will be linked to the system at IR2 by a 230.4 Kbaud microwave link and will be used for real-time analysis of selected events.

Research Staff

Hiroaki Aihara, Margaret A. Garnjost, Alan V. Barnes, Alan D. Bross, William C. Carithers, Jr., Owen C. Chamberlain Alan R. Clark, Orin I. Dahl, Christoph T. Day, Philippe H. Eberhard, David L. Fancher, Hirofumi Fujii, Angela B. Galtieri, John W. Gary, George H. Gibson, Frederick R. Goozen, Nicholas J. Hadley, John H. Hauptman, Tuneyoshi Kamae, Robert W. Kenney, Leroy T. Kerth, Werner O. Koellner, Richard R. Kofler, Stewart C. Loken, Gerald R. Lynch, Ronald J. Madaras, Richard D. Majka, J. Mallet, Philip S. Martin, Jay N. Marx, William W. Moses, Peter Nemethy, David R. Nygren, Piermaria J. Oddone, Barrie Pardoe, Morris Pripstein, Peter R. Robrish, Michael T. Ronan, Ronald R. Ross, Gilbert Shapiro, Marjorie D. Shapiro, Robert G. Smits, David P. Soroka, M. Lynn Stevenson, John D. Taylor, Harold W. Van Slyke, Henri L. Videau, K. Watanabe, William A. Wenzel, Edgar T. Whipple, Masanori Yamauchi.

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The Time Projection Chamber Operations Group

Facilities operations this year has covered the initial testing phase of the TPC: electronics checking and testing, cryogenics testing, magnet tests and field mapping, programming work, gas systems, high voltage systems, and operations work in IR2 at PEP.

PEP Experimental Facilities Coordination

The PEP experimental coordination during FY81 has involved the following activities:

a. The development of the PEP experimental areas, including special modifications needed for the experiments after their assignment to specific areas.

b. The interface of users with the PEP machine's environment.

c. Coordination of the continuing development of the support system for PEP experiments, such as on-line computer, real time links to the central computers, refrigeration plants for superconducting magnets, and design of systems for access and movement of detectors.

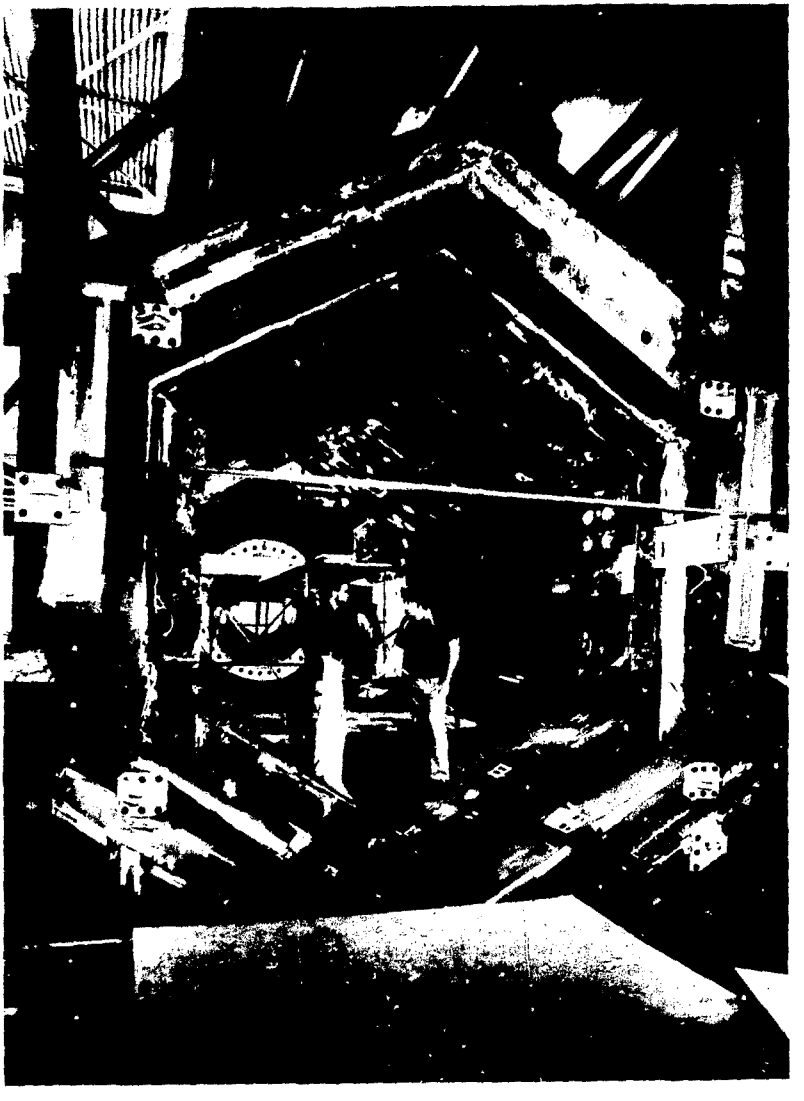
d. The evaluation of the impact of PEP proposals on equipment funds and operating resources.

e. The negotiation of agreements with the proponents on the detailed responsibility of the participating institutions and the distribution of funds for the approved experiments.

f. The monitoring of the physical development and of cost and commitments of the detector projects under development.

g. The long-range planning for the utilization of PEP. Development of the areas is not complete. A total of 20 proposals have been analyzed, and nine of these proposals have been approved for operation at PEP. These detectors have been assigned to experimental areas as follows:

Area 12:	MKII Detector
Area 2:	TPC and Two Photon Detectors
Area 4:	Magnetic Calorimeter
Area 6:	High Resolution Spectrometer and Free Quark Search



The frame which will hold the Time Projection Chamber is now in place at PEP. Shown, left to right are David Nygren, leader of the Time Projection Chamber group, and Fred Catania, experimental region coordinator. (CBB 805-6719)

Area 8:	DELCO Detector followed by the Crystal Ball
Area 10:	Monopole Search.

The coordination group monitors the development of all the detectors, including milestones in the fabrication and associated R and D cost and commitments and budgetary projections. Detailed reports are provided to the agency on the development of the entire experimental program on a quarterly basis.

Research Staff

Peter Nemethy, Piermaria J. Oddone.

Research at FNAL on Muon and Neutrino Reactions

Muon Reactions

This effort is a collaboration between this group and physicists from Fermilab and Princeton. Analysis of the experiment continues through FY81. A broad range of physics results were reported at conferences and published.

The analysis of 3-muon final states provided information on the polarization of the $J/\psi(3100)$. In addition, the study of events with a massive dimuon pair permitted determination of an upper limit for the production of Υ (9.5) by muons. Dimuons events were studied to measure the cross section for charmed meson production. The data measure the charm structure function and permit the investigation of the role of charm production in the measured scale-noninvariance of the nucleon structure function. Detailed study of the 2 muon final states also permitted determination of upper limits on the cross section for the muoproduction of mesons containing a bottom quark and for production of a neutral heavy muon.

Analysis of the data will continue in the remainder of FY81. Subjects under investigation include the inelastic production of J/ψ. Also, "exotic" events containing odd charge combinations or more than three final state muons are being studied exhaustively, and a number of explanations for these events are being considered.

Work on the one muon final state has focused on the systematic errors which affect the measurement of nucleon structure functions. Among the important effects are radiative corrections, muon energy loss, and Fermi motion. This work has significantly increased our understanding of the experiment and it is expected that a determination of the structure function $F_2(x,Q^2)$ up to Q^2-200 $(GeV/c)^2$ will be completed by the end of FY81.

Research Staff

Robert P. Ashley, Alan R. Clar, Frederick R. Goozen, Karl J. Johnson, Leroy T. Kerth, Stewart C. Loken, Thomas W. Markiewicz, Peter D. Meyers, Timothy E. Nuzum, Wesley H. Smith, Mark W. Strovink, Thomas F. Weber, William A. Wenzel.

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W.H. Smith, M. Strovink, W.A. Wenzel, R.P. Johnson, C. Moore, M. Mugge, R.E. Shafer, G.D. Gollin, F.C. Shoemaker, and P. Surko, submitted for publication in Phys. Rev. Lett., also LBL-11543.

Proposal for Extension of the Fermilab Muon Programs to Tevatron Energies

Fermilab plans to build a new, high intensity muon beam for use with the Tevatron. During FY80, we submitted a proposal to Fermilab to move our multimuon spectrometer to the new beam. This proposal (P640) has the following physics objectives:

a. A measurement of the parity-violating asymmetry

$$\frac{\sigma_{\mu^+_L} - \sigma_{\mu^+_R}}{\sigma_{\mu^+_L} + \sigma_{\mu^+_R}}$$

due to weak-electromagnetic interference over a broad range of Q^2 and $y = \nu/E$.

b. A measurement of the asymmetry

$$\frac{\sigma_{\mu^+_R} - \sigma_{\mu^-_R}}{\sigma_{\mu^+_R} + \sigma_{\mu^-_R}}$$

resulting either from two photon processes or from weak-electromagnetic interference.

c. A measurement of the nucleon structure function in deep inelastic muon scattering up to momentum transfer squared (Q^2) of 1000 (GeV/c)[*2]*.

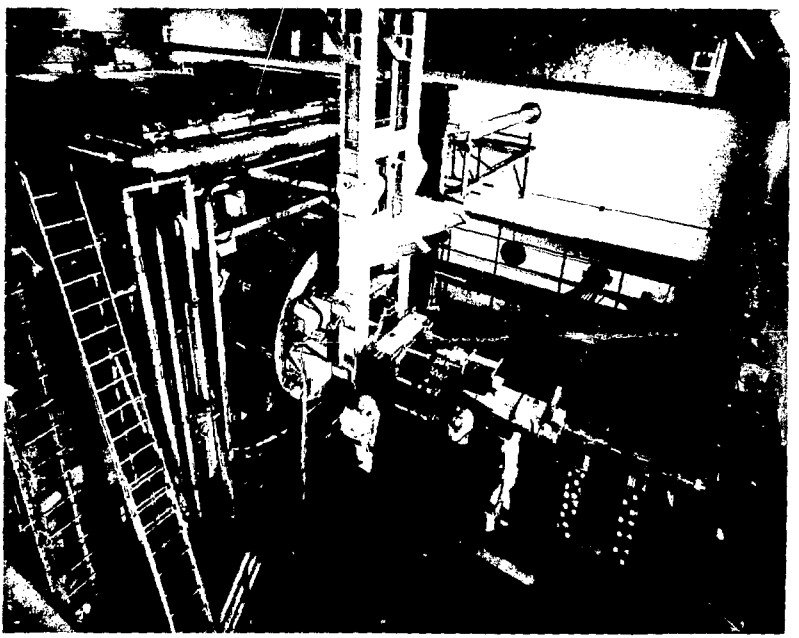
d. A measurement of dimuon final states resulting from heavy quark production.

e. A high sensitivity search for a neutral heavy lepton.

f. A measurement of high mass vector meson production.

g. A study of final states with more than 3 muons.

The proposal was reviewed by the Fermilab Physics Advisory Committee at their June 1980 meeting. Decisions on all muon proposals were deferred at that time.



The Mark II Magnetic Detection in Interaction Region 12 at PEP. The end cap was removed to repair a broken wire. Left to right are physicists Gerald Abrams, Donald Briggs, and James Strait. (CBB 815-4413)

During FY81, we prepared additional supporting material for the PAC. The Tevatron muon program is now being planned by a sub-committee of the PAC, and a decision is expected on P640 at the June 1981 meeting. We expect the proposal to be approved for running in late FY84.

We began disassembly of the multimuon spectrometer during FY81 in preparation for its move to the new beam. In particular, we have removed the drift chambers and proportional chambers from the magnet. The drift chambers will be used temporarily by members of the Princeton group in a Fermilab experiment. The proportional chambers have been installed in intersection region 2 at PEP for temporary use as a central detector for the two-photon experiment, PEP-9.

Research Staff

Robert P. Ashley, Alan V. Barnes, Alan R. Clark, Frederick R. Goozen, Karl J. Johnson, Leroy T. Kerth, Stewart C. Loken, Timothy E. Nuzum, Gerald L. Schnurmacher, Thomas F. Weber, William A. Wenzel.

Neutrino and Anti-Neutrino Reactions

a. The hadron final state in deep-inelastic neutrino scattering shows evidence of gluon radiation. An experimental test of QCD can be made. A paper is about to be submitted to *Physical Review Letters* or *Physics Letters*.

b. Several of the di-lepton events in this experiment (E546) showed the charm-particle decay point displaced relative to the primary vertex. The lifetimes of the D^0 and D^+ mesons were determined to be $3.5\,^{+3.5}_{-1.3} \times 10^{-13}$ sec and $2.5\,^{+3.5}_{-1.3} \times 10^{-13}$ sec, respectively.

c. An archival paper on the di-lepton events (both $\mu\mu$ and μe) in this experiment (E546) has been submitted to *Physical Review D*.

d. The exposure of the 15-foot bubble chamber to several dichromatic anti-neutrino beam energies makes it possible for our experiment (E388) to detect possible neutrino oscillations $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$, $\bar{\nu}_\mu \rightarrow \bar{\nu}_\tau$ with lower than usual backgrounds.

Research Staff

Gerald R. Lynch, Jeremy E. Lys, M. Lynn Stevenson.

Publications

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Search for Effects of a Right-Handed Gauge Boson

A new experiment to search for the effects of a possible right-handed gauge boson up to 600 GeV/c^2 in mass has been proposed and approved for running at TRIUMF (Vancouver). At this mass scale, experimental sensitivities are basically independent of energy within the range of accelerators which exist or are under construction. Therefore, we have chosen to concentrate upon muon decay, the only purely leptonic weak interaction which can be studied with great precision. At the TRIUMF facility, development of highly polarized muon beams has been carried furthest.

In the (V-A) form of the weak interaction and, correspondingly, in the simplest version of the Weinberg-Salam-Glashow electroweak theory, the μ^+ from π^+ decay at rest is fully polarized opposite to its direction of motion. As a consequence, the flux of decay e^+ in the μ^+ direction is predicted to vanish when the positrons reach their maximum energy. Existence of any right-handed weak currents, mediated for example by a right-handed W, instead would produce a finite flux in this region. The new experiment will make a first critical test of this prediction. The precision sought is $\sigma(\xi) = 10^{-3}$, where the polarization parameter ξ is the only Michel parameter which is sensitive to the mass of a possible right-handed gauge boson. This would represent a factor-of-13 improvement upon the accuracy of the present world average $\sigma = 0.972 \pm 0.013$. Essentially, the improvement is to be achieved by measuring a quantity proportional to $(1 - \xi)$, rather than to ξ itself.

Three experimental techniques will be used which have not previously been applied to the objective of measuring ξ:

a. Use of a liquid He μ^+ stopper within a $\geq$ 7-kGauss longitudinal field to preserve that polarization;

b. Strong emphasis on measuring the Michel-spectrum shape for the most energetic positrons emitted opposite to the μ^+ spin, where the sensitivity to ξ is uniquely high;

c. Use of large-area low-mass drift chambers near the foci of a 90° positron spectrometer, in order to combine high acceptance (250 msr) and resolution (0.5% $\Delta p/p$).

The Muon Polarimeter to be used in this measurement will be built around a 50-ton LBL dipole magnet now on loan to TRIUMF. The major pieces of equipment to be constructed are:

a. A 1-m $\times$ 25-cm dia. $\geq$ 7-kGauss solenoid magnet to be located upstream of the dipole magnet;

b. A thin-walled high-density liquid He target, preferably with the ability to detect scintillation light from the stopping muons;

c. A 44-plane 700-wire drift chamber/digitizer system. Construction of this and other Muon Polarimeter equipment is underway at LBL.

Research Staff

George Gidal, C. Oram, Herbert M. Steiner, Mark W. Strovink, Robert D. Tripp.

Limits on Neutrino Oscillations from Muon-Decay Neutrinos

A neutrino experiment on the nature of muon conservation conducted at Los Alamos also provided an upper limit on neutrino oscillations. A detailed analysis of the data has been made, and no evidence for neutrino oscillations has been found. The experiment observed neutrinos from muon decays at rest. Upper limits were established on oscillation parameters for neutrino mixing of the kind $\nu_e \leftrightarrow \nu_\mu$ and also of the kind $\nu_e \leftrightarrow \nu_i$, $i \neq \mu$. This experiment is a collaboration with the University of Berne, Switzerland; Los Alamos National Laboratory; the National Research Council of Canada; Saclay; and Yale.

Research Staff

Peter Nemethy

Publication

Limits on Neutrino Oscillations from Muon-Decay Neutrinos. P. Nemethy, S.E. Willis, V.W. Hughes, R.L. Burman, D.R.F. Cochran, J.S. Frank, R.P. Redwine, J. Duclos, H. Kaspar, C.K. Hargrove, and U. Moser, Phys. Rev. **D23**, 262 (1981).

Strong Interaction Experiments at FNAL

Experiments Using Polarized Proton and Anti-proton Beams

Lambda and anti-lambda production at Fermilab energies is so abundant that enriched antiproton, polarized proton, and polarized antiproton beams with reasonable intensity can be constructed for the use of counter physics. We propose to construct such a facility and to study the substructure of hadrons through the spin effects at high energy. We expect to measure total cross-section differences and high-x low-p inclusive pion production, using a polarized beam and a polarized target. This will be a collaborative effort involving physicists from Argonne National Laboratory; LAPP, Annecy, France; Rice University; INFN, Sezione di Trieste, Italy; and LBL.

Research Staff

Owen Chamberlain, G. Shapiro, H. Steiner.

Inclusive Production of π Mesons in pp Interactions (E-350)

Our latest FNAL experiment, E-350, investigated the reaction $\pi\ p \rightarrow \pi^0 + X$ in the forward direction. The triple-Regge formalism has been successful in fitting the $\bar{p}p$ inclusive cross sections in the kinematic region $0.8 \leq X \leq 1.0$, but this is not a very conclusive test because the formalism has so many free parameters in $\bar{p}p$ interactions. The triple-Regge predictions for the reaction $\pi\ p \rightarrow \pi^0 + X$ are very simple by comparison, and the measurement of this inclusive cross section provides a definitive test of the triple-Regge theory and extends our knowledge of the ρ trajectory to much larger values of the momentum transfer than were previously accessible.

The experiment was about midway in its analysis phase during FY80. The 100-GeV analysis was substantially completed, and only one summary paper remains to be written. The remaining 200-GeV data were partly

analyzed; only conference reports were given on these results in FY80. Data thus far from E-350 have shown that at 100-GeV the ρ trajectory asymptotes to -1 at large $|t|$. The data extend to $-|t| \leq -6$. Some discrepancies at small $|t|$ between the ρ trajectory derived from E-350 (elastic $\pi^- p \to \rho n$) have prompted more careful examination of the simple triple-Regge formalism. Some considerations of more complicated exchanges than simple ρ exchange are being investigated. The very complicated and extensive data analysis was completed during the holiday period in early FY81, using the facilities of the LBL Computer Center. At this writing, these final analyses are being examined and final results, including most of the expected journal articles, will appear in FY81.

Research Staff

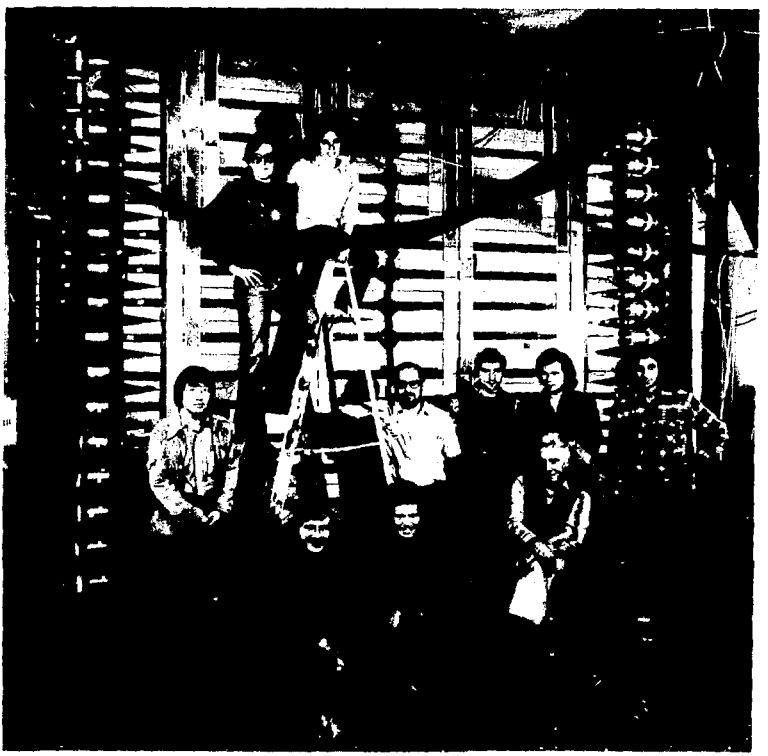
Orin I. Dahl, Rolla. . r. Johnson, Robert W. Kenney, Morris Pripstein.

Publication

Inclusive π^0 and η Production from Kaon, Proton and Antiproton Beams with Triple-Regge Region. R.E. Kennett, A.V. Barres, G.C. Fox, R.L. Walker, O.I. Dahl, R.W. Kenney, A. Ogawa, and M. Pripstein. Nucl. Phy. B 177, 1 (1981).

$\bar{p}p$ Interactions at the Fermilab Collider

Fermilab is constructing a facility for colliding protons and antiprotons at a total center-of-mass energy of 2 TeV. The schedule anticipates initial running at lower luminosity in 1984, followed by full luminosity in 1985. A collaboration of physicists from Argonne National Laboratory, University of Chicago, FNAL, Harvard University, University of Illinois, LBL, Purdue University, Texas A&M University, and the University of Wisconsin has been joined by groups from Tokyo and KEK in Japan and Pisa and Frascati in Italy to design a detector for the main interaction area.



The Free Quark Search Team shown in front of the detector. On ladder: Didier Besset and Inge Karlimer. Standing: Ting Pung, Alan Litke, Wlodzimier z Guryn, Rene Fries, and Paolo Galtieri. Seated: Paul Madden, Vincent Vuillemin, and Norman Anderson. (CBB 7910-14214)

The extremely high energies involved in 2 TeV collisions call for new approaches to detection techniques, especially in the area of calorimetry. At LBL, we have considerable experience in calorimetric innovation, having constructed the liquid argon calorimeter for the Mark II detector and the Geiger-mode calorimeter for the TPC. It is natural for us to concentrate on the calorimeters for the collider detector facility (CDF).

We are currently designing a very highly segmented hadron calorimeter to cover the intermediate angular range of 10° - 30° to the forward direction. The design is based on multiwire proportional chambers with induced cathode readout. The design emphasizes good spatial resolution and unambiguous pattern recognition in a very high multiplicity environment. This work is being carried out by W. Carithers and K. Shinsky.

A study group from LBL participated in the CDF Physics Workshop at FNAL in November 1980. This group took responsibility for studying the problem of detecting a new heavy quark – the so-called "top" quark – which should be produced at the Fermilab collider. The group has concentrated on decay schemes involving top quark decays into three jets or a jet plus an isolated lepton.

Research Staff

William C. Carithers, Jr., William Chinowsky, John A. Kadyk, K. Shinsky, George H. Trilling.

Strong Interaction Experiments at BNL

Backward Scattering and Σ^- Production in k^-p Interactions

A high precision study of the backward K^-p differential cross section from 476 to 1084 MeV/c was made. $K^-p \to \Sigma\pi^+$ was also measured. A partial wave analysis of the $\bar{K}N$ channels, including these new data, provide much improved definition of the D_{13} resonance. Some considerable doubt is placed upon previously reported resonance structure.

Research Staff

Margaret A. Garnjost, Robert P. Hamilton, Robert W. Kenney, Ting P. Pun, Robert D. Tripp.

Publications

Search for the S Meson. R.P. Hamilton, D.M. Lazarus, H. Nicholson, T.P. Pun, and R.D. Tripp, Phys. Rev. Lett. **44** 1182 (1980).

Backward K^-p Elastic Scattering and 0^+ $\Sigma\pi^+$ Production. M. Alston-Garnjost, R. Hamilton, R. Kenney, D. Pollard, R. Tripp, H. Nicholson, and D. Lazarus, Phys. Rev. **D21**, 1191 (1980). LBL-9083.

Measurement of $\bar{p}p$ Backward Elastic Scattering Cross-Section from 406 to 922 MeV/c. M. Alston-Garnjost, R. Hamilton, R. Kenney, D. Pollard, R. Tripp, H. Nicholson, and D. Lazarus, Phys. Rev. Lett. **43**, 190 (1979). LBL-9466.

Studies on Charm, $\bar{p}p$ Interactions

Emphasis has shifted in our continuing program at BNL. We are currently proposing an experiment to search for the η_c and to measure the mass and width of the η_c as a preliminary tune-up. The formation reactions $\bar{p}p \to \eta_c$ and $\bar{p}p \to \eta_c$ will be observed. In March of this year, we expect to measure the $\bar{p}$ beam intensity and purity in order to establish the tractability of the experiment. Funding and TPC involvement will be considered in judging the future of the proposal.

Research Staff

Margaret A. Garnjost, Robert P. Hamilton, Robert W. Kenney, Ting P. Pun, Robert D. Tripp.

Particle Data Center

The Particle Data Center is involved in five major activities:

a. Compilation of particle properties, and the issuance of the *Review of Particle Properties*, with the associated Data Booklet and Pocket Diary.

b. Compilation of descriptive and bibliographic information on published articles, preprints, and current experiments in progress. Publication of indexed guides to current literature and experiments.

c. Maintenance of a data base of compiled high energy physics reaction data. Periodic publication of reports and tapes covering these data.

d. Maintenance and continued development of a computerized data base management system to store, maintain, update, retrieve, and display the compiled information referred to above. The systems described in b, c, and d comprise the *Particle Physics Data System.*

e. Participation in various research projects in collaboration with LBL and other research groups.

The Particle Data Center compiles high energy physics data, and makes it available to the physics community in easily usable form. The *Review of Particle Properties* and other publications are distributed to the community periodically, and computer searchable data bases are also made available to the public. Most members of the group are also active in research projects at LBL and elsewhere.

Publication of *Review of Particle Properties*

Major revisions were made to existing sections of the *Review of Particle Properties*, and additional new sections were added. The changes included a new section on Weak Interactions of Quarks and Leptons and complete rewritings of the Relativistic Kinematics and SU(3) sections. The *Review* was published in April 1980. The listings of particle properties continued to grow at a rate of 10 per cent per annum. With our Helsinki collaborator Matts Roos, a new algorithm for dealing with statistically inconsistent data was tested on actual particle properties data. Work is continuing on problems uncovered by these tests. R.L. Kelly gave reviews of baryon spectroscopy at conferences and began serving as the High Energy Physics Section Editor for the 50th Anniversary Handbook of the American Institute of Physics.

Compilation of Bibliographic Information

During FY81 the updating of our document and proposal data bases continued. Outside collaborators in Japan and the USSR continued to encode for the document data base. Various software systems to streamline this encoding were developed. In conjunction with SLAC, we consolidated two data bases running on the SLAC/SPIRES system: the SLAC Preprints in Particles and Fields data base and the DESY High Energy Physics data base. This has now been incorporated into our bibliographic data base. The proposal data base was updated to increase the number of laboratories covered, resulting in the publication in April 1980 of the third edition of LBL-91 *Compilation of Current High Energy Physics Experiments.*

Data Base for Experimental Physics Reaction Data

Outside collaborators at Cal Tech, Durham University, Glasgow University, and Rutherford Laboratory continued to input information into the data base for experimental reaction data, utilizing the versatile Particle Physics Encoding Language previously developed for this purpose. This reaction data base is publicly accessible on the Rutherford Computer system and is widely used by British physicists. During the year, our Cal Tech collaborators acquired a new VAX-11/780 computer and began running it under the UNIX operating system. BDMS was then installed on this system, and plans were made to begin putting up the reaction data base and making it publicly accessible. Also, design work began on an "EXTRACT" system which will enable users to easily extract information of interest from this data base and then transfer such information to mathematical and graphical-display packages. The detailed objectives of the project are:

a. To make a user-data base interface that a casual user can utilize without a large investment of his or her time.

b. To make the extraction output simple and general enough to be useful for a variety of purposes, such as graphical display or numerical analysis.

c. To provide the core of the system by as early as March 1981 and then to develop additional software as needed.

As of February 1981, a prototype existed and was being tested. It was able to produce data in the format required by the SLAC graphics package TOPDRAWR,

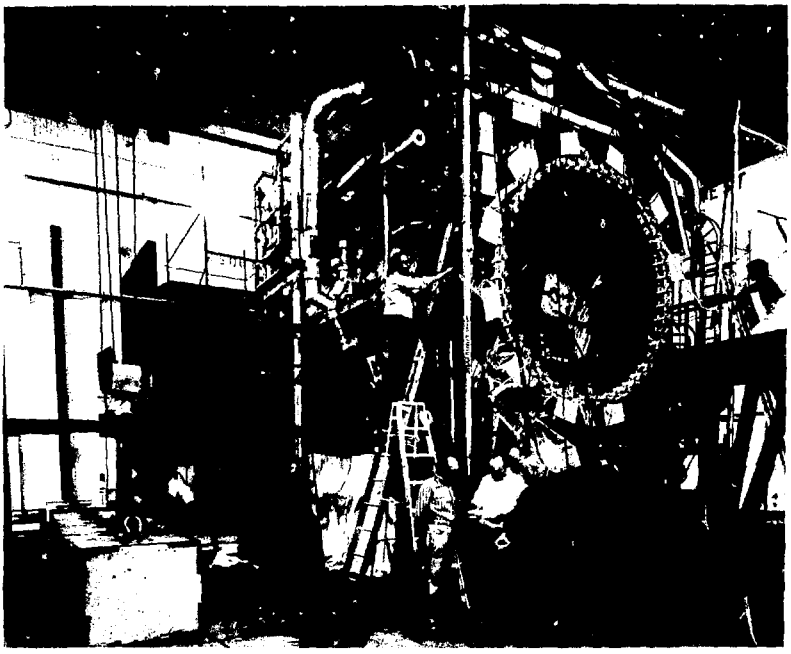
and in the format of a new and general graphics package being developed at Cal Tech. EXTRACT can also produce data in a variety of formats based upon the design of macro-oriented template files. Finally, cleaning up of the reaction data base continued in preparation for the issuing of LBL-92, an index to the data available (planned for spring 1981).

Berkeley Data Base Management System

The second generation of the Berkeley Data Base Management System has continued to be used to maintain our various data bases which enable complex queries to be carried out on these data bases. A few outside users interrogate our document data base for their own special needs.

Participation in Research Projects

Most members of the group are active in research projects with other LBL groups and with outside collaborators. R. L. Kelly is active in the CMU-LBL Partial-Wave Analysis Collaboration, which has developed approaches for combining statistical techniques and analyticity theory in the amalgamation and partial-wave analysis of pion-nucleon scattering data. Partial-wave amplitudes up to 2.5 GeV/c were obtained in 1980. This analysis represents a major advance in our quantitative knowledge of non-strange baryon resonances. Kelly and T. Shimada have investigated practical methods of Higgs boson detection in e^+e^- collisions. The dilepton signature in $e^+e^- \to H\ell^+\ell^-$ has been calculated in $SU(2)\otimes U(1)$. G. P. Yost holds a joint appointment with the Bingham Group, which is participating in photon- and (anti)neutrino- beam bubble chamber experiments at SLAC and FNAL. Yost worked on the optical calibration of the FNAL-15ft bubble chamber, applying a new method which can be used at the SLAC Hybrid Facility employing a high resolution camera on the 40-inch bubble chamber. He nearly completed a four-view geometry program to reconstruct tracks in this chamber. He also assisted with data-taking on the photoproduction experiment (BC-73) using the SHF and organized scanning at UCB. This experiment hopes to see an order-of-magnitude-more identified charmed-particle decays than the sum of all emulsion experiments (only LEBC at CERN will be competitive, and the SLAC experiment has several practical advantages). This will greatly improve the determination of charmed-particle lifetimes and decay modes and provide better identification of new



The Mark II Magnetic Detector in place at PEP where it has been recording data since PEP became operational. Physicists shown are: Gerald Abrams (on ladder at left), Gerson Goldhaber, William Davies-White, Nobel Laureate Burton Richter, and Andrew Lankford (on ladder at right). (CBB 799-13452)

types of charmed particles. T. G. Trippe's participation in the Lead Glass Wall Experiment culminated with the publication of the measured γ and π^0 spectra from $\psi(3100)$ decay. An analysis of these spectra yielded the first evidence for direct γ production at large x in ψ decay. Quantum chromodynamics predicts direct γ production consistent with that observed. Trippe began work with P. Eberhard on a paper intended to clarify the significance of the non-local effects observed in experiments inspired by Bell's analysis of Quantum Theory.

Research Staff

Charles P. Horne, Robert F. Kelly, Michael J. Losty, Alan Rittenberg, Tokuzo Shimada, Thomas G. Trippe, Charles G. Wohl, George P. Yost.

Publications

Review of Particle Properties. R.L. Kelly, C.P. Horne, M.J. Losty, A. Rittenberg, T. Shimada, T.G. Trippe, C.G. Wohl, G.P. Yost, N. Barash-Schmidt, C. Brieman, C. Dionisi, M. Mazzucato, L. Montanet, R.L. Crawford, M. Roos, and B. Armstrong, Rev. Mod. Phys. **52**, No. 2, Part II (1980).

Compilation of Current High Energy Physics Experiments. C.G. Wohl, R.L. Kelly, F.E. Armstrong, C.P. Horne, M.S. Hutchinson, A. Rittenberg, T.G. Trippe, G.P. Yost, L. Addis, D. Fryberger, C.E.W. Ward, P. Wanderer, Y. Goldschmidt-Clermont, P. Joos, T.H. Groves, Y. Oyanagi, G.T.J. Arnison, Y.M. Antipov, and F.A. Yoch, LBL-91 (1980).

N and Δ Resonances – An Experimental Review. R.L. Kelly, LBL-11150, July 1980 to be published in the Proceedings of the IVth International Conference on Baryon Resonances, Toronto, (1980).

πN, $\bar{K}N$, and KN Phenomenology. R.L. Kelly, (Jan. 1981). To be published in Proceedings of the Conference on Nuclear and Particle Physics at Energies up to 31 GeV, Los Alamos, (1981).

Recent Research Publications Not Involving Other LBL Groups

Dilepton Signature in $e^+e^- \to H\ \ell^+\ \ell^-$. R.L. Kelly and T. Shimada, LBL-11540, (Oct. 1980), to be published in Phys. Rev. D.

Pion-Nucleon Partial Wave Analysis. R.E. Cutkosky, C.P. Forsyth, J.B. Babcock, R.L. Kelly, and R.E. Hendrick, COO-3066-157, presented at the 4th International Conference on Baryon Resonances, Toronto, (July 1980).

$\pi\ \pi$ Scattering at Intermediate Energies and the Pomeron. T. Shimada and F. Wagner, Max-Planck Inst. preprint, (Sept. 1980).

Recent Research Publications Involving Other LBL Groups (LBL PDG authors in bold type)

Inclusive γ and π^0 Spectra in $\psi(3100)$ Decay and Comparison with QCD Predictions. M.T. Ronan, **T.G. Trippe**, A. Barbaro-Galtieri, J.M. Dorfan, R. Ely, G.J. Feldman, J.M. Feller, A. Fong, B. Gobbi, G. Hanson, J.A. Jaros, B.P. Kwan, P. Lecomte, A.M. Litke, D. Luke, R.J. Madaras, J.F. Martin, D.H. Miller, S.I. Parker, M.L. Perl, I. Peruzzi, M. Piccolo, and T.P. Pun, LBL-9256, to be published.

Evidence for Direct γ Production at Large X in $\psi(3100)$ Decay. M.T. Ronan, **T.G. Trippe**, A. Barbaro-Galtieri, R. Ely, J.M. Feller, A. Fong, B. Gobbi, P. Lecomte, A.M. Litke, R.J. Madaras, D.H. Miller, S.I. Parker, T.P. Pun, R.R. Ross, V. Vuillemin, and D.E. Yount, Phys. Rev. Lett. **44**, 367 (Feb. 1980).

Observation of Short-Lived Particles Produced in High Energy Neutrino Interactions. H.C. Ballagh, H.H. Bingham, W.B. Fretter, T. Lawry, G.R. Lynch, J. Lys, J. Orthel, M.D. Sokoloff, M.L. Stevenson, **G.P. Yost**, B. Chrisman, D. Gee, G. Harigel, F.R. Huson, E. Schmidt, W. Smart, E. Treadwell, J. Wolfson, R.J. Cence, F.A. Harris, M.D. Jones, S.I. Parker, M.W. Peters, V.Z. Peterson, V.J. Stenger, T.H. Burnett, L. Fluri, D. Holmgren, H.J. Lubatti, K. Moriyasu, D. Rees, H. Rudnicka, G.M. Swider, E. Wolin, R. Benada, U. Camerini, M. Duffy, W. Fry, R.J. Loveless, P. McCabe, M. Ngai, and D.D. Reeder, Phys. Lett. **89B**, 423 (Jan. 1980).

Dimuon Production by Neutrinos in the Fermilab 15-Foot Bubble Chamber. H.C. Ballagh, H.H. Bingham, W.B. Fretter, T. Lawry, G.R. Lynch, J. Lys, J.P. Marriner, J. Orthel, M.D. Sokoloff, M.L. Stevenson, **G.P. Yost**, B. Chrisman, D. Gee, A. Greene, G. Harigel, F.R. Huson, T. Murphy, E. Schmidt, W. Smart, E. Treadwell, J. Wolfson, R.J. Cence, F.A. Harris, M.D. Jones, S.I. Parker, M.W. Peters, V.Z. Peterson, T.H. Burnett, L. Fluri, D. Holmgren, H.J. Lubatti, K. Moriyasu, D. Rees, H. Rudnicka, G.M. Swider, E. Wolin, R. Benada, U. Camerini, M. Duffy, W. Fry, R.J. Loveless, P. McCabe, and D.D. Reeder, Phys. Rev. D **21**, 569 (Feb. 1980).

Rescattering in the Nucleus for $\pi^- d$ Interactions at 15 GeV/c. F.C. Porter, H.H. Bingham, W.B. Fretter, W.R. Graves, **G.P. Yost**, L.A. Dunn, H.J. Lubatti, and K. Moriyasu, Phys. Rev. D **21**, 611 (Feb. 1980).

Evidence for Gluon Radiation in High Energy Neutrino Interactions. V.J. Stenger, H.C. Ballagh, H.H. Bingham, W.B. Fretter, T. Lawry, G.R. Lynch, J. Lys, J.P. Marriner, J. Orthel, M.D. Sokoloff, M.L. Stevenson, **G.P. Yost**, B. Chrisman, D. Gee, A. Greene, G. Harigel, F.R. Huson, T. Murphy, E. Schmidt, W. Smart, E. Treadwell, J. Wolfson, R.J. Cence, F.A. Harris, M.D. Jones, S.I. Parker, M.W. Peters, V.Z. Peterson, T.H. Burnett, L. Fluri, D. Holmgren, H.J. Lubatti, K. Moriyasu, D. Rees, H. Rudnicka, G.M. Swider, E. Wolin, R. Benada, U. Camerini, M. Duffy, W. Fry, R.J. Loveless, P. McCabe, and D.D. Reeder, Madison Conference Proceedings, (Aug. 1980).

Direct Electron Production in Charged Current Neutrino Interactions. H.C. Ballagh, H.H. Bingham, W.B. Fretter, T. Lawry, G.R. Lynch, J. Lys, J.P. Marriner, J. Orthel, M.D. Sokoloff, M.L. Stevenson, **G.P. Yost**, B. Chrisman, D. Gee, A. Greene, G. Harigel, F.R. Huson, T. Murphy, E. Schmidt, W. Smart, E. Treadwell, J. Wolfson, R.J. Cence, F.A. Harris, M.D. Jones, S.I. Parker, M.W. Peters, V.Z. Peterson, T.H. Burnett, L. Fluri, D. Holmgren, H.J. Lubatti, K. Moriyasu, D. Rees, H. Rudnicka, G.M. Swider, E. Wolin, R. Benada, U. Camerini, M. Duffy, W. Fry, R.J. Loveless, P. McCabe, and D.D. Reeder, submitted to Madison Conference, (Aug. 1980).

Barrelet Moment Analysis of πN Scattering Data

New Δ Parameters from a Simpler, Cheaper, and More Reliable Partial Wave Analysis

Precise equivalence in principle has been established between the Barrelet formula for a scattering amplitude in terms of its zeros and a conventional partial wave expansion. Barrelet-moment analysis of high-selected π^+p data for lab momenta between 0.6 and 2.3 GeV/c has been compared with "standard" partial wave analysis. Our results (published in LBL-10075 and LBL-11607) are extremely close to those of the CMU-LBL group and reasonably close to the Karlsruhe-Helsinki analysis, considering certain irregular behavior of the latter. We have verified explicitly that the equivalence between the Barrelet and orthodox approaches stems from the absence of any significant "continuum ambiguity" i.e., the amplitude phase is determined by the data. The advantage of Barrelet's method is that it does not require data amalgamation and allows straightforward transmittal of data errors into amplitude errors. Barrelet analysis shows a systematic degeneracy of S31 and P31 resonances with higher-ℓ resonances, an effect which data amalgamation may have obscured in standard analysis. This was reported in LBL-10370.

Research Staff

Denyse M. Chew

Publications

Verification of the Barrelet Formula for πN Amplitude Analysis. D.M. Chew, LBL-10075 (1979).

New Δ Parameters from a Simpler, Cheaper and More Reliable πN Partial Wave Analysis. D.M. Chew, in Proceedings of Toronto Conference on Baryon Resonances (July 1980), N. Isgur, ed., p. 123 (LBL-10370, 1980).

Is There a Continuum Ambiguity for Elastic πN Amplitude?. D.M. Chew and R.E. Ely, Phys. Lett. **103**, 141 (1981). LBL-11607.

Narrow Baryon Search

Two experiments with high momentum resolution ($dP/P = 2\times10^{-4}$) have been analyzed, to detect the possible formation of narrow non-strange baryon resonances in π^-p collisions. Hoping to find resonant structures in the momentum dependence of π^-p elastic scattering, the differential cross section was measured for this reaction at angles near 90° scanning the laboratory momenta from 5.75 to 13.02 GeV/c. In a larger momentum range (2 to 14 GeV/c), the total cross section has been measured with a statistical precision $d\sigma/\sigma = 0.3\%$ at each of the 4500 measurements in fixed fractional momentum steps of $dP/P = 5\times10^{-4}$. The sensitivity of the first experience is such that signals would have been seen corresponding to the formation of a resonance with a width larger than 0.1 MeV and elasticity larger than a few percent. Within these limits no resonances were detected in either experiment.

Research Staff

Denyse M. Chew

Publications

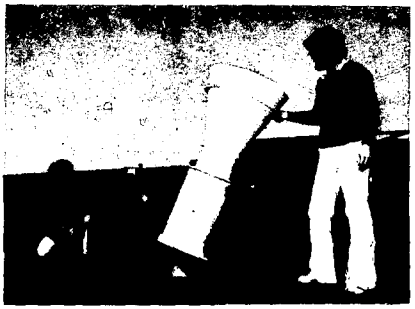
Search for Narrow Baryons in π^- p Elastic Scattering at Large Angles. P. Baillon, E. Barrelet, M. Benayoun, J. Chauveau, D. Chew, M. Ferro-Luzzi, J. Kahane, D. Lellouch, P. Leruste, P. Liaud, F. Moreau, J.M. Perreau, J. Seguinot, R. Sene, J. Tocqueville, and M. Urban, Phys. Lett. **94B**, 533 (1980).

Search for Narrow Baryons in π^- p Total Cross Section. E. Barrelet, P. Baillon, M. Benayoun, J. Chauveau, D. Chew, M. Ferro-Luzzi, J. Kahane, D. Lellouch, P. Leruste, P. Liaud, F. Moreau, J. Seguinot, R. Sene, J. Tocqueville, and M. Urban, Phys. Lett. **94B**, 541 (1980).

Astrophysics and Astronomy

Cosmic Microwave Background Radiation/ Primordial Blackbody Radiation

The experiment to detect anisotropies in the cosmic background (3 K blackbody) radiation has continued. We have measured an anisotropy at the 10^{-3} level which we interpret as due to the cosmological motion of the Milky Way galaxy. We checked this effect by flying the microwave radiometer in the southern hemisphere aboard a U-2 aircraft. We are planning to continue the U-2 measurements using a new cryogenically cooled receiver for better sensitivity. We also have a companion balloon-borne experiment to measure the anisotropy at a much higher frequency to show that anisotropy is intrinsic to the background radiation and has the proper spectral shape. We are presently searching for polarization in the radiation from a ground-based instrument and have started an experiment to measure the low frequency spectrum. We are designing a satellite version (the Cosmic Background Explorer Satellite) of the anisotropy experiment.



Shown with the apparatus used to measure polarization of primordial blackbody radiation are Philip Lubin and George Smoot. **(CBB 788-10173)**

Research Staff

Gerald L. Epstein, Scott Friedman, Phil Lubin, George F. Smoot, III, Chris Witebsky.

Publications

Southern Hemisphere Measurements of the Anisotropy in the Cosmic Microwave Background Radiation. G. Smoot and P. Lubin, Astrophys. J. **234**, L836 (1979).

Polarization of the Cosmic Background Radiation. P. Lubin and G. Smoot, Astrophys. J. **245**, (1980).

Large Scale Anisotropy in the Cosmic Background Radiation. M. Gorenstein and G. Smoot, Astrophys. J. **245**, (1980).

Fluctuations in the Microwave Background at Large Scale. G. Smoot, Physica Scripta **21**, 619 (1980).

Supernovae Detection and Observation

Both hardware and software are being built for our program to search for and observe supernovae early in their explosions. Supernovae (SN) play a fundamental role in many areas of astrophysics: they are the progenitors of black holes, neutron stars, and pulsars; they probably make all elements heavier than iron; stars, planets, and interstellar grains are made on supernova shockwaves; cosmic-rays are accelerated on the shockwaves either at the explosion itself or in interstellar space or in the enormous electric fields at the pulsar. The remnants of SN explosions are strong sources of radio, optical, and x- and γ-ray radiation.

Although about 400 SN observations have been reported in the last 6,000 years, only five were seen before maximum light. Calculations indicate substantial differences in the pre-maximum light curve, depending on the details of the explosion; yet this section of the light curve is where there is practically no data. Our search should detect one SN every three to six days at 10 to 40 percent of maximum light before the peak.

We will couple a charge-coupled imaging device (RCA CCD) to a 36-inch automated telescope and repeatedly scan about 7500 galaxies, cycling through this sample every three days. The image of the galaxy will be compared to a standard (no SN present) image of the galaxy, and checked for a brightness increase in any one image element. We are using a dedicated mini-computer, a PDP 11/44, for controlling the CCD and telescope and calculating the brightness differences. When a supernova is discovered, it will be studied in detail with existing ground-based and orbiting satellites to take optical, U.V., and γ-ray spectra.

During calendar year 1980 we finished designing the search, purchased all of the hardware, including the computer, the CCD and Dewar, and graphics display and built the electronics for clocking the signal electrons out of the CCD into the computer.

Research Staff

M. Shane Burns, Frank S. Crawford, Jr., Jordin Kare, Terry S. Mast, Richard A. Muller, Carl Pennypacker, R. Williams.

Compact Stellar Objects (Neutron Stars, White Dwarfs, Black Holes)

Our study of the unusual x-ray binary, 4U1626-67, has been completed, enabling us to establish the binary period of the system and an estimate of its orbital elements, including the masses of the components. The binary period is the second shortest known. The neutron star in the system has a mass ($\sim$ 1 solar mass) consistent with that theoretically expected for a neutron star.

A search for pulsations from the candidate optical counterpart to the binary radio pulsar PSR 1913+16 has been made. We see no pulsations down to a limit below 26 magnitude. If the reddening given for the object is correct, this limit is very difficult to explain with any known optical pulse emission mechanisms.

A systematic observing program of cataclysmic variables is in progress including: observations in the x-ray region, using HEAO-2; in the ultraviolet region using the satellite observatory IUE; and in the visible region from Lick Observatory. Both time resolved photometric observations, and spectroscopic observations are involved.

Research Staff

John Middleditch, Jerry E. Nelson.

Publications

Changes in the Optical Light Curve of the Crab Pulsar Between 1970 and 1977. J. Nelson, D.H.P. Jones, and F.G. Smith, Nature **283**, 50 (1980).

4U1626-67: A Prograde Spinning X-Ray Pulsar in a 2500 s Binary System. J. Middleditch, K.O. Mason, J. Nelson, and N.E. White, accepted for publication by The Astrophysical Journal (September 1980).

An Optical Burst from the Star Identified with the X-Ray Source 2S 1254-690. K.O. Mason, J. Middleditch, J.E. Nelson, and N.E. White, accepted for publication by The Astrophysical Journal (September 1980).

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Stressed Mirror Polishing: A Technique for Making Non-Axisymmetric Mirrors. J. Nelson, in Optical and Infrared Telescopes for the 1990's Conference Proceedings (Tucson, Arizona, 7-12 January 1980).

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Non-Axisymmetric Mirrors Produced by Stressed Mirror Polishing. J. Nelson, Precision Engineering **3**, 7 (1981).

UC Ten-Meter Telescope Project

Substantial progress was made this year on the design of the telescope optics, the telescope structure, the observatory building and dome, and the hardware for the active control of the primary mirror segments. This considerable work was the effort of several astronomers and physicists, mechanical and structural engineers, and architects.

The overall optics for the instrument were laid out and detailed specifications of design parameters and tolerances were established. A detailed design for the telescope structure was made, and its performance was extensively analyzed with both analytical techniques and computer structural analysis programs. Many of the mechanisms needed for the control and operations were designed.

A prototype of actuator/sensor/electronics control unit was fabricated and tested; it performed to the specifications needed for control of the primary mirror. Refined design and computer modeling of the global control algorithm was performed. In addition, a wide variety of topics associated with all aspects of the telescope and the building and dome were studied and documented in a series of progress reports.

Costing of the major aspects of the project, telescope structure, building, and dome was started by commercial engineers and architects familiar with this type of construction at remote locations. Funds for this project are from the University of California.

Research Staff

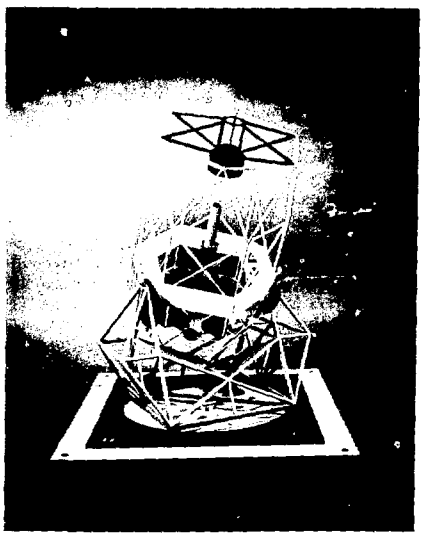
George Gabor, Leslie Hunt, Terry S. Mast, Jerry E. Nelson.

Publications

The University of California Ten Meter Telescope Project - Segmented Design. J. Nelson, in Optical and Infrared Telescopes for the 1990's Conference Proceedings (Tucson, Arizona, 7-12 January 1980).

Search for Stable Superheavy Particles

Unified and superunified theories of the fundamental interactions of physics allow for (and sometimes require) the existence of elementary particles much heavier than the proton. Some of these theories suggest that the particle could be stable on the time scale of the universe. If this is the case, then one would expect to find a remnant population of such particles in ordinary matter. Their chemistry, if singly charged, would be identical to that of hydrogen.



Model of the 10-meter telescope to be located at the summit of Hawaii's 13,769 foot Mauna Kea. (CBB 8011-13907)

We are making a search in terrestrial hydrogen for such particles. The hydrogen comes from deep sea water, presumably a representative sample of hydrogen on the earth. The LBL mass separator is used as a 50 kV spectrometer to search for constituents in the mass range from 20 to about 1000 proton masses. The final sensitivity in this range should be approximately 10^{-16} relative to hydrogen.

If such particles are found, the interpretation will affect our knowledge, not only of elementary particle physics, but also of cosmology, since their abundance will allow us to probe the earliest second of the "big bang".

We have obtained deep sea water from Prof. Hans Suess' tritium laboratory, enriched by a factor of about 100 in constituents equal to or greater in mass than tritium. A ranging technique in thin nickel foils was shown to reduce scattered beam and other sources of noise to the level that single atom detection efficiency can be achieved. Preliminary runs through the mass region up to several hundred proton masses yielded negative results at reduced sensitivity.

Research Staff

Maynard Michel, Richard A. Muller.

Earth Science

Extraterrestrial Cause for the Cretaceous-Tertiary Extinction

Platinum metals are depleted in the earth's crust relative to their cosmic abundance; concentrations of these elements in deep-sea sediments may thus indicate influxes of extraterrestrial material. Deep-sea limestones exposed in Italy, Spain, Montana, Pacific Ocean sea-floor cores, and Denmark show iridium increases of about 30 and 160 times above the background level at precisely the time of the Cretaceous Tertiary extinctions, 65 million years ago. Reasons are given to indicate that this iridium is of extraterrestrial origin, but did not come from a nearby supernova. We suggest an hypothesis to account for the extinctions and the iridium observations. Impact of a large Apollo object would inject about 100 times the object's mass into the atmosphere as pulverized rock; about 10% of this dust would stay in the stratosphere for 3-5 years and be distributed world-wide. The resulting darkness would suppress photosynthesis and the expected biological consequences match quite closely the extinctions observed in the paleontological record. One prediction of this hypothesis that has been verified is that the chemical composition of the boundary clay is markedly different from that of clay mixed with the Cretaceous and Tertiary limestones, which are chemically similar to each other. Four different and quite independent estimates of the diameter of the asteroid give values that lie in the range $10 \pm 4 km$.

Research Staff

Luis W. Alvarez, Frank Asaro, Helen Michel, Maynard Michel.

Publications

Extraterrestrial Cause for the Cretaceous- Tertiary Extinction: Experiment and Theory. L.W. Alvarez, W. Alvarez, F. Asaro, and H. Michel, Science (1980).

Radioisotope Detection with Accelerators

A new technique has been developed for measuring very low concentrations of radioisotopes. The technique uses an accelerator as a high energy mass spectrometer. This new method is orders of magnitude more sensitive than the conventional decay counting technique. The sensitivity of the new method has been proven to the satisfaction of workers in the field of radioisotope detection. However, it is not yet a working tool. Accuracy, reliability, and reproducibility must be tested and studied before large efforts at sample collection and analysis can be made.

These tests and studies will be pursued with emphasis on making the technique a useful tool for those isotopes of particular applicability to Department of Energy problems. The program will emphasize ^{14}C detection with eventual application to the analysis of atmospheric samples to study the origin of cabonaceous pollutants and for climate studies. In addition, the development of the technique to measure ^{36}Cl will be completed and exploratory work toward the measurement of ^{81}Kr will be pursued. Measurement of these isotopes is extremely important for dating old ground water at potential nuclear storage sites.

Research Staff

Terry S. Mast, Richard A. Muller, Petrus P. Tans.

Publications

Radioisotope Detection with Accelerators. T. Mast, R. Muller, and P. Tans, Proceedings of the Conference on Ancient Sun (1980).

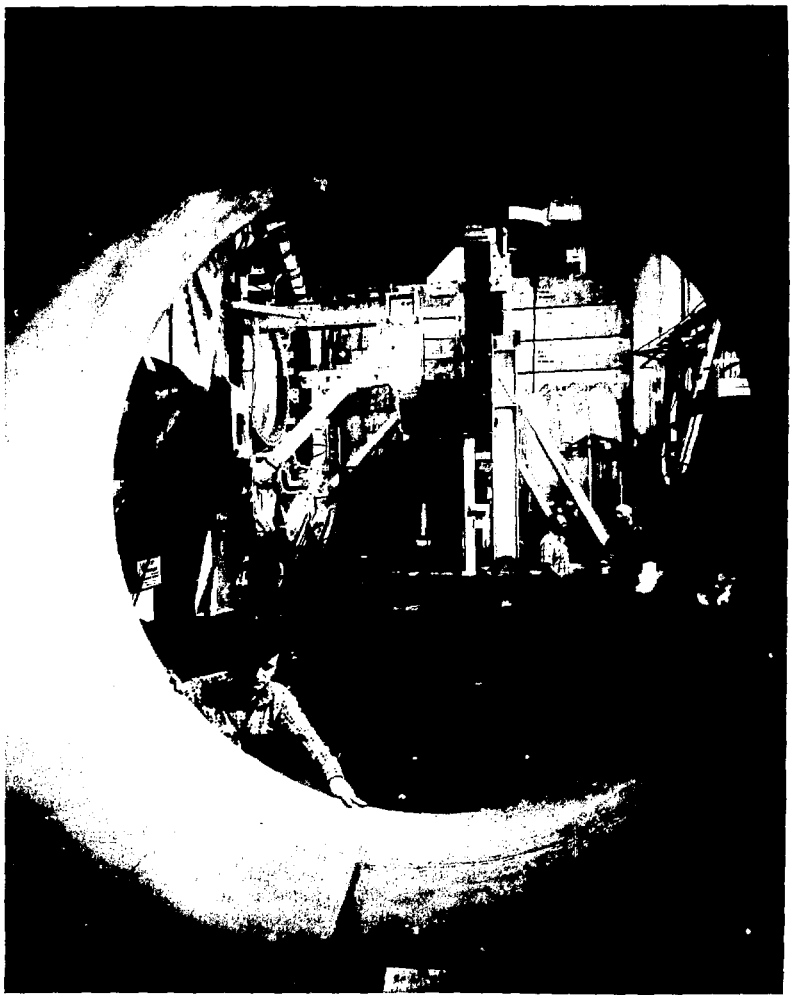
Radioisotope Detection and Dating with Accelerators. T. Mast and R. Muller, Nuclear Science Applications **1**, 7 (1980).

Determination of Atmospheric CO_2-O_2/N_2

The rise in the atmospheric CO_2 concentration, due at least in part to the combustion of fossil fuels, is expected to have a profound impact on the climate everywhere on earth. The credibility of current predictions of the future rise of atmospheric CO_2 is seriously impaired by the fact that the present CO_2 budget does not seem to be in balance. Very precise measurements of changes in the global atmospheric O_2/N_2 ratio in the course of a few years could provide the key to the solution of the "missing CO_2" problem. The technique to be used is Raman scattering from $^{16}O_2$ and $^{14}N_2$ molecules. Advantages are that O_2N_2 and CO_2 can be determined simultaneously in the same sample.

Research Staff

Petrus P. Tans.



This photograph was taken from the area of the Time Projection Chamber which will hold the magnet and drift chamber. Shown left to right are Alan Bross, Harold Van Slyke, and Robert Kenney. (CBB 815-4511)

Instrument Development and Engineering for High Energy Physics

Development Research

Development work was done on various forms of gas-filled multi-electrode detectors. This included studies of the properties of various gas mixtures to provide (a) higher electron drift velocity; (b) higher avalanche gain by use of organic low ionization potential additives; and (c) limited Geiger discharges.

Work on gas-filled detectors capable of recording large multiplicity events by creating glow discharge memories at the locations of their tracks was continued. Various configurations of wire planes, gas fillings, and readout electronics were investigated. A final configuration has been selected and an experimentally usable prototype is under construction.

Work was also continued in the use of the UV light produced in noble gases as a means of transferring position information through material barriers which are optically transparent. Different gas mixtures can be used across the barrier, which allows for optimization of properties in two different chamber sections.

Developments and measurements were done on gas-filled linear chambers with delay-line readout for various applications including high-precision small-angle scattering of x-rays from metallic alloys and powder samples. This work, done in cooperation with the metallurgy group of D. DeFontain (MMRD), enabled us to investigate the properties of fast printed-circuit delay lines capable of high data rates and position accuracy in the 100-micrometer region. Simple high-speed electronics developed for this application using I.C. amplifiers and comparators enabled both of our objectives to be realized.

Applications of gas-filled detectors in biomedical and biophysical problems have been continued. Lead-glass converters for high efficiency detection of gamma rays in the energy range 200 keV - 20 MeV have been made with high density ($\rho = 6.3$ gms/cc) out of fused lead glass tubing. The fused lead-glass matrices are made surface conducting by high-temperature reduction in a hydrogen furnace. Interaction electrons produced by incident gamma rays are drifted out of the glass matrix and into the wire plane region of a MWPC, thus providing position resolution. Applications of these to medical positron-imaging cameras and to position imaging of electron distributions within crystals are proposed. Work also continued on computer methods to solve for the electron density distribution within three-dimensional objects by imaging with annihilation gammas from positron capture or by single gamma-emitting radioisotope distributions within the object. These computer methods are applicable to MWPC detectors covering finite angles or in completely different fields such as electron microscopy or for study of reactor cores, using MWPC with ^{10}B plates for neutron detectors.

Research Staff

Terrance A. Mulera, Victor Perez-Mendez, Bradley W. Sleaford, Pamela E. Wiedenbeck.

Publications

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Limits to Image Reconstruction from Restricted Angular Input. K.C. Tam and V. Perez-Mendez, to be published in IEEE Trans. Nucl. Sci. **NS-28**, (1981). LBL-11834.

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Engineering, Evaluation, and Support Operations

The development engineering of instruments and instrumentation systems which have specific as well as broad and general applications is a continuing task. Other tasks include the research and development of particle detectors and the evaluation of commercially available devices and instruments. Operating manuals are supplied, and maintenance and support of instruments in the

Counting Pool, as well as previously designed systems used in HEP experiments, are provided. In addition, inventory records of all equipment are maintained, new equipment is procured, and consulting service on all aspects of instruments and detectors used in research programs is provided.

Large Scale Digitizer System

The Large Scale Digitizer (LSD) System, an economical modular system for simultaneous digitization of analog data from hundreds of signal channels, has been a continuing activity of our group since 1976. Techniques used in the LSD have successfully been transferred to PEP-4 and PEP-14 instrumentation. The LSI-11 microcomputer systems have been programmed to upgrade the checkout and debugging of the LSD system and individual boards. New MWPC systems are interfaced to the LSD system.

Multiwire Proportional Chambers

A number of multiwire proportional chamber (MWPC) systems have been assembled in this past year. Improvements in several areas have been made. A new preamplifier has been designed and checked out for the PEP-14 project as well as a new summing amplifier which precedes discriminators. Design has been completed for a "first-in, first-out" buffer memory for a MWPC Readout system, and the system was installed in early 1980. Two more MWPC systems have been delivered for experiments at the Bevalac. New designs of a board tester have been implemented to check out amplifiers and discriminators with our LSI-11 microcomputer systems.

We provide ongoing technical support for the MWPC systems in the field. The LSD system has been modified to perform with the PEP-14 MWPC so that, with a non-linear clock in the digitizer, the dataway-limited system of the LSD can accommodate an energy range four times greater than what the present system provides while maintaining high resolution for ± 1/3 and ± 2/3 electron charge in the quark search. A programmable trigger logic has been designed and installed for PEP-14 use.

Microcomputer Systems

The two LSI-11 systems have been performing well, and, with the addition of some peripheral equipment, they have become more powerful and flexible. New software programs have been written for the LSI-11 systems to take advantage of the higher speeds, power, and flexibility afforded by the LSI-11 systems. A basic interpretive language has been successfully implemented to work with CAMAC. The portability of the LSI-11 system has been instrumental in our ability to rapidly troubleshoot complex systems in the field when problems are often obscured by dependence on unfamiliar computers and software programs.

A very low cost computer sold by Commodore (PET Computer) has been interfaced to a tester unit for rapidly testing a large number of digitizer cards, control cards, and backplanes. This unit was sent to a vendor company which built and pre-tested printed circuit cards for LBL. The PET Computer has many other capabilities which are being investigated. Some of the more useful programs are being translated into LSI-11 use.

Electro-Optical Device Evaluation Program

Evaluation and lifetime studies of prototype microchannel plate photomultipliers are continuing activities. Because of proximity focusing, these compact devices exhibit very good timing and pulse height resolution capabilities, as well as very low sensitivity to ambient magnetic fields.

Further improvements have been made in the high-accuracy photomultiplier measuring system and the system for long time studies of the stability of microchannel plate gain because it became apparent that operational lifetime is one of the most critical characteristics of microchannel plate photomultipliers. Several inexpensive versions of conventionally designed photomultipliers have been evaluated.

Commercial development and availability of devices appropriate for high energy physics instrumentation by major manufacturers are encouraged. Manufacturers have supplied us with prototype devices without charge. Our commitment has been to advise them of our findings and to offer suggestions concerning the design criteria for development of a new generation of these devices with improved characteristics. Based on our evaluation results, some manufacturers will incorporate in their new designs microchannel plates with better secondary emitters than presently available. New emitters will provide use of a higher channel wall current that is important for high repetition rate applications.

Miscellaneous Developments

A 4-channel OR-discriminator was designed and developed, as well as a fast amplifier and timing discriminator prototype which has less than 100 ps jitter for critical timing in position sensing detectors. In another area, a developmental low-noise microwave amplifier using cooled GaAs FET's has been designed for the stochastic cooling experiment.

Technical Support and Pool Operations

General service is provided for all electronic instruments used in Physics Division programs on a continuing basis. Repair and maintenance of electronic equipment, maintaining inventory records, procuring new equipment, and providing operating manuals and consulting services on all aspects of instruments and detectors are the types of services rendered. The base of the equipment pool has effectively been expanded by coordinating it with equipment serving other LBL Divisions. The operation of this combined multi-division Equipment Pool provided

efficiencies, convenience, and better utilization of equipment than the previous separate pools.

Research Staff

George A. Constantian, Edward J. Lampo, Kai L. Lee, Branko Leskovar, Chu-Chung Lo, Michiyuki Nakamura, Curtis Nunnally, Stanley R. Olson.

Publications

A Time Projection Digitizer Test System Using a Microcomputer. C. Nunnally. Presented at the IEEE Nuclear Science Symposium, Orlando, Florida, November 5-7, 1980 and to be published in IEEE Transactions on Nuclear Science, LBL-11018, October 1980.

A Triangular Tube Proportional Wire Chamber System. D.H. Badtke, J.A. Bakken, B.A. Barnett, B.J. Blumenfeld, C.Y. Chien, L. Madansky, J.A.J. Matthews, A. Pevsner, W.J. Spangler, K.L. Lee, M. Nakamura, and S.R. Olson, submitted to Nucl. Instr. and Meth., November 1980.

Analog Calorimeter Triggers. J.M. Hauptman and M. Nakamura. TPC-LBL-81-4, October 28, 1980.

Studies of Prototype High-Gain Microchannel Plate Photomultipliers. B. Leskovar and C.C. Lo, IEEE Trans. Nucl. Sci., **NS-26**, 388 (1979). LBL-7957.

Time Resolution Performance Studies of High Speed Photon Detectors. B. Leskovar, LBL-9241, Proc. Laser 79 Opto-Electronics Conference, pp. 581-586, IPC Science and Technology Press, 1979.

Performance Studies of High Gain Photomultiplier Having Z-Configuration of Microchannel Plates. C.C. Lo and B. Leskovar. Presented at the IEEE Nuclear Science Symposium, Orlando, Florida, November 5-7, 1980, LBL-11028.

Performance Studies of the New Generation Amperex XP2020 Photomultiplier. C.C. Lo and B. Leskovar, Presented at the IEEE Nuclear Science Symposium, Orlando, Florida, November 5-7, 1980, LBL-10824.

Resolution Performance Studies of Single Stage Image Intensifier. C.C. Lo and B. Leskovar, LBL-12062, December 20, 1980.

Evaluation of the New Generation RCA 8854 Photomultiplier. C.C. Lo and B. Leskovar, LBL-11684, December 21, 1980.

Hybrid CCD Solid State Detector

A prototype system has been developed to study the use of charge-coupled devices (CCDs) for measuring the trajectories of charged particles. This is the first step in the development of a bulk CCD system usable as a high-resolution, position-sensitive target for neutral-beam, high-energy experiments. Our prototype system consists of a cryo-system capable of operating various CCDs at temperatures down to the temperature of liquid nitrogen. Current studies use an optical CCD, the Fairchild 202, and a 100×100 element array. Design work on a Hybrid CCD System using the Rockwell International 30211 32×32 array is also in progress.

Research Staff

Alan D. Bross

Denyse Chew and Robert Ely analyze data from the Quark Search experiment. **(CBB 816-5967)**

THEORETICAL PHYSICS RESEARCH

THEORETICAL PHYSICS STAFF AND PARTICIPATING GUESTS

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THEORETICAL PHYSICS RESEARCH

The major effort of the Theoretical Physics Group is research in all aspects of particle theory, using the techniques of both S-matrix theory and field theory. In addition to our concern with fundamental theoretical work, members of our group actively participate in the Laboratory's experimental program. Phenomenological methods based on general theoretical concepts are developed for this purpose and are used to interpret and analyze experimental data.

Members of the Theoretical Physics Group also direct the research of graduate student doctoral candidates, who, in the course of meeting the requirements for the Ph.D., make significant contributions to our program.

For almost thirty years, the Theoretical Physics Group has maintained a stimulating summer program. The vigor and variety of Berkeley physics research and the unusual features of the Bay Area have made it relatively easy for us to attract outstanding scientists from all over the world at modest expense. Both theoretical and experimental programs at the Laboratory benefit from these visitors, who often interact as much with experimentalists as with theorists. In addition to the participation of those few who are given some support, our summer program is enriched by a bonus of self-supporting visitors who are active in our research areas. We offer them our hospitality and are rewarded by seminars on their current work and often by their direct contributions to our research.

During the academic year, we also have visitors, eager to participate in our research, who also make significant contributions to our work. They are supported by their own institutions, special research grants, or fellowships. We cooperate with these theorists by supplying office space, limited computing facilities, and secretarial help. During FY81, 58 scientists participated in these programs.

The Theoretical Physics Group is now composed of seven faculty senior scientists, five staff senior scientists, two divisional fellows, and four postdoctoral research associates. Divisional fellows are experienced scientists of exceptional ability who are appointed for a term of five years with the expectation that they will eventually be promoted to become staff senior scientists. The postdoctoral research associates are individuals who have shown unusual ability and promise but have only recently been awarded the doctorate. They are appointed for terms of one or two years. At the present time, there are ten graduate student research assistants (GSRA) supported by DOE and three supported by other grants who are working under the direction of members of the Theoretical Physics Group.

Research in particle theory carried out during FY81 included studies in the following areas:

1. Foundations of Quantum Theory
2. Foundations of S-Matrix Theory
3. Topological Particle Theory
4. Quantum Chromodynamics (QCD)
5. Direct Confrontation of Theory and Experiment
6. Studies of Particular Field Theories

Topics which merit special mention are the development of Topological Particle Theory and work on Quantum Chromodynamics. The former is a new and still incomplete theory that has as its aim the explanation of all particle properties. Both leptons and hadrons appear naturally in the so-far-developed scheme which explains their observed quantum numbers. In our QCD research, significant progress has been made toward elucidating the predictions of a mature theory which describes many of the results of present day particle physics, once the underlying symmetries are given.

During this year, the Theoretical Physics Group was host to a highly successful summer program. This included a special two-week workshop on QCD and a one-week workshop on topological theory.

Three graduate student research associates received the doctorate in FY80:

- Daniel Friedan, *Nonlinear Models in 2 + ε Dimensions*, PhD thesis, University of California-Berkeley, Sept. 11, 1980.
- Susan Moore, *Gauge Invariant Description of Heavy Quark Bound States in Quantum Chromodynamics*, PhD thesis, University of California-Berkeley, August 13, 1980.
- Joseph Polchinski, *Vortex Operators in Gauge Field Theories*, PhD thesis, University of California-Berkeley, July 31, 1980.

Particle Physics

Foundations of Quantum Theory

The relativistic notion that what happens in one region of space time should be independent of choices between alternative possible experiments made in distant spacelike-separated regions has been shown incompatible with quantum theory independently of the questions of the existence of hidden variables or of an objective reality. Recognition of this essentially nonlocal aspect of quantum theory permits the construction of a quantum theory of reality that reconciles Einstein's demand that a complete physical theory describe physical reality itself with Bohr's claim that quantum theory is an essentially complete physical theory. Two variations of this theory are described in some detail with particular attention to the question of locality. These theories are more comprehensive than Bohr's version of quantum theory because they require no separation between the observed and observing parts of a physical system.

Foundations of S-Matrix Theory

In 1959, Landau suggested an alternative approach to relativistic quantum theory based on the idea that the singularities of the scattering function should be essentially the same as those of perturbation theory in spite of the apparent meaninglessness of the perturbation expansion itself. Numerous studies based on S-matrix principles and on axiomatic field theory have lent support to Landau's idea that the nature of the singularities of the S matrix is essentially that of the terms of the perturbation expansion, quite apart from the notions of local fields or of local Lagrangians. This indicates that Landau's suggestion is a reasonable ansatz for the maximal analyticity property of S-matrix theory: the S-matrix program would then involve showing that this ansatz is rigorously compatible with the requirements of unitarity, macrocausality, and Lorentz invariance. The direct derivation of the Landau property from the above-mentioned principles, though possible in many cases, has been blocked in general by "u = O problems," and some stronger assumption or ansatz is needed. The most direct formulation of Landau's suggestion cannot be rigorously formulated because of further divergence problems. However, a rigorously expressible property that essentially expresses Landau's idea has been formulated, along with a similar weaker property that imposes the same conditions on the locations of the singularities but only a much weaker condition on the nature of the singularities, namely the general condition that the relevant functions be regular holonomic functions. Recent mathematical results from the theory of regular holonomic functions are then used to derive from this weaker property conditions on the singularity structure of unitarity-type integrals at the troublesome u = O points. This work is a first step toward confirming rigorous compatibility of the Landau property with general S-matrix principles.

Research Staff

Henry P. Stapp.

Topological Particle Theory

Strong and Electromagnetic Sector

Topological particle theory, with the aim of explaining all particle properties through consistency, has moved forward on both strong-interaction and electromagnetic fronts. Eight quark flavors are predicted in an elementary hadron spectrum that includes baryoniums as well as mesons and baryons. Quark "confinement" is understood; "unconfined topological quarks" cannot undergo strong interactions and are interpretable as leptons. A natural explanation has emerged for charge quantization and for the observed charges of leptons and hadrons: fractional charges do not occur even though the notion of photon-quark coupling is prominent. The topological representation of the photon has a natural extension that leads to $W^{\pm}$ and Z^{0} vector bosons; a full topological theory of weak interactions seems imminent.

Research Staff

Geoffrey F. Chew, Jerome L. Finkelstein, Valentin Poenaru.

Topological Expansion

An earlier topological expansion procedure, which works well in the meson sector of hadron physics but ignores the spin degrees of freedom, has been extended to include both spin and baryons. This extension also incorporates the group theoretic properties of the constituent quark model into the topological expansion.

Research Staff

Henry P. Stapp.

Magnetic Moments of Hadrons

Work during 1980 has focused on the development of the topological theory of particle interactions. In particular, research has been conducted on an electromagnetic scheme to reproduce known results for various magnetic moments. A mechanism for generating hadronic mass differences is also under investigation.

Research Staff

Mark A. Levinson.

Quantum Chromodynamics (QCD)

String Operators in QCD

The formulation of QCD in terms of "string" operators, i.e., Wilson loop operators, has been investigated. Such operators have the advantage of being gauge invariant. Furthermore, QCD, in terms of such operators, simplifies in the large-N limit. There are still unanswered questions regarding the formulation of continuum QCD in terms of string operators.

The actual states created by string operators were considered, not the vacuum-expectation values of the operators as has been done by others. This approach can be used in a variational calculation using trial wave-functions. The light-cone frame, in which the vacuum is trivial, was employed because parameterization of a one-particle state in a known vacuum is very much simpler than parameterization of the vacuum itself.

Starting from the general results of Thorn on light-cone dynamics in the large-N limit, it was found that the one-particle states of QCD consist of an *infinite* number of "gluons" (quanta of Yang-Mills field), each with a very small fraction of the total momentum. It is easy to visualize the one-particle states if a short-distance cut-off is applied to the theory, in which case they consist of a large but finite number of gluons. These gluons form an ordered sequence, consecutively ordered gluons being very close together in ordinary space. In other words, the state formed a "string" of gluons, even though, at that stage of the problem, the string operator had not been explicitly introduced. String-like states thus appear naturally in this form of the dynamics.

The wave-functional of the string was studied at short distances. The question of the meaning of the wave-functional had first to be decided because an infinite number of variables is involved. If the string is divided into a finite number of segments and the fine details within each segment are ignored, all relevant information may be obtained by using a density matrix. The density matrix for any arbitrary sub-division of the string therefore contains all the information, and knowledge of such a density matrix is equivalent to knowledge of the wave functional. A "guinea-pig" theory, ϕ^3 in six dimensions, which possessed many of the features of the Yang-Mills theory and lacked some of its algebraic complications, was examined; and the density matrix was determined. Extension of the result to QCD appears to be a technical problem with essentially no new features.

Research Staff

Stanley Mandelstam.

Soft Structure of QCD

Problems associated with the emission of soft gluons often render QCD perturbation theory unreliable. Some re-summation technique is needed if good predictions are to be made in many processes, for example Drell-Yan and the jet structure in e^+e^- annihilation.

Research Staff

Ian Hinchliffe.

Decay of Heavy Quark Bound States

QCD correction to the total decay rate of bound states of a heavy quark and a light quark was studied including all the leading orders in collinear and infrared singularities. It is found that the total decay rate never approaches the parton limit even if the heavy quark mass is very heavy.

Research Staff

Mahiko Suzuki.

Higher Order Effects in Double Moment Ratios

A QCD calculation of higher order effects in double moment ratios in deep inelastic scattering was performed. These moments are measured in neutrino scattering. Unfortunately, the corrections turned out to be large indicating that a reliable QCD test cannot be made using this process.

Research Staff

Howard E. Haber, Ian Hinchliffe, Jonathan L. Sheiman.

Multipole Expansion in QCD

Separation of short-distance and long-distance dynamics in heavy-quark systems has been studied within the framework of quantum chromodynamics, leading to a QCD multipole expansion scheme.

Research Staff

Ken-Ichi Shizuya.

Gluon Effects for D Decays

Soft-gluon effects in nonleptonic decays of charmed mesons have been studied by use of a QCD multipole expansion. The result indicates that the soft-gluon effects may account for a significant portion of the observed lifetime difference between D^0 and D^+ mesons.

Research Staff

Ken-Ichi Shizuya.

Quark Electric Dipole Moment

In a simple QCD, the quark propagating in the instanton gas is shown to have CP-violating electric-dipole moment due to θTrFF.

Research Staff

Chang G. Han.

Dynamical Generation of Quark and Lepton Masses

We consider a model in which "light" quark and lepton masses arise dynamically and are proportional to the vacuum expectation value of a pair of color $[SU(3)_c]$ sextet fermion-antifermion.

Research Staff

Pham Q. Hung, J.J. Sakurai.

Confrontation with Experiment

Chemical Signatures for Superheavy Elementary Particles

Models of dynamical symmetry breaking suggest the existence of many particles in the 10 GeV to 100 TeV mass range. Among these may be charged particles, $X^{\pm}$, which are stable or nearly so. The X^{+}s would form superheavy hydrogen, while the X^{-}s would bind to nuclei. Chemical isolation of naturally occurring technetium, promethium, actinium, neptunium or americium would indicate the presence of superheavy particles in the forms RuX^{-}, SmX^{-}, $^{232}ThX^{-}$, $^{235,23o,238}U$, $^{244}PuX^{-}$ or $^{247}CmX^{-}$. Other substances worth searching for include superheavy elements with the chemical properties of B, F, Mn, Be, Sc, V, Li, Ne, and Tl.

Research Staff

Robert N. Cahn, Sheldon L. Glashow.

Angular Distributions and the Physics of Charmed Meson Production at the 4.028 GeV Resonance

A detailed study of angular distributions arising from $D\bar{D}$, $D^{*}\bar{D}$, and $D^{*}\bar{D}^{*}$ production at $\sqrt{s}$ = 4.028 GeV is made, including the subsequent decays $D^{*} \to D\pi$ and $D^{*} \to D\gamma$. The production amplitudes are unique except for the $D^{*}\bar{D}^{*}$ case, where there are two p-wave amplitude (S = 0,2) and one small f-wave amplitude (S = 2). It is shown that observations of the angular distributions and correlations of the π^0s and γs from the $D^{*} \to D\pi^0$ and $D^{*} \to D\gamma$ decays provide an effective way of measuring the p-wave amplitudes. These amplitudes are a reflection of the underlying hadronic interactions among the charmed and uncharmed quarks.

Research Staff

Robert N. Cahn.

D Meson Decays

A possible mechanism for the difference in lifetime between neutral and charged D mesons was reinvestigated. The decay rate for the process where a gluon is emitted from the initial D^0 has been recalculated and found to be smaller by a factor of 2 than the original calculation by Bander et al.

Research Staff

Robert N. Cahn, Young S. Kang, Mahiko Suzuki.

D and B Meson Decays

The theoretical understanding of the weak decays of heavy flavor mesons is reviewed in light of the unexpected experimental indications that D^0 and D^+ mesons may have very different lifetimes. The principal conclusion is that the lifetime ratios $\tau^+/\tau^0 \leq 3$ can be accommodated in the existing theoretical framework but that, if $\tau^+ / \tau^0 \geq 10$, our understanding of all nonleptonic weak decays is called into question.

Research Staff

Michael S. Chanowitz

Heavy Quark Systems

Due to the kinematic and dynamic simplifications possible for these large mass systems, certain properties can be analyzed within the framework of Quantum Chromodynamics. Using non-relativistic multi-pole techniques the branching ratio of Υ to charmonium bound states has been calculated giving results quite different from previous naive estimates. Using similar techniques, the production rate for F mesons in $e^{+}e^{-}$ annihilation was determined. It was found that the proposed production mechanism could account for all or much of the observed $F\bar{F}$ rate. More recently, non-perturbative effects have been estimated for ultra-heavy quarkonia, indicating unambiguously when a one-gluon-exchange potential dominates the quarkonium binding.

Research Staff

Curt A. Flory.

Production of Charmonium States by Resonant pp Annihilation

Cross sections are estimated for the production of charmonium states in $p\bar{p}$ annihilation on resonance. For processes like $p\bar{p} \to \eta_c \to \gamma\gamma$ the cross sections are about 1 nb. Non-resonant contributions are estimated and found to be much smaller. Similar rates are found for $p\bar{p} \to \eta_c \to \gamma\gamma$ and $p\bar{p} \to {}^1P_1 \to \eta_c\ \gamma \to \gamma\gamma\gamma$. Thus, these may furnish a unique means of observing these charmonium states. Upsilonic states might be observable in colliding ring $p\bar{p}$ experiments, but the cross sections are likely to be in the picobarn range.

Research Staff

Robert N. Cahn, Mahiko Suzuki.

A Possible Glueball State

Evidence is presented that there are two different states near 1.4 GeV which decay to $KK\pi$, which have been regarded as a single state in the previous literature. One is E(1420), a member of the axial vector nonet of $\bar{q}q$ states. The other is G(1440), probably a pseudoscalar. Arguments are presented which suggest that G(1440) is a glueball.

Research Staff

Michael S. Chanowitz.

Bounds on the Masses of Neutral Generation-Changing Gauge Bosons

The existence of several generations of quarks and leptons suggests the possibility of a gauge symmetry connecting the different generations. The neutral gauge bosons of such a scheme would mediate rare processes such as $K \to \mu e$, $K \to \pi e\mu$, $\mu N \to eN$ and would contribute to the $K_L - K_S$ mass difference. Using the known experimental limits for such rare processes, lower bounds for the masses of generation changing bosons are derived and are found to lie in the 10 - 100 TeV range.

Research Staff

Robert N. Cahn, H. Harari.

Test of Integral and Fractional Charge Quark Models

In general, very few processes can distinguish between integral and fractional charge quark models. Suitable processes must involve two photons and be sensitive to dynamics at arbitrarily high energies. Because of the chiral anomaly, the decays $\eta \to \gamma\gamma$ and $\eta \to \gamma\gamma$ satisfy these criteria. An analysis is presented which is independent of the uncertainties in the SU(3) mixing angle and PCAC constants which afflicted previous analyses. The results favor fractional charges.

Research Staff

Michael S. Chanowitz

Direct Photon Production in pp Collisions

An investigation was made into the possible difficulties of measuring direct photon production at the FNAL $\bar{p}p$ collider. The problems associated with backgrounds and event rates were considered and the extreme difficulty of the experiment was pointed out.

Research Staff

Ian Hinchliffe, Robert P. Kelly.

Three-Jet Production in e^+e^- Collisions

Using perturbative QCD, the structure of the hadronic final state in e^+e^- machines has been extensively studied. A complete calculation has been performed of the three jet angular distribution function to second order in the coupling constant. The results show an encouraging agreement with experimental data.

Research Staff

Stephen R. Sharpe

Test of QCD

Photon-photon annihilation in a doubly deep inelastic kinematic limit has been considered. This is potentially a completely calculable test of quantum chromodynamics, measurable at e^+e^- colliders. Questions of rate and background have been studied.

Research Staff

Alan Axelrod.

Heavy Quark Pair Production

A possible method of separating heavy quark pair production events in electron-positron annihilation at PETRA-PEP energies was proposed and examined in extensive Monte Carlo generation of events. This work was done in collaboration with Christoph Day of TPC group. The result is not as promising as one naively imagines, but this seems to be the only possibility at this moment.

Research Staff

Mahiko Suzuki.

Radiative Pion Decay

The rate $\pi \to \mu \nu \gamma$ for soft photons and muon helicity flip was calculated. This was a mechanical calculation of importance to an upcoming experiment by M. Strovink et al. to measure the Michel parameter ξ.

Research Staff

Veit Elser

Field Theory

Grand Unified Theories

The fermion-fermion Higgs terms in the context of grand unified theories have been studied. A very simple expression has been derived for the evolution of the Yukawa coupling that essentially governs the scale dependence of a fermion mass. At the one loop level, the expression is gauge invariant and involves only the representation content of left- and right-handed fermions.

Research Staff

Robert N. Cahn, Philippe L. deForcrand, Young S. Kang.

Petite Unification

We examine some less ambitious alternatives to the popular "grand unified theories," such as SU(5) or SO(10), which predict relatively little new phenomena populating the energy region of approximately 10^3 GeV to approximately 10^{15} GeV. In our schemes, new physics arises at some distance scale, not too many orders of magnitude less than the Compton wavelength of the intermediate bosons $W^{\pm}$ and Z^0.

Research Staff

J.D. Bjorken, A. Buras, Pham Q. Hung.

Cosmological Consequences of Heavy Right-Handed Neutrinos

The cosmological consequences of extremely heavy neutrinos which appear in some Grand Unified Theories have been investigated.

Research Staff

Pham Q. Hung, S. Nussinov.

Semi-Simple Lie Algebras

The techniques of Dynkin, Weyl, Freudenthal, and others permit the calculation of important properties of the representations of the semi-simple Lie Algebras. Work has begun on determining the most effective ways to apply these techniques to grand unification theories.

Research Staff

Robert N. Cahn.

CP Violation from the Higgs Sector

CP violation originating from the Higgs sector in the Weinberg-Salam model with more than two Higgs doublets has been studied by use of a mixing matrix of Higgs particles. This mixing matrix provides a concise parameterization of CP violating interactions.

Research Staff

Ken-Ichi Shizuya, S.H. Tye.

Higgs Phase-Vacuum Possibility

An SU(2) gauge theory with scalar fields in the fundamental representation is considered. Quantized in the axial gauge, this theory possesses a residual gauge invariance, and finite energy states should be invariant under the residual gauge group. The perturbative vacuum does not satisfy this condition.

A state which is residual-gauge-invariant is constructed in the form of a plasma of color describing the Higgs phase of the theory. It is shown that such a state gives a lowering of the energy compared to the perturbative vacuum. This result indicates that a non-Abelian Gauge Theory with scalar fields may have its vacuum in the Higgs phase rather than a perturbative phase with real massless gluons.

Research Staff

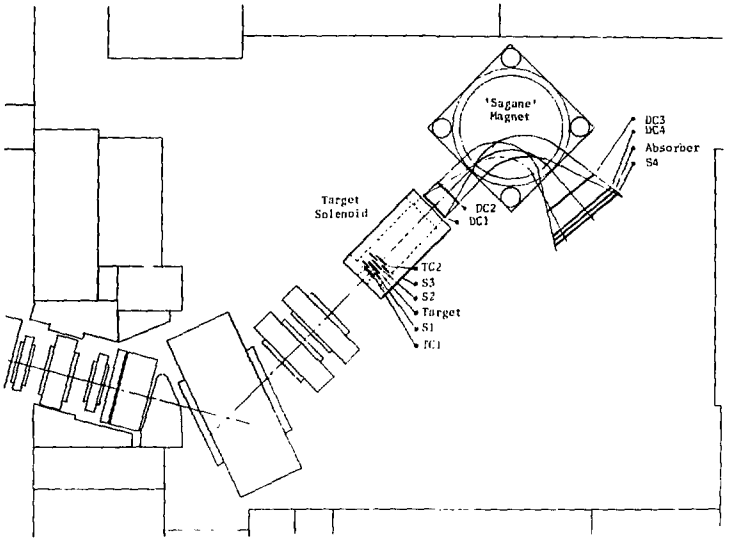
Omer Kaymakcalan.

Fermion Mass Generation

Fermion mass generation is being studied in a gauge theory where symmetry breaking occurs via the Coleman-Weinberg mechanism. In a prototypical chiral massless QED model, the two-point fermion Green's function is being calculated in perturbation theory from effective vertices and propagators in a constant external scalar field. The fermion mass is shown to satisfy the same differential equation that the effective potential has been shown to obey by Nielsen, thus giving the broken theory a consistently gauge-invariant meaning.

Research Staff

Young S. Kang.



This apparatus is being constructed for the Berkeley-British Columbia Experiment at TRIUMF. The experiment will be sensitive to the product of ξ, the polarization parameter describing μ^+, and the polarization of P_μ of the μ^+ from π^+ decay at rest. The anticipated sensitivity represents a factor of 13 improvement over the current world average. This will be achieved by measuring the rate of decay e^+ emission opposite to the μ^+ polarization direction at the high-energy endpoint. If this rate of decay is zero, the mass of any right-handed gauge boson W_R must exceed 600 GeV/c^2. Two magnets are used in the apparatus: the target solenoid's axial field "holds" the stopped μ^+ spin and focuses the forward decay e^+; the "Sagane" cylindrical dipole magnet is used in a 90° spectrometer with drift chambers DC2 and DC3 at the foci. (XBL 811-7769)

Large N Limit of Various Theories

The large N limit has been investigated for multi-component quadratic building block theories, large N factorizing configurations and large N matrix mechanics, and constrained classical systems. The work culminated in a connection between Heisenberg matrix mechanics and so-called "Large N Classical Solution". The physical interpretation was established as the set of transition matrix elements among the ground state and the "generalized adjoint" states.

Research Staff

Herbert Neuberger

Lattice Gauge Theory

This research has two main goals. The first is a better understanding of the recently discovered roughening phase transition in lattice gauge theory. The second is an investigation of finite size and finite temperature effects on Wilson Loop expectation values.

Research Staff

Martin B. Halpern

Instantons and the Large N Limit

An investigation was made of the compatibility of the 1/N expansion with (instanton) semi-classical techniques. This problem was analyzed for the CP^N models, with the conclusion that the infinite N results may be treated in this manner. The dilute gas approach for the approximate computation of a β-function within an effective lattice gauge field theory was considered in the limit $N \to \infty$. The approach appeared to work in principle but the approximations employed appeared to be unjustifiable. The question of the relevance of terms vanishing in the Poincare sense was then taken up in detail, and it was proved that the large N limit may be obtained, using instantons, in the case of a simple lattice model.

Research Staff

James P. Kowall, Herbert Neuberger.

Field Theories with Linear Couplings

Model quantum field theories with linear interactions have frequently served as approximations to more complicated theories and as proving grounds for new techniques, particularly in C*-algebraic approaches to problems of field theory. Such models, which include quantum fields interacting with classical external potentials and fields coupled linearly to other quantum-mechanical systems, have the common feature that they are solved explicitly by Bogoliubov transformation to normal form – the analogue to transformation to normal modes for systems with finite number of degrees of freedom.

Surprisingly, nontrivial algebraic questions arise even in these linear models. There exist, for example, systems of this type for which the interacting dynamics cannot be implemented as a unitary group in the Fock representation usually employed for quantum fields. Moreover, the necessity of using non-standard representations for unitary implementation of the dynamics is independent of the possibility of expressing the scattering automorphism (S-matrix) as a unitary operator in the standard representation.

Although much literature has investigated the existence of Bogoliubov transformations for various specific models, there has been no general investigation of the properties of Bogoliubov-diagonalizable systems. A complete classification of Bogoliubov transformations, according to the properties of the models they determine, is of interest because it could allow the construction of explicitly solvable models with pathological behavior mimicking that of more complicated but unsolved theories.

This classification is being investigated by characterizing both the physical properties (such as the existence of Moller wave automorphisms and scattering automorphism, asymptotic completeness, etc.) and the algebraic properties of these models in terms of the corresponding Bogoliubov transformations. This work will lead to better understanding of the representation-theoretic difficulties encountered in current theories of elementary particle interaction.

Research Staff

Henry A. Warchall.

CP Violation in a Simple σ-Model

A study of strong CP-violations due to θTrFF in a simple $U(2) \times U(1)$ σ-model. We show that in the dilute gas limit of instantons CP violation is independent of the density of instantons.

Research Staff

Chang G. Han.

Other Theoretical Work

Statistical Physics

We have been studying interacting systems of the Bose type as a model for the excitation spectrum of the superfluid state. The path integral formalism provides a convenient structure for such investigations since it lends itself to semi-classical approximation. We have examined the Euler-Lagrange equations obtained from the steepest descent approximation and have found the many vortex state in two dimensions. We are presently studying the analogous equations in three dimensions in order to construct a model of the Landau roton excitation.

Some future plans involve the investigation of the helium analogue of the Josephson effect.

Research Staff

Harry L. Morrison.

Helmholtz Equation

The boundary distribution technique for solution of the Helmholtz equation has been extended to cases in which surface waves are present. In such situations the distribution does not decrease to zero at large distances from a scattering center, and special techniques were developed to guarantee proper behavior of the asymptotic wave solutions. A computer program incorporating the analytic ideas involved is being developed.

Research Staff

Robert J. Riddell, Jr.

Quench Phenomena

Two months, July and August, were spent at Brookhaven National Laboratory working in the Magnet Division, Isabelle Project. Research included studies of longitudinal and transverse quench propagation in Isabelle coil configurations, quench diagnostics, and stability against perturbations. The work on transverse quench propagation was reported in Isabelle Technical Note No. 234 (17 Oct. 80), *Theory of Transverse Quench Propagation.*

Research Staff

John D. Jackson.

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Accelerator Theory

Stability of a Beam in Presence of a Cavity Resonance

A particle beam in an accelerator (say, a synchrotron) is affected by periodic widenings of the vacuum chamber which are associated with the r.f. accelerating equipment. We neglect accelerating fields and treat the widened regions as passive cavities with resistive conducting walls, traversed by a beam of constant average velocity. A perturbation of the longitudinal charge distribution of the beam may have a Fourier component almost coinciding in frequency with one of the resonant frequencies of a cavity. The perturbed beam produces a field in the cavity, which, acting back on the beam and enhanced by resonance, tends to produce beam instability. The problem is to delineate the range of accelerator parameters (geometrical parameters, velocity distribution, beam current density) for which instabilities with small growth times might occur.

Adapting the classical Landau theory of plasma oscillations, we have treated the linearized Maxwell-Vlasov equations so as to eliminate the axial electric field (which appears initially in the Vlasov equation) in favor of Fourier components of the field in the cavity region. We thereby come closer to dealing with the normal modes of the system than one does in the conventional approach of accelerator theory based on the "coupling impedance," which is defined in terms of the axial field. The resulting infinite set of self-consistent equations for the cavity field coefficients is rewritten by means of a Watson-Sommerfeld transformation and a procedure to eliminate the resonant mode from the equations to be solved. The result is a very practical scheme for computation of unstable growth rates; it avoids numerical solution of large sets of equations and works for virtually any choice of accelerator parameters. The new calculational scheme and the incorporation of Landau-Vlasov self-consistency constitute substantial improvements on earlier work of Keil and Zotter [Particle Accelerators 3, 11 (1972)]. Calculations of growth rates for realistic situations are in progress.

Research Staff

Robert L. Warnock

Inertial Fusion

Research continues on problems in accelerator theory aimed at developing high-energy heavy-ion accelerators to serve as igniters for inertial-fusion pellet targets. The goal of this program is to develop commercial-scale electric power plants. The work is carried out in collaboration with members of the Accelerator and Fusion Research Division. During 1980, attention was focused on two topics. The first is the theory of longitudinal ion dynamics in induction linear accelerators, described in the Annual Report for the preceding year; also, a paper on the work has been published. Work on the second topic began late in 1980 because of a request from the program management to undertake an independent review of previous work on systems using an rf linac with storage rings as a first step in conducting further work on these systems. Thus far, the effort has reexamined an earlier study which emphasized the role of the six-dimensional phase space constraint of system designs and its use as a guide in system design in the light of new target requirements and other changes.

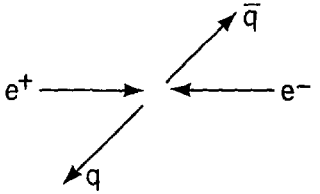
Research Staff

David L. Judd

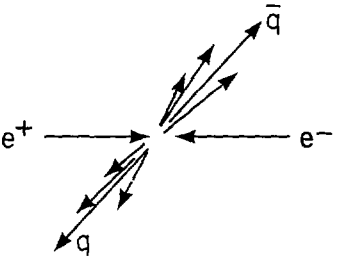
Fermilab $\bar{p}p$ Collider Project

Participation in this project primarily has involved consultation on beam-lines, study of alternative lattices for the superconducting Tevatron, and design of the precooler/decelerator/accelerator ring.

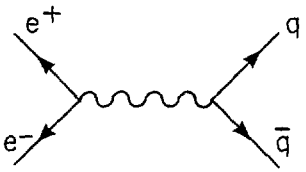
A difficulty with the Tevatron is that it must function both as an accelerator and as a colliding beam storage ring. However, it is constrained by the geometry of the



Pair production



Quarks within jets



$e^+e^- \longrightarrow q\,\bar{q}$

Point-like $\mu^+\mu^-$
Spin 1/2

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2 Q^2}{16E^2}\,\beta\left[1+\cos^2\theta+(1-\beta^2)\sin^2\theta\right]$$

Q = charge of q (relative to e)
β = velocity of q
θ = production angle
E = beam energy

Quark production at PEP. (XBL 8110-1478)

conventional-magnet main ring, which was designed purely as an accelerator. The problem primarily concerns the long-straight sections, especially those to be used for the collisions. Various designs have been made by other workers, notably D. E. Johnson and G. Guignard.

In order to give those responsible for constructing this machine further options, we have proposed two lattice schemes with qualitative differences from those of Johnson and Guignard. The first, worked out in detail, is a ring with two low-β long straight sections for collisions and four relatively high-β straights. All of these insertions are matched to the normal cells both in beta function and dispersion, unlike either the conventional main ring or previous designs. The low beta sections have β = 1.5m and dispersion α_p = .5 m at the center of 24.5 m long interaction regions. The high-beta straights are similar to those in the main ring. The second scheme proposes a way to make symmetric Tevatron insertions (FDLDF) even

though those of the main ring are antisymmetric (FDLFD) by reversing the polarity of the quadrupoles in the intervening areas.

A great amount of effort has been devoted to design of the precooler ring. Antiprotons from the target will be injected into this ring at 4.5 GeV and stochastically cooled in momentum, decelerated to 200 MeV for transfer to the Electron Cooling Ring, cooled and accumulated there, then accelerated in the precooler to 8 GeV and injected into the main ring. An alternative scheme replaces the electron cooling accumulator with a stochastic cooling accumulator.

LBL work on the precooler ring has included these phases:

a. Design (with James MacLachlan) of a ring using magnets from the ZGS.

b. Design of a comparatively strong focussing ring, incorporating certain ideas of T. E. Collins. This ring had four zero dispersion straight sections and is described in the *Tevatron Phase I Design Report*, February 1980.

c. Design of rings with variable transition energy. This feature would be especially useful with boxcar style injection near transition, followed by cooling after the transition energy had been shifted.

d. Design of a ring, likely to be adopted, with two $\alpha_p = 0$ straights and two $\alpha_p \neq 0$ straights, each with 20 m clear space. This configuration is suitable for injection, extraction, momentum, and transverse cooling. Orbit properties such as tunes, maximum beta-values, chromaticity, and transition energy appear quite favorable.

Research Staff

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Stochastic Cooling

Stochastic cooling is an essential feature of $\bar{p}$ accumulation schemes for high energy physics experiments. In addition, cooling systems may significantly increase the lifetime of stored particle beams. The theoretical effort in stochastic cooling has focussed both on extending the understanding of the stochastic cooling process for coasting and bunched beams and on designing practical systems for $\bar{p}$ accumulation.

The basic theoretical description of stochastic cooling is in terms of a Fokker-Planck equation which includes multiple particle effects, amplifier noise, and signal suppression factors which are directly related to the dispersion integrals of beam instabilities. From this basic framework moment, equations have been written which include the effects of finite notch filter depth and provide simple formulas to aid in the design process. The Fokker-Planck equation has been rewritten in a form which emphasizes the interrelation between Schottky noise and signal suppression and more directly addresses the limitations on the magnitude and frequency domain shape of the system transfer functions. Simple criteria have been developed to optimize cooling rates and avoid instabilities.

The cooling of bunched particle beams would provide additional flexibility in designing accumulation scenarios. For example, continuous cooling and deceleration may lead to faster cooling than sequential methods.

The difficulties encountered in understanding system feedback effects are analogous to those found in bunched beam instability theory, and a computer simulation has been developed to address this issue. It appears that spread in synchrotron frequency for bunches is the analogous mixing mechanism to revolution frequency spread for coasting beams. In the simulation, it is found that a perfectly harmonic bucket does not sustain cooling after times of the order of a synchrotron period. However, the natural nonlinearity of the usual RF bucket does allow cooling to proceed past one synchrotron period. Various nonlinear forces have been included in the simulation and are currently being studied.

In parallel with the simulation effort, a theoretical formulation of bunched beam cooling is underway. The basic Schottky spectrum as sampled by cooling particles has been analyzed. The feedback or signal suppression effect is more complicated for bunches because finite length effects couple coherent modes. Some methods from finite plasma theory appear to be useful in understanding this phenomenon.

Research Staff

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Venus

Work on this project was carried out in the areas of lattice design, operating parameters, and injection systems for a system that could provide up to 20 GeV/A heavy-ion beams with intensity of about 4×10^{10} pps in fixed target mode, and luminosity of about 2×10^{28} $cm^{-2}s^{1}$ in the colliding beam mode. For this purpose a lattice was designed for the main rings. These would be two, vertically separated, 143-m radius rings, crossing each other vertically at 0.7 mrad and in six 16-m interaction regions, so that each beam is alternately in the upper or lower magnets in successive sextants. This crossing geometry would permit either coasting or bunched colliding beam operation, though the former has been emphasized thus far in the parameter selection. This geometry also gives a straightforward magnet structure for the insertions containing the interaction regions. Each sextant consists of eight separated-function FODO cells with four tesla dipole magnets. The interaction-point beta function values, magnet lengths, apertures, etc., are all taken to be consistent with a choice of transverse stacking for the fixed-target mode and longitudinal stacking for the colliding-

beam mode. These studies strongly suggest that this strategy is the best for VENUS, particularly in minimizing circulating beam current and magnet apertures, though they are not definitive.

Extensive work has also been done to design injection systems. Several different schemes were looked at. All start with the SuperHILAC, have one or two booster synchrotrons, and a few use a recirculating loop. The possible boosters range in energy from 0.5 - 4 GeV/A and in sizes of 1/7, 1/2, and 1 times that of the main ring. While no single system has yet been chosen, this work has made considerable progress. For example, it has become reasonably clear that one should accelerate in a booster to at least 0.5 GeV/A and completely strip the ions before injecting into the main rings. The principal problems encountered in this work involve choosing transfer energies, ring sizes, and stacking numbers so as to have reasonable r.f. voltages and magnet power to avoid space charge limits and retain reasonable main-ring apertures, particularly in the low-beta quadrupoles.

Research Staff

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Beam-Beam Effects in Single Pass e^+e^- Colliders

A study was made using envelope theory and particle simulation with the object of facilitating parameter choices that maximize luminosity and minimize bunch disruption. The collisions are defined by the particle energy γ, particle/bunch N, emittance ϵ, bunch length δ_z, and interaction point beta-function β. Insight is obtained by reference to the hypothetical collision of infinite streams maintained at a constant radius by space-charge focussing. If the collider bunches were to meet with the same linear density and radius as these infinite equilibrium streams, they might be expected to maintain this radius during the collision and suffer no disruption. This cannot be achieved perfectly, however, because all particles do not first enter the opposing bunch at the same longitudinal position.

By scaling the bunch radius, angular spread, etc. by equilibrium values, it is possible to characterize any collision by only two dimensionless quantities: the betatron phase advances $\Delta\mu_o$ and $\Delta\mu_e$ that the particles would have if the bunch radius were constant during the collision at the initial or equilibrium values respectively. The equilibrium values are given by $\beta_e = 4\epsilon\gamma\sigma_z/(r_e N)$, rms radius, and angle $\sigma_e = \sqrt{\epsilon\beta_e}$, $\sigma'_e = \sqrt{\epsilon/\beta_e}$; the phase advances by $\Delta\mu_e = 2\sigma_z/\beta e$ and $\Delta\mu_0 = 2\sigma_z/\beta 0$. Also, if the radius were constant, the luminosity would be $L = f N^2/(4\pi\epsilon\beta)$. If L is known for given conditions, we use the preceding formula to define a β_{eff} and $\Delta\mu_{eff} = 2\sigma_z/\beta_{eff}$.

A series of runs was made using a particle simulation program from which curves of outgoing rms angle ratio σ'_F/σ'_c and luminosity parameter $\Delta\mu_{eff}$ were made vs. $\Delta\mu_0'$, for different values of $\Delta\mu_e$. These computer experiments verified the scaling and showed:

a. Initial and final angles σ'_o/σ'_f are equal when $\Delta\mu_o$ is approximately $2\Delta\mu_e$;

b. At $\Delta\mu_o$ approximately 3, σ'_f/σ'_c is minimum, of order unity; and $\Delta\mu_{eff}$ is maximum, with value about 4.

This study is more complete than previous ones, which only looked at the dependence on a single quantity, the disruption parameter $D = \Delta\mu_o \times \Delta\mu_e$.

Research Staff

Alper A. Garren, Joseph J. Bisognano.

Transverse Longitudinal Coupling

For very intense beams, both transverse frequencies and the frequencies of longitudinal disturbances are characterized by the plasma frequency. This contrasts with the more familiar case of high energy accelerators in which space charge effects are a small perturbation on both longitudinal and transverse motion. In that case, most stability questions can be considered as purely longitudinal or transverse because the basic frequencies differ by orders of magnitude. We are studying the behavior of a continuous beam to discover the extent to which the older concepts should be modified for intense beams.

Two approaches have been pursued: a Vlasov treatment of a beam uniform longitudinally with a K-V transverse distribution and a fluid model based on a transverse distribution of approximately circular orbits with longitudinal and transverse temperatures. The fluid model proved to be too simplified to describe instabilities of interest which depend on detailed correlations in velocity space. However, it was relatively easy to derive a closed algebraic formula for mode eigen-frequencies, assuming circular orbits in the transverse plane and including a longitudinal velocity spread. This model is quite unrealistic in its description of transverse motion but provides a quick insight into the influence of transverse motion on what are usually regarded as longitudinal stability questions. For that reason, the dispersion relation is being examined.

The case of a K-V transverse distribution is more difficult to treat mathematically; the eigen-value equation takes the form of an infinite determinant. Numerical procedures are being used to approximate the eigen-values for both longitudinal and transverse modes.

Research Staff

Lloyd Smith

Beam Break-Up Mode

A notorious instability in electron linacs is called the beam break-up mode. A slightly off-center beam excites a wave-guide mode which further deflects the beam. As a result, the tail end of the beam is lost because of the large induced transverse motion. This effect has been examined for intense ion beams in an induction accelerator and seems to be unimportant, largely because the deflecting mode in the induction modules have a sufficiently low Q-value that the deflecting fields do not build up to a dangerous level.

Research Staff

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COMPUTER SCIENCE AND MATHEMATICS

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COMPUTER SCIENCE AND MATHEMATICS

The Computer Science and Mathematics (CSAM) Department conducts basic and applied research in a variety of computer science and mathematics disciplines. The research program encompasses four basic research areas: (1) advanced analytical and numerical methods for solving partial differential equations related to energy technology; (2) innovative approaches to the manipulation, analysis, and display of large, complex data sets; (3) investigation of advanced computer concepts, distributed architectures, and computer networks; and (4) the development and evaluation of analytical and statistical methodologies and techniques used for specific epidemiological studies investigating the impact of environmental pollution upon human health.

Funding for basic research is provided by the Applied Mathematical Sciences (AMS) research program and the Office of Health and Environmental Research (OHER) in the Office of Energy Research, DOE. Supplemental funding for research, development, and demonstration projects is provided by other federal agencies, including the U.S. Department of Labor Employment and Training Administration, the National Aeronautics and Space Administration, and the U.S. Army Corps of Engineers, as well as the Electric Power Research Institute. The combination of basic research with practical prototype projects and applications provides a rich base for innovative solutions to research problems in information systems development, computer networking, epidemiological studies, and the application of numerical methods to energy technology.

The CSAM staff is comprised of over fifty computer scientists, mathematicians, engineers, computer technicians, and administrative personnel. UC Berkeley and UC San Francisco faculty, post doctoral appointees, and graduate students are included. CSAM sponsors workshops, colloquia, and seminars and provides supervision of graduate students in the masters' and doctoral programs in applied mathematics and computer science at UC Berkeley.

Analytical and Numerical Methods

Applied Analysis

Sampling and Probabilistic Methods

Work in applied analysis centers on three areas. The first area is the development of numerical techniques for obtaining solutions that are discontinuous or nearly discontinuous for hyperbolic and parabolic partial differential equations. Such solutions occur very often in applications; however, the usual tools of numerical analysis often depend on smoothness assumptions that are not realized in these cases. The numerical techniques being developed are based on sampling rather than averaging and make use of "dictionaries" of known phenomena as building blocks of probabilistic numerical schemes. These techniques are proving to be successful in a number of physical applications including turbulence theory, multiphase flow through a porous medium, and combustion theory.

During 1980, a major breakthrough was made in the understanding of numerical methods suitable for the description of complex phenomena in hydrodynamics. The idea of sampling a self-similar solution, which is the basis of the random choice method, was extended to complex physical systems through use of the notion of self similarity dimension (Hausdorff dimension). If the Hausdorff dimension of a singular set can be determined for a physical system in two or three dimensions, a device is then available for describing the statistics of its behavior. Such a determination was accomplished for turbulence in three dimensions, with or without combustion.

We have developed further methods for solving nonlinear hyperbolic equations, which involve random choice ideas as well as those of the MUSCL scheme of van Leer, monotonization procedures, and flux convection. These methods have been applied successfully in a number of engineering areas.

Detailed analyses were made of the stability of flame fronts and the process of generating vorticity through the thermal expansion of gases that cross such fronts. A Markov model of the repair-misrepair process of cell survival was studied.

Capillarity Phenomena

The second research area involves the analysis of the nonlinear elliptic partial differential equations arising in the study of capillary free-surfaces. Here, the work is concerned with questions of the existence, stability, and qualitative behavior of solutions of these equations, particularly when these questions relate to areas of physical, biological, and engineering sciences in which capillarity plays a significant role. This work has produced new results concerning the possible configuration of liquids that

are freely suspended or that are confined to a space they partially fill.

New analytic and computational results were obtained for the discontinuous behavior of free-surfaces in trapezoidal and other domains. To verify our mathematical results, we continued to devise physical experiments in a low gravity environment.

Image Reconstruction from Projections

Our third research area is the reconstruction of images of objects from projection data of their transverse sections. The work is directed towards developing optimal numerical schemes, as well as understanding the mathematical constraints on different forms of tomography. Special emphasis is placed on the effects of limiting the number or range of the directions defining the projections. This work is applicable to X-ray and emission tomographies, transmission electron microscopy, nondestructive testing, and nuclear magnetic resonance (NMR) reconstruction.

The development of reconstruction algorithms for limited angle X-ray tomography continued. Particular attention was devoted to the three-dimensional situation arising in nuclear magnetic resonance (NMR) reconstruction. A detailed study was made of the underlying mathematical structure to be used in assessing the degree of conditioning of the reconstruction problem as a function of the angular amount of data. It was shown that the same "accident" that allows for a detailed analysis of the situation in the two-dimensional case carries over to the more complex three-dimensional case.

One of the end products of this investigation should be the obtaining of a performance curve that relates the expected quality of the reconstruction to the amount of data recorded and processed.

Computational Mathematics

Research in computational mathematics emphasizes the development of mathematical, numerical, and statistical methods related to the study of energy processes, typically in cases requiring the solution of ordinary and partial differential equations. The topic of primary interest is the development of methods for the numerical solution of discrete approximations to elliptic partial differential equations. The development of fast-direct methods and the coupling of these and other methods with the conjugate gradient method have made possible the solution of problems that would otherwise not have been feasible within normal limitations on computing requirements. Furthermore, the reliability and ease of using these methods make them generally attractive. These and related methods are being developed for the iterative solution of elliptic equations that are nonlinear or have discontinuous coefficients.

New numerical methods have been developed for solving the Poisson equation and the first biharmonic problem on irregular regions. These hybrid methods incorporate both integral-equation and fast-direct techniques. We have begun development of a variant of a method to solve equations with discontinuous coefficients arising in fluid-flow interface problems.

Numerical Methods For Partial Differential Equations

In these studies, computational and graphical techniques are being developed for analyzing turbulent combustion phenomena, such as those that occur in an internal combustion engine, and multiphase porous flow phenomena, such as those that occur in petroleum or geothermal reservoirs. The goal is the construction of realistic models that are suitable for comparison with experiments and are capable of being used for engineering purposes. The specific features of the methods being developed are: (1) the use of sampling and random choice procedures and (2) the use of "dictionaries" of known phenomena as building blocks in the numerical schemes. These features enable resolution of the major difficulties that have stood in the way of the application of other numerical techniques to the study of physical combustion phenomena and of porous flow phenomena in which there are sharp fronts. These methods, unlike others, have little or no numerical diffusion and thus no cell Reynolds number restrictions, i.e., they can deal realistically with high Reynolds number fluid flow. Because the methods are based on sampling rather than averaging, they can take into account the effect of organized structures (coherent eddies) in a flow. This feature is very important for combustion models because chemical phenomena are greatly affected, even determined, by the existence of coherent eddies and will not be reasonably reproduced if such eddies are not taken into account.

Combustion

A detailed turbulent combustion model has been built based on our vortex and Huygens principle methods. In cooperation with experimental groups at LBL, we have investigated a number of realistic flame models, and problems involving ignition, flame stabilization, and flame instability have been studied. Our random choice method has been used to study transition from deflagration to detonation, and a substantial start has been made on the effort to develop efficient, three-dimensional turbulence models.

Technical advice and computer programs have been provided to combustion and turbulence researchers at the combustion facility at SANDIA, the auto lab of the University of Michigan, and the combustion groups at Princeton, NYU, and elsewhere.

Flow in Porous Media

Work continued on extending the random choice method to solve the Buckley-Leverett equation for the

two-dimensional case. The effects of gravity and capillary pressure have been included, as well as the effects of the dependence of fluid velocity on saturation. A scheme for sharp fronts, based on Huygens's principle, is being developed and shows promise of avoiding the shortcomings of the fractional splitting technique used previously.

Graphical Visualization

During the past year, there has been renewed interest in the area of scientific graphics. The realization that the proper visualization of scientific data not only yields a better understanding of the numerical results, but also can suggest new approaches to the underlying model has produced a common ground for applied mathematicians and computer scientists. Numerical models were developed to simulate two-dimensional flow inside a rectangular region with combustion, similar to that of an internal combustion engine. Interactive color graphics were used to outline clearly the motion and burning of the fuel, with different colors corresponding to the amount of combustion still to take place at various points. Work was also begun on the problem of visualization of three-dimensional turbulence. Interactive programs were written to enable full three-dimensional rotation and perspective viewing of particle paths.

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Information Analysis Techniques

Data Management Research

The purposes of the data management research program are to identify the characteristics and problems of managing large statistical data bases and to develop techniques that specifically address these problems.

We use the term "statistical" data bases to describe data bases which are amenable to statistical summaries. Typical examples are found in socio-economic, demographic, energy, and scientific applications, such as population, health, and environmental data; information on energy production, consumption and import/export; data gathered in experiments; and data resulting from the monitoring of events over time, such as ocean temperatures or seismic activity. The efficient management of these data bases is vitally important in monitoring energy trends, energy planning activities, and statistical analysis of experimental, collected, or observed data.

Some of the more important characteristics of statistical data bases are:

- They typically contain a combination of descriptive elements for each data value measured, counted, or observed. Often, it is not possible to store descriptive data with the data base because too much storage space is required. Thus, efficient storage and access techniques are necessary.
- The quantity of data is very large. Some data bases, such as the census data or energy data collected over time, have an order of magnitude of 10^9 bytes. Efficient compression techniques are important, as is the necessity to develop software for managing mass storage devices.
- It is often necessary to derive summary and other statistics from data bases. Such "summary sets" proliferate rapidly with each application. Management of summary sets is required to control data redundancy, maintain the integrity and validity of the data, and keep track of the origin of derived data.
- The number of attributes and data bases is very large (hundreds and even thousands of attributes), making it difficult to remember names, values, and formats of attributes. This requires techniques for organizing data bases and for developing user interfaces for easy access.

To solve these problems, the data management research program conducts complementary activities in three areas: data modeling, enhanced user interfaces, and efficient data compression and access. In data modeling, the emphasis is on developing conceptual models for summary sets, directory structures for meta-data (data about the data bases), and neutral internal models to facilitate a multiplicity of user interfaces. User interfaces are designed to simplify user access, especially by users who are not experts in computer usage. Efficient data compression and access is achieved by taking advantage of the special characteristics of statistical data bases which facilitates organizing specialized hardware that would lead to the development of a special purpose data management machine.

LBL's role in the EIA National Energy Information System (NEIS) project is the development of advanced solutions to special problem areas of the NEIS. This should lead to the development of prototype software and design papers for the benefit of the NEIS project. LBL's research complements the development work by providing insight into potential solutions and by proposing and experimenting with solutions that are still a few years away from development.

Modeling Summary Data

Statistical data bases typically represent descriptive information about measured data values. A data base about gasoline consumption by type by state by month is an example where type, state, and month are descriptive (or category) attributes and gasoline consumption is a measured (or summary) attribute. The distinction between category and summary attributes is important because summaries (or other statistics) can be computed for a summary attribute over one or more category attributes. In the example above, one can summarize gasoline consumption over types and states to produce total U.S. consumption by month. The various summaries that can be produced from the original data are referred to as summary data.

By modeling the semantics of summary data one can achieve the following benefits:

- Views of summary data can exist virtually, i.e., a user can view a summary set and refer to it even if it does not physically exist. Furthermore, it is not necessary to explicitly define each view. This is a great advantage in summary data because it is impossible to foresee all the useful views. It also avoids the overhead of managing a large set of explicitly defined views.

- Automatic aggregation can be achieved. Because the semantics of summary data are represented in the model, it is possible to infer from the query conditions the elements over which aggregation should be performed. For the example above, a query of the form "What is the gasoline consumption for Alabama in March?" would automatically aggregate over type, since type was not specifically mentioned in the query.

Automatic aggregation implies a simpler user interface. This simplification is significant because query languages usually have complex constructs for aggregation functions.

The generality of the modeling concepts was shown by applying them to a general data model (the relational model). An experimental system has been implemented and interfaced to the INGRES data management system.

A Semantic Core Model

User interfaces vary in style and complexity and are usually based on a particular data model. The purpose of a semantic core model is to provide a neutral common basis for different data models and different user interfaces.

The core model is not necessarily visible to users. It is an internal model that must be general enough to represent the semantics of many data models. Our work has shown that general mapping structures can be defined to represent a variety of modeling concepts that are known in the literature. The advantage of such a core model is that it affords a single implementation of a data management system to which a variety of user interfaces can be interfaced.

While the structures of the semantic core model are not necessarily intended to be directly incorporated into an end-user interface for data base access, they do provide a formalism with direct application to the task of data base design and specification. Our own investigations of the issues of data base design for statistical data bases show how fundamental semantic modeling concepts, such as generalization hierarchies with appropriate adaptation and packaging, can facilitate the specification task in this domain.

This task has analogues in the problems of program (software) specification and knowledge representation. Many issues overlap and much insight can be drawn from on-going research in the areas of programming languages and artificial intelligence. Abstract data types and semantic network formalisms may be cited as two examples. This year, we have collaborated with other researchers to work toward more interdisciplinary understanding of common issues.

Another facet of the core model is that it fills the role in DBMS architecture known as the "conceptual model" or "conceptual schema". This is a comprehensive representation of the logical description of an integrated data base together with a representation of the mapping to computer-oriented storage and access structures. A by-product is the definition of a uniform interface to the lower-level physical access machinery under which a multitude of different implementations may be accommodated. The advantage of the core model is that it provides a particularly clean match for mapping the user-level modeling structures, found useful in the statistical data base environment, to the physical organizations required for efficient implementation.

The SUBJECT System

SUBJECT is a system for organizing and accessing large statistical data bases. It can be used by novices with practically no training. At the same time, experienced

users are provided with efficient ways of accessing the data. A novice user can browse through the data and then express queries. The user interface represents data in a menu format that eliminates the need to remember names, values, and formats of data elements.

The main concept of the SUBJECT system is the modeling of summary data in an acyclic directed graph. This modeling technique is powerful because it can model not only the logical layout of the data but also descriptions about the data (meta-data). A collection of data bases can be clustered into subject categories, providing a well-organized way of finding the content of data bases by subject.

A user can enter the SUBJECT system at the root node of the directed graph to obtain a global view of the data in the system. By selecting a subject category, the user proceeds to more detailed descriptions of information he requires. He can continue to browse the meta-data to familiarize himself with the data bases and eventually select a data file. At this point, he can continue to explore the file and express a query in the same mode of moving around the directed graph.

Experienced users can search for a SUBJECT data file by keys to quickly locate a desired data file They can then express query conditions in the usual fashion by moving around the directed graph. The system also provides *automatic aggregation of summary* sets and access to documentation associated with nodes in the graph.

SUBJECT differs from the conventional approach where users are required to access the meta-data first, remember names and formats of attributes, and then express a query in a query language. Often the two actions are performed on two separate systems, such as a directory/dictionary system and a data management system.

Applied to the NEIS project, SUBJECT has the capability to represent the meta-data, and to search and browse these descriptions. Furthermore, because it contains structural and descriptive information of the data sets, one can access the *data* directly from the meta-data. In terms of the NEIS, the Data Resources Directory (DRD) is the meta-data and the forms, files, and reports represent the data sets. Thus, SUBJECT has the potential to access files, forms, and reports *directly* through the DRD The power of SUBJECT lies in modeling the structure of data sets, enabling a user who is browsing through the DRD to specify the data set desired. The user can then continue through the same interface to express a query on the data set, using the same menu technique augmented with a few commands.

During 1980, DRD was loaded into SUBJECT, a simple exercise because the necessary mechanisms already existed in SUBJECT. However, to experiment with the ability of SUBJECT to also access the data, a test data base was loaded. The use of SUBJECT on this data base and the DRD was demonstrated to NEIS project personnel in Washington in November 1980.

Another demonstrated feature of the system is the ability to aggregate over any arbitrarily chosen rows or columns of the data set. Specific functionality needed for the DRD was discussed extensively with users. For example, data validation requires the ability to find, not only forms with certain facet descriptions for a given form, but also other related forms. This implies that browsing of the DRD is useful in both going down the facet hierarchies and traveling back up.

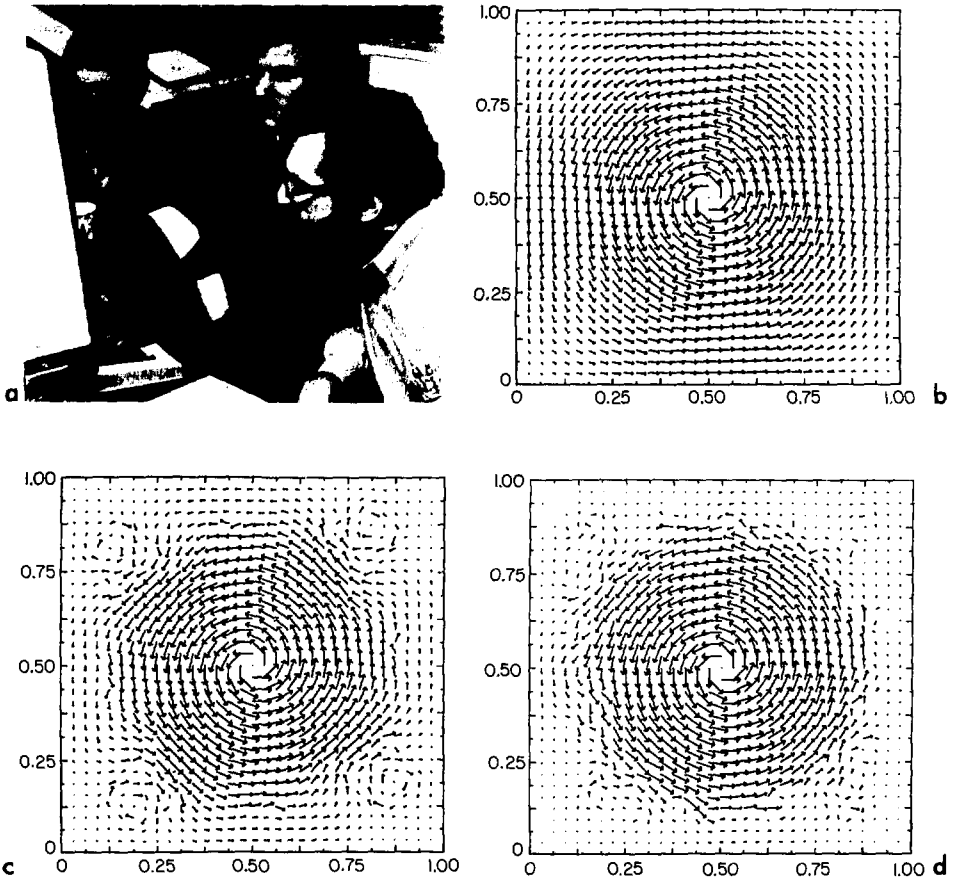
The next task is the use of SUBJECT for mapping from the cross-product of multiple facets of the DRD into the sets of forms, files, and reports. This work requires an efficient mapping function because it is a mapping from a huge number of possible combinations in the cross-product of the facets into a relatively small number of data sets. There are 8-10 facets in the DRD, each containing 10-100 leaf elements. The cross-product is in the order of 10^{10} - 10^{20} combinations that need to be mapped to hundreds or, at most, thousands of data sets.

Efficient Data Compression and Access

The management of large data bases requires data compression techniques to reduce the volume of data. However, data access usually suffers because of the need to decompress the data at the time of access. Most compression schemes require access time that is linear with the number of elements that have to be decompressed. We have developed techniques for compressing statistical data bases that require logarithmic access time. These techniques are possible because we take advantage of the special characteristics of statistical data bases.

Statistical data bases are often "sparse" (i.e., they contain a large number of zero or "empty" values) or they have a prevalence of some values which we term "constants." An example is seismic monitoring, which has no activity, or very low activity, for long periods of time. In addition, these constants tend to cluster, suggesting compression in a form of counts. Our techniques organize these counts into headers enabling a logarithmic access search to be performed. Furthermore, the headers are organized into "tree structures" with a large base of logarithmic search, on the order of 100. This provides access to a data base on the order of 10 bytes with only three to four page I/O reads.

Another form of data compression can be achieved for data values. Often, small values are stored in more space than necessary (e.g., four bytes) because the range of possible values is large. For example, four bytes may be needed to store population values that can range up to a few million in a few large cities but may have only small values for a large number of small towns and counties. The representation of small values in a small space (e.g., one byte) can offer significant savings. We have shown that the technique used for compressing strings of constants can also be used for compressing strings of small values. Therefore, a single generalized technique can be



Alexandre Chorin, James Sethian, and Paul Concus research numerical simulation of combustion. A combination of vortex tracking methods, boundary-layer techniques, and flame propagation is used to model two-dimensional viscous, incompressible flow inside a closed square region. Added to that motion are a random walk by the blobs to simulate diffusion, a potential flow to satisfy normal boundary conditions, and a technique to create vortex elements along solid walls to satisfy tangential boundary conditions. Combustion is added through a flame advection algorithm based on Huygens's principle. In the upper right frame, flow is started with a counterclockwise swirl (Reynolds number 1000, time 0.2 seconds). At later times, the development of backflow in the corners and the formation of small eddies are observed (lower left frame, time 0.8 seconds; lower right frame, 1.7 seconds). (XBB 818-8603, XBL 8111-12458, 8111-12547, and 8111-12459)

used to compress both conditions, while providing logarithmic access time. Depending on the distribution of values, these savings can achieve 50-80 percent compression.

Another significant compression technique compresses repeating values across records. The compression of cross product spaces is achieved by storing the values of each attribute range once and by using an array linearization algorithm for access of the data values. Since the access requires only a computation, it needs no page I/O for locating the data and is therefore extremely efficient. The same technique is also used in the SUBJECT system mentioned above. An interesting by-product of the constant compression scheme is its use in the case of partial cross-products where not every combination of the cross-product is valid.

An Expert System

There are many situations involving statistical data bases with data management software which does not provide sufficient mechanisms to insure the validity and integrity of the data base. We have investigated the use of artificial intelligence techniques to augment the capabilities of data management software. In particular, a model for representing an oil flow network has been developed using an existing system called FRL (Frame Representation Language). Its goal is to achieve the automatic maintenance of data integrity, thus reducing the burden on the user and providing more accurate and complete information.

Some examples of problems that can be handled by such an expert system are discussed below.

- *Incompleteness.* In the real world, knowledge is often incomplete, may be reported late, and be unattainable, vague, or inaccurate. A partial solution to this problem can be found by using default knowledge to substitute typical or standard values for missing information. Procedural knowledge can also be used to calculate needed but missing information. Explicit default values can be maintained for use when information is missing.
- *Constraints.* Constraints often exist between pieces of information. Changes in one fact imply subsequent changes in others. As facts change, these constraints can be used to update other pieces of information. Procedural attachments to data implement constraints by enabling automatic computation of side effects to automatically update constrained information.
- *Arbitrary Change.* In the real world, facts may be incorrectly reported, arbitrarily changed, or simply become out of date. Potentially, deductions based on these facts would be invalid. The problem is one of maintaining the validity of conclusions or other facts derived from antecedent facts which are potentially invalid. The expert system can monitor changes of data values. These techniques ensure that, when facts can be arbitrarily changed by external forces, consequences of those facts can be maintained.
- *Semantic Requirements.* Information is semantically constrained. To preserve the integrity of a data base, it is important that new information meet these semantic requirements. For instance, months cannot have more than 31 days; similarly, New York currently cannot be a producer of oil. Our representation language provides a simple method for associating requirement predicates with semantic definitions so that only information which fulfills these tests can be added to the data base.

Data System Modeling

The organization of data systems is still an art. The work described below is intended to formalize some of the aspects of designing data systems. This work describes a data model and a data manipulation language that uses formal specification mechanisms to maintain the correctness and integrity of data bases. It also discusses a conceptual model used to generate responses to users employing natural language constructs.

We are concentrating on data base problems of software systems with the following characteristics:

a. The data base is the most important component of the system.

b. The system has a large number of transaction types that can update, access, and analyze the data base, which itself has a very complex description, i.e., the data base schema may have hundreds of record types and thousands of attributes.

c. The data base may have a large number of missing or unknown values.

d. The integrity of the data is very important.

e. The queries on the data base are very often complex, with multiple record types that may be referred to in a single query.

f. The users of the data system may include casual users whose means of communication is natural language.

The following summarize the work and the results that address the above characteristics:

a. *Design of a data model and its data manipulation language (DML).* The model contains abstraction constructs that represent complex data bases with missing and unknown values. The model uses modern features such as "aggregation and generalization" hierarchies and uses procedural attachments to enrich the

semantics of the data object. The DML has constructs that handle these features in the data model.

b. *Formal specification of the semantics of the data model and its DML.* A loosely described data model and the effects of its DML constructs can generate confusion, ambiguities, and misunderstandings among data base designers, system implementors, programmers, and users. For very large data bases, the formal definition of the meaning of the constructs in the data model and its DML is very important as a foundation to lessen the number of human errors caused by a lack of understanding.

c. *"Correctness" of operations expressed in the DML on the data model.* Because it is important to preserve the integrity of data, we have developed formal proof mechanisms to verify properties of the effects of operations, based on the formal specification mentioned above.

d. *High level optimization of queries expressed in the DML.* Because of the size of the data base and its complexity, a quick way of achieving near-optimal processing of queries is needed. Our method performs estimations without the presence of low-level constructs, such as indices and pointers. This method reduced the complexity of evaluating queries from exponential to order of n^3.

e. *Methodology for using the data model and its DML to design data systems.* Integrating the system building process and the data base design process is still an art. A design method called "taxonomic programming" was developed with systems that are hierarchically organized, with each level of the hierarchy as a self-contained sub-system.

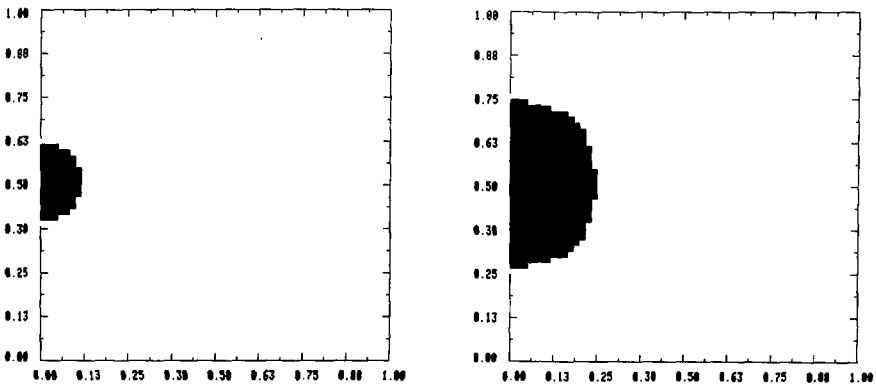
f. *Casual user interface to the data system.* One aspect of a casual user interface is the presentation of results. We have developed an English sentence generator that uses a semantic network for representing data base information.

Graphics User Interface

The main motivation for a graphics user interface comes from the difficulties of using current query languages. There are several factors contributing to these difficulties.

a. The user has to remember too many details. The names of files, records, and attributes are needed as parameters to the query language. To express a query, the user also must remember the query language syntax and the units and formats of the attributes.

b. The syntax is too awkward. Most high level query languages are based on mathematical con-



In another simulation, a premixed combustible mixture is ignited at the center of the left axis, and the flame is seen to burn normal to the front (Reynolds number 1000. Time: left frame, 0.2 seconds; right frame, 1.0 seconds). The dark areas correspond to the burned regions; the white areas are unburned. (XBL 8111-12461 and 8111-12453)

cepts, such as predicate calculus or algebra, which are often difficult for users to learn. In addition, the complexity of the query language stems from the fact that the underlying data model is not rich enough in semantics.

c. There is no feedback during the query process. Typically, there are no facilities to build queries in a piecemeal fashion with feedback of partial results available to the user. It is very frustrating to try the same query many times until it is "just right".

d. There is a lack of organization at the schema level. Users can be overwhelmed by a complex schema with hundreds, or even thousands, of elements. Users should be able to view the schema organized into levels of abstractions, thus dealing with a few elements at a time.

A graphics user interface to remedy the above deficiencies was specified and designed. It is based on the "entity-relationship" model where relationships are represented explicitly in the system to form a network structure. The graphics interface helps the user concentrate on the parts of the network relevant to his query. He can also specify query conditions in multiple steps to eliminate query language syntax. The display of information on the screen lessens the need to remember names of data base objects, and the graphics structures provide an alternative to query language expressions that use syntactic constructs.

Computer Graphics

Presentation of scientific data has long been one of the principal uses of non-interactive computer graphics. The considerable capacity of the human visual system to process spatial information, as opposed to tabular information, makes it clear that graphical presentation can provide better understanding of experimental data, the results of numerical models, and the functioning of these models. The step from non-interactive to interactive manipulation of the graphical representation of numerical data enables insertion of a non-algorithmic component into the display system, namely the user. The interactive, dynamic display of information, such as used in computer aided design systems, is a less common situation for general scientific data, however, due to hardware and software restrictions. New algorithms for interactive, dynamic display of scientific data will be developed and existing display algorithms will be adapted to an interactive environment.

Two common uses demonstrate the limitation of non-interactive graphics. In the first case, the user produces large numbers of images, hoping to find one which displays the critical relationships within the data. For example, one can produce many three dimensional rotations of a geometric structure looking for a particular, critical, part of the structure. In the second case, the image is produced based on an algorithmic determination of display parameters, such as the isopleth levels within a contour plot, which may or may not show the important data characteristics. In the interactive environment, the presence of the user represents a non-algorithmic mechanism for the manipulation of the available display parameters. The expertise or scientific intuition of the scientific user would permit rapid adaptation of an image to display the critical piece of information. In the example above, the contour plot of a pressure field containing a shock front with algorithmically chosen contour levels may completely hide the relatively small field oscillations immediately behind the front. Displayed and observed interactively, the researcher might quickly detect and focus on these oscillations as the important information, rather than the magnitude of the shock front itself.

The use of dynamic display hardware (that is, hardware capable of transforming the image independently of the host computer) is crucial, particularly when display of the information involves a three-dimensional representation. Three dimensional representations are useful, not only for situations in which the geometry is inherently three-dimensional, but also when one or more of the dimensions is used to encode non-geometric information, such as representing a surface in three space. Changing the image fast enough for interactive manipulation requires three-dimensional coordinate transformations to be made in the display hardware. Furthermore, perspective or other projectional representations of three-dimensional imagery are not the only display techniques which might be used. New types of hardware, capable of integral holography and virtual image projection, present the possibility of truly three-dimensional displays without geometric projection onto a plane (i.e., the display surface).

The Approach to Graphics Research

The basic research problem divides itself into three parts. The first is the design of the display in the final image by determining the type of representation that would best present the important aspects of the data. For example, in the display of a vortex, it may be decided that the surface of constant curl would best represent the critical information needed for display, and the design of the display image would result in the selection of a surface as the type of display to be presented. In the case of a scalar field, such as density or pressure, the optimal display might be the representation of the field values as gray levels, requiring gray levels to be selected and displayed on a suitable device. In the vector field example, the representation of the vectors as arrows might display the important information, or the more elaborate process of determining streamlines through the field and their subsequent display in either two or three dimensions may be the optimal way of visualizing the critical information. It is possible that temporal sequences of any of the above may be essential if the information being displayed is time dependent.

The second part of the problem is the extraction of the data required for the chosen representation. The

numerical model, the data which are available, may not directly provide the information required for the particular type of display desired. For example, if one has a three-dimensional scalar field, the desired display may show isoplethic surfaces in three dimensions. To go from the scalar field to the surface requires determination within the three-dimensional field of the boundaries at which surfaces are to be drawn. From these boundaries, one needs to construct the geometric description of the surface so that it can be displayed. Another example is a desire to display streamlines when given a vector field. In this case, the step from the data (vectors) to display information (streamlines) involves the solution of a partial differential equation, a numerical analysis problem in its own right, required for the graphic display.

The third part of the problem is the actual generation of the image on a display device. In the streamline example above, the streamlines will be given as a sequence of three-dimensional coordinates. Since we need a display of a three-dimensional entity, we must construct the appropriate transformation to project a two-dimensional display. If the final display is to be a surface, such as the surfaces of constant value of a scalar field, the surface will probably have to be displayed not only in a three-dimensional representation but also with the hidden portions of the surface either removed or de-emphasized in order to avoid confusion. If gray levels are used as the type of representation for a scalar field and if these gray levels occur in three dimensions with the image similar to a variable density cloud (for example, a cloud chamber particle detector), the gray values must be projected to the two-dimensional display, and compensation must be made for the transparency of the parts of the image that might be in front of the point of interest. Finally, if temporal sequencing is a desired part of the display, there must be some way of representing that sequence. The evolving structure can be observed in a single image by displaying several steps of a sequence on the display surface simultaneously and de-emphasizing those steps that are further away in time. Another possibility is that the structure could evolve in a movie-like sequence from frame to frame. Both of these display situations require careful tailoring of software and hardware to achieve the desired display effect.

Related Problems in Graphical Display

In addition to the basic graphical display problem, there are several related problems. First, in an interactive environment, the design and implementation of the user interface to the available display parameters enables, for example, the geometric manipulation of the display itself. This is crucially important in the use of display techniques.

A second problem is image capture for non-interactive presentation of the image for publication, reports, and technical discussion. Production of hard copies of the image frequently requires reconstruction of the image at a higher resolution than is possible on an interactive display, in terms of both its spatial characteristics and its color and gray level resolution. When the display was built up over a period of time through a closely coupled user interaction at a graphic work station, image capture can be a considerable problem. To recreate the state of the image as it appears on the display surface one has to go through the entire history of the parameter manipulations made by the user, some of which may have accumulative effects.

A final related problem concerns structuring the information to be displayed so that the image may be manipulated to emphasize those parts of the display which are most important. In general, this falls into the area of image segmentation. The interactive work station manipulation of the image requires logical groupings of the graphics primitives that produce the image into image segments which are a structure at a higher level. For example, in a display of three-dimensional streamlines, it should be possible to emphasize or de-emphasize the individual streamlines within the display from the work station console to highlight critical paths or areas, such as streamlines leading into a vortex. This could be done using a pick device or a pointing device at the graphic work station. However, to do so, the graphic primitives representing the streamlines must be grouped into logical entities.

Current Graphics Development

Scientific Data Display. The use of computer graphics for scientific data display is well established at LBL. The Integrated Data Display System (IDDS) is a collection of high level algorithms used to facilitate the display of scientific information. IDDS capabilities include display of two- and three-dimensional vector fields as arrows; two-dimensional vector fields as streamlines; and two-dimensional scalar fields as gray levels, contour lines, or three-dimensional surfaces [$z = f(x,y)$]. IDDS can use logarithmic and polar coordinate systems, in addition to permitting certain cartographic coordinate transformations to be made. During 1980, IDDS has evolved in the direction of machine independence of the code itself, making it available to a wider audience of users, as well as undergoing continual change and improvement of the display techniques. The capability of color and solid area fill have been integrated with the high level data display routines. Consequently, it is now possible to produce contour plots with the isoplethic lines color coded to indicate their relative levels. For contour lines, one may select colors that move through the spectrum from red through blue in a way that indicates the relative values of the level lines. More refined algorithms have been developed for automated drawing of axes and axis labels for both linear and logarithmic graphs. Various capabilities for cartographic base maps have been developed that enable base maps to be displayed with the data, thereby providing the geographic context for geophysical data.

Although, in the past, most of the use of IDDS has been noninteractive use on large scientific computers, its migration to super minicomputers, specifically the CSAM

RCF VAX equipment, has been undertaken to convert this collection of scientific display algorithms to an interactive environment. Furthermore, the first steps were taken toward addressing the problem of segmenting the output of high level algorithms to enable graphic work station manipulation, for example, the streamline highlighting method described previously.

Device Independent Graphics. In the area of low level graphic support, all graphics, to be done well, depend on a solid, device-independent graphic system to transform information from the higher level code into the display in a way which is as transparent to the user as possible. Specifically a fair amount of effort has gone into developing device drivers for the newly acquired, high resolution rides from buffer and color files recoder. These devices are the hardware "corner stones" for research in color graphics.

The need to display raster information, which might be produced by synthetic imagery of surfaces or remote sensing imagery, such as LANDSAT information, has lead to the development of techniques for device-independent raster graphics. This is an area which has not been considered in most device-independent systems. In collaboration with George Washington University, we are developing virtual device interfaces and graphic meta files which will help solve the image capture problem for hardcopy.

Color in Computer Graphics. Potentially, the value of color in graphic display is great. The human eye is approximately an order of magnitude more sensitive to color variations than it is to monochromatic gray level variation. This provides the opportunity to enhance the clarity of data differentiation and the scope of data coding. Work is in progress to provide device-independent color, specifications, varied user interfaces to color, and the evaluation of the effectiveness of color in various display situations.

The application of color graphics in development of numerical methods can be highly effective. Numerical models of turbulent combustion yield results that are particularly amenable to representation by colors. In one numerical model currently under development, a uniform grid is imposed on the combustion domain, dividing it up into a set of uniform cells. Each cell is assigned a value corresponding to the proportion of the cell that has burned. By using a continuous change of colors from white to pink to red to correspond with the proportion of burned fuel, we can color the cells in such a way that the human eye can determine the location of the flame front and sense the amounts of combustion remaining in a given cell or collection of cells. This information is difficult to extract from a tabular field of numbers. In addition, because the numerical method limits the accurate location of a flame front to the length of a cell, the continuous nature of color enables the human eye to accept this numerical error rather than be pinned down to a false sense of exactitude in the front location given by numerical displays. Another use of color in combustion models under study is the representation of differing density and pressure values in the flame area.

Graphic Design and Communication

Concern for effective, high-quality graphic images has led to investigation of standards for depiction of charts, maps, and labeled reports. Where possible, the preferred means of depiction, with higher legibility and greater suitability for mass production or distribution, have been emphasized. Eventually, these will become default options for the display of graphics.

An additional concern has been the implementation of high-quality, solid-fill character fonts. These typographic characters will permit more legible displays, even with small characters. They will also permit additional dimensions of information coding, e.g., a distinction between roman and italic letters of the same type family. This investigation and implementation are being made in collaboration with Pacific Northwest Laboratories (PNL) and George Washington University (GWU).

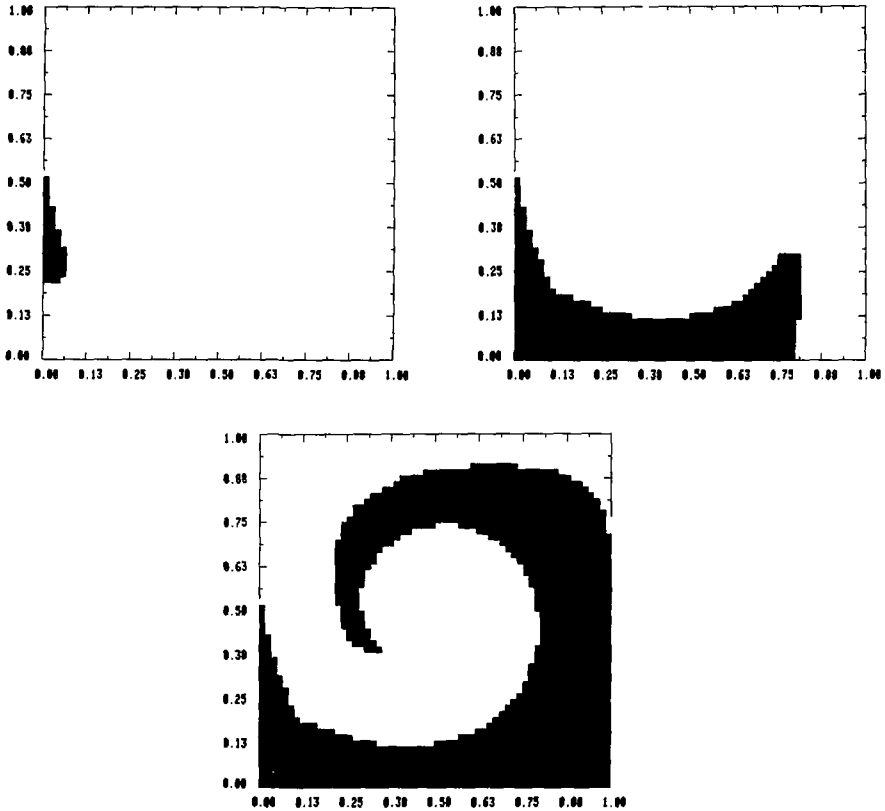
Graphic Representation of Fuzzy Sets

A capability for characterizing data by linguistic expressions has been developed using concepts and quantitative techniques from fuzzy set theory. Linguistic expressions define subjective categories, enabling an analyst to look at data from different perspectives and different levels of detail. Subjective categories help blur inappropriate distinctions when data is imprecise and when undue precision does not apply to an analytic task. Subjective categories also support multi-objective decision making and performance evaluation in situations where goals, objectives, and trade-offs may not be well defined. Color displays for category membership, based on the fuzzy nature of color categories, have been developed and refined to help analysts visualize where and how well data fit a given characterization.

Thematic Mapping Developments

Thematic mapping capabilities are being improved with the addition of new types of maps, including bivariate maps and complex symbol maps. Bivariate choropleth maps show the spatial variation of two variables, as well as the geographic correlation between them. Complex symbol maps use pie graphs or other multi-component symbols to display the values of several related variables on a single map.

The thematic mapping module will be used as a test vehicle to demonstrate different techniques of user interaction.



The results of a side ignition and a swirl flow together are shown in these two frames (Reynolds number 1000, flame speed 0.2).
(XBL 8111-12460, 8111-12455, and 8111-12456)

SEEDIS

Managers, analysts and technicians are faced with an increasing need to integrate economic, environmental, and demographic data into project planning and management. The use of this data is motivated by rapidly increasing sophistication in the use and allocation of limited resources, both tangible and intangible. The concern for effective resource allocation and the social impact of projects is reflected in constantly increasing legislative and administrative requirements.

We are conducting two research, development, and demonstration projects which attempt to address some of these needs: the Socio-Economic Environmental Demographic Information System (SEEDIS) and the Distributed Computer Network (DCN). While the data bases currently installed in SEEDIS are of an environmental, economic, and demographic nature motivated by a number of demonstration projects, we believe that the techniques used in SEEDIS/DCN are generally applicable to a broad range of information system requirements and projects.

The users of SEEDIS/DCN need a flexible system for the formulation, evaluation, implementation, and monitoring of policy alternatives. SEEDIS/DCN addresses the need for flexibility, responsiveness, data integration, display, and analysis and at the same time provides a working system and a test bed for new ideas. The use of a developmental system is very important to researchers who desire to test their ideas in a live environment, and the feedback from the users is invaluable. In turn, the users are able to express their concerns to the implementors, who can make real changes to the tools with which the users work.

We feel that DCN best satisfies the requirements for flexibility and responsiveness while SEEDIS develops software for distributed data base management, data integration, analysis, and display techniques. At the same time, this approach presents the SEEDIS/DCN project with a number of research issues which must be identified and resolved before the use of such systems can become widespread. SEEDIS is:

- An interactive, distributed information system running on a network of VAX computers which is used for information systems applications as well as research and development;
- A set of information management and analysis tools for production applications; and
- A major collection of data bases for various geographic levels and time periods drawn from the United States Census Bureau, Department of Energy, Department of Labor, Bureau of Economic Analysis, Department of Commerce, and other sources.

The goal of SEEDIS is to provide functionality of data management statistical analysis and graphical display within a unified framework. Other systems which deal with statistical data bases [including Statistics Canada's RAPID DBMS, the Domestic Information Display System (DIDS) developed by NASA and the Department of Commerce, and the UPGRADE system developed by the Sigma Data Corporation for the Council on Environmental Quality] attempt to provide this capability. Unlike most other such systems, SEEDIS has attempted to provide for multiple underlying data storage structures and subsystems. It is intended to serve as a "software bus" providing an easy and relatively transparent interchange of data and data descriptions among a variety of storage and access methods, search and retrieval tools, display and analysis facilities, and user interfaces, including both LBL-developed subsystems and software developed elsewhere.

Data Base Management Within SEEDIS

To provide for integration of more general data files into the SEEDIS environment, the SEEDIS data model is being improved to incorporate such files. The components of research and design for such generalized data models includes investigation of specification languages rich enough to include:

- Multi-dimensional arrays (summary output from cross tabulations);
- Hierarchical files (such as Census Public Use Sample and Survey of Income and Education, County Business Patterns, and LABSTAT); and
- Data element specific extensions, including generalized missing data specification and handling, general specification of default output formats, and intra-record data element relationships.

Data compression schemes are used to optimize storage costs and computing time. At the same time, well designed compression schemes assist in the efficient searching of records for specific attributes. We are working to define a standard access protocol to support multiple access schemes within a single system and to provide for the interchange of data between SEEDIS and other systems.

Research in distributed data base management is motivated by the need for cooperation and sharing between sites. Work is needed in the areas of file allocation, caching, efficient network utilization, and access to "foreign" data bases. File allocation is the process of determining the permanent location of data within the network. Caching is the allocation of temporary space for high-use files and the control of space allocation. Efficient network communication depends on good protocols for query descriptions and the correct division of labor between local and remote processing for minimization of computing and communications costs. Access to "foreign" data bases gives one system access to data maintained by another system. This access is essential for three reasons: (1) each system is optimized for different functionality; (2) responsibility for maintaining the data remains with the originating organization; and (3) duplicate storage of the data would be too expensive. The SEEDIS/DCN project and related projects within CSAM have made a variety of contributions toward understanding and solving these problems. Work on virtual machine architecture provides a basis for data bases distributed across heterogeneous systems. Directory schemes have been identified and are being tested. Experiments in accessing foreign data bases has led to a better understanding of data translation techniques and to the consideration of data base structure translation, e.g., how to represent a foreign data base structure in a local data directory.

Problems of distributed access and control under study include:

- File sharing capability (the ability for programs and users to access remote files);
- Device sharing capability (the ability to access remote peripherals);

- Down-link loading (the ability to transmit a system to a remote computer and have it run there);

- Retrieval request processing (the tradeoff between remote data access and retrieval of specified data and the access of complete files for processing at the host node);

- Data manipulation decisions regarding remote or local processing; and

- Recovery and retransmission (the ability to "hold" retrieval requests if remote machines or peripheral devices holding data are off-line).

During 1980, LBL experimented with access methodologies such as the Network Access Machine (NAM) developed by the National Bureau of Standards and the HASP protocol for remote job entry to IBM and IBM-compatible hardware. While demonstrations of access have been achieved, software and methodologies for extracting data from dramatically different data storage structures have not yet been developed.

Data Manipulation

One of the basic activities an analyst performs with data obtained from an information system is manipulation of that data to create new or derived data for insight into the meanings of the data. The manipulation may be as straightforward as computing the ratio of two numbers or more complex than disaggregating an employment matrix from state geography to component cities using population as a proxy variable.

SEEDIS provides a framework for the study of data manipulation. During this study, the modules QUERY and AGG/DISAGG were created to do the operations described above. The operation of these modules has enabled us to identify the weak points in the underlying data structures which make the manipulation algorithms unduly complex and difficult to implement. The operations of data manipulation include:

- General arithmetic computations;
- Simple statistical averages;
- Totaling and subtotaling;
- Matrix operations, including transposition, row and columns collapsing (aggregation), matrix addition and multiplication; and
- Aggregation/disaggregation from summary to detail records (states to cities, counties to Federal Regions, etc.).

In all the above operations, special attention must be paid to data elements which are themselves ratios (e.g. percent black population) or which have missing data values for particular instances of records.

A user's manual was prepared explaining the commands and functions of the QUERY module to enable users to select and create new data elements and to collect running totals on CODATA work files. QUERY was improved to include a comprehensive and standard method of handling missing values in data records and extended to incorporate custom statistical functions.

A preliminary version of the AGG/DISAGG module was implemented to provide an automatic means of combining data archived at different geographic levels (e.g., 1970 and 1980 counties).

To address the problem of finding an appropriate DBMS tool for major applications systems development (such as the Regional Automation System), a study of available DBMS tools was begun in mid 1979. The purpose of this study was to evaluate available and potential commercial candidate DBMS tools on the basis of: flexibility of the data model, functionality of the query language, functionality of the report generator, functionality of screen data entry, and completeness of utilities (recovery, logging, load).

The SEEDIS staff completed a preliminary evaluation of commercially available data base management systems suitable to ETA administrative requirements. This evaluation was a comprehensive study of DBMS systems currently available on the software marketplace or other systems expected to be on the market sometime in the next year. Evaluation was made on the basis of vendor presentations, manuals and other documentation, contact with other users of systems, and actual operation of one vendor-supplied system (ORACLE). Although the ongoing development of DBMS systems demonstrates that the best system-of-choice in the future may not be the best one currently available, critical project requirements dictated the procurement of a system upon which development could begin. On the basis of this evaluation, two copies of the DRS system marketed by Advanced Data Management of Princeton N. J. were acquired. We are continuing to evaluate other systems as they become available.

User Interfaces for Human-Computer Interaction

The goal of user interface research is to establish a common framework for user interfaces across a wide variety of applications modules. Components of such a generalized user interface include tables to define the functionality of specific applications, hardware device characteristics, and user preferences.

Benefits of such a user interface foundation include the ability to easily make changes in the interface to application modules, provide consistency in terminology and syntax across different applications, provide different styles of interaction according to user preferences, and modify and refine those styles to best suit each individual user. Ideas for creating such a user interface have been developed, and research is beginning on possible implementations.

Work was started on the redesign of the SEEDIS user interface. The following goals and development tasks were agreed upon:

- A new user interface to SEEDIS would be developed which would simplify menu displays, improve data selection, standardize global commands, extend the on-line help facilities, and hide complex operations from naive users. This interface was implemented during the fourth quarter of fiscal 1980.
- A comprehensive redesign of the user interface and additional SEEDIS functionality would take place during the next fiscal year.

Statistical Analysis

Once specific geographic areas and data elements have been identified and aggregation procedures have been performed, SEEDIS users need to be able to perform a variety of standard statistical calculations. Among commonly desired statistical functions are:

- Binning algorithms for conversion from continuous to discrete values,
- Operations (aggregations, partitions) on multidimensional contingency tables,
- Interpolation procedures to establish congruency of aggregate data,
- Time series analysis, and
- Econometric analysis.

Preliminary investigations have led to the installation of three major statistical systems on the LBL nodes of DCN: MiniTab, PSTAT, and SPSS. Each of these systems has particular advantages and disadvantages; none has been integrated into the SEEDIS framework because of their peculiar "monolithic" input-output structure and operation. During the past year, procedures have been developed that enable SEEDIS users to move subsets of data to SPSS to perform needed calculations.

Mass Storage Technology

The characteristics of a mass storage device desired for SEEDIS and other DOL applications include: physical capacity beyond that of disk storage; reasonable access speed to individual data sets (less than a minute on the average); and data transfer rates equivalent to tape (greater than 500,000 bytes/second).

Currently the majority of small area SEEDIS data sets, which comprise about 95% of total SEEDIS data, do not reside on DCN disks because the disks are filled to capacity with county level data. These data sets have been stored in high density tape on the LBL computer center's Automatic Tape Library, which has a CALCOMP tape robot as its central hardware device.

Current development of laser video-disk mass storage products indicates possible availability of a prototype machine in early 1982. In the meantime, mass storage will continue to rely upon 6250bpi tapes and networked access. Three proposed access methodologies for retrieval of data from the Automatic Tape Library robot device within the LBL Computer Center will be investigated, with possible prototype testing. The one best suited to processing the 1980 Census and other large data bases for long-term archival retrieval will be implemented.

Information Systems Projects

1980 Census Project

The goal of the SEEDIS 1980 Census Project is to provide integrated data management for the estimated 50 billion bytes of data from the 1980 census and to produce approximately 4 million pages of reports tailored to ETA planning needs for a wide variety of geographic entities including states, counties, SMSAs, Federal Regions, Prime Sponsors, cities, and school districts. Report contents will be specified by an ETA Census Planning Committee, in cooperation with LBL technical staff, and will augment Census Bureau publications by providing unpublished data from machine readable files, integrated computer graphics (maps and charts), and computed indicators tailored to planning requirements for ETA programs.

Specific components of the Census Project are:

- Design and development of report table specifications in cooperation with Region IX and National Office ETA task forces;
- Investigation of hardware/software for high quality typography and graphics;
- Acquisition and installation of hardware sufficient to support 1980 Census processing;
- Software development for report definition and automated report generation testing and sample production;
- Preparation of training materials for actual report definition entry by Region IX ETA personnel;

- Software development for report production scheduling and distribution;
- SEEDIS system enhancement to provide an adequate environment for Census processing;
- Acquisition and installation of summary tape data and geographic base files from the 1980 decennial census into SEEDIS; and
- Report generation testing and sample production.

Design of the 1980 Census report tables, including special purpose graphics, tabulation, computations, and layout, will be carried out in cooperation with Region IX and National Office ETA task forces. Draft tables of the reports will be revised for clarity and visual appeal and will be improved to take advantage of typesetting technology on an ongoing basis throughout the year.

Investigation of state-of-the-art computer-driven, high-speed typesetting printers and graphics output devices will continue. Our focus will be on the capabilities of the XEROX-9700 laser printing device, which prints at 10,000 lines per minute and can provide interleaved graphic output. Of particular interest is typesetting software, including multiple typeface fonts and forms rule, and graphics software features.

The 1980 Census report cycle for the Department of Labor is now in its formative stages. The general approach will be to design and implement a report generation tool sufficiently general to produce reports in at least as wide a variety of formats as those available for 1970 Manpower Packages, reports which can be directly designed and input by DOL professional staff.

The Summary Tape Files (STF) of the 1980 Census will be released in a phased fashion over the next few years. Within each STF, data summarized for states with small populations will be released first, followed by data for states with larger populations. This will create a need for scheduling software to manage STF installation, compression, archiving, report production on a state-by-state basis, and primary and secondary distribution. The goal of such scheduling software will be to assure that production is handled efficiently without unreasonable delay and that production errors, reruns, and bottlenecks are correctly identified as they occur.

LBL will acquire, install, and test Census Summary Tape Files as they become available. Installation software will be tested with the Richmond Test Tapes obtained from the 1979 trial census conducted in Richmond, Virginia.

Geographic base files (map outlines) will be acquired and installed as they become available. They will be tested with existing mapping software and compared visually with equivalent or similar 1970 map files.

Machine readable data dictionary files from the Census Bureau will be acquired with the data tapes, and a procedure to create the appropriate SEEDIS data dictionaries will be applied as part of the data installation.

Report Generation Testing and Sample Production

The process of report production consists of retrieval of data from SEEDIS installed data bases for specified (particular) geography, aggregation to other levels of geography as desired, computation of derived values, and insertion of values into report templates written to tape for driving the typesetting printer.

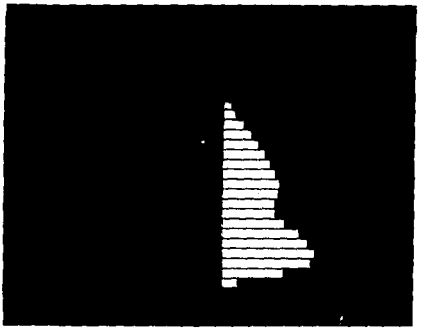
All report processing will be thoroughly tested on the Census Field Test Files before actual production begins. Sample production runs will be made on summary tape files received during FY 1981.

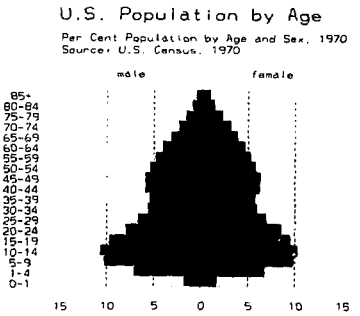
Labor Market Projections Model

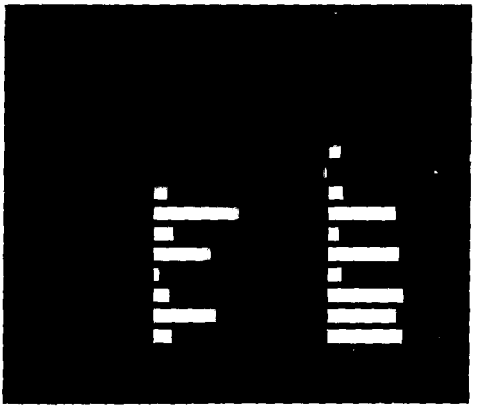
The affiliated State Employment Security Agencies (SESAs) of the Department of Labor-Employment and Training Administration (DOL-ETA) supply local planners in CETA projects with estimates of persons in need of manpower services. This information is not used to determine funding levels but instead enables local planners to make intelligent estimates of local needs. The estimates of local needs are then used to distribute funds which have been allocated previously. Using its Labor Market Projections Model (LMPM), LBL has developed an estimation procedure which can be used to provide data on persons in need of manpower services for use by local SESA analysts. LMPM is a computerized model which integrates data from a number of sources (1970 Census, CPS, SIE, migration, etc.) and for a variety of geographic areas (states, SMSAs, and prime sponsors). A variety of extrapolations and predictions can be made from this data. The resultant reports provide the levels of geographic detail which are of most interest to local acquisition and testing of important and useful data bases.

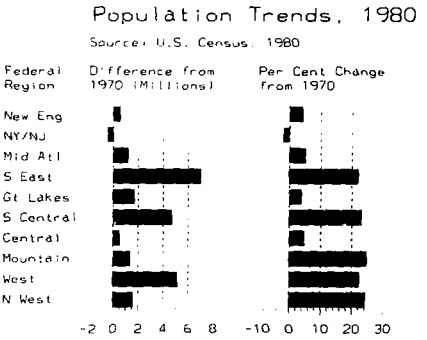
The success of LMPM as an informational source is based on the familiarity and interactions of the analysts with these two independent models. To assist in this process, LBL prepared two publications describing the LMPM models. The publication concerning the projections model, "A User's Guide to the Population, Labor Force and Unemployment Projections Model," is designed to project population, labor force and unemployment. The methodology underlying the model is explained in detail, and chapters are provided on interpreting the output and the various input options that are available. The second publication, "Updating Census with Current Population Survey Data," concerns the CPS-updates model and describes the method used to update socio-economic characteristics available at the local level in the 1970 Census by using the Current Population Survey (CPS) for March 1970 and the current year. The two publications were incorporated into one document and published by the Labor Market Information Division as *The Labor Market Projections Model Handbook*, Monograph No. 3 in the LMI Monograph Series.

As in the past, LMPM uses two methods to estimate current socio-economic indicators at the local level: (1)









These bar charts display portions of the extensive socio-economic and demographic data contained in SEEDIS. Researchers and analysts are able to compose a display in a variety of formats. For example, the shaded bars can be displayed in color on a black background. The same information can also be shown in shadings on a white background. Ongoing research is directed at making the display of data as effective as possible in terms of visual communication. (XBB 819-8633 and 819-8634)

updating the 1970 Census using the most recent March Current Population Survey (CPS) sample data; and (2) projecting population, labor force, and unemployment by race, sex, and age. Furthermore, this past year, LBL collaborated with Dr. Malcolm Cohen of the University of Michigan in producing estimates of the 1980 labor force.

CPS-Census Updates. The method utilizes CPS data to provide general economic indicators for the population, as well as demographic population breakdowns. Updated Census estimates are computed by multiplying the 1970 Census data by the ratio of target year CPS data to 1970 CPS data. Essential to this computation is a careful comparison of Census data categories with CPS data items. Tabulations equivalent to the Census tables are then performed on the CPS data. The difficulty with this procedure is that regional data is being used to update local area data.

In the past, CPS updates were run for 21 regions across the United States consisting of 11 states and 10 combinations of states. This was the greatest detail available when using the 1970 and the 1975 CPS samples together. However, the CPS sample size was recently

enlarged, and it is now possible to obtain state level data for every state. Currently, CPS updates are run for 30 regions formed by 19 states and 11 combinations of states, the greatest detail available in the 1970 CPS. However, after the 1980 Census, it will be possible to run the CPS updates for each of the 50 states.

Population, Labor Force, and Unemployment Projections. The second method uses a refined cohort component method to project population, labor force, and unemployment for each state, SMSA, and prime sponsor. This involves the separate projection of births, deaths, and net migration to give population by race, by sex, and by five-year age cohorts for a particular area. Using total population estimates for the target year received from the Bureau of the Census, these cohort projections are then normalized to add up to a control total for that area. The labor force and unemployment projections are based on the labor force and unemployment of the geoarea in the base year, national changes in the labor force and unemployment from the base year to the target year, and the population projections for the target year, as calculated above.

During the past year, the goal was to make the results more accessible and useful to the SESA analysts by converting the projections model from the Control Data Corporation 6600 in the LBL Computer Center to the SEEDIS VAX-11/780. As a first step, the data base upon which the projections model depends has been installed in SEEDIS. Using the various graphing and mapping routines in SEEDIS, this data can be displayed easily according to user specifications. Furthermore, this data can also be combined with any of the other data available in SEEDIS, for example, the 1970 Census.

The programs that perform the projection calculations are also now operating on the VAX. Once a user-friendly interface has been written, they too will be installed in SEEDIS. In the past, many of the special requests that have been run at LBL have required changing the control totals and rerunning the Projections Model. With the model in SEEDIS on the VAX, this could easily be done at a regional office. SESAs could dial an ETA regional office VAX and run the model.

Substantial improvements were made to the population projections model, both to the underlying methodology and to the print-out of the results.

1. A migration submodel, developed for geoareas that are counties or sums of counties, estimates current migration flows by using total net migration estimates and the pattern of the area as determined by the 1960-1970 net migration rates. To develop and test this submodel, the population projections to 1975 were compared with the population projections developed by Richard Irwin at the Bureau of the Census. This comparison showed that a problem existed with the 25-29 year age cohort due to an interaction between the student and the migration submodels. Further adjustments were then made to the migration submodel to reduce this interaction.

   After the migration submodel was completely debugged, the state level population projections to 1975 produced by this submodel were compared with those provided by the Bureau of the Census. In every instance, the submodel produced considerably better results than had been obtained previously using the plus-minus technique to update the 1960-1970 net migration rates. To describe the methodology used in this submodel, the document *A Computerized Model to Estimate Current Net Migration Rates by Race, Sex, and Age* was written. It will be sent to the SESA analysts this fall, together with the standard output.

   The plus-minus technique used to update migration rates at the sub-county level was extended to provide for change of sign in some cases. It was felt that this gave better results than using the old outdated migration rates and distributing the differences between the projected population and the desired population over all race/sex/age cohorts. This is possible because most migration, whether in or out, occurs in the 15-34 year age groups.

2. While converting to the VAX, the methodology underlying the projections model was improved. In particular, the population projections for each race/sex/age cohort in substate areas was forced to equal the population projection for that same race/sex/age cohort at the state level.

3. To make the calculation of the unemployment projections consistent with the labor force projections, a CPS adjustment factor was introduced. The use of this factor adjusts the March-April 1970 unemployment rate of the area under study to the 1970 "annual" CPS, a widely used and more accurate source of labor force data than the Census.

4. Unemployment projection checks were installed to insure that the unemployment rates were always below 100%. Previously, it was possible for the projected unemployment rate to be above 100% in areas with very sparse data and/or unusually high unemployment for a particular race/sex/age cohort in 1970.

5. The projection model has always relied upon state-provided inputs to calculate the labor force and unemployment projections. To increase the flexibility of the model and to take advantage of the knowleuge of the local area analysts, several optional inputs were added this past year. Analysts may now submit up to three labor force and unemployment control totals. This enables the analyst to compare "high" unemploy-

ment with "medium" and "low" unemployment. Many state analysts took advantage of this increased flexibility and submitted some of the optional inputs.

6. The contents of the large volume of output for each area were redesigned to make it more intelligible and more useful to the analysts. As in the past, tables are printed showing the input data, the intermediate calculations, and the resultant projections. This portrayal enables the analyst to trace what led to a particular result, if so desired. Using summary tables, the analyst can easily compare results for various race, sex, and age groups.

The population projections model has been greatly strengthened by these changes. As a result, the labor force and unemployment projections are also improved. To further strengthen the labor force and unemployment projections, the factors estimating change in labor force participation rates and unemployment rates from 1970 to 1978 were changed to state level, where possible. Where state level data were not available, regional data were used. Previously, national level changes were used. Thus changes from state-to-state, as well as changes over time, are now recognized. This data was obtained from the annual Current Population Surveys.

1980 CETA Eligibility Estimates. LBL collaborated with Dr. Malcolm Cohen of the University of Michigan in preparing a publication containing estimates of the 1980 labor force and CETA population, using estimates based on the March 1980 Current Population Survey. The collaborative effort took advantage of the microdata processing capabilities at the University of Michigan and the graphing and mapping capabilities of SEEDIS at LBL.

When tapes containing the CPS were received by Michigan, they were tabulated to provide estimates by various demographic characteristics of both the labor force and the CETA population at the state level. Using the network access machine (NAM) on the UNIX computer, these estimates were transferred from Michigan to Berkeley where graphing and mapping routines from SEEDIS were used to display the estimates. The resultant maps and the bar charts were sent to Michigan for inclusion in the publications that were mailed out to each of the fifty states.

ESARS Data Retrieval Project

The ESARS Data Retrieval Project is a demonstration of SEEDIS concepts applied to the management of a large administrative data base from a management information system. The ESARS Data Retrieval Project is undertaken to demonstrate the following conceptual problems in a prototype production mode:

- Distributed management information on a computer network,
- Information transfer across a heterogeneous mix of computers,
- Data management concepts applied to administrative data bases, and
- Data integration of administrative and socioeconomic data into a unified structure for information display and statistical and performance analysis.

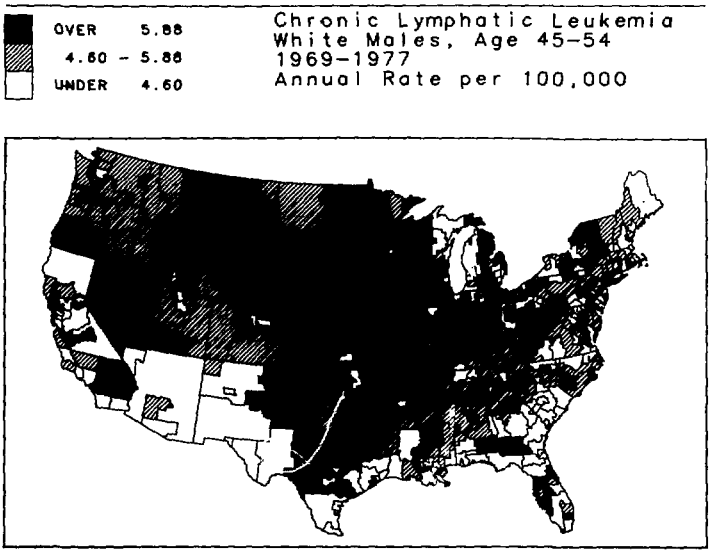
ESARS is a continuing demonstration project which provides management facilities for multidimensional tabular summary files containing administrative information taken from the Employment Security Automated Reporting System. Data consist of a large data base, approximately 40,000 tabular cells per geographic area, with a complicated hierarchical structure. The project currently provides for centralized software development within the SEEDIS context on the LBL node of DCN, with distribution of developed software to other nodes of DCN for actual operational testing.

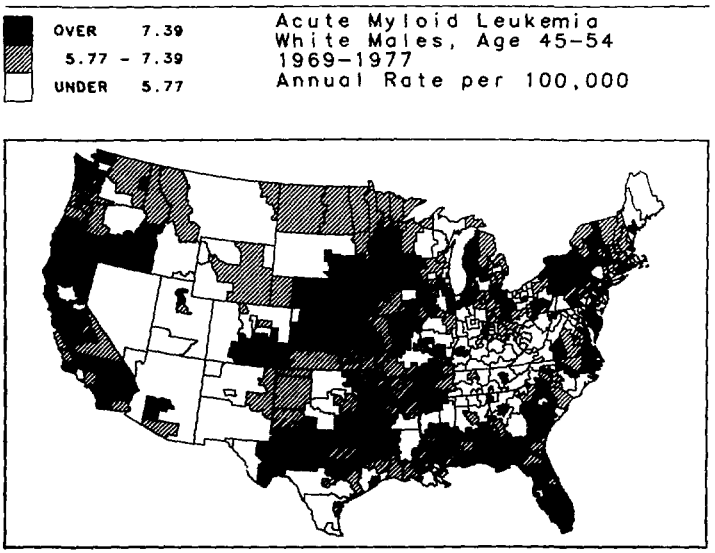
Computer-Based Information Systems for Civil Works Planners

The U.S. Army Corps of Engineers contributes to support of the SEEDIS Project for development of capabilities of particular use to civil works planners. During 1980, the primary foci of these development efforts were redesign of the SEEDIS user interface and preparation of documentation on various aspects of the system. As described in the section above, SEEDIS is a testbed distributed information system used for selected applications as well as research and development. "Real world" users, such as civil works planners from the Army Corps of Engineers, provide information on innovative features actually used and feedback on areas that need improvement. Substantial efforts were made to incorporate suggestions from Army and other users into redesign of the SEEDIS user interface. In addition to online documentation created as part of the user interface, a new Beginner's Guide to SEEDIS was prepared and distributed.

Because LBL's primary mission is research and development rather than production data processing, its staff cannot always respond to Army and other users who may have a need for extensive consultation or production processing. To meet such needs and to help make SEEDIS more accessible to its non-programmer users, the Corps of Engineers has helped to establish an Applications Service Center run by the State Data Program/Survey Research Center Data Library on the University of California's Berkeley campus. This new center provides:

- On-call service to fulfill urgent data requests;
- Expanded service for access to data not found in standard profile packages;
- A path through which a limited number of sponsored users can utilize experimental graphic resources available only at LBL, and thus provide test users for such systems; and
- Access to data which currently is still available only on the CDC computers and not on the VAX version of SEEDIS.





Environmental and epidemiological research includes development of analytical techniques and data for investigation of radiation-related diseases such as leukemia, lung cancer, and congenital birth defects. During 1980, major effort was devoted to developing a comprehensive description of the epidemiology of recent leukemia mortality. Cell-type distinction proved important in identifying geographic patterns. These two maps contrast mortality rates for two cell types in white males, 45 years and over. In the upper map, a high level of mortality is seen in the Midwest for chronic lymphatic leukemia; the lower map shows that acute myloid leukemia had a high level of mortality on the West Coast.

(XBL 821-56, 821-57)

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Advanced Computer Concepts

Advanced Computer Concepts is primarily concerned with understanding the integration and engineering of computing "systems," both hardware and software, concentrating on what will be possible five years hence. The effort may be characterized as applied computer science research, bridging the gap between purely theoretical computer science and the future operational needs of DOE computing.

The basic research program is interdisciplinary within computer science, with one thread binding together the different areas of interest: the notion of "ensemble." Although many other research groups are working on specific components of computing systems, the Advanced Computer Concepts effort tries to make a computing system work as a whole.

Software Engineering

The software engineering effort was a necessary precursor to make the problems in the other disciplines tractable. With the virtual operating system approach providing a stable foundation, software architecture and related issues can be addressed with some confidence that the results will survive rapidly changing computing technology. Software engineering research at LBL covers software architecture, software management, and fortran evolution.

Software Architecture

Architectural analysis of software is analogous to the separation of hardware into its structural components such as integrated circuits and busses. The goal is to do for software what "TTL" (Transistor to Transistor Logic) has done for hardware: provide plug compatible components. The discipline of structured programming has made advances in this area, but even the most structured programs can not be regarded as plug compatible because the interfaces are not available. This research applies the latest results from fundamental research in software architectures to the software tools project.

The architectural decomposition of software can be carried out at several levels of granularity. At the highest level, programs act on data to perform a specified transformation. Programs can be further separated into user-interface and algorithmic modules. The algorithmic modules can also be described in terms of more atomic pieces of the particular algorithm. This form of separation can continue until one reaches the level of machine instruction that represents the most atomic units in which a particular task may be specified.

Three basic levels of granularity were identified in the software tools package: virtual machine, utilities, and command language. At the virtual machine level, suggested improvements include process environment manipulation and more dynamic terminal interaction. At the utility level, cleaner separation of user interface modules from algorithmic modules has been recommended. At the command level, extension of the notion of pipelines to networks of communicating processes is a possible improvement.

Process environment manipulation is greatly needed for the virtual machine. The ability for processes to share environments is essential but very difficult to do portably. This problem is given high priority. Direct terminal screen control is another area needed to provide modern display interfaces.

Attention at the utility level is focused on separating the user interface from the underlying algorithms. Traditionally, the user-interfaces of programs have been tightly coupled with their algorithms, and most programs cannot benefit from newly developed user-interface techniques. These limitations also prevent incorporation of these programs into higher-level groupings because consistency is impossible without some means of controlling the user interface.

A study of existing interface separation techniques resulted in the design specifications for a prototype, portable system. The portability issue is of primary importance because it permits interface separability in a wide variety of environments.

Software Management

Software management is a generalization of the source code control problem outlined in the 1979 Annual Report. The general problem is to keep track of textual data generated and modified by more than one person, with several versions of the text active simultaneously. This problem spans many DOE applications, including source code control, proposal generation and tracking, and inventory control.

The emergence of computer systems for word-processing has shown that many common computer projects can be characterized by three basic properties:

1. The data used in the project consists of an ensemble of files containing inter-related textual material.
2. The maintenance of this data requires controlled, concurrent updating by several individuals.
3. Several versions of the output of the project may be generated in time, with some text shared among the different versions.

The purpose of this research is to develop techniques for the management of these systems, called "time-dependent, multi-threaded systems of text." While the classic example is computer source code control, other examples of interest within the DOE community include proposal generation, authorship and review of technical papers, requests for proposal (RFP's), and proposal tracking.

In addition to the text management aspects of these systems, issues in data representation will be studied. Although it may be sufficient to merely provide electronic analogues to traditional pen and paper algorithms, e.g., red ink corrections on a typewritten page, the ability of the computer to cross-correlate modifications may require development of totally new representation methods. This will necessitate inter-disciplinary collaboration in the fields of computer graphics and artificial intelligence.

These systems do not lend themselves easily to traditional data base structures because of the textual nature of their domain. Both relational and hierarchical models place strict limits on the structure of the entities which they manipulate. Data base management principles, such as locking and journaling, will be extremely important in the design of a multi-threaded text control system. This research has two basic goals: establishment of most of the control system requirements, with special emphasis on operating system support needed, and design and implementation of a prototype system satisfying these requirements for testing and measurement.

Most systems have focused on the time-dependent nature of program development, while ignoring the concurrent modification problem. In-depth studies of the capabilities of existing systems was completed, enabling the critical features of such a management system to be isolated. Design of a portable version of such a system was initiated.

FORTRAN Evolution

Fortran evolution extends the FORTRAN programming language to include accepted results of software engineering research in language design. This activity seeks to standardize the field-tested language constructs already in existence by identifying and evaluating successful implementations and incorporating the best into a standard.

The FORTRAN language design completed in FY79 was presented for review at other DOE sites during FY80. LBL personnel participated actively in the Language Working Group (LWG) Activities and assumed primary responsibility for the DOE site review. Presentations were made at 12 sites chosen as regional centers. The proposals also were described in a seminar at Oxford University later in the year. Other LWG participants made presentations at meetings of SHARE and VIM user groups and at meetings of SIAM and ANSI-X3J3.

One important feature of the FORTRAN language extensions is emphasis on array processing. Application using large arrays of data can achieve improved performance through the use of those extensions whether or not special array-oriented hardware is employed. Compilers will be able to exploit the higher-level algorithm description specified by the array syntax rather than deducing array operations by analysis of a lower-level description of the problem.

The American National Standards Technical Committee on FORTRAN (ANSI X3J3) is considering array processing for future standardization. Since publication of the most recent FORTRAN standard in 1978, this committee has been engaged in the design and specification of an advanced FORTRAN language to provide needed modern features while maintaining compatibility with former versions of FORTRAN. LBL personnel actively participate in these activities.

Initial proposals for all principal features of the advanced FORTRAN language were considered by X3J3 during FY80. Committee members evaluated the various proposals prior to beginning the integration phase. Previous discussions of array processing features, in the context of the DOE Language Working Group, provided valuable insight during the evaluation of array proposals by X3J3. A major activity of X3J3 during 1980 identified the "core" features of the proposed future standard Fortran language.

The DOE Language Working Group has proposed new group roles to benefit the ACC laboratories and to more closely match the resources currently available for this work. The proposed new roles include the following:

- Providing input to X3J3, tracking progress of new FORTRAN language design and development, and reviewing actions in terms of the needs of the Laboratories;
- Functioning as an information exchange on higher level languages between the laboratories; and
- Providing input to hardware and software vendors concerning the common programming language needs of the laboratories.

The group also developed a recommendation for an experimental "transportable FORTRAN system," including a portable compiler "front-end." Initial studies concerned the specifications of a "common programming environment." Elements include common operating system features, common mathematical library specifications, and common program development tools.

Distributed Systems

The use of long-haul research networks for scientific collaboration and experimentation is now commonplace. Local-area network technologies are evolving rapidly. The evolution of these technologies and their application to highly heterogeneous computing environments is important to the DOE community.

Distributed systems effort at LBL covers the following major research topics:

- Software architectures for communications processing,
- Network-based interprocess communication schemes,
- Network protocol issues, and
- Interconnection technologies for constructing networks.

Software Architectures for Communications Processing

Research in communications processing is primarily concerned with the study, design, and development of software architectures which are more efficient, deliver higher performance, and produce better overall design factorizations than existing patterns. This research includes software engineering, operating system concerns, and development of efficient front-end systems which can successfully offload most network processing functions from larger hosts.

Existing operating systems, especially time-sharing systems, have proven unsuitable for communications processing. New network protocols will consume an even larger percentage of system resources because of their increased complexity compared to existing protocols. This has generated renewed interest in front-end processors. Although previous efforts have been only marginally successful, we believe new insights into the host/front-end protocol issue will result in significant progress. "Low-cost" protocols have been developed, some in the context of local area networks which will allow host offloading without introducing the same complexity into the host/front-end protocol. The rapid evolution of microprocessor technology provides a number of candidate processors for network front-end use. Unfortunately, this same rapid evolution can lead to forced obsolescence of hardware and software systems unless they are designed with processor-independence in mind.

A major problem is the availability of software architectures that can support such front-end systems. In process based operating systems, 60 to 80 percent of the processor can go solely into multiplexing. Although the traditional solution to such a problem is to purchase a more powerful processor, it may be necessary to re-evaluate process-based operating systems as the foundation upon which to build communications systems. If it is found that process-based architectures are too costly for use in such applications, other architectures must be found to satisfy the needs of communications processing.

For utmost speed, "real-time" programs with tight performance constraints normally are written as monolithic programs. While these programs generally meet performance objectives, they have the same problems as other software monoliths: they can be neither comprehended nor maintained.

We think there are alternative formulations which offer the conceptual elegance, engineering manageability, and comprehensibility of the traditional process structure without sacrificing performance objectives. The central aims of this work are design, implementation, and evaluation of a communications-oriented operating system founded on these new non-process ideas.

Work done during 1980 resulted in the development, installation, and evaluation of the Rand network front-end software for the VAX RCF system at LBL. This enabled the VM/UNIX system to become a host on the ARPANET. While this had obvious mission-oriented aspects, it also established a valuable collaborative channel for future work.

Interprocess Communication

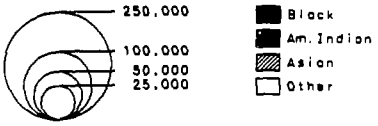
Research into network-based interprocess communication (IPC) centers on the development of IPC schemes which are more suitable for network environment than existing mechanisms. The scheme being developed at LBL is essentially a software analog of the Ethernet hardware. The main result of this model is a "multicast" IPC mechanism which contains, but is more general than, the usual "point-to-point" mechanism.

Some of the features necessary in a general-purpose IPC mechanism are:

1. The mechanism must support multi-cast communication, i.e., one writer should be able to send a message to several readers by writing the message only once *without* incurring a large overhead.

2. The mechanism should be secure, to ensure that the message traffic is not available to unauthorized processes.

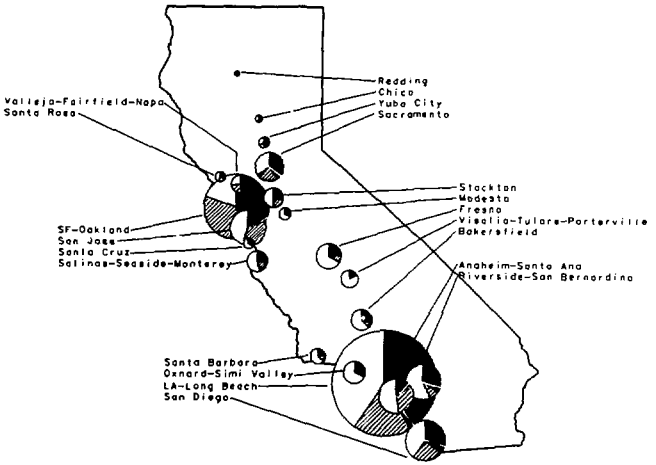
3. It should be easy for a process to rendezvous with other processes which are already using the mechanism.



Minority Population, 1980

Symbols are proportional to the total nonwhite population which is listed in thousands of persons.

California Standard Metropolitan Statistical Areas



Thematic mapping capabilities of the Socio-Economic Environmental Demographic Information System (SEEDIS) include production of complex symbolic maps. The above map, showing minority racial distributions for Standard Metropolitan Statistical Areas (SMSAs) in California, was prepared using data from the 1980 Census of Population. Advance Report PHC80-V-6. (XBL 822-7818)

4. There should not be an enforced protocol when using the mechanism, to avoid limiting use of the mechanism for arbitrary communication.

Due to the lack of any previously designed mechanism satisfying these requirements, a test mechanism was developed based upon some of the ideas used in the hardware Ethernet pioneered at the Xerox Palo Alto Research Center. The bases of this mechanism, termed virtual or software aethers, were implemented on four operating systems. Initial test results indicated that the aethers provide the media for more complex, multi-process, data-flow connections, in addition to providing the functionalities of traditional "point-to-point" mechanisms as simple subsets.

Network Protocol Issues

Work on the network protocols includes collaboration with other computer scientists. The major concern is the troubling mismatch between the complexity of the new DOD standard protocols, IP and TCP, and the requirements of high-performance local networking. The new protocols require very large amounts of computing power, and it is doubtful that they can support highly distributed systems composed of many modest-sized machines. This research involves serious examination of and experimentation with "connection-less" and other "low-cost" protocols. We believe this study is of paramount importance if the potential of local area networks is to be realized.

Recently, there has been considerable debate over the desirability of network protocols not based on connections. Moreover, experience with connection-based protocols has led several researchers to reconsider connectionless protocols. Researchers at LBL, Rand, and Mitre are comparing experimental connectionless protocols with their connection-oriented counterparts. Primary reasons for these investigations are the computational complexity of the new connection-oriented protocols (DOD TCP is a good example) and the difficulty of reconciling this complexity with the goals of high-performance local area networks. The underlying belief is that protocols can and should be much simpler if the expectations held for local networks are to be realized.

Interconnection Technologies

Work on interconnection technologies concerns tracking leading-edge developments in local area networks. There is increasing competition between the two major cable-based architectures: baseband (Xerox Ethernet) and wide-band (Sytek and Mitre) systems. The chief difference is sharing cable bandwidth with other signals such as voice and video. Products based upon both architectures are starting to enter the marketplace. Our participation in this area consists of assembling experimental hardware; interacting with potential vendors; evaluating hardware and software offerings to determine how they can be best put to use; and, to a lesser degree, trying to influence product design to meet DOE's anticipated needs by using off-the-shelf systems. While network protocol development can be made in a vacuum, serious, productive protocols must be designed with a keen understanding of what can be expected of the hardware base.

One problem in configuring a local network as an integrated ensemble is constructing it with existing hardware. While the new "standard" network technologies offer some help, vendor claims of universality have not been substantiated. Because most of the new network offerings include their own layers of protocols, integrating these pieces in an in-situ software environment is a very serious problem. It is not feasible to custom-engineer major software components for each new device to be added to a local network. Experimentation with new hardware will develop general integration strategies, which can provide a method for easily integrating other new products.

Protocol-gateways, using protocol translators to make alien protocols cooperate, is a related problem. Although linking networks through gateways affects the protocol design of constituent networks, this program is studying ways to build a protocol-gateway using protocols which operate on a particular set of networks. These gateways are listed under interconnection techniques.

The most significant accomplishment has been an in-depth study and analysis of local area networking hardware and software offerings. Also, initial analysis has been performed on the proposed Xerox-Digital-Intel Ethernet standard. We expect details of the higher-level protocols to be announced in the near future. Participation in some of the DOD IP/TCP meetings has already provided some insight into the problems with those protocols, focusing attention on other kinds of interconnection protocols. As a result, the acquisition of Ethernet hardware for evaluation is expected at the end of the year.

Performance Evaluation

Performance evaluation is currently concerned with understanding file storage systems and developing algorithms which expedite the efficient use of such systems. While this research should be of some use in tuning existing systems, its primary effect will be on the design of storage systems for new, high-performance computers. The research effort has concentrated on understanding file systems and storage hierarchies.

Requirements for storage continue to grow both in speed and size, and storage system design remains a major technical and economic problem for computer systems. The growing storage requirements stem from the increasingly complex computations being attempted by scientific users.

Previously infeasible computations are now practical because of increasing speed and declining costs of computing hardware. New detector, digitizing, and telemetry equipment has made the collection of very large data files increasingly common and has increased demands for

ıge. Furthermore, faster processors require faster storage if the storage system is not to be a bottleneck.

Storage systems are typically configured as a hierarchy of devices. At the top of the hierarchy are modest amounts of fast expensive memory; the lower levels are comprised of larger amounts of slower, cheaper memory. References to storage have been observed to exhibit "locality of reference". Most references are addressed to information which has been referenced recently or which is "near" information referenced recently, possibly adjoining information stored in a sequential file. Thus it is possible to obtain a shorter average access time and a cheaper average storage cost by judiciously moving information between levels of the storage hierarchy.

Access times to various storage devices span a range of about eight orders of magnitude, while the cost per bit of the various storage media ranges across five orders of magnitude. Therefore, the proper design and management of storage hierarchies is essential to the technical and economic feasibility of high performance computer systems.

Increasingly, decisions concerning the migration of information between levels of the storage hierarchy are being automated. The goals of this automation are:

1. Reduced programmer effort, both in terms of skill and time.
2. Increased freedom to alter the storage system architecture without affecting user written software.
3. Improved hardware utilization.

Our research program concerning the choice of appropriate policies for automatically managing the migration of data within storage hierarchies has three parts. The first consists of an effort to model storage reference behavior by using statistical characterization studies made of storage reference traces taken from existing computer systems.

The second part of the research program concerns the development, modeling, and choice of good policies for automatically managing the placement and movement of data within the storage hierarchy. This involves storage reference traces as input to programs simulating cache management policies. More detailed traces enable investigation of more sophisticated cache management policies. The availability of traces from several sites enables assessment of various policies across varying workloads.

The third area of research consists of configuration design studies to choose appropriate storage technologies for various levels of the storage hierarchy and to size levels for achieving cost and performance goals. Again, the availability of several traces will enhance the credibility of the conclusions.

New and improved algorithms were developed for calculating the performance of the Least Recently Used (LRU) replacement policy as a function of the size of the cache. These algorithms also facilitate the study of the most commonly used file cache replacement policy. Because of its simplicity and widespread use, LRU represents the standard against which other cache policies are judged.

Acquisition of traces for the Automatic File Migration Project has been concluded. Traces from several sites were obtained and reduced to usable format. Statistical characterization studies of file reference behavior have been conducted on the trace data.

Research Computing Facility

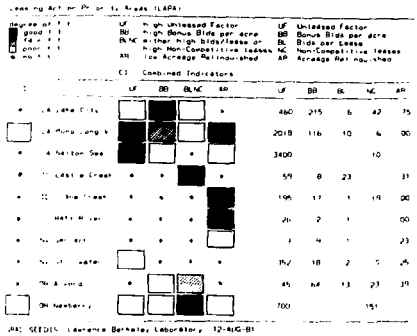
The Research Computing Facility (RCF) provides the computational resources needed to support the ongoing basic research in applied mathematical sciences. It serves as a testbed for the evaluation and deployment of new computing capabilities, as well as serving as the hub of the Electronic Mail System. Maintenance and development of the RCF, including integration and evaluation of emerging computing technologies, is a collaborative effort with other DOE research sites and with researchers throughout the university and industrial communities.

This year, effort focused on migration from a PDP-11/70 to a VAX 11/780 and the development of the Network Front-End system to support the VAX on the ARPAnet. The first production VAX system running the existing ARPAnet protocols was the result of continuing collaboration with other researchers at the Rand Corporation, Computer Corporation of America, Mitre, Stanford, SRI International, and Lincoln Laboratories. The results of these efforts are being made available to other organizations, with special emphasis being placed on transporting this technology to the other DOE National Laboratories using ARPAnet (ANL and LASL).

Distributed Computer Network

The Distributed Computer Network (DCN) is an experimental network of minicomputers established as a framework and testbed for basic research in networking techniques, user interfaces, and distributed information technology. The project is jointly funded by the Department of Labor Employment and Training Administration (ETA) and DOE. The major goal of the DCN is to provide shared access to the socio-economic, environmental, and demographic data bases and the sophisticated data retrieval, analysis, and display systems which comprise the Socio-Economic Environmental Demographic Information System (SEEDIS).

The Distributed Computer Network has three components: the applications developed to exploit the computer systems and network; the computer programs which provide and use network functionality; and the hardware which supports that functionality. The network consists of three systems at ETA sites in San Francisco, Seattle, and Washington, DC; three computer systems at LBL; one system at George Washington University, Washington, DC; and a system at Pacific Northwest Laboratories, Richland,



Concepts and quantitative techniques from fuzzy set theory have been incorporated into the data display and analysis capabilities of SEEDIS. The ability to characterize data by linguistic expression is applied to the question, "Which geothermal areas have the best potential for successful development?" This chart shows how each geothermal area considered fits the ideal case described by "high" and "low" on five indicators. The chart helps focus attention on where and how well data meet the ideal case to some degree, while suppressing extraneous detail where data do not fit at all. When all indicators are of equal importance and no tradeoffs, exceptions, or missing data are considered, the indicators can be combined to present a summary, as shown by the dots at the left of the chart. More often, however, comparing rows of shaded boxes helps evaluate choices when complex factors need to be considered. (XBB 819-8653)

Washington. Each computer system is a Digital Equipment Corporation VAX-11/780 machine. The geographically remote nodes communicate via leased lines and modems; the LBL machines are interconnected using high-speed dedicated lines. One system at LBL is dedicated to basic research functions and runs the UNIX operating system. Each of the other machines runs VMS, a variety of other vendor-supplied software, and the SEEDIS data retrieval, analysis and display systems. During 1980, the telecommunications base was stabilized. All computer systems and network connections are running stably. Additional semiconductor memory, storage capacity, and access lines were installed to support the growing user community, increasing storage requirements, and expanding network traffic.

Development and enhancement to the SEEDIS software, as described in an earlier section, increased the utility of the network nodes in many ways. Basic research issues in the development of distributed information systems are addressed in the framework of DCN as a prototype facilitating the exploration and implementation of research concepts.

The software tools developed at LBL were installed at all DCN sites. Training classes were held for the users of the tools, and documentation is available to new users. The software tools include a text editor, formatting programs for printing documents, a mail system, and many other tools useful for the development of programs, documents, etc.

LBL plays a technical support role, assisting the Employment and Training Administration in the definition of application requirements, the evaluation of development and implementation strategies, and the acquisition or utilization of software and tools for applications development.

Evaluation and selection of a data base management system (DBMS) for administrative applications continued throughout the year. Available systems were examined with respect to the following criteria:

- Functional capability of the query language,
- Flexible data structuring,
- Data entry and transaction facility,
- Transaction logging, recovery and check-point restart,
- Data security and privacy,
- Ad hoc query and report generation,
- Physical data base size, and
- Efficiency.

In September 1980, DRS was acquired to provide substantial data base management functionality for the development of major ETA administrative applications. The evaluation of data base management systems will continue, including extensive interface with vendors to address problems of efficiency, improved query and data representation languages, and portability across operating systems.

The Digital Equipment Corporation operating system (VMS) and networking software (DECNET) were installed on all of the network nodes, except the LBL UNIX system. LBL staff installed software revisions and new releases, developed procedures to enable remote site personnel to install these new systems, and served as a test site for developmental versions of several DEC software products.

Enhanced network functionality included two major capabilities: route-through and virtual terminals. Route-through provides the necessary facilities for data to be forwarded from one site to another through an intermediate site in the network without explicit programmer intervention. Virtual terminal function allows a user at any terminal to run on any of the machines in the network without having to dial the machine directly. The network node connected to the terminal simply connects the user directly to the machine that is needed. The implementation of these network capabilities has greatly increased the utility and accessibility of distributed data bases and has proven the effectiveness of interaction between nodes.

Research Staff

Rosemary B. Allen, Donn F. Davy, Helena W. Gin, William H. Greiman, Dennis E. Hall, Paula K. Hawthorn, Loren P. Meissner, Irma V. Miranda, Michael D. O'Dell, Frank Olken, Juan M. Porcar, Deborah K. Scherrer, Alan J. Smith, Joseph S. Sventek, Lester N. Tabata.

Environmental and Epidemiological Studies

Populations at Risk to Environmental Pollution

The Populations at Risk to Environmental Pollution (PAREP) project is expanding and utilizing the existing health and environmental pollution data base at LBL. The data base contains information on air-quality, human mortality, population (age-, sex-, and race-specific), geographic location, and a number of socio-economic indicators for each county in the United States. The data base has been supplemented by broader air-quality data and age-specific mortality and incidence data and with a variety of user-oriented computer tools. These data and computer facilities comprise a powerful integrated information system, useful for epidemiologic investigations into the relationships of disease and environmental pollution.

The present epidemiological data base will be further expanded, the methodological and computer techniques for statistical analysis and display will be further developed, and important biostatistical/epidemiological issues will be addressed.

The typical epidemiologic study focuses on the individual as the unit of investigation. The PAREP project has collected and begun to analyze data, called ecological data, where the basic unit is a group of individuals. The methodology for analyzing this type of data is not well-developed and consists of only a few techniques. The PAREP project has evolved specialized statistical methods to deal with ecological data. Without statistical tools, the utility of ecologic data for epidemiologic study is much reduced. Investigation of methodologic problems that surround the use of ecologic data will provide new understandings of the influences of environmental pollution in the human disease process. Major portions of the PAREP data base have been widely distributed and are being used in parallel studies involving human health and environmental pollution by other Department of Energy laboratories and in other federal ageneies.

The ecologic patterns of disease for specific causes of death were described and analyzed. This analysis involved the use of standardized, age-adjusted mortality rates for county level data. A second important epidemiologic effort was the completion of a study of cancer incidence in the San Francisco Bay Area and its association with two air pollutants, total suspended particulate and carbon monoxide. The methodology and results serve as a prototype for a similar nationwide investigation. The consequences of ecologic regression analysis were studied extensively, particularly cases where this statistical approach is applied to the association between mortality and air quality. A small investigation of histology-specific prostate cancer incidence and socio-economic status was also completed. Finally, a descriptive study of the epidemiology of cell-type specific leukemia mortality (adult and childhood) is well under way and will be completed in the near future. This study employed 1969-1977 leukemia mortality data integrated in to the PAREP data base to study the recent epidemiology of leukemia in greater detail than was previously possible.

Cancer Incidence Study

The study of the adverse health effects of low-level radiation is an area of great importance to the Department of Energy. Unexpected events, such as the Three Mile Island accident or a reported local upswing of cancer incidence rates, demand sophisticated capabilities for timely and responsible epidemiological analysis.

Building on resources and expertise acquired in the PAREP project, the investigators will develop data and techniques for the analysis of radiation-related diseases such as leukemia, lung cancer, and congenital birth defects. During 1980, the major effort was a comprehensive description of the epidemiology of recent leukemia mortality and the development of analytic techniques required for specific analyses. The same goals, applied to a broader set of diseases, will be part of this project.

Investigation will expand to other diseases that are thought to be sensitive to radiation influences. The timely and careful analysis of unexpected exposures and locally reported increases in disease rates (e.g., cancer in Rocky Flats, Colorado) requires epidemiological expertise coupled with sophisticated data management and statistics capabilities. These criteria are critical for the assessment of health-related questions concerning energy alternatives.

Leukemia mortality was studied from several different points of view. Geographic variation was analyzed, age and secular trends were described, and relationships of leukemia mortality to seventeen socio-economic variables were investigated with the use of several analytic techniques. These analyses, which are both age-specific and cell-type specific, produced new epidemiologic information on six disease entities: acute lymphocytic and mylocytic leukemia in children; acute lymphocytic, acute mylocytic, chronic lymphocytic, and chronic mylocytic leukemia in adults. This study is a departure from previous work because cell-type information is not usually available. Past studies generally did not distinguish the different forms of leukemia mortality.

The importance of cell-type distinction emphasized different epidemiologic patterns among the six leukemia cell types studied in this project. For example, acute lymphocytic leukemia among children has no strong association with socio-economic status as measured by income levels but shows a strong negative association in adults. On the other hand, adult acute mylocytic leukemia has no association with income. Similar distinctions have been fully described for seventeen different variables including

elevation. Elevation has been studied in the past as a possible etiologic factor in leukemia mortality frequency because of the increase in radiation at higher altitudes. However, no strong association was observed in the present data.

Several methodologic issues concerning the analysis of rare causes of death recorded at the county level were addressed. Since these data involve aggregate data (ecologic variables), the process of producing a valid analysis is not straightforward. For example, usual regression techniques are extremely biased when applied to ecologic data. New techniques are under development and several have been tested, but a completely satisfactory approach is not yet available.

Air Pollution and Human Health

During the past decade, a number of major studies have assessed the effects, if any, of air pollution upon human health. Because of the impossibility of conducting carefully designed case-control studies, most of this research has relied on ecologic data on air quality, mortality, and socio-economic status (SES) routinely collected by a number of different federal government agencies. The supposedly long time intervals between pollution exposure and observable effects, coupled with the difficulty of obtaining comparable data over long time periods, have led most investigators to explore only the geographic variations in mortality, air quality, and SES.

The collective findings of these investigations are inconclusive. The shortcomings of ecological data are well known, foremost among them being the confounding effect of important unmeasured variables, such as dietary and smoking habits, and the loss of sensitivity resulting from treating large groups of individuals as the unit of analysis. Little can be done about these limitations beyond describing their effect and, to some extent, incorporating information from specific case-control studies. For these reasons, some critics contend that ecologic studies are without value.

On the other hand, there is no adequate alternative method for studying the long term effects of low level air pollution upon human health. We will explore the methodological problems in detail, concentrating on factors that may have led to erroneous conclusions in earlier published analyses. Five major topics will be investigated: (1) ecologic inferences, (2) sample size, (3) epidemiology of respiratory diseases, (4) interpolation of air quality data, and (5) data validation.

During 1980, investigators replicated and extended the work of Mendelsohn and Orcutt, using the PAREP/SEEDIS data base to further understand the "ecologic regression approach" for studying air pollution and health. Further work performed on the issue of aggregation bias analyzed data both at the county level and at the level of Public Use Sample areas defined by the 1970 United States Census. Health data from the National Center for Health Statistics were combined with 22 variables from other sources and 3 measures of pollution (TSP, SO_2, and NO_2) to provide a data set to study and characterize the problems of "ecologic regression analysis."

In parallel with the study of regression techniques estimates of average air quality data were developed for counties, census tracts, and public use sample areas. Generalized computer algorithms were developed for efficient processing of ambient air quality data for testing for outliers and for interpolating data for individual monitoring stations.

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