

Silicon Process Technology for Monolithic Memory by R. H. Collins, E. G. Grochowski, and W. D. North, p. 2. The successful design and production of high density, high speed monolithic memory circuits that can operate efficiently over wide current ranges can be directly attributed to the development of a new silicon process technology based on the <100> crystal orientation. To provide optimum capability to fabricate these circuits with high yields, process modifications to accommodate larger starting substrates (wafers) have also been adopted. Detailed electrical characterization of the resulting devices has confirmed improved circuit operation, demonstrating that improved gain at low current and good junction quality are consequences of the process modifications.

Design Innovations of the IBM 3830 and 2835 Storage Control Units by G. R. Ahearn, Y. Dishon, and R. N. Snively, p. 11. The IBM 2305 Fixed Head Storage and IBM 3330 Disk Storage provide significant performance improvements over previously available disk facilities. Many of the improvements were made possible by the design of the control units, which are complex systems that integrate analog and digital interfaces. Definition of control unit requirements and characteristics permitted a large degree of commonality to be achieved between the two control units. The available design alternatives and implementations are discussed.

Readout Performance Analysis of a Cryogenic Magneto-optical Data Storage System by B. R. Brown, p. 19. An analysis of readout signal and noise generation is presented for a magneto-optical data storage system which uses a single laser beam for both Curie-point thermal writing and Faraday readout of magneto-optical films. The analysis is applied to a cryogenic beam addressable file model which utilizes GaAs injection lasers and doped EuO film.

Theories of the Distribution of Deposit from Sputtered Disk and Rectangular Electrodes by R. E. Jones, Jr., p. 27. Theoretical expressions for the distribution of deposits sputtered from disk-shaped and rectangular electrodes are derived for cases of 1) uniform emission obeying the cosine emission law, 2) distorted "under cosine" and "over cosine" emission, 3) additional emission confined to the peripheries of the electrodes and obeying the cosine emission law, and 4) distorted "inward" emission from the peripheries.

Cross-coupled Thyristor Storage Cell by W. Jutzi and C. H. Schuenemann, p. 35. A symmetrical, cross-coupled, two-thyristor storage cell with 1 μ W stand-by power dissipation and 60 nsec switching time is described. When integrated in silicon planar technology each thyristor consists of a vertical *npn* transistor and a lateral *pnp* transistor.

Efficient Evaluation of Array Subscripts of Arrays by A. Hassitt and L. E. Lyon, p. 45. The APL language allows

subscripted expressions such as $A[I;J;K]$, where A is an array and I , J and K may be scalars, vectors or arrays of any size and shape. We describe an efficient method of evaluating these expressions. The method is quite general and yet it does recognize all the special cases in which multiple subscripts can be reduced to a simpler form. We show how the same mechanism can be used to evaluate other selection operations, such as transpose, and how selection operations may be combined.

Experiments on Page Size, Program Access Patterns, and Virtual Memory Performance by D. J. Hatfield, p. 58. The assumption about virtual memory systems that as overhead (time for access and software page management) decreases page size should be reduced is not always a good one. Recent experiments indicate that larger page sizes can provide better performance for programs that make highly localized use of memory space.

Sputter-etching of Heterogeneous Surfaces by L. I. Maissel, C. L. Standley, and L. V. Gregor, p. 67. In conventional sputter etching, heterogeneous surfaces are eroded at generally unpredictable rates. The reasons for this are discussed and a solution to the problem is given: Based on control of redeposition, the technique involves the use of a device called a "catcher," which is placed near the target of the sputtering chamber to trap re-emitted particles. Experiments are described which confirm the effectiveness of the approach.

Ge Epitaxial Refill Deposition Techniques for Fabricating Pedestal Transistor Structures by V. J. Silvestri, T. B. Light, H.-N. Yu, and A. Reisman, p. 71. An etch-epitaxial refill technique is described for the fabrication of integrated high-speed Ge transistor structures having a pedestal configuration. The device areas surrounding 0.1 ohm-cm mesa structures were refilled with Ge having a resistivity range of 1 to 10 ohm-cm, providing low parasitic capacitance in the passive area of the base-collector junction. Processes and techniques were developed for minimizing the ridge that tends to form at the edge of the deposited SiO_2 mask. Electrical properties and junction characteristics of the epitaxial regions are discussed and some device results presented.

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Model for Time-dependent Raindrop Size Distributions; Application to the Washout of Airborne Contaminants by F. F. Abraham, S. K. Jordan, R. N. Kortzeborn, and H. G. Kolsky, p. 91. We have developed a model for computing time-dependent behavior in raindrop size distributions for a variety of initial conditions. The model permits the inclusion of a spatially varying atmospheric profile and takes evaporation and coalescence of raindrops into account on a dynamic basis. We have applied this model to the washout process by rain, whereby small airborne particles are scavenged below a rain cloud. In comparing our results with

those of previously published time-independent models, we found that the time-dependent effects greatly altered washout at lower elevations.

Rationale, Limitations, and Assumptions of a Northeastern Forest Growth Simulator by D. B. Botkin, J. F. Janak, and J. R. Wallis, p. 101. A cooperative agreement between Yale University and the 1970 summer program of the IBM Research Division resulted in a flexible computer program to simulate the growth of the uneven-aged, mixed-species stands of trees on the 10-meter by 10-meter experimental plots of the Hubbard Brook Ecosystem Study in the White Mountains of northern New Hampshire. Annual increments of tree growth are based on species, tree size, and allocation of available light among the competing trees of the plot. Site quality differences between plots are assigned primarily by the concept of tree-growing degree-days, although soil moisture storage during the growing season and plot rockiness are also considered. Species succession, individual tree suppression and release, and other dynamic properties of forest stands have been successfully reproduced using the program. Additional field measurements are needed to further verify the model and to extend its applicability to nutrient cycling and other aspects of the Hubbard Brook Ecosystem Study. We believe that the simulator could readily be extended to include most other tree species of northeastern North America and also to match data from other sites through appropriate adjustment of program parameters.

Subsurface Hydrology at Waste Disposal Sites by R. A. Freeze, p. 117. One result of the growing concern over surface-water pollution has been an increase in the popularity of ground-based waste disposal practices that save the streams but have a high potential for subsurface pollution. One of these, sanitary landfill, appears quite promising in its ability to handle large waste loads with a minimum of contamination; but two others, waste lagoons and deep-well injection of liquid wastes into geologic formations, lead to irreversible subsurface pollution. In all cases, the mechanism of pollution is an interaction between the pollutant source and the existing soil-moisture and groundwater flow systems. A mathematical model of the subsurface flow can be used to predict this interaction and to assess the impact on the environment of a proposed disposal site. The model applied in this paper can predict transient and steady state subsurface flow systems in two or three dimensions and includes consideration of both the saturated and the unsaturated zones. It can be applied at the reconnaissance stage on a regional basis to analyze a large number of alternative sites and at the chosen site to test the efficiency of various design alternatives and to provide guidance in the design of a monitoring system. The model predicts only convective transport and does not consider dispersion or hydrochemical reactions.

Estimate of Subsidence in Venice Using a One-dimensional Model of the Subsoil by G. Gambolati, p. 130. This work applies a one-dimensional model, based on K. Terzaghi's

theory of vertical consolidation, to the calculation of land subsidence in the Venetian Lagoon, caused by extraction of water from artificial wells. Certain assumptions are made in order to compensate for the scarcity of data currently available, and these are discussed with regard to both the geophysical characteristics of the subsoil and the decline in piezometric level in the various strata. The interpretation of the results shows a direct correlation between water extraction and surface subsidence.

Nonsupervised Crop Classification through Airborne Multispectral Observations by G. Nagy and J. Tolaba, p. 138. Current methods of terrain classification by means of airborne multispectral observations are reviewed with emphasis on the selection of training sets for determination of the categorizer parameters. A method of selecting sample regions for assigning identities to the spectral signatures on the basis of statistically determined similarities, rather than on *a priori* considerations, is suggested. This method has been tested on data collected on two flights with the University of Michigan scanner over an agricultural region in California. We have found that a simple clustering algorithm, modified to take into account specific features of the crop-census problem, can be used to obtain the desired homogeneous regions with relatively little computation and that very sparse sampling of these regions is sufficient to assign the appropriate category to each cluster. Viewed as a two-stage sampling procedure, clustering improves the second stage classification on 15 crops from 20 to 50 percent over a random selection of the primary sampling units. The accuracy increases to 73 percent when only five classes are considered, with further improvement to 88 percent when a majority decision based on known field boundaries is used.

Interactive Computer-based Game for Decision-making in Ecology by T. I. Peterson and P. N. Wahi, p. 154. This paper describes a prototype Ecology Decision Game which has been developed for experimental use within IBM. The paper is directed to those in ecology desiring to use similar techniques in developing programs that interrelate computing, management science, mathematics, and APL for training and educational purposes. The game is implemented in two modes: an *author* mode, which permits an author to write his own scenario; and a *player* mode, which enables a person to play the game. Features of the game exploit interactive capabilities for both modes. The particular scenario written for the game treats decision-making in the environmental area of solid-waste management. Three submodules explore progressively more complicated situations that give rise to management science problems: shortest route, transportation, and maximal flow. By active and passive role-playing, and controlled and uncontrolled learning, the player is given the opportunity to use quantitative tools to refine his subjective judgments.

Air Quality Diffusion Model; Application to New York City by L.-J. Shieh, P. K. Halpern, B. A. Clemens, H. H. Wang,

and F. F. Abraham, p. 162. An experimental multisource air pollution diffusion model based on the Gaussian plume formulation is described. The model incorporates point and area sources, time and space dependence of source strengths, and time and space dependence of meteorological variables. Numerical simulation of the SO₂ concentration distribution for New York City on January 11, 1971, agrees favorably with experimental measurements.

Numerical Investigation of the Atmospheric Dispersion of Stack Effluents by C.-C. Shir, p. 171. This report describes a numerical method based on the best gradient-transfer theory currently available for computing pollutant concentration distributions downwind from a stack. The vertical inhomogeneity of the atmosphere and ground roughness are included in the model. Vertical wind and temperature profiles are calculated numerically from given values of ground roughness and wind speed and relative temperature at stack height. An equation governing the plume from the stack is solved by a finite difference method. The numerical results, compared with several experiments, suggest that ground roughness is an important parameter and that disagreement between different sets of experimental data may be due to different values of this parameter. The effect of wind is found to be small under neutral conditions. The effective mean wind decreases to a minimum value a short distance from the stack and then increases downwind.

Appendix—Three-dimensional interpretation of the two-dimensional advection-diffusion equation by W. E. Langlois, p. 178.

Overlap Emissivity of CO₂ and H₂O in the 15- μ m Spectral Region by N. Braslau, p. 180. Radiative transfer in model atmospheres including CO₂, water vapor, ozone, and clouds can be explored by computer simulation for the purpose of predicting the mean temperature at the surface of the earth. Where two or more gases have overlapping absorption lines, the overlap emissivity determined from the band-averaged expressions is a possible source of uncertainty. This method has been tested in a 250-cm⁻¹ region around 15 μ m where the CO₂ absorption overlaps the tail of the water vapor rotation band. Published high resolution spectra of these gases enable the overlap effects to be calculated for small spectral intervals and summed over the band. This calculation was made and compared with the value given by the approximate treatment for the same gas concentrations, pressure, and temperature. Agreement was within 10 percent, indicating that the more detailed spectral calculation is unnecessary.

A Model of Charge Transfer in Bucket Brigade and Charge-coupled Devices by L. G. Heller, W. H. Chang, and A. W. Lo, p. 184. Investigation of bucket brigade (BB) and charge-coupled devices (CCD) has resulted in the development of a general model for these devices and their various modes of operation. Similarities and differences

between BB and CCD are discussed. The nonlinear partial differential equation of charge motion composed of self-induced drift, thermal diffusion, and electrode fringe-field terms is used to study CCD numerically. The factors that affect charge transfer are investigated by varying the stored charge density, the device length, the transfer-gate-to-storage electrode voltage, and the fringe field. The results include several plots of charge transfer vs time.

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Preface: Mechanical Technology by J. L. Hibbard, p. 202.

Mechanics of Film Adhesion: Elastic and Elastic-Plastic Behavior by W. T. Chen and T. F. Flavin, p. 203. A peel test is a useful method for comparing the behavior of various adherends and adhesives. An exact analysis of the mechanics of the peel test would be of great help in the interpretation of test results in terms of the bulk properties of the materials, and of the failure mechanism of the bond. The existing theories of peeling apply to *elastic* peel films, *very thin* elastic or viscoelastic adhesive, and a *rigid* substrate. In many applications the film is metallic, stressed beyond its elastic range; the elasticity of the substrate is often similar to that of the adhesive; and the adhesive may be quite thick compared to the film, or may be wholly absent as in electroplated components. In this paper, the effects of non-elastic behavior of the film are analyzed. Results from the use of computer programs that incorporate an analytical model of steady state peeling are presented and compared with experimental data.

Viscoelastic Behavior of Computer Tape Subjected to Periodic Motion by G. W. Baumann, p. 214. The purpose of this study was to develop a theoretical means for predicting the longitudinal motion of computer tape in a high-performance tape drive. In particular, this paper treats the motion that is governed by traveling velocity-stress wave reflections, attenuations, and interactions in the length of tape between the tangency point at the capstan and the tangency point at the stubby column in the drive.

The motion of the tape was determined by solving the classical, damped, one-dimensional wave equation subject to the appropriate boundary conditions. J. C. Snowdon's low-damping constitutive model was used to describe the viscoelastic behavior of the tape. The solutions for simple boundary conditions were experimentally verified by mechanical impedance techniques. More complex boundary conditions, such as those for vacuum columns, were experimentally studied to determine the true mathematical boundary conditions.

This paper also discusses simple unreflected harmonic waves, simple reflected harmonic waves, and general periodic reflected waves as examples. The significance of the wave interactions in the design of tape drives is considered.

Dynamic Control of Spring-driven Mechanisms by R. E. Bishop and C. C. Wilson, p. 222. A common method for moving a machine member from one position to another is the use of a spring. Spring-driven devices are simple, inexpensive, and easy to implement; however, the velocity characteristics of such devices leave much to be desired. The velocity increases from the initial position to the final position resulting in a maximum velocity, and therefore maximum energy in the mechanism, at the final position. The simplest method of stopping the device, a rigid stop, results in high impact forces and undesirable noise. Many methods have been developed for limiting the velocity of spring-driven mechanisms, such as the centrifugal friction brakes used in telephone dials and fans used in music boxes. Other approaches such as dashpots or shock absorbers have been used to decelerate devices. This paper discusses a method for both velocity control and deceleration by the use of a single pneumatic cylinder. In addition, a method of reducing velocity variability due to differences among the work functions of the mechanism is described, and the application of such a device to a paper-cutting mechanism is presented. The concepts and theory presented are general and therefore apply to the entire class of spring-driven mechanisms.

IBM Copier Scanning System by D. A. Beaty, T. A. Hoskins, T. H. Richards, and H. W. Simpson, p. 231. The quality of the copy to be produced by the IBM Copier was of utmost importance in the machine development. This dictated that the amplitude of the vibrations of the document scanning system during scan be limited to a very low level. The design considerations, analysis, simulation, and instrumentation used to assure adequate performance of the system are described.

Some Design Considerations for a Document Sorting Machine by J. L. Zable and J. C. Yarrington, p. 239. A document reader-sorter is analytically studied to determine the effect of document velocity on the number of documents that can be sorted reliably in a given interval of time, and a formula is derived that relates the effect of various design parameters to the throughput of a document sorting machine. One of these parameters, selector response time (i.e., indexing time), is investigated in detail. Both analytical and graphical design techniques are developed to minimize the response time of the selector. These techniques, which are explained by simple examples, are quite general and can therefore be applied to many other incrementing devices.

Acoustic Signal Analysis for Noise Source Identification in Mechanisms by R. H. Peterson, A. D. Ackerman, and R. E. Zelenski, p. 249. Proper interpretation of the time and frequency characteristics of machine noise provides information useful in identifying and quantifying noise sources in complex mechanisms. The use of commercial acoustic instrumentation led to the development of unique analog instrumentation for noise-time analysis and ultimately to a real-time analog-digital signal analysis capability. The hybrid system described in this paper provides the time and

frequency resolution necessary for noise source identification and evaluation.

Holographic Interferometry Deformation Study of a Printer Type-piece by A. D. Wilson and D. H. Strobe, p. 258. Holographic interferometry with a pulsed ruby laser is used to determine printer type-piece deformation caused by impact of the print hammer. A variety of type-piece designs are examined. Effects of impact velocity and hammer-type-piece alignments are studied. Means of obtaining stress information from the holographic data are considered. Cubic spline methods are used to smooth the holographic data and to obtain continuous first and second derivatives. The stresses calculated from the holographic data agree well with those obtained by other means such as finite element analysis. Some limitations of the holographic technique as well as its advantages are discussed.

Considerable type-piece twisting is observed; this was not expected or known previously. The most significant result is that a type-piece tends to twist when impacted by the hammer at any point other than the exact center. The twist angle is of the same magnitude as the angle of out-of-plane motion of the type. Hence the type may impact the platen on one corner or side edge. Also, the type bends greatly in the necked down region adjacent to the character and does not pivot by a large amount at its bearing point. Twisting motion is propagated from one end of the type to the other.

An Application of White Light Interferometry in Thin Film Measurements by C. Lin and R. F. Sullivan, p. 269.

An application of the white light interferometry technique has been developed for measuring the thickness of thin films. The technique is used in the development of sliders which serve as carriers for the magnetic transducers (read/write elements) that operate in close proximity to magnetic disks. With the proper design of a surface contour and the applied load on the slider, a self-acting air bearing is created under the slider due to the boundary layer existing on a rotating disk.

To evaluate the performance of these sliders, parameters such as surface contour and steady-state slider-to-disk spacing must be determined. Since these parameters have a magnitude of only a few wavelengths of visible light, a light interference technique was chosen for their measurement. Conventionally, measurements of this kind are made with monochromatic light. However, when measurement magnitudes are less than $1\text{ }\mu\text{m}$, the resolution of white light interferometry surpasses that of the monochromatic technique.

The white light interference pattern is a continuous color spectrum instead of the dark and bright fringes of the monochromatic technique. For a film thickness of less than $1\text{ }\mu\text{m}$ these colors can be identified to a resolution of $0.05\text{ }\mu\text{m}$, as compared with 0.15 to $0.20\text{ }\mu\text{m}$ for the visible monochromatic fringes of the technique currently applied to the measurement of these parameters.

Removal of Numerical Instability in the Solution of Nonlinear Heat Exchange Equations by J. W. White, p. 277.

Current relaxation methods used by most large-scale thermal-computation programs for solving steady-state temperature distributions are subject to numerical instability when radiation is present in the system under study. The instability is usually due to the linearization of the numerical formulation of the governing equations and manifests itself as an oscillatory or divergent solution. A new method of solution is presented, which takes advantage of the diagonal dominance of the coefficient matrices of the linear and nonlinear transfer modes and uses a Gauss-Seidel system relaxation method together with a Newton-Raphson root-evaluation technique. System solution appears similar to that for a diagonally dominant linear system for all magnitudes of radiation. Test cases show the method to be monotonically convergent over the entire range of the radiation parameter considered, while previous methods were found to fail at certain magnitudes of the nonlinear term.

Design and Fabrication of Heat Transfer Surfaces from Superplastic Material by J. B. Randolph and F. K. King, p. 283.

The production of complex heat transfer surfaces (i.e., those without straight fins) is restricted by available fabrication techniques, materials, geometries, and cost. Based on the superplastic sheet thermoforming process, a new technique for fabricating these complex surfaces by a relatively simple, low cost process has been developed. The resulting surfaces have excellent heat transfer characteristics and can be used in a wide variety of applications. Surface design is discussed, and heat transfer and flow friction test data on various surface patterns are presented. The application of these results to unique design situations is demonstrated and particular examples are discussed.

Stationary Temperature Profiles and Heat Flux Distribution in a Plastic-encapsulated Circuit Package by J. A. Paivanas, p. 292.

Thermal characteristics that are important to structural integrity are analyzed herein for a TTL, plastic-encapsulated package. By assuming that total module heat during operation is engendered at idealized junctions between lead wires and the chip surface, an analysis of its dissipation has been undertaken to determine internal steady-state temperature profiles and heat flux distribution. Based on junction heat sources of equal strength and on certain adiabatic assumptions, the multi-wire package has been modeled as a single-wire "composite" incorporating postulated heat dissipation mechanisms in representative plastic-to-wire and chip-to-lead frame thermal circuits. These circuits are treated, respectively, by axisymmetric and one-dimensional analyses. Instead of a partial differential equation approach in the former treatment, a less complicated method is devised which leads to characterization by a pair of linear ordinary differential equations. Their closed-form solution gives expressions for calculating two-dimensional temperature profiles and heat flux fractions. The resultant

analyses are applied to a module containing 14 lead wires and operating at a given power level. The plastic and wire temperature profiles are seen to be nonlinear in the neighborhood of the chip surface and to coalesce axially into a common, essentially linear form in the outlying regions of the module. Constituent heat fluxes are also calculated for each thermal circuit, and some implications of the overall results to thermal stress are qualitatively discussed.

Analytical and Experimental Thermal Analysis of Multiple Heat Sources in Integrated Semiconductor Chips by R. D. Lindsted and D. A. DiCicco, p. 303.

Because of the complexity and interconnection density of today's integrated circuit chips, experimental measurement of individual transistor or diode junction temperatures under typical powered conditions has become increasingly difficult. In order to provide meaningful thermal data, other approaches have had to be devised. In the work described by this paper, an analytical model has been used to determine the steady state junction temperature rise on an integrated circuit chip. The effect on junction temperature of heat source size, geometry, and number of adjacent heat sources has been studied. Experimental testing on specially prepared chips has verified the analytical results.

Monitoring Microinch Displacements in Ultrasonic Welding Equipment by F. J. Crispi, G. C. Maling, Jr., and A. W. Rzant, p. 307.

This communication describes two non-contacting techniques for dynamic measurement of high frequency microinch displacements, which have been applied in monitoring the dynamic displacement of the magnetostrictive transducer system used in ultrasonic welding. One technique consists of a light reflecting scheme that uses a fine fiber optic probe. The probes are available in a range of sizes and, in general, can be used to measure displacements of from zero to 0.030 in. at low frequencies and from 5 to 5000 μ in. at any frequency below 100 kHz. The second method, an acoustical technique, leads to results similar to those obtained with the reflective system and can be used with a 0.030-inch diameter acoustic probe; this technique has been used in a frequency range well above that usually associated with probe tube measurements.

Design Considerations for a Magneto-optic Cryogenic Film Memory by A. M. Patlach, p. 313.

It has been shown that certain materials, because of their ability to rotate the polarization vector of plane polarized light, can be applied to very large data-stores. One such material (iron-doped europium oxide) requires an operating temperature below 100 K. To produce an experimental device with superior cost/performance, a rotating disk file configuration was chosen. In developing this machine there were many unique demands placed on bearing technology, vacuum technology and system configuration. These and some material considerations, as well as the novel engineering features, will be described.

Preface: Mathematics of Numerical Computation by *S. Winograd*, p. 334.

A-stable, Accurate Averaging of Multistep Methods for Stiff Differential Equations by *W. Liniger and F. Odeh*, p. 335. Several low-order numerical solutions of stiff systems of ordinary differential equations are computed by repeated integration, using a multistep formula with parameters. By forming suitable linear combinations of such solutions, higher-order solutions are obtained. If the parameters are properly chosen the underlying solutions, and thus the higher-order one, can be made A-stable and strongly damping with respect to the stiff components of the system. A detailed description is given of an algorithmic implementation of the method, which is computationally efficient. Numerical experiments are carried out on some test problems, confirming the validity of the method.

Hopscotch Difference Methods for Nonlinear Hyperbolic Systems by *A. R. Gourlay and J. L. Morris*, p. 349. In a recent series of papers, one of the authors has developed and demonstrated properties of a computational algorithm for solving partial differential equations. This process, known as the hopscotch algorithm, has been studied particularly with reference to the efficient integration of parabolic and elliptic problems. In the present paper attention is directed to the application of the technique to the numerical integration of first-order nonlinear hyperbolic systems. While maintaining the properties of the hopscotch process as applied to parabolic problems, it is shown that one of the novel schemes generated by this approach has an added bonus, namely, maximum stability for a variable choice of damping or pseudoviscous term. This property should be of particular value in the solution of problems with shocks. A class of hopscotch Lax-Wendroff schemes is also studied.

Parallel Shooting Method for Boundary-value Problems: Application to the Neutron Transport Equation by *J. Canosa and H. R. Penafiel*, p. 354. A direct method is given for the solution of the spherical harmonics approximation to the Boltzmann equation for neutron transport in slab geometry. The roundoff instability of the problem is eliminated by performing linear transformations of the matrices involved, which ensure that the matrix columns are linearly independent. The novelty of the method lies in that only a minimum number of matrix transformations is performed, the precise number being determined dynamically, efficiently, and in a new way by the program itself in the course of the computation.

Finite Difference Formulas for Neumann Conditions on Irregularly Shaped Boundaries by *L. E. Alsop and A. S. Goodman*, p. 365. A method, based on finite element techniques, is described for obtaining finite differences for Neumann conditions on irregularly shaped boundaries. The

resultant difference equations may be used in both time-dependent and -independent problems. As an example, the propagation of an elastic surface wave (Rayleigh wave) around a 90° corner is studied. The results of this simulation compare favorably with laboratory experiments.

Turán Formulae and Highest Precision Quadrature Rules for Chebyshev Coefficients by *C. A. Micchelli and T. J. Rivlin*, p. 372. Expansions of functions in series of Chebyshev polynomials are frequently used in numerical analysis. The coefficients occurring in the expansion are definite integrals; the purpose of this paper is to investigate numerical integration formulae for the coefficients of highest degree of precision.

Automatic Computation of Exponentials, Logarithms, Ratios and Square Roots by *T. C. Chen*, p. 380. It is shown how a relatively simple device can evaluate exponentials, logarithms, ratios and square roots for fraction arguments, employing only shifts, adds, high-speed table lookups, and bit counting. The scheme is based on the cotransformation of a number pair (x, y) such that the $F(x, y) = f(x_0)$ is invariant; when x is driven towards a known value x_0 , y is driven towards the result. For an N -bit fraction about $N/4$ iterations are required, each involving two or three adds; then a termination algorithm, based on an add and an abbreviated multiply, completes the process, for a total cost of about one conventional multiply time. Convergence, errors and simulation using APL are discussed.

Enveloping an Iteration Scheme by *W. L. Miranker*, p. 389. The problem of determining the optimal values of relaxation parameters for a linear iteration is solved. The optimal iteration scheme is achieved by a second-order linear iteration method.

Numerical Properties of a Multivariate Ritz-Trefftz Method by *W. E. Bosarge, Jr. and C. L. Smith*, p. 393. In this paper the numerical properties of the Ritz-Trefftz algorithm are discussed in the context of the numerical approximation to the linear parabolic regulator problem using multivariate splines. The algorithm is first derived in the problem context and the resulting linear algebraic system is discussed. Such properties as definiteness and band structure are treated. The algorithm is applied to a number of sample control problems, and it is shown that the method yields efficient and highly accurate continuous approximations to the solutions of the selected sample problems. Computer implementation of the general algorithm is also discussed.

Recursive Evaluation of Padé Approximants for Matrix Sequences by *J. Rissanen*, p. 401. An algorithm is described for calculating the existing Padé approximants to any sequence $A_0, A_1, \dots$ of $s \times t$ -matrices. As an application the algorithm gives a new way for finding the minimal polynomial of any square matrix A and the inverse of the characteristic matrix $xI - A$.

On the Convergence of Gradient Methods under Constraint by P. Wolfe, p. 407. The mathematical programming problem discussed is the convergence of a certain popular type of gradient procedure for maximizing a function under inequality constraints. An example shows that convergence to a solution need not always occur, and a theorem shows that under certain circumstances the gradient method does converge.

Finding All Shortest Distances in a Directed Network by A. J. Hoffman and S. Winograd, p. 412. A new method is given for finding all shortest distances in a directed network. The amount of work (in performing additions, subtractions, and comparisons) is slightly more than half of that required in the best of previous methods.

Maintaining a Sparse Inverse in the Simplex Method by J. A. Tomlin, p. 415. Improved methods are discussed for handling sparse matrices in practical linear programming. An analytical comparison is made of four methods for updating the inverse in the iterations following a reinversion. Of these, one technique using the elimination form of inverse is selected for some computational experiments and its advantages in terms of speed and sparseness demonstrated.

Mixed-integer Algorithms for the (0,1) Knapsack Problem by M. M. Guignard and K. Spielberg, p. 424. An enumerative scheme is presented for the (0,1) knapsack problem as a specialization of the state enumeration method. Techniques are explored for rendering search procedures more efficient by systematic use of information generated during execution of the algorithm. The inequalities of Benders and Gomory-Johnson are exploited to yield implicit enumeration tests in the special case of the knapsack problem. In a comparative study of eight algorithms and of the utility of certain approximations and inequalities, computational results are given for twelve knapsack problems, each having ten (0,1) variables. The effectiveness of these enumerative algorithms are thus tested in a relatively simple framework.

Linear Convergence of the Conjugate Gradient Method by H. P. Crowder and P. Wolfe, p. 431. There are two procedures for applying the method of conjugate gradients to the problem of minimizing a convex, nonlinear function: the "continued" method, and the "restarted" method in which all the data except the best previous point are discarded, and the procedure is begun anew from that point. It is demonstrated by example that in the absence of the standard initial starting condition on a quadratic function, the continued conjugate gradient method will converge to the solution no better than linearly. Furthermore, it is shown that for a general nonlinear function, the nonrestarted conjugate gradient method converges no worse than linearly.

On the Davidenko-Branin Method for Solving Simultaneous Nonlinear Equations by R. P. Brent, p. 434. It has been conjectured that the Davidenko-Branin method for

solving simultaneous nonlinear equations is globally convergent, provided that the surfaces on which each equation vanishes are homeomorphic to hyperplanes. We give an example to show that this conjecture is false. A more complicated example shows that the method may fail to converge to a zero of the gradient of a scalar function, so the associated method for function minimization is not globally convergent.

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Combinatory Programming and Combinatorial Analysis by W. H. Burge, p. 450. The principal purpose of this paper is to illustrate by means of simple examples a technique for deriving programs and generating functions from set descriptions. The paper discusses certain interesting correspondences among types of trees, which follow from the use of the technique, and it demonstrates close connections between programming techniques and some aspects of combinatorial theory.

Recursive Computational Procedure for Two-dimensional Stock Cutting by J. C. Herz, p. 462. A recursive algorithm is implemented to give high computational speeds in the solution of a cutting-stock problem. Optimal edge-to-edge cutting is shown to be achieved more easily by recursive programming than by conventional methods. The technique features preliminary discretization, which lowers the memory requirements in the computational procedure. A comparison is made between this recursive algorithm and two iterative algorithms previously given by Gilmore-Gomory. The limitations of the algorithms are discussed and some numerical results given.

Inductance Calculations in a Complex Integrated Circuit Environment by A. E. Ruehli, p. 470. This paper describes a method for calculating multiloop inductances formed by complicated interconnection conductors. Knowledge of these inductances leads to useful information concerning the design of such systems. In the approach pursued here, the conductor loops are divided into segments for which so-called partial inductances are calculated. The partial inductances are then appropriately added to yield the desired loop inductance.

Existence and Uniqueness of the Solution to Holland's Equations for a Class of Multicolumn Distillation Systems by D. S. Billingsley, p. 482. The Holland equations for a multiunit system of distillation columns, interconnected so as to contain recycle loops, can be expressed as a matrix generalization of the Holland equations for a single complex column. Proof of the existence and uniqueness of a positive solution for the single-column case has previously been given. In this paper a proof is given for the case of a multiunit system containing one recycle loop.

Compiling Optimized Code from Decision Tables by H. J. Myers, p. 489. This paper reviews the structure of decision

tables and methods for converting them into procedural code. It describes new optimization methods, which are applied before, during, and after code generation. Some results from an experimental decision table processor are provided.

Widely Convergent Method for Finding Multiple Solutions of Simultaneous Nonlinear Equations by *F. H. Branin, Jr.*, p. 504. A new method has been developed for solving a system of nonlinear equations $g(x) = 0$. This method is based on solving the related system of differential equations $dg/dt \pm g(x) = 0$ wherein the sign is changed whenever the corresponding trajectory $x(t)$ encounters a change in sign of the Jacobian determinant or arrives at a solution point of $g(x) = 0$. This procedure endows the method with a much wider region of convergence than other methods (occasionally, even global convergence) and enables it to find multiple solutions of $g(x) = 0$ one after the other. The principal limitations of the method relate to the extraneous singularities of the differential equation. The role of these singularities is illustrated by several examples. In addition, the extension of the method to the problem of finding multiple extrema of a function of N variables is explained and some examples are given.

Detection of Discontinuities in Passivating Layers on Silicon by NaOH Anisotropic Etch by *I. J. Pugacz-Muraszkiewicz*, p. 523. Discontinuities in glasses deposited on silicon substrates are readily detected by a silicon-preferential etch that uses single component alkali solutions. The etchants can be applied to thermally grown oxide films, pyrolytically-deposited passivating layers or sputtered quartz. The character of the discontinuities in these films is shown and the size can be estimated (although both observations are subject to the limitations of the optical tools used for observation or micrography). When applied in the temperature range below $+70^{\circ}\text{C}$, the etchant attacks the oxides insignificantly and the concentration, as well as the temperature, is chosen for convenience. Above $+70^{\circ}\text{C}$ the passivating layers, particularly thermal SiO_2 , are etched at higher rates, and the etching effects must be taken into account if the oxide thickness is less than $1000 \text{ \AA}$. The etchants are applicable to intrinsic as well as extrinsic silicon up to a doping level of 10^{20} cm^{-3} .

Nuclear Backscattering Analysis of Nb-Nb₂O₅-Bi Structure by *J. F. Ziegler, M. Berkenblit, T. B. Light, K. C. Park, and A. Reisman*, p. 530. The technique of nuclear backscattering has been used to analyze the interface reactions of Nb-Nb₂O₅-Bi multilayer films. This new analytical technique is explained in detail. It has been concluded that the drastic and erratic changes in the electrical properties of niobium oxide switchable resistor devices that take place at 450°C are associated with the gross migration of oxygen from the oxide to the niobium layer. The accompanying reactions of bismuth with the oxide are relatively moderate, diffusing less than $3 \times 10^{11} \text{ atoms/cm}^2$ of bismuth into the oxide layer.

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Theory on the Speed of Convergence in Adaptive Equalizers for Digital Communication by *G. Ungerboeck*, p. 546. This paper presents an analysis of the convergence properties of adaptive transversal equalizers minimizing mean-square distortion. The intention is to reveal the influence on the speed of convergence exerted by the number of taps, the step-size parameter in the adjustment loops, and the spectrum of the unequalized signal. Attention is focused on the convergence of the expected mean-square distortion. Several approximations are made in the analysis, among them the approximation of higher-order statistics by second-order statistical parameters. Comparison with results obtained by computer simulation, however, shows that the theory developed renders a quite accurate picture of the convergence process.

Previous work in this field demonstrated the limits set to the speed of convergence by the extreme values of the power spectrum of the unequalized signal. It is shown here that, with regard to the mean-square distortion, the influence of the number of taps will usually dominate by far. The theory provides a simple criterion for convergence and answers the question of how to attain the fastest convergence.

A New Class of Automatic Equalizers by *R. T. Sha and D. T. Tang*, p. 556. A new class of automatic equalizers with very fast convergence is discussed in this paper. This fast convergence is accomplished by means of an iterative procedure which successively makes higher-order approximations on the desired equalizer function. The iterative procedure can be conveniently realized in the form of transversal filter stages in cascade. For a given distortion $D < 1$, the residual distortion at the equalizer output after n iterations can be reduced to no more than D^{2^n} in the noise-free cases. When this approach is applied to the feed-forward part of a recursive structure, the front distortion (due to precursors) can be reduced in a similar fashion without unduly increasing the overall distortion. The resulting distortion, mainly in the rear end, can then be cancelled out via feedback paths. Other topics treated include certain generalizations, the truncation error due to limited length in cascaded equalizer sections, and the effect of noise. Several numerical examples are also presented to illustrate the effectiveness of the approach.

Computational Model of a Closed Queuing Network with Exponential Servers by *F. R. Moore*, p. 567. A simplification and extension to Gordon and Newell's approach to closed queuing networks is derived. The equations, valid for exponential servers, with one server being a multiserver, greatly reduce the computation time required by the former approach. In addition, simplified equations for the details of the queuing network are derived.

Exact Implicit Enumeration Method for Solving the Set Partitioning Problem by *P. Michaud*, p. 573. The

partitioning problem may be stated as follows: Minimize $\sum_{j=1}^m c_j x_j$ subject to $\sum_{j=1}^m a_{ij} x_j = 1, i = 1, \dots, m,$

where a_{ij} and x_j are binary numbers.

The proposed method consists in solving a new problem equivalent to the original one, the solution of this new problem being obtained by implicit enumeration. Computational experience indicates that this approach yields good results; for example, problems involving several hundred variables were solved in a few seconds.

Optimum Storage Allocation for Initial Loading of a File

by J. A. van der Pool, p. 579. When a file is loaded into a direct access storage device using key-to-address transformations, the number and size of storage blocks can be selected. In this study, a selection that minimizes the combined cost of storage space and accesses to the storage device is determined for the case where no record additions or deletions occur after loading.

The analysis is based on the assumption that for a given set of keys, a transformation exists that gives a uniform probability distribution over the available addresses. Under this assumption, formulas are derived for the average number of overflow records and for the average number of accesses required to retrieve a record.

Given these formulas, the costs are expressed as a function of storage used, number of accesses, cost per unit of storage, and cost per access. Minima are computed for a range of block sizes and operational conditions. The results seem to indicate that current file design practices are abundant with storage space.

Finally, the results are condensed in an easy to use approximate formula.

Magnetic Bubble Memory Organization

by W. F. Beausoleil, D. T. Brown, and B. E. Phelps, p. 587. Magnetic bubbles offer promise of data storage at a lower cost than is possible using semiconductor technologies. However, a memory using magnetic bubbles is most economically implemented in the form of long shift registers, rather than as a random access storage device. This plus a lower shift rate than is possible with semiconductors suggests relatively long average access times. This shortcoming is largely overcome by an organizational technique called dynamic ordering, which can reduce the average number of shifts needed to access data. A dynamically ordered magnetic bubble memory, when combined with one or more smaller semiconductor

memories in a hierarchy, should provide both large capacity and good performance with reasonable economy.

Development of Water-soluble Systems for Use in Industrial Soldering Processes

by P. W. H. Schuessler, R. M. Poliak, and H. G. Peters, p. 592. This communication discusses the engineering considerations involved in the design of low-polluting water-soluble systems for use in mechanized soldering processes. New formulations for water-soluble fluxes, lubricants, and solder masks are described and test data are presented.

Charge Transfer Complex Formation of Trinitrofluorenone with Polyvinylcarbazole and Ethylcarbazole

by G. Weiser and H. Seki, p. 598. The molar absorption constants of the charge-transfer complexes of PVCz:TNF and of ethylcarbazole:TNF and the respective equilibrium constants for the formation of these complexes in a tetrahydrofuran solution have been determined by absorption measurements. Both materials exhibit two charge-transfer absorption bands. It is shown that these two bands correspond to two transitions of only one charge-transfer complex rather than to two complexes with different geometrical configurations of donor and acceptor molecules. For the PVCz:TNF complex the equilibrium constant is determined as $K = 0.5$ l/mole, which is much smaller than the value $K = 3.05$ l/mole found for the complex of ethylcarbazole and TNF.

Multiconductor Transmission-line Theory in the TEM Approximation

by W. T. Weeks, p. 604. Starting with Maxwell's equations, the transmission line equations are derived for a system consisting of an arbitrary number of conductors. The derivation is rigorous for long lossless conductors embedded in a uniform perfect dielectric. The presentation is essentially tutorial, most of the results being well known, at least for two- and three-conductor systems. The novelty lies in the point of view adopted in obtaining a systematic generalization to the case of an arbitrary number of conductors. Explicit expressions are obtained for the electric and magnetic fields in the dielectric surrounding the conductors, and a rigorous formulation is given for the problem of calculating the coefficients of capacitance and inductance.

Solution of the Complete Symmetric Eigenproblem in a Virtual Memory Environment

by A. A. Dubrulle, p. 612. Algorithms for the complete symmetric eigenproblem are studied from the viewpoint of performance in a virtual memory environment. The preferred algorithm is based on tridiagonalization and the implicit QR algorithms. Implementation factors that affect execution time are discussed.

Steady State Mathematical Theory for the Insulated Gate Field Effect Transistor by D. P. Kennedy and P. C. Murley, p. 2. A two-dimensional mathematical analysis is presented of the mechanisms of operation for an insulated gate field effect transistor (IGFET). Included in this analysis are qualitative and quantitative comparisons between conventional one-dimensional theory and a rigorous two-dimensional computer solution for the IGFET. It is shown that many characteristics of device operation deduced from conventional theory cannot be verified on a two-dimensional basis because of mechanisms not presently taken into consideration by the theory. A modified one-dimensional mathematical theory is therefore proposed, to account for these mechanisms, that is in adequate agreement with a rigorous two-dimensional computer solution for this semiconductor problem.

Computer Interference Analysis by W. Chang, p. 13. This paper describes a single-server queuing model with Erlang input, which can be used for computer congestion analysis. The model is intended primarily for small computer systems in which the CPU is needed for input/output operations, which aggravates the interference problem.

The model provides such information as the queuing time distribution for channel requests and the CPU delay due to channel interference. The model is illustrated by numerical examples, and procedures for the analysis are shown.

Optimum Storage Allocation for a File in Steady State by J. A. van der Pool, p. 27. A file of fixed-length records in auxiliary storage using a key-to-address transformation to assign records to addresses is considered. The file is assumed to be in steady state, that is that the rates of additions to and of deletions from the file are equal.

The loading factors that minimize file maintenance costs in terms of storage space and additional accesses are computed for different bucket sizes and different operational conditions.

Transport Properties of the Semiconductor Superlattice by P. J. Price, p. 39. Precise calculations have been made, by Monte Carlo methods, of electron transport properties of the Esaki superlattice. The calculations were on a single-particle space-homogeneous basis, with a model of the superlattice which could be reasonably close to reality. Steady-state longitudinal drift-velocity/field characteristics were obtained, for four sets of parameter values; they exhibited the expected maximum followed by negative differential mobility. The accompanying variations of the longitudinal and transverse energy averages were also obtained, and the distribution functions for longitudinal wavevector and transverse energy were investigated. The frequency dependences of the differential mobilities (in-phase and out-of-phase components) were obtained in some representative cases; they exhibited a "Bloch resonance."

Age-specific, Deterministic Model of Predator-Prey Populations: Application to Isle Royale by D. C. Gazis, E. W. Montroll, and J. E. Ryniker, p. 47. A deterministic model is proposed for the description of predator-prey systems in which the prey has an age-specific vulnerability to predation. The model is developed on the basis of observations of the moose and wolf populations of Isle Royale, Michigan. The moose are divided into three groups, the very young, the adults, and the very old or sick. The three groups have different vulnerability to predation by a single population of wolves. The model incorporates a saturation effect for the moose population and a satiation effect for the wolf population. It appears to reproduce quite well the almost monotonic trend toward equilibrium observed since the arrival of wolves on the island.

Digital-to-analog Converter having Common-mode Isolation and Differential Output by G. A. Hellwarth and S. Boinodiris, p. 54. A digital-to-analog converter (DAC) is described that has transformer-coupled isolation for both power and data inputs and provides a true differential output. The DAC provides a 10-bit, 10.23-V unipolar output of either polarity, depending on which of the two output lines is used as the load reference potential. The common-mode potential may be as large as 250 V, and below 120 Hz the common-mode rejection typically exceeds 100 dB. The isolated, balanced circuit eliminates environmental noise problems and permits long cabling lengths without loss of dc accuracy. The DAC is an analog output feature available on the IBM System/7, a small computer designed for data acquisition and real-time automation applications.

An AlN Switchable Memory Resistor Capable of a 20-MHz Cycling Rate and 500-picosecond Switching Time by R. F. Rutz, E. P. Harris, and J. J. Cuomo, p. 61. We report here the operational characteristics of multistable resistance switching devices made from thin sputtered layers of AlN. These devices exhibit switching between high and low resistance states when proper electrical signals are applied. Repetitive switching at 20-MHz rates has been achieved, and switching times in the best units have been observed to be less than 500 picoseconds. These are believed to be the first active electronic switching devices to be reported utilizing AlN.

Amorphous Metallic Films for Bubble Domain Applications by P. Chaudhari, J. J. Cuomo, and R. J. Gambino, p. 66. We have found that sputtered amorphous films of Gd-Co and Gd-Fe have perpendicular magnetic anisotropy. The demagnetized domain configuration consists of stripe domains, and bubble domains were nucleated in an applied field. By controlling the sputtering conditions, films with a wide variety of magnetic properties were obtained.

APLGOL, an Experimental Structured Programming Language by R. A. Kelley, p. 69. An experimental programming language called APLGOL adds structured

programming facilities to the existing framework of APL. The conventional semantics of APL is unaltered and only minor changes are incorporated in the syntax. The advantages of the proposed interstatement structuring and control are outlined.

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Empirically Derived Micromodels for Sequences of Page Exceptions by P. A. W. Lewis and G. S. Shedler, p. 86. Based on a statistical analysis of actual computer program address traces, some results are presented of a study aimed at deriving empirically valid stochastic models for program reference patterns in a computer system operating under demand paging. For the address traces examined, a semi-Markov model for the (univariate) point process of page exceptions is formulated and found to be an adequate characterization of the data.

Bounds for Weight Balanced Trees by J. Rissanen, p. 101. It has been shown that the cost W of a weight balanced binary tree satisfies the inequalities, $H \leq W \leq H + 3$, where H is the entropy of the set of the leaves. For a class of "smooth" distributions the inequalities, $H \leq W \leq H + 2$, are derived.

These results imply that for sets with large entropy the search times provided by such trees cannot be substantially shortened when binary decisions are being used.

Optimum Storage Allocation for a File with Open Addressing by J. A. van der Pool, p. 106. File organizations utilizing key-to-address transformation and open addressing are studied. A simulation method and a Markov model, which were used for evaluation, are presented. The cost of retrieval as a function of storage space and accesses is also formulated. The minimum of the combined costs for different operational conditions is determined.

Quasimaximum Likelihood Estimators for Two-parameter Gamma Distributions by E. W. Stacy, p. 115. The Gamma probability distribution is defined by the density function $[\beta^\alpha \Gamma(\alpha)]^{-1} \exp(-x/\beta)$. This paper presents new estimators for the parameters α^{-1} and β . Required calculations are simple, primarily involving the inner product of certain elementary statistics and their logarithms. Both of the new estimators are shown to be unbiased. The variance formulas for each and their covariance formula are derived—counterparts of these for the method of moments (MM) and the method of maximum likelihood (ML) not being known except in the asymptotic form. Curve-fitting results from samples of size 50 are provided. They support the proposition that the new quasimaximum likelihood estimators (QML) are at least as effective as MM and ML estimators. Illustrative estimation based on samples of size 5 also is presented for comparison; the results highlight relative smaller variances for the ML estimators. The same Monte Carlo

results signal a possibility that significant negative bias occurs with both the MM and ML techniques if small samples are used.

Theory of MNOS Memory Device Behavior by A. V. Ferris-Prabhu, p. 125. This paper extends the direct-tunneling theory of MNOS memory device behavior to account for traps that are distributed both spatially and energetically. It shows that the Pulver and Dorda model is a special case of the Ross and Wallmark model, which is itself a restricted version of the more general theory proposed here.

A general equation for the total charge transfer is derived, for monoenergetic and for energetically uniform trap distributions, for high fields as well as low fields. The theory predicts the time dependence of the total charge transfer to be initially linear, then roughly logarithmic, and finally to reach saturation. There is no essential difference in the results whether the trap distribution is monoenergetic or energetically uniform. The operational dependence on characteristic parameters is investigated and found to be greatest for changes in the extent of spatial distribution of traps. The switching time varies inversely with trap density and tunnelling probability, and exponentially with the oxide thickness.

Axioms and Theorems for a Theory of Arrays by T. More, Jr., p. 135. Array theory combines APL with set theory, transfinite arithmetic, and operationally transformed functions to produce an axiomatic theory in which the theorems hold for all arrays having any finite number of axes of arbitrary countable ordinal lengths. The items of an array are again arrays. The treatment of ordinal numbers and letters is similar to Quine's treatment of individuals in set theory. The theory is developed first as a theory of lists.

This paper relates the theory to the eight axioms of Zermelo-Fraenkel set theory, describes the structure of arrays, interprets empty arrays in terms of vector spaces, presents a system of axioms for certain properties of operations related to the APL function of reshaping, deduces a few hundred theorems and corollaries, develops an algebra for determining the behavior of operations applied to empty arrays, begins the axiomatic development of a replacement operator, and provides an informal account of unions. Cartesian products, Cartesian arrays, and outer, positional, separation, and reduction transforms.

Automatic Equalizers having Minimum Adjustment Time by M. Karnaugh, p. 176. Two new types of automatic equalizers for telephone lines are discussed. The modular configurations shown are designed for minimum adjustment time and are ready to receive data as soon as the response of the unequalized line has been measured. Two forms of such equalizers are compared with respect to upper bounds on the residual distortion.

Comparison of Two Methods of Modeling Stationary EEG Signals by *T. Bohlin*, p. 194. This paper compares the performances—when applied to stationary EEG signals—of two methods of modeling stochastic time-series; viz, a maximum-likelihood search method for a mixed autoregressive and moving-average time-series, and the well-known method of least-squares identification of a prefiltered autoregressive series. Computing effort per step is derived for different-order search strategies, expressed in the number of a set of basic operations and also in equivalent number of likelihood function evaluations. Power spectra and total computing effort are evaluated and compared for four representative EEG samples. It appears that the least-squares method is generally superior because iteration is not needed, and in spite of the fact that higher orders are needed instead.

X-ray Image Subtraction by Digital Means by *C. K. Chow, S. K. Hilal, M.D., and K. E. Niebuhr*, p. 206. A conventional method of removing unwanted background information from radiographic images is to use photographic techniques. An alternative approach is the digital processing of x-ray difference images. This approach offers the advantage over photographic methods in that it permits the performance of nonlinear operations, such as compensation for film characteristics, thus offering greater flexibility in the presentation of x-ray images and greater reliability in their interpretation. This paper describes the features and implementation of a new digital approach and presents experimental results obtained from processing two sets of angiograms.

Action Potential of the Motorneuron by *F. A. Dodge, Jr. and J. W. Cooley*, p. 219. The excitability of various regions of the spinal motorneuron can be specified by solving the partial differential equation of a nerve fiber whose diameter and membrane properties vary with distance. For our model geometrical factors for the myelinated axon, initial segment and cell body were derived from anatomical measurements, the dendritic tree was represented by its equivalent cylinder, and the current-voltage relations of the membrane were described by a modification of the Hodgkin-Huxley model that fits voltage-clamp data from the motorneuron. In order to compute spike waveforms that match experimental observations, 1) the dendritic membrane must be inexcitable, 2) the voltage threshold of the initial segment of the axon must be ten millivolts lower than that of the cell body, and 3) the density of sodium conductance in the initial segment must be ten times greater than in a typical unmyelinated axon.

Identifying and Understanding Patterns and Processes in Human Shock and Trauma by *R. M. Goldwyn, E. J. Farrell, H. P. Friedman, M. Miller, and J. H. Siegel, M.D.*, p. 230. The aim of this paper is to provide an overview of an on-going collaborative effort of research physicians, computer

scientists, and statisticians to develop a quantitative way of understanding the clinical course of a critically ill and injured patient. The method is based on a multivariable analysis of time series of individual physiologic measurements. The ultimate goal is to reduce a large body of complex physiologic data to an information base that is relatively small and simple so that abnormal patterns may be exposed in a manner that can be directly interpreted and utilized at the bedside by the attending clinician to improve patient care. In this paper we describe some contributions made toward reaching this goal.

Performance of Very High Density Charge Coupled Devices by *N. A. Patrin*, p. 241. The results of an experimental study of the performance of very high density 8, 128, and 256 bit CCD shift register structures are presented. The primary topics discussed include transfer efficiency, frequency response, impact of "fat zero" operation, and observed temperature dependency.

Theory and Computer-aided Analysis of Lossless Transmission Lines by *C. W. Ho*, p. 249. A theoretical analysis of coupled and uncoupled lossless transmission lines is presented. A new method for deriving the conductance matrix *G* is described. Networks containing such lines have been simulated in the time domain and some results obtained from simulation of two example networks are given.

Refractive Index Dispersion in Semiconductor-related Thin Films by *A. J. Warnecke and P. J. LoPresti*, p. 256. A technique is described for determining refractive index dispersion throughout the uv-visible spectrum in semiconductor-related transparent thin films. The dispersion constants that have been measured can be used in the design of optical systems and in photolithography. Measurements were made with the LASER-VAMFO interferometer. Calculations and analyses are also described which show the accuracy and repeatability of the technique. Data were taken for 28 different thin-film materials, and representative refractive index dispersion curves are shown for some of them. The dispersion constants for each material evaluated are also presented.

Experimental Study of Deadline Scheduling for Interactive Systems by *D. D. Chamberlin, H. P. Schlaeppli, and I. Wladawsky*, p. 263. This paper outlines a resource allocation strategy called deadline scheduling, which is intended for use in interactive systems. Experiments are reported in which simplified versions of deadline scheduling and two time slicing strategies are modeled and compared under identical conditions. Results suggest that deadline scheduling, primarily by reducing paging overhead, provides faster response and supports more interactive users concurrently than do the two time slicing methods.

Asymptotic Expansion for Small Magnetic Fields of Acoustoelectric Attenuation in Nondegenerate Semiconductors by *J. S. Lew*, p. 270. The semiclassical

analysis of acoustoelectric effects involves an infinite sum

$$S(c,x) = ic \exp(-x) \sum_{n=-\infty}^{\infty} (n+ic)^{-1} I_n(x),$$

in which both arguments c and x depend on the magnetic field B . Recently Lebwohl, Carlson, and Mosekilde have found an integral representation for this sum, through which now we identify $S(c,x)$ as a generalized hypergeometric function. Moreover we derive an asymptotic series for $S(c,x)$ in the limit of small B , whose coefficients, in a parameter z , involve the iterated integrals of the complementary error function.

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Numerical Calculation of Self-Focusing and Trapping of a Short Light Pulse in Kerr Liquids by *F. Shimizu*, p. 286. Self-focusing and trapping of an intense, short light pulse is discussed on the basis of a parabolic scalar wave equation which includes a quadratic nonlinear refractive index. When the finite relaxation time of the nonlinear index is taken into account, the propagation properties of the transient solution differ considerably from those of the time-independent solution. Based mainly on the results of our numerical calculations, we show that contraction of the self-focusing pulse stops at a finite radius and that part of the pulse remains trapped beyond this focal point. The limiting radius decreases rather rapidly with increasing input power as well as with pulse width. However, if we assume a cutoff radius, the resulting filament accounts for experiments performed with multimode lasers. Effects of stimulated Raman scattering and dispersion are also discussed.

Effects of Dispersion on Steady State Electromagnetic Shock Profiles by *S.-T. Peng and R. Landauer*, p. 299. In nonlinear electromagnetic media the various portions of a wave can travel with different velocities, which can result in the formation of electromagnetic shock waves. The structure of such a steady state shock is determined by an equilibrium between the velocity differences that tend to sharpen the shock and the sources of dispersion that cause a broadening of the shock. Several nonlinear transmission line models are examined for the nature and existence of a single-valued steady state shock. In all cases a nonlinear shunt capacitance is assumed. If the dispersion arises from the relaxation behavior caused by a resistance in series with the nonlinear capacitance, a steady shock always exists, its width decreasing as the extent of the nonlinearity generated by the shock increases. If the series resistance is itself shunted by another capacitance, the relaxation process is not manifested at very high frequencies. This system yields a critical condition for the existence of a continuous single-valued steady state wave profile. If the line has too little dispersion, the steady state profile is multivalued and therefore physically unrealizable.

These dispersion requirements are equivalent to the condition that the velocity of small, high frequency signals ahead of the shock must be greater than the velocity of the shock itself. It is believed that this condition is a broadly applicable

criterion for the existence of a stable, single-valued, steady state wave profile. While this hypothesis is not proved analytically, it is supported here by plausibility arguments and by analysis of another system in which the dispersion is included in the linear series inductance rather than in the nonlinear shunt capacitance.

On a Nonlinear Diffusion Equation Describing Population Growth by *J. Canosa*, p. 307. A nonlinear eigenvalue problem is solved analytically to obtain the shock-like traveling waves of Fisher's nonlinear diffusion equation, with which he described the wave of advance of advantageous genes. A phase-plane analysis of the wave profiles shows that the propagation speed of the waves is linearly proportional to their thickness. The analytic solution is asymptotically accurate in the limit of infinitely large characteristic speeds. However, as they have a minimum threshold value which is not zero, the asymptotic solution turns out to be highly accurate for all propagation speeds. The wave profiles of Fisher's equation are shown to be identical to the steady state solutions of the Korteweg-de Vries-Burgers equation that are obtained when dissipative effects are dominant over dispersive effects.

Linearization of Cauchy's Problem for Quadratic Semilinear Partial Differential Equations by *P. D. Gerber*, p. 314. The technique of linearization is applied to quadratic semilinear systems of n first-order partial differential equations. By introducing a related linear algebra A , we combine analytic and algebraic arguments to obtain a class of linearizable systems. We relate the coefficients of such systems to the center of A and show that, for hyperbolic systems, the ideals of A decouple the system into disjoint subsystems each having its own single wave number.

The Design of APL by *A. D. Falkoff and K. E. Iverson*, p. 324. This paper discusses the development of APL, emphasizing and illustrating the principles underlying its design. The principle of simplicity appears most strongly in the minimization of rules governing the behavior of APL objects, while the principle of practicality is served by the design process itself, which relies heavily on experimentation. The paper gives the rationale for many specific design choices, including the necessary adjuncts for system management.

General Arrays, Operators and Functions by *Z. Ghandour and J. Mezei*, p. 335. This paper discusses "general arrays," i.e., arrays in which the items are either scalars or other arrays. Functions are defined to construct, select from, restructure, and in general manipulate such arrays. Operators are presented as functions whose arguments or values are other functions that can be other than scalar functions. The exposition is shortened and simplified by presenting the material throughout in terms of APL.

System Formulation and APL Shared Variables by *R. H. Lathwell*, p. 353. The problem of providing communication

with APL programs was approached by formulating systems as collections of autonomous processors communicating on interfaces consisting of shared variables. This paper discusses the formulation of a theoretical APL system and cites experience with a prototype APL shared variable system which both uses and provides shared variable interfaces.

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Decomposition of a Data Base and the Theory of Boolean Switching Functions by C. Delobel and R. G. Casey, p. 374.

The notion of a functional relation among the attributes of a data set can be fruitfully applied in the structuring of an information system. These relations are meaningful both to the user of the system in his semantic understanding of the data, and to the designer in implementing the system. An important equivalence between operations with functional relations and operations with analogous Boolean functions is demonstrated in this paper. The equivalence is computationally helpful in exploring the properties of a given set of functional relations, as well as in the task of partitioning a data set into subfiles for efficient implementation.

Characterization of Program Paging in a Time-sharing Environment by Y. Bard, p. 387. This paper describes a method for predicting the paging behavior of a program in a virtual memory multiprogramming environment. The effect of overall system activity on the program is summarized in one parameter, the page survival index. The model correlates well with observations taken on programs running under CP-67. The model can be used for paging load prediction, simulator input verification, and evaluation of program rearrangement and sharing.

Response Time Characterization of an Information Retrieval System by H. F. Silverman and P. C. Yue, p. 394.

A methodology for computer performance evaluation based on the statistical characterization of response time is described. The results of its application to an information retrieval system are presented. The first part of the paper gives a general discussion of measurement techniques, data reduction procedures and the structure of the system being examined. A set of "system environment" parameters and a set of "job" parameters are then defined and appraised in terms of actual measurements collected over two different weekly periods. Various ways of using the statistical characterization for improving performance are then considered.

An Analysis of Page Allocation Strategies for Multiprogramming Systems with Virtual Memory by D. D. Chamberlin, S. H. Fuller, and L. Y. Liu, p. 404.

In a multiprogramming, virtual-memory computing system, many processes compete for the main storage page frames and CPU's of the real system. It is customary to define a subset of these processes called the "multiprogramming set" (MPS), and to allocate resources only to those processes currently in the MPS. Each process remains in the MPS for a limited time

and is then demoted. The system paging manager controls the size of the MPS; it allocates the available page frames among the processes in the MPS and fetches appropriate pages into the page frames.

A model is described that assumes the most critical resources of the system to be page frames and the paging channel (i.e., there is no significant CPU contention). The model makes certain assumptions about the page fault rate of processes as a function of page frames allocated, and about the page fetch time as a function of mean load on the paging channel. The model also incorporates a definition of the value of a given page allocation in terms of system throughput.

The model is used to study various strategies for choosing an MPS and allocating page frames among processes. For simple cases, the model yields an exact optimal strategy. A heuristic strategy is proposed for dealing with more complex cases, and is shown by the model to be reasonably near optimal. The heuristic strategy monitors the page fault rate of each process and chooses an allocation such that each process can be executed at a reasonable rate, while ensuring that the paging channel is neither overloaded nor underloaded.

A Decision-feedback Receiver for Channels with Strong Intersymbol Interference by H. Kobayashi and D. T. Tang, p. 413.

This paper deals with the problem of equalizing channels containing strong intersymbol interference. Typical of such channels are those of digital magnetic recording systems and data communication systems with partial-response signaling. First we discuss reasons that a conventional receiver with a linear equalizer cannot efficiently compensate for distortion in such channels. We then present a new receiver configuration in which the equalizer and quantizer are embedded in an inverse filter circuit that eliminates major intersymbol interference components. This configuration allows us to use a simple iteration algorithm to adaptively adjust the equalizer. Application of the scheme to digital magnetic recording data is discussed as an illustrative example.

Lower Bounds for the Partitioning of Graphs by W. E. Donath and A. J. Hoffman, p. 420. Let a k -partition of a graph be a division of the vertices into k disjoint subsets containing $m_1 \geq m_2, \dots, \geq m_k$ vertices. Let E_c be the number of edges whose two vertices belong to different subsets. Let $\lambda_1 \geq \lambda_2, \dots, \geq \lambda_k$ be the k largest eigenvalues of a matrix, which is the sum of the adjacency matrix of the graph plus any diagonal matrix U such that the sum of all the elements of the sum matrix is zero. Then

$$E_c \geq \frac{1}{2} \sum_{r=1}^k m_r \lambda_r.$$

A theorem is given that shows the effect of the maximum degree of any node being limited, and it is also shown that the right-hand side is a concave function of U . Computational

studies are made of the ratio of upper bound to lower bound for the two-partition of a number of random graphs having up to 100 nodes.

Dislocations in Gadolinium Gallium Garnet ($\text{Gd}_3\text{Ga}_5\text{O}_{12}$): III. Nature of Prismatic Loops and Helical Dislocations

by J. W. Matthews, E. Klokholm, and T. S. Plaskett, p. 426.

Thin garnet films suitable for magnetic bubble devices can be made by depositing the film material onto nonmagnetic garnets such as $\text{Gd}_3\text{Ga}_5\text{O}_{12}$ (GGG). The performance of these devices is influenced by the dislocation content of the films. This, in turn, depends on the dislocation content of the substrate. Dislocations in the substrate can be detected by means of the birefringence they induce, or from the etch pits formed where they meet the sample surface. Most of the dislocations revealed by these techniques have been climb loops around inclusions and helical dislocations. This paper describes an optical method for determining the sign of the stresses at inclusions and nature of loops and helical dislocations. The method has shown that iridium inclusions are compressed by the matrix and that the loops and helices in GGG are extrinsic; they grow either by the emission of vacancies or the absorption of interstitial atoms.

Design and Characteristics of n-Channel Insulated-gate Field-effect Transistors by D. L. Critchlow, R. H. Dennard, and S. E. Schuster, p. 430. An n-channel insulated-gate field-effect transistor technology established at IBM Research has served as the basis for further development leading to FET memory. Designs and characteristics of experimental devices of 500 and 1000 Å gate insulator thicknesses are presented, with particular attention to the effects of source-drain spacing.

Theory and Operation of Space-charge-limited Transistors with Transverse Injection by S. Magdo, p. 443. The development of a new device, called the space-charge-limited (SCL) transistor with transverse injection is reported in this paper. A theoretical model for space-charge-limited transistors, both npn and pnp, on high-resistivity silicon substrates is described and a quantitative analysis is given. Experimental results for SCL transistors are presented to support the model's validity. According to the model, current in SCL transistors is controlled by the base of a parallel-connected lateral transistor in two ways. First, the base of the parallel transistor controls the potential step in the high resistivity base of the SCL transistor. Second, the base of the parallel transistor injects carriers in the direction transverse to the SCL current flow. These carriers are of types opposite to those that carry the current flow in the SCL transistor and thus partly neutralize the space-charge in the current flow. The carriers propagate, predominantly by drift, across the high-resistivity base region of the SCL transistor. The resulting base transit time is about two orders of magnitude faster than that of a bipolar transistor with equal base width. No charge storage takes place in saturation. These features and the very low device capacitances make the SCL transistor attractive for low-power, fast-switching

applications. Current gains as high as 70,000 are obtained at low current levels. The current gain decreases at higher current levels because the parallel lateral transistor turns on. It is also demonstrated that complementary pairs of SCL transistors can be fabricated with three masking steps, including metalization.

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Design and Operation of ETA, an Automated Ellipsometer

by P. S. Hauge and F. H. Dill, p. 472. The design and operational features are described for a computer-assisted ellipsometer (called ETA for Ellipsometric Thickness Analyzer), developed to provide reliable, real-time measurement of field-effect transistor gate insulator thickness in a manufacturing environment. ETA illuminates the sample with light of fixed polarization and uses a rotating analyzer to measure the polarization of the reflected light. Sample alignment is done automatically by ETA, so that usually no operator adjustments are required. Fourier analysis of the light transmitted by the analyzer is used to reduce noise and enhance measurement precision.

In its normal mode of operation (incident light linearly polarized at 45°), ETA can measure single and double-layer films of SiO_2 and Si_3N_4 in the thickness range of 300 to 800 Å with precision comparable to that of conventional ellipsometers. Other modes of operation, which make use of a fixed-position compensator in the incident light path, allow precise measurement of thin films (0 to 300 Å) and permit use of ETA as a general-purpose ellipsometer. The typical time interval required for wafer alignment, data acquisition, analysis and recorded output of film thickness is about five seconds, and the measurement reproducibility is typically about 1 Å.

Rapid, Precise, Computer-controlled Measurement of X-Y Coordinates by M. Kallmeyer, K. Kosanke, F. Schedewie, B. Solf, and D. Wagner, p. 490.

An experimental x-y measurement system is described that was designed for the high-speed, high-precision measurements required in integrated circuit manufacturing and for optical measurement applications in which a sufficiently large data base is required for statistical process analysis. The technology for this experimental system differs considerably from that of conventional optical measuring systems in current use and utilizes a computer for data acquisition, manipulation and evaluation. The system, utilizing the edge detection principle, presently operates at a measuring speed of 2.5 cm/s. An analysis gives both the short-term and the long-term precision of the system. The standard deviation for the short-term precision is 0.038 μm.

Interactive Use of a Time-shared Process Control Computer in Electrophotographic Sensitometry by B. H. Schechtman, S. S. So, and E. W. Luttmann, p. 500.

The usefulness of electrophotographic exposure sensitometry as a

means of characterizing and evaluating new photoconductor materials has been extended by coupling the experiment to an on-line computer. This automated system provides several new functional capabilities not realistically attainable in manual operation and drastically reduces the time lag in the exchange of information between research workers who prepare materials and those who evaluate the materials. These various improvements have been achieved by extensive use of interactive graphic techniques and a user-oriented data-base organization.

Dimensional Measurement and Defect Detection Using Spatial Filtering by A. L. Flamholz and H. A. Froot, p. 509.

A new method is described that utilizes coherent bandpass spatial filtering and subsequent superposition to form filtered images in which small differences in size and geometry of the original object are readily detected. The theoretical basis is discussed and experiments described in which signal ratios of about 10:1 are obtained for a diameter change of 2.5 percent of a clear circular disc. The method is used to process in parallel a 57-mm evaporation mask containing 12,000 holes, each being 0.1 mm in diameter. The size of each hole is accurately gauged and small imperfections are indicated in the filtered image.

Optical Techniques for Measurement of Chamber Spacing by J. C. Chastang, p. 519.

Two optical methods were investigated for accurately measuring the gap, or chamber spacing, that separates two closely spaced transparent plates. The first method uses a special microscope in which the main feature is a unit-magnification catadioptric system that gives an aberration-free image of the chamber outside the plates, where it is accessible to a high-power objective. The second method is based upon the light section principle, whereby the image of a slit is projected onto the boundaries of the chamber and is thus doubled. The reflected images are observed with a microscope and the degree of separation, which is proportional to the chamber spacing, is measured. Accuracy better than 2 μ m is obtained for the two techniques. The

choice of the appropriate method depends on the surface quality of the chamber boundaries.

Logical Reversibility of Computation by C. H. Bennett, p. 525.

The usual general-purpose computing automaton (e.g., a Turing machine) is logically irreversible—its transition function lacks a single-valued inverse. Here it is shown that such machines may be made logically reversible at every step, while retaining their simplicity and their ability to do general computations. This result is of great physical interest because it makes plausible the existence of thermodynamically reversible computers which could perform useful computations at useful speed while dissipating considerably less than kT of energy per logical step. In the first stage of its computation the logically reversible automaton parallels the corresponding irreversible automaton, except that it saves all intermediate results, thereby avoiding the irreversible operation of erasure. The second stage consists of printing out the desired output. The third stage then reversibly disposes of all the undesired intermediate results by retracing the steps of the first stage in backward order (a process which is only possible because the first stage has been carried out reversibly), thereby restoring the machine (except for the now-written output tape) to its original condition. The final machine configuration thus contains the desired output and a reconstructed copy of the input, but no other undesired data. The foregoing results are demonstrated explicitly using a type of three-tape Turing machine. The biosynthesis of messenger RNA is discussed as a physical example of reversible computation.

Approximating Pre-emptive Priority Dispatching in a Multiprogramming Model by H. A. Anderson, Jr., p. 533.

The formulation of the closed queuing network model of a multiprogramming computer system is generalized to allow each task to have its own set of facility service rates and I/O device selection probability distribution. In the model, processor sharing is assumed for different types of customers. It is shown through a series of investigations that the model reasonably approximates preemptive priority dispatching.

On-line Measurement of Paging Behavior by the Multivalued MIN Algorithm by L. A. Belady and F. P. Palermo, p. 2. An algorithm is presented that extracts the sequence of minimum memory capacities (MMCs) from the sequence of page references generated by a program as it is executed in a demand paging environment. The new algorithm combines the advantages of existing approaches in that the MMCs are produced in a single pass, as is the output of the MIN algorithm for a single memory size, and the MMC sequence is identical to the optimum stack distances provided by the OPT algorithm, which requires two passes.

A hardware implementation is outlined as an extension to existing page management mechanisms. The resulting device could be used to produce continuously the MMC information, while the (paging) machine executes the program at essentially full speed. The paper also discusses the possible impact of the algorithm on the study of program behavior and on the development of space sharing (paging) algorithms. Finally, a proof is provided that the algorithm in fact produces an output identical to that of OPT.

Register Assignment Algorithm for Generation of Highly Optimized Object Code by J. C. Beatty, p. 20. A register assignment algorithm is described that, in contrast to traditional methods, permits a high level of optimization at both local and global levels. This involves splitting local register optimization into two phases, with global assignment intervening. Because novel techniques are used in the global assignment procedure, it is described in detail. Experimental results with a prototype implementation are presented in which object code improvements on the order of 25 percent over a production optimizing compiler were obtained. No attempt was made to assess manpower costs of a final implementation nor to weight them against expected improvements in generated code.

Water Vapor as an Oxidant in BBr_3 Open-tube Silicon Diffusion Systems by R. F. Lever and H. M. Demsky, p. 40. The use of water vapor as an oxidant in place of oxygen enables a wide range of surface concentrations to be obtained in a single-step process. The concentration of boron at the silicon surface is found not to be constant throughout the diffusion process because, at the temperature used, the oxide growth is not parabolic.

Potential Distribution of an Inhomogeneously Doped MIS Array by W.-H. Chang and H.-S. Lee, p. 47. A numerical method is used to obtain the potential distribution of a two-dimensional, inhomogeneously doped MIS array under pulse voltage operation. The effects of interface charge and of impurity doping and its locations on the surface potential profile are presented. The technique is useful for designing an appropriate surface potential profile for ion-implanted charge-coupled devices.

Numerical Calculation of Normal Modes for Underwater Sound Propagation by H. M. Beisner, p. 53. Hartree's method for calculation of atomic wave functions is applied to the Schroedinger-like normal mode equation for underwater sound propagation. Rapid convergence was obtained for the twelve normal modes at five Hertz with a typical velocity profile. The normal modes are given, along with an example of the pressure field, and a means for numerical calculation of the near field modes is suggested.

Stability Criterion for Recursive Filters by P. Pistor, p. 59. A new criterion is derived that relates the stability of two-dimensional recursive filters to the properties of its cepstrum. It provides a procedure for the decomposition of unstable recursive filters having nonzero, nonimaginary frequency response into stable recursive filters. The optimal solution of the decomposition problem is discussed, including numerical implementation and nonrecursive solutions. Several numerical examples show the potentialities and limitations of the rules for decomposition and for truncation of the operators.

Economic Order and Surplus Quantities Model by M. N. El Agizy, p. 72. A standard mathematical model for inventory management is known as the Economic Order Quantity (EOQ) model. In this communication the EOQ model is extended to include the possibility of determining how much, if any, excess stock should be sold at the beginning of a decision period. The new model is of practical importance for situations in which a formal inventory management system is to be instituted while substantial inventories exist or when changes in demand, ordering costs, or carrying and interest charges require recomputation of the economic order quantity.

Preparation of Large-area Electron-transparent Samples from Silicon Devices by G. Das and N. A. O'Neil, p. 76. A technique using a pulsating chemical jet has been developed for thinning and polishing large areas (750 to 1000 μm in diameter) of silicon devices. The thickness can be reduced to a few micrometers. This technique has been used to prepare bipolar and FET samples for transmission electron microscopy. Physical characterization of more than twenty devices can be achieved by one sample preparation.

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Interface Imaging by Scanning Internal Photoemission by T. H. DiStefano and J. M. Viggiano, p. 94. A scanning internal photoemission (SIP) technique is used to obtain a high resolution map or image of the potential energy barrier at an insulator interface. The image is produced by displaying the internal photocurrent produced by a monochromatic beam of light scanned across the sample. A special technique was developed for focusing the light to a spot less than one micrometer in diameter. Photoemission images of a Si-SiO₂ interface "stained" with a fractional monolayer of sodium are

presented along with photoemission and reflectively images of a Nb₂O₅-Bi interface. These SIP images show inhomogeneities related to structural variations, impurities, and defects at the interface that previously were inaccessible to observation.

Calculations of Stable Domain Radii Produced by Thermomagnetic Writing by B. G. Huth, p. 100.

Calculations are performed to determine the stable radius of a cylindrically symmetric domain nucleated in magneto-optical films during thermomagnetic writing with a laser beam. A critical bound on domain size is calculated which determines whether or not a domain of given radius, once nucleated, will be stable. The analysis shows that for a ferromagnetic material such as MnAlGe, the domain dimensions can grow beyond the local region of material that is heated above the Curie temperature. For ferrimagnetic thin films having a compensation point T_{comp} , stability depends on the difference between ambient and compensation temperatures, $\Delta T = T_a - T_{\text{comp}}$. With $\Delta T \approx 0$, wall energy dominates and the critical radius can be calculated from $R_c = \sigma/(2MH_c)$.

Accuracy of the Diffusion Approximation for Some Queuing Systems by M. Reiser and H. Kobayashi, p. 110.

This paper presents the results of a rather extensive study of the accuracy of the diffusion approximation technique as applied to queuing models. The motive for using the diffusion process approximation here is to develop realistic analytical models of computing systems by considering service time distributions of a general form. We first review the theory of the diffusion approximation for a single server and then develop a new and simplified treatment of a queuing network system. The accuracy of this approximation method is then considered for a wide class of distributional forms of service and interarrival times and for various queuing models. The approximate solutions and exact (or simulation) solutions are compared numerically in terms of the means and variances of queue sizes, server utilizations, the asymptotic decrements of the distributions, and the queue size distributions themselves.

The accuracy of the diffusion approximation is found to be quite adequate in most cases and is considerably higher than that obtained by an exponential server model that is prevalent in computer system modeling.

Investigation into Scheduling for an Interactive Computing System by H. A. Anderson, Jr. and R. G. Sargent, p. 125.

This paper describes a statistical evaluation of the performance of the swap scheduling algorithm of an interactive computer system and an investigation into foreground-background scheduling to improve system performance. Input traffic, computer service time demands, and system performance were statistically analyzed. Based on the results of these analyses performance enhancements for

the system were determined and then evaluated through use of a validated simulation model.

Parallel Solution of Recurrence Problems by P. M. Kogge, p. 138.

An m th-order recurrence problem is defined as the computation of the sequence $x_1, \dots, x_N$, where $x_i = f(\mathbf{a}_i, x_{i-1}, \dots, x_{i-m})$ and $\mathbf{a}_i$ is some vector of parameters. This paper investigates general algorithms for solving such problems on highly parallel computers. We show that if the recurrence function f has associated with it two other functions that satisfy certain composition properties, then we can construct elegant and efficient parallel algorithms that can compute all N elements of the series in time proportional to $\lceil \log_2 N \rceil$. The class of problems having this property includes linear recurrences of all orders—both homogeneous and inhomogeneous, recurrences involving matrix or binary quantities, and various nonlinear problems involving operations such as computation with matrix inverses, exponentiation, and modulo division.

Self-directional Microwave Communication System by E. L. Gruenberg, H. P. Raabe, and C. T. Tsitsera, p. 149.

This paper describes a communication system in which sending and receiving terminals automatically generate beams focused upon each other, which arise solely from ambient noise. The terminals are amplifying retrodirective arrays of antenna elements. Analysis and experiment are used to prove and verify the system concept. Some engineering considerations pertinent to system operation under various conditions are also analyzed and discussed.

Image Data Compression by Predictive Coding I:

Prediction Algorithms by H. Kobayashi and L. R. Bahl, p. 164.

This paper deals with predictive coding techniques for efficient transmission or storage of two-level (black and white) digital images. Part I discusses algorithms for prediction. A predictor transforms the two-dimensional dependence in the original data into a form which can be handled by coding techniques for one-dimensional data. The implementation and performance of a fixed predictor, an adaptive predictor with finite memory, and an adaptive linear predictor are discussed. Results of experiments performed on various types of scanned images are also presented. Part II deals with techniques for encoding the prediction error pattern to achieve compression of data.

Image Data Compression by Predictive Coding II:

Encoding Algorithms by L. R. Bahl and H. Kobayashi, p. 172.

This paper deals with predictive coding techniques for efficient transmission or storage of two-level (black and white) digital images. Part I discussed algorithms for prediction. Part II deals with coding techniques for encoding the prediction error pattern. First, we survey some schemes for encoding if the error pattern is assumed to be memoryless. Then a method is developed for encoding certain run-length distributions. Finally, some experimental results for sample documents are presented.

On Optimization of Storage Hierarchies by C. K. Chow, p. 194. A simple model of the storage hierarchies is formulated with the assumptions that the effect of the storage management strategy is characterized by the hit ratio function. The hit ratio function and the device technology-cost function are assumed to be representable by power functions (or piece-wise power functions). The optimization of this model is a geometric programming problem. An explicit formula for the minimum hierarchy access time is derived; the capacity and technology of each storage level are determined. The optimal number of storage levels in a hierarchy is shown to be directly proportional to the logarithm of the systems capacity with the constant of proportionality dependent upon the technology and hit ratio characteristics. The optimal cost ratio of adjacent storage levels is constant, as are the ratios of the device access times and storage capacities of the adjacent levels. An illustration of the effect of overhead cost and level-dependent cost, such as the cost per "box" and cost for managing memory faults is given and several generalizations are presented.

Loss of Point-to-Point Traffic in Three-Stage Circuit Switches by M. Karnaugh, p. 204. A theoretical study is made of simple analytical models for the point-to-point loss of telecommunication traffic caused by blocking in three-stage circuit switches. Two new models are compared with Jacobaeus' frequently used model and with some simulation results to determine regions of acceptable accuracy. The effects of random hunting and sequential hunting for routes are compared by simulation.

The results apply to space-division link systems and also to some time-division switches of current interest. In the case of random hunting, the new models give improved agreement with simulation results. The overestimate of loss inherent in the Jacobaeus method, however, is found to be acceptably low when the numbers of primary and tertiary matrix switches are not small, e.g. > 10. We lack a good analytical model for the sequential hunting method, which is found to result in lower traffic loss for the switches being studied.

Efficient Algorithm for the Partitioning of Trees by J. A. Lukes, p. 217. This paper describes an algorithm for partitioning a graph that is in the form of a tree. The algorithm has a growth in computation time and storage requirements that is directly proportional to the number of nodes in the tree. Several applications of the algorithm are briefly described. In particular it is shown that the tree partitioning problem frequently arises in the allocation of computer information to blocks of storage. Also, a heuristic method of partitioning a general graph based on this algorithm is suggested.

Photolithography in Integrated Circuit Mask Metrology by H. R. Rottmann, p. 225. Photoresist technology is shown

to have important advantages over the use of high-resolution silver halide films in dimensional metrology for integrated circuit masks. Experimental techniques are shown for the use of photoresist and chrome images in the study of image quality and uniformity and in analysis of the causes of image degradation. This method is applied to *in situ* lens evaluation and to the measurement of the precision of photorepeater stepping tables used in mask fabrication. In addition, the value of 0.3 μm is established as the practical limit of dimensional tolerance in the present photolithographic technology, and its significance to the advancement of the state of the art in mask manufacture is discussed.

Analysis of an AC Gas Display Panel by C. Lanza, p. 232. The details and results for a one-dimensional numerical analysis of the gaseous discharge occurring at a single intersection of an ac gas panel are reported. A particular object of the program is the determination of the electric field magnitude as a function of both position and time, taking into account the field distortion due to the space charge. The calculations are based on the Townsend avalanche mechanism but omit the dynamic role of metastable neon atoms in a Penning gas mixture. The calculated electrical properties of the panel are compared with experimental values.

Simulation of Cyclic Operation of a Gas Panel Device by F.-M.-T. Lay, C.-K. Chu, and P. H. Haberland, p. 244. This paper presents a numerical simulation model for the operation of a gas panel discharge cell with a neon-argon mixture. The model is based on a Townsend avalanche or direct ionization mechanism and secondary emission, as well as Penning collisions or indirect ionization. Charges on the dielectric walls are included, but space-charge field distortion is neglected. Cyclic operation of the cell is studied in detail and the effects of geometric and electrical parameters (e.g., gap and pulse widths) on the operating characteristics of the cell (e.g., write, sustain and erase voltages) have been obtained. The results are in good agreement with experimental data where available.

On Proving Correctness of Microprograms by A. Birman, p. 250. This paper describes the results of an investigation in proving the correctness of microprograms. The vehicle used is the S-machine, which is a very simple "paper" computer. The approach to the proof of correctness is based on formally defining the machine-instruction level and the microprogramming level of the given machine, and then showing that these "interfaces" are equivalent through the use of a concept called algebraic simulation.

Channel Equalization Using a Kalman Filter for Fast Data Transmission by D. Godard, p. 267. This paper shows how a Kalman filter may be applied to the problem of setting the tap gains of transversal equalizers to minimize mean-square distortion. In the presence of noise and without prior knowledge about the channel, the filter algorithm leads to faster convergence than other methods, its speed of

convergence depending only on the number of taps. Theoretical results are given and computer simulation is used to corroborate the theory and to compare the algorithm with the classical steepest descent method.

Stress Analysis of Glass-Bonded Ferrite Recording Heads by *T. Tang*, p. 274. Glass-bonded ferrite recording heads are subject to appreciable thermal stress because of the difference in thermal expansion between glass and ferrite in the temperature range of the glassing cycle. A theoretical analysis reveals the complexity of stress distributions in the structure and pinpoints the critically stressed areas in which a potential fracture or a magnetic degradation of the material may occur. It is found that the stresses are sensitive not only to the thermal mismatch of the component materials but also to the structural configuration. Low stress levels can be achieved by matching expansions of the materials and by proper head design, particularly in the optimization of fillet angle and fillet height.

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Optimal Pricing for an Unbounded Queue by *D. W. Low*, p. 290. The maximization of expected reward is considered for an $M_p/M/s$ queueing system with unlimited queue capacity. The system is controlled by dynamically changing the price charged for the facility's service in order to discourage or encourage the arrival of customers. For the finite queue capacity problem, it has been shown that all optimal policies possess a certain monotonicity property, namely, that the optimal price to advertise is a non-decreasing function of the number of customers in the system. The main result presented here is that for the unlimited capacity problem, there exist optimal stationary policies at least one of which is monotone. Also, an algorithm is presented, with numerical results, which will produce an ϵ -optimal policy for any $\epsilon > 0$, and an optimal policy if a simple condition is satisfied.

Effects of Serial Programs in Multiprocessing Systems by *W. F. King III, S. E. Smith, and I. Wladawsky*, p. 303. A model of a multiprocessing, multiprogramming computer system with serially reusable programs was developed to study the effect of serial programs on system performance. Two strategies for implementing serially reusable programs were investigated, a *wait* strategy in which the processor waits until the serial program is available, and a *switch* strategy, in which the processor is freed to do other work. Relative performances and asymptotic conditions as functions of the number of processors, processes, serially reusable programs, and the fraction of time each process executes serially reusable programs were obtained. Quantitative results are presented showing that the switch strategy is superior. The wait strategy causes quick saturation when the number of processes is increased.

Optimal Task Switching Policy for a Multilevel Storage System by *T. Kaneko*, p. 310. Capacity demands for computer

memory are increasing. A multilevel storage system provides an economically feasible solution without seriously affecting the total response time. An M -level storage system is considered in this paper. The capability of a digital computer with a multilevel storage system is best enhanced in a multiprogramming environment. In a high level storage system, determination of a best task switching policy becomes an important consideration. In this paper a queuing network is introduced to describe distribution and flow of tasks in the system. An optimal switching policy is determined in relation to the system's overhead time. It is shown that in heavily CPU-limited cases the determination becomes a very simple one; namely, the best policy is given as the threshold level at which the accumulation of the average access time exceeds the overhead time.

Determining Hit Ratios for Multilevel Hierarchies by *J. Gecsei*, p. 316. The applicability of stack processing for evaluation of storage hierarchies has been limited to two-level systems and to a very special group of multilevel hierarchies. A generalization of stack processing, called joint stack processing, is introduced. This technique makes possible the efficient determination of hit ratios for a class of multilevel hierarchies—staging hierarchies. These hierarchies are rather realistic in the sense that they allow for multiple block sizes and multiple copies of data in the hierarchy. Properties of storage management schemes that lend themselves to joint stack processing are studied, and the notion of distributed hierarchy management is described and illustrated.

Iterative-Interactive Technique for Logic Partitioning by *M. Hanan, A. Mennone, and P. K. Wolff, Sr.*, p. 328. A method is developed for partitioning a computer logic design into subsets by combining a constructive method, used for the initial partition, with iterative improvement techniques. These iterative techniques are implemented in an interactive computing environment, which further enhances their efficiency and usefulness. An overview of the system is presented, several algorithms discussed and experimental results given.

Microcoded Modem Transmitters by *M. F. Choquet and H. J. Nussbaumer*, p. 338. This paper describes various microcoded designs for modem transmitters. The digital echo modulation technique, originally introduced by J.-M. Pierret, is applied to cover the case of a fully digital universal modem. The capabilities of several microcoded modem designs are presented and their limitations are discussed.

Quantitative Electron Microprobe Analysis of Thin Films on Substrates by *D. F. Kyser and K. Murata*, p. 352. Monte Carlo simulation procedure is developed for kilovolt electron beam scattering and energy loss in targets consisting of thin films on thick substrates. Such calculations have direct application to the nondestructive quantitative chemical analysis of ultra-thin films in the electron microprobe (an electron probe x-ray microanalyzer), utilizing characteristic

x-ray fluorescence. Angular elastic scattering is calculated in the electron trajectory simulation with the screened Rutherford expression for cross section, and energy loss between elastic scattering events is calculated with the continuous-slowing-down approximation of Bethe. The contribution to x-ray fluorescence from the film due to backscattered electrons from the substrate is accounted for.

For elemental films, the Monte Carlo simulation predicts intensity ratios k_i for characteristic x-rays from the film, referenced to standards of thick elemental samples. No film standards are required, and the mass thickness of any elemental film on any substrate can be determined from theoretical calibration curves. The model has been verified by measurements on films of Si, Cu, and Au on Al_2O_3 over wide ranges in E_0 , and t . For alloy films, calibration curves are generated and graphically iterated to provide independent analysis of weight fractions C_i and total mass thickness ρt . Films of Mn_3Bi , and Co_3Pt , were successfully analyzed with $\rho t \leq 100 \mu\text{g}/\text{cm}^2$.

Drop Formation in a Liquid Jet by H. C. Lee, p. 364. A one-dimensional analysis of drop formation in a liquid jet is developed under the assumption that the axial velocity of the axisymmetric, nonviscous liquid jet remains independent of the radial coordinate. The resulting equations are used for both linear and nonlinear analyses. In the linear form, this model provides a stream stability relation comparable to that of Rayleigh; transient solutions are obtained for given initial conditions of an infinite stream. For the nonlinear equations, numerical simulation was done to study the satellite drop formation; with the present model, the satellite drop is always formed.

Bulk Queue Model for Computer System Analysis by W. Chang, p. 370. A bulk queue model was developed for analyzing a multiprogrammed computer system. It can be used in conjunction with closed queuing models to study message queuing in a teleprocessing system. The model is based on an imbedded Markov chain analysis.

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Interatomic Potentials and Defect Energetics in Dilute Alloys by P. S. Ho and R. Benedek, p. 386. Effective interatomic potentials for impurities in aluminum have been constructed according to pseudopotential theory. Based on a local model potential, impurity valence and size factors are defined and their effects on the potential discussed. With these potentials, detailed calculations based on a Green's function lattice statics method are made for the impurity-vacancy binding energy and the difference in diffusion activation energies for an impurity and a host atom.

Within the range of valence and size factors studied, it is found that the binding energy is generally small and depends primarily on the valence rather than the size, whereas the

migration energy shows larger increases with both valence and size factors. Contributions from the lattice relaxation energies are important, particularly for impurity migration. The results can account satisfactorily for the experimental data of nontransition-metal impurities, but less so for the noble-metal impurities. Dielectric screening of the ion by the conduction electrons is important in determining the potential and must be properly accounted for in calculations of the energetics for impurities.

Steady Solution for Circumferentially Moving Loads on Cylindrical Shells by D. B. Bogy, H. J. Greenberg, and F. E. Talke, p. 395. The steady, forced-wave solution is obtained for loads that travel with constant speed on a simply supported circular shell, the motion of which is damped externally by air. Critical speeds are identified above which the waveform, which is a standing wave in moving coordinates, exhibits shorter wavelengths in front of the load than behind it. At supercritical speeds the solution becomes unbounded, because of loss of stability, in the limit of no damping.

Equivalence of Memory to "Random Logic" by W. E. Donath, p. 401. A model of the design process for computer logic is used to estimate the number of bits of memory required to replace a so-called "random logic" circuit. The model can also be used to compare the respective time delays of array logic and random logic.

String Path Search Procedures for Data Base Systems by S. P. Ghosh and M. E. Senko, p. 408. This paper structures algorithms for the translation of set theoretic queries into procedures for the search of arbitrary complex networks constructed on a data base using three basic types of strings. A method for parameterization of queries which is appropriate for accessing string structures is outlined and it is shown how the properties of string structures can be used to construct an algorithm for finding a search path with minimum path cardinality for a given query addressed to such a network. (The term data management system is used instead of data base management system.)

Analysis of Exception Data in a Staging Hierarchy by D. P. Gaver, P. A. W. Lewis, and G. S. Shedler, p. 423. This paper is an analysis of program address trace data in a demand-paged computer system with a three-level staging hierarchy. Our primary objective is to explore the data both graphically and numerically, using methods that may be useful when other data traces become available. In addition, plausible point-process type models are fit to the data. Such an approach, combining data-analytic procedures with probability modeling, should prove useful in understanding program behavior and thus will aid in the rational design of complex computer systems.

Structure Dependence of Free-Charge Transfer in Charge-coupled Devices by W. H. Chang and L. G. Heller, p. 436. A detailed numerical analysis of

charge-coupled-device (CCD) charge transfer is described and discussed. The analysis is based on solving the transport equation with a time-dependent surface field calculated from the actual device configuration. Devices with different oxide thicknesses and devices with electrode gaps are examined. The total field is found to play an important role in charge transfer for all cases studied. The effective channel length is modulated by the net field present and is a function of time and electrode configuration. The transfer is found fastest and the effective channel length shortest when the charge is transferred from a region of low oxide capacitance into a region of high oxide capacitance. A low-capacitance electrode gap slows the charge transfer process.

MINI: A Heuristic Approach for Logic Minimization by *S. J. Hong, R. G. Cain, and D. L. Ostapko, p. 443*. MINI is a heuristic logic minimization technique for many-variable problems. It accepts as input a Boolean logic specification expressed as an input-output table, thus avoiding a long list of minterms. It seeks a minimal implicant solution, without generating all prime implicants, which can be converted to prime implicants if desired. New and effective subprocesses, such as expanding, reshaping, and removing redundancy from cubes, are iterated until there is no further reduction in the solution. The process is general in that it can minimize both conventional logic and logic functions of multi-valued variables.

Generating Test Examples for Heuristic Boolean Minimization by *D. L. Ostapko and S. J. Hong, p. 459*. This article describes simple methods of generating many-variable test-case problems for heuristic logic minimization studies. Covering problems and coloring problems are converted into Boolean functions that are useful test cases for minimization.

Addendum to "Loss of Point-to-Point Traffic in Three-State Circuit Switches" by *M. Karnaug, p. 465*.

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Preface by *H. B. Michaelson, p. 479*.

Aerodynamic Aspects of Disk Files by *E. Lennemann, p. 480*. Airflows between centrally clamped, rotating, rigid disks are investigated with respect to the type of flow pattern, the parameters that influence nonuniform flow, and the effects of various flow patterns on disk stability. The experimental method uses a water-flow modeling technique for the airflow. The observed flow patterns are highly unsteady. The configuration and position of the shroud and slider arm are found to be the major parameters that influence flow characteristics. A reduction of disk flutter by a factor of 12 can be achieved when the unsteady flow pattern is changed to a steady flow pattern.

Engineering Design of a Disk Storage Facility with Data Modules by *R. B. Mulvany, p. 489*. The design of the IBM

3340 Direct Access Storage Facility with IBM 3348 Data Modules incorporates new concepts and required the development of several innovative components, including newly designed magnetic read-write heads. The heads start and stop in contact with the disk and use a tri-rail, air-bearing slider having a low mass. Each data module includes read-write heads, a head carriage, disks, and a disk spindle.

The rationale is discussed for the design concepts and for several components, including the data module, head and arm assembly, and the moving-coil linear actuator. A method of improving data integrity, utilizing a "disk-defect skipping" procedure, is described and its performance implications discussed.

Design of a Disk File Head-Positioning Servo by *R. K. Oswald, p. 506*. The engineering design of a head-positioning system for an interchangeable-medium disk file is considered. Emphasis is placed upon three specific functions within the positioning system: (1) encoding and demodulation of information from the dedicated servo surface, (2) compensation and dynamics of the track-following control system, and (3) implementation of control electronics for a quasi-time-optimal, track-accessing control system. The examples used are taken from the IBM 3340 Disk Storage Facility.

Dynamic Response of Self-acting Foil Bearings by *K. J. Stahl, J. W. White, and K. L. Deckert, p. 513*. A new approach to the analysis of wide foil bearings is investigated. The equation of motion for a finite length of tape is coupled to the transient lubrication equation for the air film between the tape and the recording head. Compressibility and slip flow are retained in the fluid mechanics equation; flexural rigidity and high-speed dynamic effects are retained in the tape equation. The steady-state solution to the coupled equations is obtained as the limiting case of the transient initial value problem. Describing the system equations relative to the undeflected tape (as opposed to conventional foil-bearing theory, which uses the head as the reference surface) permits investigation of noncircular head geometries. In addition, wave propagation effects in the tape and the interaction of waves in the tape with the air-bearing region may be studied.

White Light Interferometry of Elastohydrodynamic Lubrication of Foil Bearings by *S. M. Vogel and J. L. Groom, p. 521*. This paper describes an experiment performed to verify the one-dimensional model of elastic foil behavior developed by Stahl, White, and Deckert. In the experiment, a loop of tape one-inch wide passes over a stationary recording head, and the air-film thickness between the head and the foil is determined using white light interferometry. Measured data for various experimental conditions are compared with the predictions of the model and also with prior foil-bearing analyses. The influence of parameters such as tape thickness, head radius, tape tension, etc. on the nature of the spacing field is demonstrated.

Infrared Laser Interferometer for Measuring Air-bearing Separation by J. M. Fleischer and C. Lin, p. 529. The design and characteristics are presented for an infrared instrument capable of measuring air-bearing separation distances over a mechanical bandwidth ranging from dc to 30 kHz. The measurement technique involves monitoring optical intensity variations of the interferometric cavity formed by two air-bearing surfaces. This intensity varies between a minimum at zero separation and a maximum at a distance equal to one-quarter of the optical wavelength. For air-bearing distances less than 1 μm , a convenient source is the 3.391 μm infrared line of the helium-neon laser. By continually monitoring a fraction of the intensity of the optical source, a real-time analog division can be performed on the spacing signals to produce an output independent of laser intensity variations. Room-temperature indium arsenide detectors were selected for their high responsivity and rapid rise time.

Transition from Boundary Lubrication to Hydrodynamic Lubrication of Slider Bearings by R. C. Tseng and F. E. Talke, p. 534. The transition from boundary lubrication to fully hydrodynamic lubrication is investigated for air-lubricated slider bearings using the electrical resistance method. Intermittent contacts are shown to exist even under conditions for which the numerical solution of the Reynolds equation or white light interferometry predicts steady state spacings in the spacing region from 0.125 to 0.25 μm . The transition is similar to the one found in the presence of liquid films, being influenced for a given surface roughness of disk and slider by load, speed, and hydrodynamic design.

Hand-held Magnetoresistive Transducer by C. H. Bajorek, C. Coker, L. T. Romankiw, and D. A. Thompson, p. 541. The initial design of a vertical magnetoresistive head in a hand-held wand for reading magnetically encoded price tags and credit cards is discussed. The performance of the head (e.g., resolution, signal shape and amplitude, and signal-to-noise ratio) is analytically and experimentally evaluated as a function of the configuration of the sensor, head-to-medium interface, and sensor processing and materials.

Thermally Induced Pulses in Magnetoresistive Heads by R. D. Hempstead, p. 547. The thermal response of a magnetoresistive head is analyzed for frictional heating between the head surface and dust particles or other asperities on the recording medium surface during relative motion of head and medium. A theoretical model is presented showing that pulses are induced in the output of a magnetoresistive head as a result of this frictional heating. The model predicts the dependence of these noise spikes on the thermal properties of the substrate and cover chip for the magnetoresistive head, the dimensions of the magnetoresistive stripe, the head-medium relative velocity, and the rate of frictional heat generation. Experimental verification of the theoretical model is obtained by scanning a focused laser beam across a head.

Numerical Analysis of the Shielded Magnetoresistive Head by R. W. Cole, R. I. Potter, C. C. Lin, K. L. Deckert, and E. P. Valstyn, p. 551. Numerical computations for the shielded magnetoresistive head are reported and compared with previous analytic and experimental results. Linear resolution is found to be essentially the same as for inductive heads. Output amplitude is in the range 50 to 175 V per meter track width for a sense current density of $5 \times 10^{10} \text{ A/m}^2$.

Ferrite Film Recording Surfaces for Disk Recording by R. L. Comstock and E. B. Moore, p. 556. Ferrite thin films have been prepared using a chemical deposition process; hematite and substituted hematite films were formed by spin coating a diluted solution of the metal nitrates on a substrate and subsequently heating the substrate in air to 300°C to crystallize the film. Magnetic ferrite films were formed by reducing the films in a wet hydrogen atmosphere. Process parameters, which have evolved from studies on spin coating and reduction on 7.62- and 35.56-cm substrates, have been determined that result in desirable magnetic properties. Experimental studies of film composition and morphology are reported. It has been determined both theoretically and experimentally that film thickness near 0.125 μm is optimum for high-density recording with heads with gap lengths of approximately 1 μm spaced about 0.5 μm from the film. A TiO_2 undercoat (0.125 μm) on the Al-Mg alloy substrate was prepared by chemical vapor deposition and resulted in improved magnetic properties. Magnetic properties of the films and magnetic recording performance of disks using Ti and Al substrates with the TiO_2 undercoat are reported.

The Remanent State of Recorded Tapes by G. Bate and L. P. Dunn, p. 563. Measurements are reported on the in-plane and the perpendicular components of the remanence a tape acquires on passing through the steady field of a recording head. The tape coatings were oriented and unoriented particles of $\gamma\text{-Fe}_2\text{O}_3$, oriented CrO_2 and unoriented Co-substituted $\gamma\text{-Fe}_2\text{O}_3$. The two writing heads used had 10 μm - and 2.25 μm -gaps, respectively. In each case the in-plane magnetization increases at first with increasing writing current, and eventually reaches a peak that is less than the maximum in-plane remanence produced on the same sample by an electromagnet. For higher values of writing current, in-plane magnetization in the tape actually decreases. The perpendicular remanence is not large enough to explain the difference between the in-plane remanence acquired from the head and the remanence acquired in a magnet.

The perpendicular component of the field from the writing head is shown to have two adverse effects on the remanence of the tape. First, it produces a perpendicular magnetization that ranges from 2 percent to 15 percent of the in-plane component. Second, it causes a reduction in the in-plane component to occur near the surface of the tape closest to the writing head. The reduction can be as large as 15 percent of the maximum in-plane remanence and will obviously have an

adverse effect on recording performance, particularly at high densities.

Noise in Disk Data-recording Media by J. L. Su and M. L. Williams, p. 570. Measurements were made of recording medium noise in erased disks using an in-contact magnetoresistive element and an inductive head supported on an air bearing slider. Four types of coatings on aluminum disks were examined: thin, transition-metal alloy film, CrO_2 , FeCo particle, and $\gamma\text{-Fe}_2\text{O}_3$. Results obtained by means of three measurement techniques are in qualitative agreement and indicate that: (1) dc-erased noise of alloy film disks is 14 to 20 dB lower than that of particulate disks measured; (2) dc-erased noise of particulate disks measured is 6 to 16 dB above their bulk-erased noise; (3) although dc noise of particulate disks increases with write current, dc noise of alloy film disks is independent of write current; (4) the shapes of the noise spectra are similar in dc-erased particulate $\gamma\text{-Fe}_2\text{O}_3$ disks and FeCo particle coated disks; and (5) significant modulation noise is detected on particulate disks but not on alloy film disks. The observed dc-erased noise spectrum is compared with the model for small particle noise and is then used to estimate the size of particle agglomerates or voids.

Switching Speeds in Magnetic Tapes by R. F. M. Thornley and J. A. Williams, p. 576. Comparative measurements are reported on the switching speeds of three different magnetic tape materials, as determined by application of short field pulses of well-defined duration and magnitude. A sensitive measure of the change in magnetization is the length of applied pulse required for the peak readback signal to drop from 60 percent to 40 percent of its peak value. This pulse length was 2.6 ns for a $\gamma\text{-Fe}_2\text{O}_3$ tape, 4.1 ns for a CrO_2 tape, and 1.4 ns for a cobalt-substituted $\gamma\text{-Fe}_2\text{O}_3$ tape.

Optimal Rectangular Code for High Density Magnetic Tapes by A. M. Patel and S. J. Hong, p. 579. IBM's 6250 bpi 3420 series tape units require a powerful error-correcting code for the standard 9-track format. The optimal rectangular code (ORC), presented here, is designed to correct any single-track error or, given erasure pointers, any double-track error in the tape. The code achieves this by conforming to a rectangular codeword of which two orthogonal sides are check bits. The code is specially tailored from a general class of b -adjacent codes. The ORC can be implemented without a buffer for encoding and offers a simple error-correction mechanism. The code can be generalized to multiple-channel applications.

Approximating Complex Surfaces by Triangulation of Contour Lines by *E. Keppel*, p. 2. An algorithm is described for obtaining an optimal approximation, using triangulation, of a three-dimensional surface defined by randomly distributed points along contour lines. The combinatorial problem of finding the best arrangement of triangles is treated by assuming an adequate objective function. The optimal triangulation is found using classical methods of graph theory. An illustrative example gives the procedure for triangulation of contour lines of a human head for use in radiation therapy planning.

Stream Processing Functions by *W. H. Burge*, p. 12. One principle of structured programming is that a program should be separated into meaningful independent subprograms, which are then combined so that the relation of the parts to the whole can be clearly established. This paper describes several alternative ways to compose programs. The main method used is to permit the programmer to denote by an expression the sequence of values taken on by a variable. The sequence is represented by a function called a *stream*, which is a functional analog of a coroutine. The conventional **while** and **for** loops of structured programming may be composed by a technique of stream processing (analogous to list processing), which results in more structured programs than the originals. This technique makes it possible to structure a program in a natural way into its logically separate parts, which can then be considered independently.

Scheme for Invalidating References to Freed Storage by *D. B. Lomet*, p. 26. A storage management scheme is described that supports the invalidation of addresses to freed storage and thus, in that sense, provides a secure system. Unlike previous virtual memory techniques, the allocated areas of our scheme can vary from the very large, requiring multiple pages of storage, to the very small, in which several can be contained on a single page. Special treatment is accorded procedure activation storage so as to provide increased effectiveness for this important case. The interaction of this deletion scheme with garbage collection techniques is also examined. Finally, the relative advantages of retention and deletion strategies of storage management are considered.

Parametric Analysis of Queuing Networks by *K. M. Chandy, U. Herzog, and L. Woo*, p. 36. We consider a queuing network with M exponential service stations and with N customers. We study the behavior of a subsystem σ , which has a single node as input and a single node as output, when the subsystem parameters are varied. An "equivalent" network is constructed in which all queues except those in subsystem σ are replaced by a single composite queue. We show that for certain classes of system parameters, the behavior of subsystem σ in the equivalent network is the same as in the given network. The analogy to Norton's theorem in

electrical circuit theory is demonstrated. In addition, the equivalent network analysis can be applied to open exponential networks.

Approximate Analysis of General Queuing Networks by *K. M. Chandy, U. Herzog, and L. Woo*, p. 43. An approximate iterative technique for the analysis of complex queuing networks with general service times is presented. The technique is based on an application of Norton's theorem from electrical circuit theory to queuing networks which obey local balance. The technique determines approximations of the queue length and waiting time distributions for each queue in the network. Comparison of results obtained by the approximate method with simulated and exact results shows that the approximate method has reasonable accuracy.

Device Design Considerations for Ion Implanted n -Channel MOSFETs by *V. L. Rideout, F. H. Gaensslen, and A. LeBlanc*, p. 50. Device design considerations are presented for ion implanted, n -channel, polysilicon gate, enhancement-mode MOSFETs for dynamic switching applications. A shallow channel implant is used to raise the magnitude of the gate threshold voltage while also maintaining a low substrate sensitivity (i.e., without substantially increasing the dependence of the threshold voltage on the source-to-substrate "backgate" bias). Design trade-offs between channel implantation energy and dose and substrate bias were examined using both computer analyses and experimental devices. The design objective was to identify the combination of these three parameter values that gives both a low substrate sensitivity and a steep subthreshold conduction characteristic under the conditions of a gate threshold voltage of 1 V and a substrate bias range of 0 to -1 V. One-dimensional and two-dimensional computer analyses were performed to predict the effect of the device parameters on the electrical characteristics. MOSFETs were then fabricated to investigate the extremes of the design parameter range, and the experimental and predicted device characteristics were compared. An enclosed device structure proved particularly useful in evaluating the subthreshold characteristic at very low values of drain current.

Keyboard Method for Composing Chinese Characters by *E. F. Yhap*, p. 60. A keyboard method is described that allows a user to form Chinese characters. The user's keystrokes activate internal logic, which performs the necessary scaling and positioning of the character components. An initial design using a 40-key keyboard is described, together with approximations of the character shapes produced by given keying sequences. Rough estimates of speed range from eight to 33 characters per minute.

Segment Synthesis in Logical Data Base Design by *C. P. Wang and H. H. Wedekind*, p. 71. Identification and representation of entities and their relationships relevant to an application are some of the key problems in logical data base design. This paper presents an approach to synthesizing

logical segments that are representations of such entities and relationships. The major steps in this design are 1) collect all the pertinent functional relations in the application domain; 2) remove redundant relations to obtain a minimal covering set; 3) minimize the number of relations in the covering set to obtain an optimal set of relations in the third normal form; and 4) combine relations into logical segments according to prescribed performance requirements and projected information maintenance activities. Synthesis of logical segments for an airline reservations application is used as an illustrative example.

Composite Priority Queue by *T. W. Gay and P. H. Seaman*, p. 78. This paper presents formulas for calculating waiting time for customers in a queue with combined preemptive and head-of-line (nonpreemptive) priority scheduling disciplines and describes the reasoning behind them. This work has been applied in the development of programmable terminal control units.

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An Introduction to Array Logic by *H. Fleisher and L. I. Maissel*, p. 98. After a discussion of the reasons for choosing to implement logic in array form, a detailed description of the nature of array logic is given. Topics specifically discussed include general array structures and implementation, influence of decoder partitioning, design of logic arrays, output phase, "split" variables, feedback in logic arrays, and reconfiguration.

Hardware Implementation of a Small System in Programmable Logic Arrays by *J. C. Logue, N. F. Brickman, F. Howley, J. W. Jones, and W.-W. Wu*, p. 110. Large Scale Integration, LSI, is the means by which digital circuits have achieved remarkable manufacturing cost reductions but, unfortunately, at the expense of higher engineering design costs. Programmable Logic Arrays, PLAs, exploit many of the benefits of LSI but without the high engineering design costs. This paper describes an experiment in the design and implementation of a small complex system in array logic. The IBM 7441 Buffered Terminal Control Unit was selected for this comparison because it is a small but complex terminal controller implemented in dual in-line packaged transistor logic, DIP-TL, with small to medium scale integration.

Array Logic Macros by *J. W. Jones*, p. 120. A macro design approach is discussed which combines the cost-effective attributes of array logic structures with those of random logic. These macros utilize the following features: (a) internal feedback registers for performing sequential logic, (b) masking and submasking to reduce the number of words in the array for certain functions, (c) control of the array's output level to vary the apparent size of the array, (d) decoding on input pairs and/or EXCLUSIVE ORing on output pairs for increasing the number of logic levels, and (e) random-access memory in the feedback and its use in interrupt handling. The macros are explained by specific design examples. This paper

also discusses standard logic circuits in combination with an array structure to produce a component that can be used efficiently in specific data processing areas. The designer may elect to define an array logic macro which is a combination of some of the features given in this paper. The guideline for this selection is based upon the features necessary in an array structure to be competitive with a random logic LSI chip.

Polarization and Depolarization in PSG Films by *L. Kasprzak and A. Hornung*, p. 127. The temperature dependence of the polarization in thin phosphosilicate glass (PSG) films is characterized by an activation energy $\Delta H = (0.39 + 0.039Et)$ eV, whereas the decay mechanism has an activation energy of 0.5eV. The flatband voltage shift due to PSG polarization was linear with applied fields as large as $5.5 \times 10^6 \text{ V} \cdot \text{cm}^{-1}$. The effective time constants for the polarization and depolarization are distinctly different. Polarization occurs an order of magnitude faster than depolarization. A physical model has been postulated to explain the observed effects.

Storage Hierarchy Optimization Procedure by *J. E. MacDonald and K. L. Sigworth*, p. 133. The goal of storage hierarchies is to combine several storage technologies in such a way as to approach the performance of the fastest component technology and the cost of the least expensive one. This paper presents optimization techniques for a storage hierarchy subject to quantity-sensitive component costs. It is assumed that a finite (and probably small) set of technologies is available. Each technology is characterized by an access time and two cost parameters. We assume that statistical summaries of address sequences are available. We present solutions to four problems of increasing complexity: 1) minimization of access time for a fixed cost and preassigned page sizes; 2) optimization of a generalized price-performance function under preassigned page sizes; 3) minimization of access time for a fixed cost when page sizes are allowed to vary; 4) optimization of a generalized price-performance function when page sizes are allowed to vary.

Block-oriented Information Compression by *H. Ling and F. P. Palermo*, p. 141. Data base statistics play an important role in conventional information compression. For a large data base, the acquisition of data base statistics becomes a very difficult task. This paper presents a new scheme for information compression that does not use information statistics. Each information block is represented by two sub-blocks called the *alphabet* and the *generator*. The *alphabet* contains the linearly independent elements; the *generator* is computed through the linear combination of the linearly dependent elements. The total length of these two sub-blocks is generally shorter (never greater) than the original block.

High Speed Transistor with Double Base Diffusion by *S. Magdo and I. Magdo*, p. 146. A high speed bipolar transistor has been fabricated by using double base diffusion to reduce

the base resistance R_b . The base resistance forms two important time constants, $R_b C_D$ and $R_b C_C(R_i/R_E)$ with the emitter diffusion capacitance C_D and collector capacitance C_C dominating the switching delay of the circuits. We demonstrate that the base resistance of a single base diffused device can be reduced by a factor of four by using double base diffusion without affecting its cut-off frequency $f_i = 7$ GHz. The double base diffusion also increases the punchthrough voltage of the device from 3 to 7V.

On Dislocations in $\text{GaAs}_{1-x}\text{P}_x$ by S. Mader and A. E. Blakeslee, p. 151. Misfit dislocations in epitaxially grown layers of $\text{GaAs}_{1-x}\text{P}_x$ with a lattice constant gradient are examined by transmission electron microscopy. In specimens with (113) A growth planes, they form a three-dimensional arrangement of glissile and sessile dislocations. Cross slip is an important process in the generation of the dislocations. High resolution microscopy shows 1) glissile dislocations dissociated into partial dislocations and 2) undissociated sessile Lomer dislocations. These differences are attributed to contributions to the dislocation core energy from wrong bonds and dangling bonds. Screw dislocations are also thought to be undissociated, which facilitates cross slip and multiplication of dislocations.

What Is a Multilevel Array? by A. L. Rosenberg and J. W. Thatcher, p. 163. In intuitive terms, a multilevel array is either a scalar or an array each of whose elements is a multilevel array. The "semantics" of multilevel arrays can be easily expressed in terms of a notion of selector, which is basically that of the Vienna Definition Language. These selectors provide both a notational device for accessing multilevel arrays and a clean mathematical definition of "multilevel array with data domain D ." However, the definition so obtained lacks the recursive flavor of the intuitive definition. By means of an axiomatic characterization of multilevel arrays, the selector-based definition and the recursive definition are shown to be equivalent.

Combinatorial Solution to the Partitioning of General Graphs by J. A. Lukes, p. 170. This paper reviews a dynamic programming procedure for the partitioning of connected graphs with integer-weighted nodes and positive valued edges. The upper bound on the number of feasible partitions generated using this technique is shown to grow factorially in the number of graph nodes. The use of graph properties is then introduced to reduce the number of feasible partitions generated in the determination of the optimal partition. Depending upon the structure of the graph, the use of these properties can cause a significant reduction in the computation time and storage space required to partition the graph.

Automatic Structuring of Programs by G. Urschler, p. 181. A method is described that allows the translation of a traditionally written (unstructured) program into a set of top-down structured, semantically founded, GOTO-free modules. The method reveals not only the logic of a given

program in a most natural way, but it also reduces code duplication to a minimum. It is further shown how the obtained structured program can be mapped back into a GOTO program in such a way that all GOTOs are backwards branches and their number is minimal. The connection between recursively and iteratively structured programs is demonstrated using the WHILE, DO FOREVER, and multilevel EXIT statements. Extensions of the method show the structuring of source programs containing block structures and subroutines.

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Preface by R. Ashany, p. 210.

Application of the Page Survival Index (PSI) to Virtual-memory System Performance by Y. Bard, p. 212.

The Page Survival Index (PSI) was defined in a preceding paper where it was used to describe the behavior of individual programs running in a time sharing environment. Here we show how a system-wide value of PSI can be calculated on the fly by the operating system. This value can be used to estimate users' memory requirements and to control system performance by maintaining the proper multiprogramming level. Simulation results show that a scheduler based on these concepts can achieve significant improvements in system performance.

Predicting Working Set Sizes by P. Bryant, p. 221.

Empirical analyses of data on working set size are reported. The data do not support the hypothesis that working set sizes are normally distributed. The data suggest various algorithms for predicting working set size based on the program's past history. Several representative algorithms are discussed and evaluated.

Patterns in Program References by W. F. Freiberger, U. Grenander, and P. D. Sampson, p. 230. This paper describes

a study of some of the characteristics of program referencing patterns. Program behavior is investigated by constructing stochastic models for the page reference mechanism and evaluating the validity of the assumptions made through comparison with empirical results. The notion of a regime process is shown to play a useful role in describing the observed phenomena mathematically. The study falls within the realm of a rapidly growing field of computer science known as compumetrics, where quantitative and qualitative methods are being applied to the study and evaluation of computer performance.

Tailoring Programs to Models of Program Behavior by D. Ferrari, p. 244. This paper considers the premise that, in

addition to trying to solve the virtual-memory-system performance problem by devising a storage management strategy suitable for the broad spectrum of behavior exhibited by programs, efforts also be made to tailor the behavior of each program to the model underlying the storage

management strategy under which the program will have to run. It is observed that a viable approach to program tailoring is offered by restructuring techniques. The application of dynamic off-line techniques to the tailoring problem is discussed, and an algorithm which may be used to fit program behavior to the working set model is described in detail as an example. The performance of this algorithm in dealing with two real-program traces is experimentally evaluated under a variety of conditions and found to be always satisfactory.

Design of Experiments in Simulator Validation by *M. Schatzoff and C. C. Tillman*, p. 252. A common problem encountered in computer system simulation is that of validating that the simulator can produce, with a reasonable degree of accuracy, the same information that can be obtained from the modeled system. This is basically a statistical problem because there are usually limitations with respect to the number of controlled tests that can be carried out, and assessment of the fidelity of the model is a function of the signal to noise ratio. That is, the magnitude of error which can be tolerated depends upon the size of the effect to be predicted. In this paper we describe, by example, how techniques of statistical design and analysis of experiments have been used to validate the modeling of the dispatching algorithm of a time sharing system. The examples are based on a detailed, trace-driven simulator of CP-67. They show that identical factorial experiments involving parameters of this algorithm, when carried out on both the simulator and on the actual system, produced statistically comparable effects.

Performance Analysis of a Multiprogrammed Computer System by *W. Chiu, D. Dumont, and R. Wood*, p. 263. A combination of analytical modeling and measurement is employed for the performance analysis of a multiprogrammed computer system. First, a cyclic queue model is developed for the system under study. Then, model validation is attempted in both controlled and normal environments. The success of the model is demonstrated by its prediction of performance improvements from system reconfigurations. Reasonable correlation between the measured performance and the model predictions under various degrees of multiprogramming is observed. Finally, possible system reconfigurations are explored with the insight gained from the performance analysis.

Terminal Response Times in Data Communications Systems by *J. H. Chang*, p. 272. A response time analysis for a general class of terminals-to-computer subsystem is presented in this paper. The model used is based on the most advanced data communications system in which terminals are connected to Terminal Control Units (TCU) that are in turn connected to local Front-End Processors (FEP). The line control procedures used to interface a TCU and an FEP may be half-duplex Binary Synchronous Communications (BSC), half-duplex Synchronous Data Link Control (SDLC), or full-duplex SDLC. The models presented here can be used

to determine bottlenecks in the entire system and to facilitate the initial phase of system design and configuration.

Queuing Networks with Multiple Closed Chains: Theory and Computational Algorithms by *M. Reiser and H. Kobayashi*, p. 283. In this paper a recent result of Baskett, Chandy, Muntz, and Palacios is generalized to the case in which customer transitions are characterized by more than one closed Markov chain. Generating functions are used to derive closed-form solutions to stability, normalization constant, and marginal distributions. For such a system with N servers and L chains the solutions are considerably more complicated than those for systems with one subchain only. It is shown how open and closed subchains interact with each other in such systems. Efficient algorithms are then derived from our generating function representation.

Solution of Queuing Problems by a Recursive Technique by *U. Herzog, L. Woo, and K. M. Chandy*, p. 295. A recursive method for efficient computational analysis of a wide class of queuing problems is presented. Interarrival and service times are described by multidimensional Markovian processes while arrival and service rates are allowed to be state dependent.

Approximate Analysis of Central Server Models by *C. H. Sauer and K. M. Chandy*, p. 301. Service time distributions at computer processing units are often nonexponential. Empirical studies show that different programs may have markedly different processing time requirements. When queuing disciplines are first come, first served, preemptive priority or nonpreemptive priority, models reflecting these characteristics are difficult to analyze exactly. Available approximate techniques are often too expensive for parametric analysis. Inexpensive approximate techniques for solution of central server models with the above characteristics are presented. The results of these techniques are validated with simulation results.

Central Server Model for Multiprogrammed Computer Systems with Different Classes of Jobs by *W.-M. Chow*, p. 314. A computer system can usually be interpreted as a closed network with two different types of servers. It is then possible to convert the network into a single server system with state-dependent arrivals. This paper investigates the stationary behavior of a single server queue with different classes of jobs. It is assumed that the input process has state-dependent exponential inter-arrival times and preemptions at the server are not allowed. The exact solution is obtained by finding the relationship between the time average probability distribution and the departure average probability distribution. The latter can be derived, based upon an imbedded Markov Chain.

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Vibrating Reed Internal Friction Apparatus for Films and Foils by *B. S. Berry and W. C. Pritchett*, p. 334. An apparatus

is described which permits for the first time the resolution of anelastic relaxation effects in evaporated metallic thin films and ion-implanted surface layers of silicon. The composite samples consist of the film or layer of interest on a carrier substrate having the form of a thin cantilevered reed. Low external losses and an exceptionally good span of operating frequencies are obtained by integrally bonding the substrate to a supporting pedestal and by using electrostatic drive and detection for the transverse modes of vibration. The internal friction can be measured with relatively simple instrumentation, at pressures below 10^{-5} torr (1.33×10^{-3} Pa) and over the temperature range -190°C to 550°C . The apparatus has considerable versatility for work in a number of areas, including the investigation of metallic foils prepared by sputter-cooling.

Modular Hall Masterslice Transducer by R. J. Braun, p. 344. The Hall masterslice transducer combines modern IC (integrated circuit) technology with a modular design concept to provide a flexible multifunction approach to magnetic sensing. Its sensing element, a controllable Hall cell, is integrated with the associated circuitry on a masterslice chip, mounted in a flux concentrator module that forms the basic building block for diverse application packages. The device has several auxiliary control electrodes that allow fixed or externally variable offset voltage control and magnetic field simulation, as well as threshold, hysteresis, and gain adjustments. Integral flux concentrators provide the module with an efficient magnetic flux path and chip cooling. Three application categories—switches, proximity sensors, and current sensors—are discussed and various application package designs are presented.

LRU Stack Processing by B. T. Bennett and V. J. Kruskal, p. 353. Stack processing, and in particular stack processing for the least recently used replacement algorithms, may present computational problems when it is applied to a sequence of page references with many different pages. This paper describes a new technique for LRU stack processing that permits efficient processing of these sequences. An analysis of the algorithm and a comparison of its running times with those of the conventional stack processing algorithms are presented. Finally we discuss a multipass implementation, which was found necessary to process trace data from a large data base system.

Codes for Self-clocking, AC-coupled Transmission: Aspects of Synthesis and Analysis by S. J. Hong and D. L. Ostapko, p. 358. We consider NRZI waveform codes that satisfy a given set of run-length constraints and the upper bound on the accumulated dc charge of the waveform. These constraints enable the codeword to be self-clocking, ac-coupled, and suitable for data processing tape and communication applications. Various aspects of synthesis and analysis of such codes, called (d, k, C) codes, are illustrated by means of several examples. The choice of the initial state

of the encoder is shown to influence the length of the data sequence over which the encoder must look-ahead.

Zero-Modulation Encoding in Magnetic Recording by A. M. Patel, p. 366. This paper deals with waveform encoding methods in which binary data are mapped into constrained binary sequences for shaping the frequency spectrum of corresponding waveforms. Short and long pulse widths in the waveform are limited by constraints on the minimum and maximum run-lengths of zeros in the coded sequences. These constraints reduce the intersymbol interference in magnetic recording and provide an adequate rate of transition for accurate clocking. Signal power at low frequencies is limited by means of a constraint on a parameter that corresponds to the maximum imbalance in the number of positive and negative pulses of the waveform. This constraint on the maximum accumulated dc charge also eliminates the zero-frequency component.

Zero modulation is one such code that is especially suitable for magnetic recording channels. The encoding and decoding algorithm is presented. A one-to-one correspondence between binary data and constrained sequences is established by creating data states that are isomorphic to the charge states having the same growth rate. Sequences with other values of run-length and charge constraint are examined as candidates for other codes with zero dc component.

High-Speed Dynamic Programmable Logic Array Chip by R. A. Wood, p. 379. This paper describes the circuit design of a programmable logic array chip using four-phase dynamic circuits, operating at a nominal cycle time of 230 nanoseconds. Bootstrap circuit techniques are used to obtain high function and performance by satisfying some special requirements of PLA designs. These include a simple means for two-bit partitioning of the data inputs, a noninverting buffer circuit between precharged arrays, and a fast, compact on-chip driver for heavily loaded arrays. Multiphase clocking enables the use of master/slave type JK flip-flops with minimum circuitry and power dissipation. A polarity hold function is provided at the outputs to allow interfacing the dynamic design to static output circuits.

Interpolation with Discontinuous Functions: Application to Calculation of Shocks by W. L. Miranker and A. Morreeuw, p. 384. An interpolation procedure, which uses a step function plus a polynomial correction, is devised and studied for application to the numerical solution of problems having discontinuous solutions. We apply the interpolation procedure to the calculation of shock waves produced by a single convex conservation law. The resulting algorithm does not have the usual undesirable numerical features associated with shock-wave calculations. The stability and convergence of the algorithm is also demonstrated.

Multifont OCR Postprocessing System by W. S. Rosenbaum and J. J. Hilliard, p. 398. A series of techniques is being

developed to postprocess noisy, multifont, nonformatted OCR data on a word basis to 1) determine if a field is alphabetic or numeric; 2) verify that an alphabetic word is legitimate; 3) fetch from a dictionary a set of potential entries using a garbled word as a key; and 4) error-correct the garbled word by selecting the most likely dictionary word. Four algorithms were developed using a technique called vector processing (representing alphabetic words as numeric vectors) and also by applying Bayes maximum likelihood solutions to correct the OCR output. The result was the development of a software simulator which processed sequential fields generated by the Advanced Optical Character Reader (in use by the U.S. Postal Service in New York City), performed the four functions indicated above, and selected the correct alphabetic word from a dictionary of 62,000 entries.

Ferromagnetism in Bi- and Te-substituted MnRh by J. C. Suits, p. 422. A series of experiments shows that substitution of Bi into antiferromagnetic MnRh causes this alloy to become ferromagnetic. The Curie temperature of $(\text{Mn}_{0.8}\text{Bi}_{0.2})\text{Rh}$ is 185K and the moment is $3.5\mu_B$ per formula unit. Substitution of Te instead of Bi gives similar results. This effect is consistent with a model of competitive ferromagnetic and antiferromagnetic exchange in MnRh-type compounds.

Comment on "Bulk Queue Model for Computer System Analysis" by E. W. Stacy, p. 424.

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Preface by R. Ashany, p. 434.

Computation of Lower Bounds for Multiprocessor Schedules by E. B. Fernández and T. Lang, p. 435. A multiprocessing system composed of identical units is considered. This system is executing a set of partially ordered tasks, with known execution times, using a non-preemptive scheduling strategy. Lower bounds on the number of processors required to compute the tasks before a deadline, and on the minimum time to execute the tasks with a fixed number of processors, are of great value for the determination of the corresponding optimal schedules. In this paper, methods for the efficient computation of the lower bounds obtained by Fernández and Bussell are discussed. Computational improvements for the case of general partial orders are reported, and further reductions of the number of operations are shown to be possible for special graphs (trees, independent chains, independent tasks).

Dynamic Partitioning of the Main Memory Using the Working Set Concept by M. Z. Ghanem, p. 445. An algorithm to divide the main memory among N competing programs with different characteristics, running in a multiprogramming and virtual memory environment, is proposed. The algorithm is based on an optimal allocation policy, which is derived in this paper, using the concept of the working set. A brief description of the hardware

implementation of the algorithm is also presented. It is shown that under this optimal allocation policy "the value of a page-frame" (the amount of reduction in the page fault rate if an additional page frame is allocated to that program) to each program is the same.

Study of Memory Partitioning for Multiprogramming Systems with Virtual Memory by M. Z. Ghanem, p. 451. In this paper, we investigate the effect that the shape of the lifetime function has on the optimal partition of the main memory of a computer among N programs, where the criterion of optimality is maximization of CPU utilization. We used a simple queuing model as a base for understanding this interrelationship. The lifetime function is the average of the execution intervals of a program as a function of the amount of memory allocated. When the lifetime function is convex and is proportional to m^α , where m is the size of memory, then the optimal partition is obtained by dividing the main memory equally among q of the N programs (q is the optimal degree of multiprogramming). Thus, the best partition is always one of two policies; allocate all memory equally among the q programs or allocate all memory to one program. When the lifetime function has a degenerate S shape (is proportional to m^α when $m \leq m_0$ and remains constant beyond m_0), then there exists a memory size m such that no program can have a memory other than m or m_0 ; if any program has a memory size greater than m_0 , each other program should have a memory size that is equal to or greater than m_0 .

Introduction to Regenerative Simulation by S. S. Lavenberg and D. R. Slutz, p. 458. A recently developed method for estimating confidence intervals when simulating stochastic systems having a regenerative structure is reviewed. The paper is basically tutorial, but also considers the pragmatic issue of the simulation duration required to obtain valid estimates. The method is illustrated in terms of simulating the M/G/1 queue. Analytic results for the M/G/1 queue are used to determine the validity of the simulation results.

Regenerative Simulation of a Queuing Model of an Automated Tape Library by S. S. Lavenberg and D. R. Slutz, p. 463. Recently, techniques have been developed for estimating confidence intervals when simulating stochastic systems having a regenerative structure. These techniques are applied to the simulation of a queuing model of a computer system's automated tape library. Theoretical and practical issues related to the application of these techniques are addressed. An interesting feature of the automated tape library represented in the queuing model is that certain queues have finite capacity; when these queues are filled to capacity certain services are prevented from occurring. The regenerative techniques are used in conjunction with multiple comparison procedures to make statistically valid statements about the effect of the finite queue capacities on performance.

Sequential Server Queues for Computer Communication System Analysis by W. Chang, p. 476. A queuing model with

two sequential servers is developed to analyze performance in computer and communication systems. In one case the CPU is the first server and the terminal and its associated communications equipment are the second server. In a second case the CPU and the channel are the first server and the auxiliary storage device is the second server. We study the queuing behavior of the sequential server systems with Poisson arrivals, general service time distributions, and several service disciplines, including bulk arrivals, message priorities, and the input and output queues. The stationary distributions of the queue lengths and waiting times are determined by using an imbedded Markov chain analysis. Several examples are given to illustrate the applications of these models to practical problems.

Analysis of a Loop Transmission System with Round-Robin Scheduling of Services by *R. M. Wu and Y.-B. Chen*, p. 486. A finite population, multi-queue model is developed for a loop transmission system. Approximate expressions for the state transition matrix and other system variables are derived in recursive forms. It is also shown that a number of useful system parameters, such as average message response time, average cycle time, and average response time conditioned on message length, can be obtained. The analytical results have been validated by simulation.

Optimal Scheduling Strategies for Real-Time Computers by *U. Herzog*, p. 494. In order to fulfill response time constraints in real-time systems, demands are often handled by means of sophisticated scheduling strategies. This paper first shows how to describe and analyze arbitrary combinations of preemptive and non-preemptive (head-of-the-line) priority strategies and, second, presents an algorithm that yields the optimal priority strategy, taking into consideration constraints on the response time.

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Theory of Liquid Ink Development in Electrophotography by *Y.-O. Tu*, p. 514. When an electric field is present across two different fluid dielectrics having a common plane boundary, some disturbances in the interfacial boundary are found to grow in time. The liquid ink development process is viewed as the result of varying instability of the oil-ink interface as a function of the differing field gradient in light and dark areas of the exposed image. In an analysis of the disturbances into normal modes, the theory relates the effects upon instability due to potential difference across the oil, the surface tension, the respective viscosities of the oil and the ink, and the finite thicknesses of the oil, ink, and the photoconductor layer. The threshold potential difference for the onset of instability is also given.

Multiconic Surfaces by *B. Dimsdale and K. Johnson*, p. 523. Multiconic surfaces are a generalization of the type of surface called polyconic in numerical control of machine tools. The general theory is developed in this paper using a new

parametrization. In the original form there was a problem as to whether or not a point that satisfies surface equations actually belonged to the intended surface. This difficulty is removed by the new technique.

Algorithms for calculation of line and plane intersections with the surface and for calculation of normal vectors, volume, and surface area are given for classes of defining functions of which it is required only that they have appropriate conditions of continuity and differentiability.

Examples are given of surfaces developed using spline functions. Preliminary comparative estimates of design and numerical control processing times are included.

Threshold Voltage Characteristics of Double-boron-implanted Enhancement-mode MOSFETs by *P. P. Wang and O. S. Spencer*, p. 530. Threshold voltage characteristics are presented for a double boron-ion-implanted *n*-channel enhancement MOSFET device for high speed logic circuit applications. A 15- Ω -cm high resistivity *p*-type (100) substrate was used to achieve low junction capacitance and low threshold substrate sensitivity. A shallow boron implant was used to raise the threshold voltage, and a second, deeper, boron implant was used to increase the punch-through voltage between the source and the drain. This design is especially beneficial for short channel devices, while maintaining the low junction capacitance and low threshold substrate sensitivity of the high resistivity substrate. A one-dimensional analysis was performed to predict the effects of ion implantation dose and energy on the device characteristics, and a quasi two-dimensional analysis was used to account for the short channel effect. The calculated results agree well with the behavior of experimental devices fabricated in the laboratory.

Computation of Incident Solar Energy by *J. V. Dave, P. Halpern, and H. J. Myers*, p. 539. Computations of the daily and annual totals of the solar energy incident upon south-facing tilted flat surfaces were carried out for several cloudfree atmospheric models after taking into account, somewhat arbitrarily, the contribution due to sky radiation and that due to radiation reflected by the ground. Representative variations of these quantities are discussed as a function of several parameters such as geographical latitude of the location, tilt angle of the surface, atmospheric transmission characteristics, sky-radiation contribution, and ground reflectivity.

Model for Interactive Data Base Reference String by *M. C. Easton*, p. 550. A particularly simple Markov chain model for a reference string is described. The model, which is only slightly more complicated than the independent reference model, generates strings that have a locality property and that have a specified probability distribution of references over pages. Expressions are obtained for expected working-set size and expected working-set miss ratio. The model is used in an examination of the effect of grouping pages into blocks and

in a discussion of the problem of evaluating the effect of changes in the size of the data base. Predictions of the model are shown to agree closely with observations of a string of data base references generated by an interactive data base system having a large number of concurrent users.

HEME: A Self-Improving Computer Program for Diagnosis-Oriented Analysis of Hematologic Diseases by *B. J. Flehinger and R. L. Engle, Jr., p. 557.* HEME, a computer program for diagnosis-oriented analysis of hematologic diseases, accepts as input information about a patient and provides as output an ordered list of suggested diagnoses, an analysis of the logic behind these diagnoses, and a list of tests relevant to these diagnoses and not yet performed. The decision algorithm is based on Bayes' Theorem. Each disease in the system is individually analyzed, and the probability that the patient has the disease vs the probability that he does not is calculated. Bayesian methods of statistical inference are utilized in that the prior probabilities of the diseases and the probabilities of findings in given diseases were initially estimated from the judgment of experienced hematologists with the intention that they be modified automatically as data are accumulated. This program is intended for use in teaching hematology, as an aid to diagnosis, and as a means for studying the diagnostic process.

Modified Nodal Approach to DC Network Sensitivity Computation by *C. W. Ho, p. 565.* Programming techniques are presented for computing dc sensitivity vectors of nonlinear electronic circuits. The modified nodal approach is used as the method of formulation for the circuit equations, in which multiple performance objectives can be accommodated. Numerical examples illustrate some of the techniques discussed.

Mathematical Construct for Program Reorganization by *D. P. Pazel, p. 575.* A mathematical formalism is described through which a program is given a symbolic representation and, with the application of several basic formulas, may be transformed into an equivalent representation giving rise to a reorganized program. Examples are given in which programs are simplified (e.g., code is reduced) or reorganized into a structured form. In effect a mathematics is described that

applies to programs in much the same manner as Boolean algebra applies to switching circuits.

On Some Relations between the Laplace and Mellin Transforms by *J. S. Lew, p. 582.* Several earlier papers have applied some identities relating the Laplace and Mellin transforms; this note develops certain such identities, achieving greater generality and rigor. Specifically each of these transforms is expressed as a contour integral involving the other, and an expansion of the Laplace transform is derived in terms of the functions $(s \cdot d/ds)^n (1+s)^{-1}$ with coefficients defined by the Mellin transform.

Amorphous GdCoCr Films for Bubble Domain Applications by *J. Schneider, p. 587.* Amorphous GdCoCr films of various composition ratios made by rf bias sputtering are investigated for their applicability as bubble domain supporting materials. Film compositions around $Gd_{0.13}Co_{0.65}Cr_{0.22}$ have temperature-insensitive magnetizations between 240 K and 350 K with $T_{comp} \approx 120$ K and $T_c \approx 630$ K. Reduction of the Cr content from 21.8 to 20.3 at. percent causes an increase of the magnetization by a factor of three. Thermal cycling of these films between 290 K and 570 K does not change the magnetization noticeably, nor does annealing for up to six days at 520 K.

The films are found to be very susceptible to contamination by the residual oxygen present in the vacuum chamber during sputtering. Films contaminated with 3 to 13 at. percent oxygen have coercivities around 800 A/m (10 Oe), whereas films which were oxygen-free according to microprobe investigations show coercivities less than 80 A/m (1 Oe).

Effect of Submicrometer Transducer Spacing on the Readback Signal in Saturation Recording by *F. E. Talke and R. C. Tseng, p. 591.* Experimental results for frequency response and halfpulse width of digital recording signals have been obtained for submicrometer transducer spacings, for the case of a flexible disk flying in close proximity to a rigidly mounted conventional ferrite recording head. Using optical flying heights rather than an "effective spacing," together with a modification of the Williams-Comstock write-process slope criterion, we have obtained excellent agreement between experimental results and theoretical predictions. This suggests that the notion of effective spacing can be avoided.

Preface by R. Ashany, p. 2.

Computers and the Space Program: An Overview by C. C. Kraft, Jr., p. 3.

Development of On-board Space Computer Systems by A. E. Cooper and W. T. Chow, p. 5. This paper describes the functions, characteristics, requirements, and design approaches of the on-board computers for seven space vehicles—Saturn I, Orbiting Astronomical Observatory, Gemini, Saturn IB, Saturn V, Skylab, and Space Shuttle. The data contained in this paper represent an encapsulation of sixteen years of space-borne-computer development. In addition, the evolution of computer characteristics such as size, weight, power consumption, computing speed, memory capacity, technology, architectural features, software, and fault-tolerant capabilities, is summarized and analyzed to point out the design trends and the motivating causes. The evolution in utilization of the on-board computers; their interface with sensors, displays, and controls; and their interaction with operators are summarized and analyzed to show the increasing role played by computers in the overall space-vehicle system.

Redundancy Management Technique for Space Shuttle Computers by J. R. Sklaroff, p. 20. This paper describes how a set of off-the-shelf general purpose digital computers is being managed in a redundant avionics configuration while performing flight-critical functions for the Space Shuttle. The description covers the architecture of the redundant computer set, associated redundancy design requirements, and the technique used to detect a failed computer and to identify this failure on-board to the crew. Significant redundancy management requirements consist of imposing a total failure coverage on all flight-critical functions, when more than two redundant computers are operating in flight, and a maximum failure coverage for limited storage and processing time, when only two are operating. The basic design technique consists of using dedicated redundancy management hardware and software to allow each computer to judge the "health" of the others by comparing computer outputs and to "vote" on the judgments. In formulating the design, hardware simplicity, operational flexibility, and minimum computer resource utilization were used as criteria.

Performance Modeling of Earth Resources Remote Sensors by R. H. Kidd and R. H. Wolfe, p. 29. A technique is presented for constructing a mathematical model of an Earth resources remote sensor. The technique combines established models of electronic and optical components with formulated models of scan and vibration effects, and it includes a model of the radiation effects of the Earth's atmosphere. The resulting composite model is useful for predicting in-flight sensor performance, and a descriptive set of performance parameters is derived in terms of the model. A method is outlined for validating the model for each sensor of interest.

The validation for one airborne infrared scanning system is accomplished in part by a satisfactory comparison of predicted response with laboratory data for that sensor.

Digital Image Processing of Earth Observation Sensor Data by R. Bernstein, p. 40. This paper describes digital image processing techniques that were developed to precisely correct Landsat multispectral Earth observation data and gives illustrations of the results achieved, e.g., geometric corrections with an error of less than one picture element, a relative error of one-fourth picture element, and no radiometric error effect. Techniques for enhancing the sensor data, digitally mosaicking multiple scenes, and extracting information are also illustrated.

Skylab Attitude Control System by T. R. Coon and J. E. Irby, p. 58. The attitude stabilization and control system for Skylab evolved from an analog controller into a fully digital processing system. Features of this system include a software-determined attitude reference to provide general maneuvering ability, an in-orbit programming capability, the use of large control moment gyros for attitude control, and the use of vehicle maneuvers to desaturate gyro momentum. The objectives, requirements, and implementations of the control system software are described, along with the rationales for certain design decisions and discussion of some system dynamics and actual performance.

Large Space Telescope by F. J. Hudson, p. 67. The Large Space Telescope, which is scheduled to be put into orbit above the Earth's atmosphere by NASA in the early 1980s, is a large, multipurpose optical instrument that is being designed to provide an increase in observational capability of nearly 100× with respect to brightness, 10× in resolving power, and a substantial bandwidth improvement over ground-based facilities. This paper describes, from a functional performance viewpoint, the LST system and, in greater detail, the on-board Data Management and Pointing Control Systems.

Launch Processing System by F. Byrne, G. V. Doolittle, and R. W. Hockenberger, p. 75. This paper presents a functional description of the Launch Processing System, which provides automatic ground checkout and control of the Space Shuttle launch site and airborne systems, with emphasis placed on the Checkout, Control, and Monitor Subsystem. Hardware and software modular design concepts for the distributed computer system are reviewed relative to performing system tests, launch operations control, and status monitoring during ground operations. The communication network design, which uses a Common Data Buffer interface to all computers to allow computer-to-computer communication, is discussed in detail.

Real-Time Orbiter Abort Guidance by V. S. Sohoni, p. 84. This paper describes a real-time abort guidance algorithm which determines the time sequence of the powered maneuvers and the orientation of the thrust vector throughout

an abort-mission action initiated during the orbiter ascent phase. It involves guiding a heavily loaded Space Shuttle vehicle, passing through severe environmental conditions, back to a designated landing area. A graphical example and estimates of the computer requirements are included.

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Submicrometer Stripes and Bubbles in Amorphous Films by P. Chaudhari and S. R. Herd, p. 102. Lorentz microscopy is used to study amorphous thin films of Gd-Co-Au and Gd-Co-Mo having a range of Q values. Stripe and bubble formation are shown as a function of perpendicular bias fields and pulsed or rotating in-plane fields. In the presence of an in-plane field, stripes contain a pair of Bloch lines and break into rows of Bloch-line containing bubbles. A unichiral stripe, however, forms a unichiral bubble that is stable to higher perpendicular bias fields than are Bloch-line bubbles. Bloch-line rotation in bubble walls in the presence of external rotating fields is demonstrated, and Bloch-line motion due to sweeping in-plane walls is shown. The rare occurrence of four Bloch lines in a 0.2- μm bubble is observed, as is the pearl-like accumulation of multiple Bloch lines in walls of irregularly shaped domains.

Bubble Lattice Motions Due to Modulated Bias Fields by B. E. Argyle, J. C. Slonczewski, and O. Voegeli, p. 109. We observe that periodic variations of bias field can couple to a close-packed lattice of magnetic bubbles to produce a steady rotation of the bubble lattice (RBL). Pulsed fields excite various other many-body phases as well. The physical motions of such bubble arrays can be described by "lattice melting," "evaporation," and "rotating galaxies." The RBL phase is stable over wide ranges of pulse width and amplitude when the film is thick and the lattice is confined either by a circular ion-milled groove or by radially symmetric inhomogeneous fields from the excitation coil itself. Microsecond pulsed fields of $-0.05 \times 4\pi M_s$, applied to a lattice of five- μm bubbles produce a net displacement of up to 1.5 μm /pulse at the rim of a lattice 23 bubbles across and 250 μm in diameter. Sinusoidal bias modulation in the range 1 to 30 MHz produces a spectrum of lattice rotational velocities vs frequency having both signs. At frequencies near the low end of the spectrum both the magnitude and the sign of the rotation are sensitive to drive amplitude. A tentative theory attributes lattice rotation to nonlinearities involving the bubble-deflection effect. The mechanism is strong enough to account for the observed magnitude of rotational frequency and can explain its resonant peaks and sign changes.

Storage Management Operations in Linked Uniform Shift-Register Loops by T.-C. Chen and C. Tung, p. 123. A new storage structure, called a uniform ladder, consists of a linear array of equal shift-register loops, each holding one record and linked by flow-steering switches. Data exchange across a loop boundary is mandatory if the controlling switch is on and forbidden if off. For MRU (Most Recently Used)

storage management, the most important operation is the climbing of data to the top of the ladder from a depth of D loops, which takes only $(D + 1)/2$ record periods in the uniform ladder. Program switching is enhanced by efficient schemes for partial environmental exchanges and also by internal block transfers. A pushdown stack can be efficiently implemented by a change in the record storing technique.

Effects of Abrupt Changes in Film Thickness on Magnetic Bubble Forces by T. W. Collins and R. W. Cole, p. 132.

Forces on a magnetic bubble due to abrupt asymmetric changes in the surface configuration of the magnetic film are investigated theoretically and experimentally. A model is derived for calculating the forces on a bubble as it is being moved by conductor propagation through a thickness gradient in the film. An experiment is described in which the forces necessary to move a bubble through this transition region are measured and compared with predicted values computed from the model. Results are presented for a 20° gradient with a cut 0.62 μm deep in a garnet film, nominally 3.8 μm thick, prepared by liquid phase epitaxy.

Bases for Chain-complete Posets by G. Markowsky and B. K. Rosen, p. 138. Various authors (especially Scott, Egli, and Constable) have introduced concepts of "basis" for various classes of partially ordered sets (posets). This paper studies a basis concept directly analogous to the concept of a basis for a vector space. The new basis concept includes that of Egli and Constable as a special case, and one of their theorems is a corollary of our results. This paper also summarizes some previously reported but little known results of wide utility. For example, if every linearly ordered subset (chain) in a poset has a least upper bound (supremum), so does every directed subset.

Given posets P and Q , it is often useful to construct maps $g: P \rightarrow Q$ that are *chain-continuous*: supremums of nonempty chains are preserved. Chain-continuity is analogous to topological continuity and is generally much more difficult to verify than *isotonicity*: the preservation of the order relation. This paper introduces the concept of an *extension basis*: a subset B of P such that any isotone $f: B \rightarrow Q$ has a unique chain-continuous extension $g: P \rightarrow Q$. Two characterizations of the chain-complete posets that have extension bases are obtained. These results are then applied to the problem of constructing an extension basis for the poset $[P \rightarrow Q]$ of chain-continuous maps from P to Q , given extension bases for P and Q . This is not always possible, but it becomes possible when a mild (and independently motivated) restriction is imposed on either P or Q . A lattice structure is not needed.

Drop Formation from a Liquid Jet: A Linear One-dimensional Analysis Considered as a Boundary Value Problem by W. T. Pimbley, p. 148. Using a one-dimensional model, the author studied drop formation using a boundary value perturbation, rather than a spatially periodic one as considered by Rayleigh. The Rayleigh

solution becomes the high jet velocity approximation to this linear analysis. At lower velocities the analysis shows that the medium becomes dispersive, and drop formation characteristics are quite different from that predicted by Rayleigh. In an appendix, the gross momentum balance and flow rate conservation are used to consider drop formation from a stream.

Objects and Values: The Basis of a Storage Model for Procedural Languages by D. B. Lomet, p. 157. A model for storage in procedural languages is presented. Its fundamental notion is to strictly distinguish values from storage objects. Several difficulties in current languages are resolved in this model, e. g., the problem of flexible locations and the meaning of the term type. In the light of the storage object/value dichotomy, several notions are found to be covered by the term type. The implications of the model are explored with respect to the more conventional data constructs of procedural languages as well as to sets and how they might be provided. Finally, data extension mechanisms are considered. Whereas the treatment here is not complete, the template concept introduced in the model does suggest a useful framework for providing the much talked of but seldom realized benefits of data extensibility.

Error Correcting Codes for Satellite Communication Channels by C.-L. Chen and R. A. Rutledge, p. 168. This paper addresses the problem of efficient forward error correction on differentially encoded, quadriphase-shift-keying (DQPSK) channels. The approach is to design codes to correct the most probable error patterns. First the probability distribution of error patterns is derived. Then a class of convolutional codes that correct any single two-bit error is described. Finally a threshold decodable code that corrects all single, and many double, two-bit errors is presented.

Electric Motor Requirements for Positioning an Inertial Load by J. H. Meier and J. W. Raider, p. 176. This paper deals with the motor, the inertia ratio, and the power input requirements for moving an inertial load over a specified distance in a specified time. A linear speed-torque relationship is assumed, and selected motor parameters are normalized to the load to establish generally applicable solutions and characteristic curves. Emphasis is placed on the velocity-time diagrams and the relationship among the inertia ratio, the rated motor power, and the electrical input power. It is shown that optimization is possible for input power at stall, input power immediately following torque reversal, and average input power. Computer generated curves are presented for these three cases, and their relationships are discussed. Finally, it is shown that the motor time constant has a great influence on power requirements.

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Generalized Kraft Inequality and Arithmetic Coding by J. J. Rissanen, p. 198. Algorithms for encoding and decoding

finite strings over a finite alphabet are described. The coding operations are arithmetic involving rational numbers l_i as parameters such that $\sum_i 2^{-l_i} \leq 2^{-\epsilon}$. This coding technique requires no

blocking, and the per-symbol length of the encoded string approaches the associated entropy within ϵ . The coding speed is comparable to that of conventional coding methods.

Analysis of the Berlekamp-Massey Linear Feedback Shift-Register Synthesis Algorithm by F. G. Gustavson, p. 204. An analysis of the Berlekamp-Massey Linear Feedback Shift-Register (LFSR) Synthesis Algorithm is provided which shows that an input string of length n requires $O(n^2)$ multiplication/addition operations in the underlying field of definition. We also derive the length distribution for digit strings of length n . Results show that, on the average, the encoded length is no greater than $n + 1$. Furthermore, we exhibit a connection between step 1 of the Ling-Palermo algorithm and the LFSR Algorithm, and the LFSR Algorithm turns out to be computationally superior.

Deep-UV Conformable-Contact Photolithography for Bubble Circuits by B. J. Lin, p. 213. The techniques of deep-ultraviolet (UV) conformable-contact photolithography are described and some preliminary work reported on their application to the fabrication of high-density bubble memory circuits by single-level masking. A quantitative analysis of tolerance requirements for linewidth, mask-to-wafer gap, and exposure is made for printing with conventional UV and deep-UV, for feature sizes in the range $2.5 \mu\text{m}$ to $0.1 \mu\text{m}$. A new type of mask-to-wafer holder is described, utilizing a diaphragm to achieve contact. The holder can be used for either a conformable wafer or a conformable mask, or for both conformable wafer and mask, and for the liquid gap technique. Developmental bubble memory circuits on amorphous and garnet materials have been fabricated using deep-UV conformable-contact photolithography, electroplating, liftoff, and ion milling.

Lattice Dynamics with Three-Body Forces: Solid Xe and Kr by J. A. Barker, M. L. Klein, and M. V. Bobetic, p. 222. Phonon dispersion curves, elastic constants, and the pV isotherms are calculated for solid Xe and Kr at 0 K using quasiharmonic lattice dynamics derived from multiparameter pair potentials. The computations account for the Axilrod-Teller-Muto three-body triple-dipole forces that arise in third-order perturbation theory. Approximate allowance is also made for anharmonic effects and, in the case of Xe, for three-body, third-order, dipole-quadrupole interactions and the three-body dipole interactions that arise in fourth-order perturbation theory. The over-all agreement with experimental phonon data is good except, in the case of xenon, for the lowest-energy phonons in the $\langle 110 \rangle$ direction. This has the consequence that the shear elastic constant $(C_{11} - C_{12})/2$ and the zero temperature Debye theta are somewhat lower than current experimental values.

LSI Yield Modeling and Process Monitoring by C. H. Stapper, p. 228. This paper describes an analytical technique for quantifying and modeling the frequency of occurrence of integrated circuit failures. The method is based on the analysis of random and clustered defects on wafers with defect monitors. Results from pilot line data of photolithographic defects, insulator short circuits, and leaky pn junctions are presented to support the practicality of the approach. It is shown that, although part of the yield losses are due to the clustering of defects, most product loss is from random failures. The yield model shows good agreement with actual product yields.

Delayed Closed-Loop Scheme for Stepping Motor Control by B. Bechtle, C. Schünemann, G. Skudelny, and V. Zimmermann, p. 235. An efficient method for control of stepping motor speed and position, the delayed closed-loop (DCL) mode, is described. The new technique permits control of high-speed motor motion by means of a programmed speed-displacement characteristic. The method combines the static-speed control characteristic of the open-loop mode with the stable dynamic behavior of the closed-loop mode. Unlike other schemes for delayed closed-loop control, the present configuration features an extension of delay time to more than one step duration, significantly improving the velocity control. The phase angle can also be varied to $\pm 180^\circ$, permitting adequate control of deceleration as well as acceleration. A stability analysis is made of the DCL control method. In an illustrative example, the technique is applied to control of the carriage drive on an experimental high-speed line printer.

Optimization of Single Expressions in a Relational Data Base System by P. A. V. Hall, p. 244. This paper examines optimization within a relational data base system. It considers the optimization of a single query defined by an expression of the relational algebra. The expression is transformed into an equivalent expression or sequence of expressions that cost less to evaluate. Alternative transformations, and combinations of several transformations, are analyzed. Measurements on an experimental data base showed improvements, especially in cases where the original expression would be impracticably slow in its execution. A small overhead was incurred, which would be negligible for large data bases.

Dependence of Ink Jet Dynamics on Fluid Characteristics by C. A. Bruce, p. 258. Measurements of jet velocity, separation length, and stream stability (freedom from random fluctuations in drop position) were made for several fluids, including two inks. The data were then compared with modified fluid flow and jet stability equations. In one case velocity is related to applied pressure drop through a flow equation that depends primarily on the shape and size of the nozzle and on fluid viscosity. In the other case Weber's equation is modified to include forced oscillation, so that separation length is related to the voltage applied to a piezoelectric crystal, to disturbance growth rate, and to

velocity. These two equations were applicable to "normal" liquids (those having good stream stability) having viscosities between 0.9 and 4.3 grams/(second · meter) and dynamic surface tensions between 20 and 60 grams/s², but not to dilute solutions of a high molecular weight polymer, owing to their viscoelastic character. Furthermore, the stream stability of the polymer solutions was poor and depended inversely on concentration and molecular weight.

Amorphous Materials for Micrometer and Submicrometer Bubble Domain Technology by C. H. Bajorek and R. J. Kobliska, p. 271. A review and critique is made of those material and processing issues that pertain to the implementation of micrometer and submicrometer bubble devices on amorphous films. Adequate reproducibility and uniformity have been achieved in ternary amorphous films prepared by rf sputtering and their magnetic characteristics are very similar to those of analogous garnet films. Factors that may limit application to the amorphous films include defects and dielectric breakdown in insulating layers, sensitivity to annealing, and larger, but not prohibitive, coercivities. A salient problem common to both garnet and amorphous materials is attainment of sufficiently large values of Q to ensure stable device operation.

Complex Convolutions via Fermat Number Transforms by H. J. Nussbaumer, p. 282. An approach is described for computing complex convolutions modulo a Fermat number. It is shown that this technique is particularly efficient when the complex convolution is computed by means of Fermat Number Transforms and leads to improved implementation of complex digital filters.

Speckle Pattern Interferometry of Vibration Modes by I. M. Andrews and J. A. Leendertz, p. 285. An optical facility is described for the study of the vibrational behavior of engineering test pieces. Time-average holography and electronic speckle pattern methods of analysis are combined into one system. The speckle pattern method is used for the identification of resonances, frequency tuning, and object alignment, thereby optimizing the number of holographic exposures. An evaluation is made of the electronic speckle pattern method for the detection of vibration modes of three-dimensional objects. The method is shown to detect resonant vibration readily on object faces inclined at angles up to 60° to the viewing direction.

Comment on "Segment Synthesis in Logical Data Base Design" by G. Wiederhold, p. 290.

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Automatic Programming Through Natural Language Dialogue: A Survey by G. E. Heidorn, p. 302. This paper describes and compares four research projects whose goal is to develop an automatic programming system that can carry on a natural language dialogue with a user about his

requirements and then produce an appropriate program. It also discusses some of the important issues in this research area.

On Natural Language Based Computer Systems by S. R. Petrick, p. 314. Some of the arguments that have been given both for and against the use of natural languages in question-answering and programming systems are discussed. Several natural language based computer systems are considered in assessing the current level of system development. Finally, certain pervasive difficulties that have arisen in developing natural language based systems are identified, and the approach taken to overcome them in the REQUEST (Restricted English QUESTION-Answering) System is described.

REQUEST: A Natural Language Question-Answering System by W. J. Plath, p. 326. REQUEST is an experimental Restricted English QUESTION-answering system that can analyze and answer a variety of English questions, spanning a significant range of syntactic complexity, with respect to a small *Fortune*-500-type data base. The long-range objective of this work is to explore the possibility of providing nonprogrammers with a convenient and powerful means of accessing information in formatted data bases without having to learn a formal query language. To address the somewhat conflicting requirements of understandability for the machine and maximum naturalness for the user, REQUEST uses a language processing approach featuring: 1) the use of restricted English; 2) a two-phase, compiler-like organization; and 3) linguistic analysis based on a transformational grammar. The present paper explores the motivation for this approach in some detail and also describes the organization, operation, and current status of the system.

Conceptual Graphs for a Data Base Interface by J. F. Sowa, p. 336. A data base system that supports natural language queries is not really natural if it requires the user to know how the data are represented. This paper defines a formalism, called conceptual graphs, that can describe data according to the user's view and access data according to the system's view. In addition, the graphs can represent functional dependencies in the data base and support inferences and computations that are not explicit in the initial query.

Bicubic Patch Surfaces for High-Speed Numerical Control Processing by B. Dimsdale and R. M. Burkley, p. 358.

Parametric bicubic patch surfaces have been used for some time in manufacture and design. It is convenient to have such surfaces available as standard numerical control surfaces using the APT programming language. A major drawback is that they are costly to use for data processing of numerical control programs. If, however, nonparametric bicubics are used, computer time, and hence cost, can be reduced dramatically. This paper details a strategy and algorithms for this purpose. Experimental data suggest that computer costs are comparable

to, or somewhat lower than, the costs for processing tabulated cylinder surfaces.

Column Access of a Bubble Lattice: Column Translation and Lattice Translation by B. A. Calhoun, J. S. Eggenberger, L. L. Rosier, and L. F. Shew, p. 368. The use of a regular array, or lattice, of magnetic bubbles for the storage of information requires two kinds of functions: the read-write functions involving the generation and discrimination of bubbles with different wall structures, and the access functions involving the insertion and removal of bubbles at selected locations in the lattice. In a column-accessed bubble lattice device, accessing is accomplished by first translating the lattice to position the desired column of bubbles in an input-output access channel and then translating this column along the channel to a detector area outside of the lattice while simultaneously introducing new bubbles from a generator area at the other end of the channel. An analysis of the influence of device design parameters on access rate indicates that the most important parameters are the column translation rate and lattice capacity. A device is described that was designed to study the translation of a lattice of bubbles and of a single column of bubbles within the lattice. Quasistatic operating margins and dynamic measurements of this test device indicate that the column-access configuration provides feasible means for the rapid access of bubbles from a lattice.

Scanning Electron Beam Lithography for Fabrication of Magnetic Bubble Circuits by T. H. P. Chang, M. Hatzakis, A. D. Wilson, A. J. Speth, A. Kern, and H. Luhn, p. 376. A high-resolution technique is described for the experimental fabrication of Permalloy patterns for magnetic bubble circuits having linewidths as small as 3000 Å. The system includes a computer-controlled electron beam, automatic registration, a modified field-stitching method, and exposure control to compensate for proximity effects. Patterns are formed either by electroplating or by evaporation. The system can be used either for directly writing on bubble wafers or for fabricating masks for x-ray or conformable-mask printing.

Design of a Swinging Arm Actuator for a Disk File by J. S. Heath, p. 389. An integral disk enclosure that incorporates a novel head-positioning actuator concept is used in the IBM System/32 and in recently announced terminal controllers, such as the Retail Store Controller and the Communication Controller. Based on a swinging arm rather than the conventional linear carriage, the actuator presented the designers with opportunities to create a simplified mechanism and to gain advantages in reliability and cost. This paper describes the geometrical, structural, and electromechanical basis of the design.

Fast Beamforming with Circular Receiving Arrays by H. P. Raabe, p. 398. The Fast Fourier Transform (FFT) can be applied to circular arrays receiving wideband sonar radiation. As with conventional beamforming, the FFT serves in the first stage to divide the spectrum into narrow frequency bands.

Then the array element responses of each band are analyzed in a second stage of FFTs for the Fourier components (modes) of the array excitation function for the respective band. Application of weights of the mode responses, to simulate the radiation efficiency of the modes for any given element radiation pattern and to control the array pattern, yields the Fourier components of the beam pattern. To integrate these Fourier components, inverse FFTs follow which yield as many beam pattern samples as there are array elements.

Structure and Magnetic Anisotropy of Amorphous Gd-Co Films by A. Onton, N. Heiman, J. C. Suits, and W. Parrish, p. 409. It is found that the structure of amorphous Gd-Co films, as revealed by x-ray diffraction, is correlated with the magnitude of bias voltage present during the sputter deposition. Films sputter deposited with zero bias voltage typically show one broad peak in an x-ray diffraction spectrum, and films sputter deposited with -100 volts bias show two broad peaks with a shoulder between them. These structural differences appear to be related to the perpendicular magnetic anisotropy in these films.

Comment on "Segment Synthesis in Logical Data Base Design" by P. A. Bernstein, p. 412.

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Cubic Splines with Infinite Derivatives at Some Knots by A. Inselberg, p. 430. A generalization of cubic spline interpolation with vertical slopes at some knots is proposed. An existence theorem including an algorithm for constructing such generalized splines is proved. The resulting splines are obtained in closed form and they are partition invariant.

Stochastic Modeling of Processor Scheduling with Application to Data Base Management Systems by S. S. Lavenberg and G. S. Shedler, p. 437. This paper is concerned with the stochastic modeling of processor scheduling and of queuing due to contention for resources in data base management systems. The processing services rendered in searching the data base and retrieving and processing information are modeled explicitly, as is the algorithm used to schedule these services on the processor. The scheduling of the processor is based on a total priority ordering of a set of queues for processing service. A queuing model incorporating the processor scheduling algorithm for IMS (Information Management System) is formulated in order to illustrate the modeling ideas. The model is analyzed under rather general distributional assumptions, based on the observation that certain stochastic processes in the model are cumulative processes defined over the same embedded semi-Markov process. The model is not used in a performance study of IMS, nor is it proposed that the model developed here is one upon which a performance study of IMS should be undertaken. The model should be viewed as illustrative of stochastic models which can be constructed to incorporate algorithms for processor scheduling.

Exploratory Analysis of Access Path Length Data for a Data Base Management System by D. P. Gaver, S. S. Lavenberg, and T. G. Price, Jr., p. 449. An exploratory approach is taken to analyze a vast quantity of data recorded during the running of the data base management system IMS (Information Management System). The collection of data analyzed is a sequence of access path lengths for a day-long period. The number of segments accessed by IMS when searching a data base in order to retrieve a specified segment for a user is called an access path length. Part of the motivation for the analysis is to suggest reasonable stochastic models for the access path length sequence that can be conveniently utilized as input models for a stimulation model of an IMS installation. The exploratory approach taken to the data involves the use of graphical displays and simple numerical summaries to reveal characteristics of, and patterns in, the data. Some simple ways are presented in which the structure of the data revealed by the analysis can be incorporated into an input model for a system simulation.

Statistical Analysis of Non-stationary Series of Events in a Data Base System by P. A. W. Lewis and G. S. Shedler, p. 465. Central problems in the performance evaluation of computer systems are the description of the behavior of the system and characterization of the workload. One approach to these problems comprises the interactive combination of data-analytic procedures with probability modeling. This paper describes methods, both old and new, for the statistical analysis of non-stationary univariate stochastic point processes and sequences of positive random variables. Such processes are frequently encountered in computer systems. As an illustration of the methodology an analysis is given of the stochastic point process of transactions initiated in a running data base system. On the basis of the statistical analysis, a non-homogeneous Poisson process model for the transaction initiation process is postulated for periods of high system activity and found to be an adequate characterization of the data. For periods of lower system activity, the transaction initiation process has a complex structure, with more clustering evident. Overall models of this type have application to the validation of proposed data base subsystem models.

A General Methodology for Data Conversion and Restructuring by V. Y. Lum, N. C. Shu, and B. C. Housel, p. 483. This paper presents a methodology and a model for data conversion or translation. The model assumes that both source and target systems are available and that conversion interfaces may be required to interact between these systems and the conversion system. To achieve data conversion or translation using this approach, two languages are needed: 1) a language to describe the data structures, and 2) a language to specify the mapping between source and target data. This paper describes these two languages, DEFINE and CONVERT and gives numerous examples to show the capabilities of these languages and how they can be used in

data conversion and restructuring. Both languages are high level and nonprocedural and have the power to deal with most situations encountered in data conversion processes. In addition, the paper also describes some of the facilities in the languages specifically designed for data checking in a data conversion process.

Digital Filtering Using Complex Mersenne Transforms by *H. J. Nussbaumer*, p. 498. Complex Mersenne Transforms are defined in a ring of integers modulo a Mersenne or pseudo-Mersenne number and can be computed without multiplications. It is shown that under certain conditions, these transforms can be computed by means of fast transform algorithms and permit the evaluation of digital convolutions with better efficiency and accuracy than does the Fast Fourier Transform.

Derivation of Miss Ratios for Merged Access Streams by *G. S. Shedler and D. R. Slutz*, p. 505. An access stream is the sequence of storage accesses made by an executing program; a merged stream results from the multi-programming of a number of individual access streams. Assuming that LRU (least recently used) miss ratio functions for individual streams are known, we consider the problem of predicting the LRU miss ratio function for merged streams. Each access stream is modeled as a sequence of independent, identically distributed LRU stack distances which evolves in time as a Poisson process and the merged stream is taken to be the superposition of these processes. For an arbitrary number of such streams, a closed form expression for the expected miss ratio function is obtained.

An Analysis of Buffer Paging in Virtual Storage Systems by *W. G. Tuel, Jr.*, p. 518. Storage buffers are often used to hold temporary results or data that may be re-referenced in the near future. If these buffers are pagable, searching the buffer may cause a high number of page exceptions. A model of this phenomenon is postulated, and compared with experimental data.

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Walsh Functions for Digital Impedance Relaying of Power Lines by *J. W. Horton*, p. 530. Impedance distance relaying for fault-protection of a plurality of high-voltage lines has not been accomplished with a minicomputer because of the burden of time placed upon these computers. A new method for computing impedance from data samples is proposed, which would employ only the computer operations of Add, Subtract, and Shift. This is valuable because these operations are one to two orders of magnitude faster on present day minicomputers than the operations of Multiply, Divide, Square, and Square Root. The new method is based upon the use of Walsh functions. When compared with the best competitive method, this new method shows superiority in speed and an accuracy that meets proposed objectives.

Buffer Overflow in a Store-and-Forward Network Node by *P. J. Schweitzer and S. S. Lam*, p. 542. Equilibrium behavior of a store-and-forward network node with finite buffer capacity is studied via a network-of-queues model. The positive acknowledgment protocol is explicitly modeled and consumes part of the buffer pool. The principal results are the buffer overflow probability, the mean delays, and the distribution of queue lengths as functions of the buffer capacity and traffic levels.

Scheduling as a Graph Transformation by *E. B. Fernández and T. Lang*, p. 551. The scheduling of a set of tasks, with precedence constraints and known execution times, into a set of identical processors is considered. Optimal scheduling of these tasks implies utilizing a minimum number of processors to satisfy a deadline, or finishing in minimal time using a fixed number of processors. This process can be seen as a transformation of the original graph into another graph, whose precedences do not violate the optimality constraints and has a unique basic schedule. Analysis of this transformation provides insight into the scheduling process and also into the determination of lower bounds on the number of processors and on time for optimal schedules.

SEQUEL 2: A Unified Approach to Data Definition, Manipulation, and Control by *D. D. Chamberlin, M. M. Astrahan, K. P. Eswaran, P. P. Griffiths, R. A. Lorie, J. W. Mehl, P. Reisner, and B. W. Wade*, p. 560. SEQUEL 2 is a relational data language that provides a consistent, English keyword-oriented set of facilities for query, data definition, data manipulation, and data control. SEQUEL 2 may be used either as a stand-alone interface for nonspecialists in data processing or as a data sublanguage embedded in a host programming language for use by application programmers and data base administrators. This paper describes SEQUEL 2 and the means by which it is coupled to a host language.

Data Organization in Magnetic Bubble Lattice Files by *C.-K. Wong and P. C. Yue*, p. 576. In this paper, we discuss several aspects of data organization in the framework of a recently developed magnetic bubble memory technology known as a bubble lattice file. A dynamic ordering scheme, different from those implemented in conventional T-I bar bubble memories, is proposed. This ordering is particularly suited for bubble lattices. Some performance figures are included for comparison.

Procedural Representation of Three-dimensional Objects by *D. D. Grossman*, p. 582. A system of PL/I procedures has been written that permits geometric objects to be described hierarchically. The objects are themselves represented as PL/I procedures, allowing very general use of variables. By effectively intercepting subprogram calls, the system provides a means of modifying the semantics associated with any object without modifying the object's procedural description.

Determining the Three-dimensional Convex Hull of a Polyhedron by A. Appel and P. M. Will, p. 590. A method is presented for determining the three-dimensional convex hull of a real object that is approximated in computer storage by a polyhedron. Essentially, this technique tests all point pairs of the polyhedron for convex edges of the convex hull and

then assembles the edges into the polygonal boundaries of each of the faces of the convex hull. Various techniques for optimizing this process are discussed. A computer program has been written, and typical output shapes are illustrated. Finding the three-dimensional convex hull is approximately the same computer burden as eliminating hidden lines.