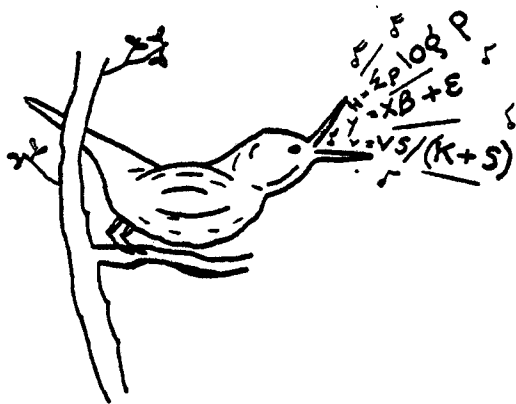


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BIOSYSTEMS MODELING

Abstracts of Current and Recent Work at

North Carolina State University

*Biomathematics Series No. 1
Institute of Statistics Mimeograph No. 1202
Raleigh, December 1978*

DEDICATION

This volume inaugurates the Biomathematics Series of the Institute of Statistics.

It is especially fitting on this occasion to acknowledge our debt to Henry L. Lucas, who guided the Biomathematics Program at North Carolina State University from organization of the germinal conference at Cullowhee in August 1961, until his death in June of 1977. During that time, Biomathematics at NCSU progressed from a topic of conversation to an established graduate degree program within the Department of Statistics.

It is fitting also to acknowledge our debt to Gertrude M. Cox, who as Director of the Institute of Statistics and as a member of the NIGMS Committee on Epidemiology and Biometry, played a central role in facilitating the conference and in initiating the subsequent program. Her death in October of 1978 was a loss to both the biomathematical and statistical communities.

Certain it is that the genius of Curly Lucas and of Miss Cox will continue to inspire teaching and research in biomathematics. As we stretch toward newer heights, we stand upon the shoulders of these giants. To them, we dedicate this series.

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INTRODUCTION

Recent years have seen an upsurge in the development and use of mathematics as a tool for the study of biological systems. The Biomathematics Program at North Carolina State University serves as a focal point for research and training in the development and application of such tools. As this booklet attests, such work is a part of the activity in many departments across campus. The purpose of this booklet is to help establish communication between research workers with related methodological and applications interests.

The question of what to include is a difficult one to resolve. The intent is to include biological work in which mathematical science plays a central role, and mathematical work of clear relevance to biology. However, application of this guideline is not always unambiguous. Most biological research has some mathematical content and most work in mathematical science is at least potentially applicable to biology. For this reason, and also because our own communications network is imperfect, the booklet should not be taken as a complete or exhaustive compilation. We hope that it is a reasonable representation.

In all, there are contributions from twenty-three departments. This includes one from North Carolina A & T State University, which we hope is harbinger of an expanded communications network.

Included are abstracts of recently published work and descriptions of work in progress, as well as research plans presented for the purpose of inviting collaboration between experimenters and theorists.

The abstracts are grouped by department of the first-named author. In the case of abstracts with several authors from different departments, the abstract is entered in the Listing by Departments under each department.

The subject index is compiled in terms of broad subject matter categories. Each abstract is listed in one to three categories. The indexing is undoubtedly imperfect, and for that we apologize. In updated editions, we plan to ask authors to suggest their own index categories.

We would warmly welcome any comments directed at improving the usefulness of updated editions.

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North Carolina A&T State University,
Department of Chemistry

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INTRACELLULAR OXYGEN TRANSPORT

I. S. Longmuir and J. A. Knopp
Department of Biochemistry

A new method for measuring intracellular oxygen concentration using the quenching of fluorescence of pyrenebutyric acid by oxygen has yielded an unexpected finding. In non-respiring cells, in which the PO_2 is uniform throughout, there is a very gross heterogeneity of oxygen concentration. In approximately 5% of the area the solubility coefficient is greater than in water and in a substantial fraction is little more than zero. Since we are looking at a two-dimensional projection of a three-dimensional structure, the true heterogeneity may be much greater. The picture that develops is of a series of channels of high oxygen solubility surrounded by areas of low solubility. This appears to indicate that oxygen may diffuse through tissue through distinct channels only.

The significance of this is being studied in collaboration with Dr. Mochizuki in Yamagata, Japan. We have constructed models in which oxygen moves rapidly through discrete channels to sites of maximum utilization and then using a PDP computer constructed models of intracellular distribution. We hope that the final model will be testable using our U.V.T.V. microscope system.

AUTOMATIC DATA ACQUISITION
AND PROCESSING IN AMINO ACID ANALYSIS

R. R. Randall, J. A. Knopp, G. J. Young,
H. R. Horton, and F. B. Armstrong
Department of Biochemistry

Quantitative amino acid analysis is of fundamental importance in protein chemistry and in biochemical studies in general. The automated protocol developed by Moore and Stein relies on ion-exchange chromatography to separate various amino acids and on the reaction of amino acids with ninhydrin to indicate elution of an amino acid from the ion-exchange column. Qualitative identification of the amino acid is made principally by the time at which it elutes and, to a lesser extent, by the characteristic shape of the eluting peak. Quantification of amino acids consists of integration of each peak, since the amount of the amino acid present is proportional to the area under its peak. Traditionally, peak areas have been calculated manually, a tedious and imprecise process. This project seeks to eliminate the tedium and to minimize the imprecision in data processing.

Primary data consist of a continuous millivolt signal from the phototube of the amino acid analyzer. The computer is a North Star Horizon-1 (Z-80 CPU), equipped with one minifloppy disk drive, 32K read-write memory, serial I/O port, and parallel I/O port. The analog-to-digital (A-D) converter was constructed using a Burr-Brown ADC80AG-12 chip.

Software used with the system includes standard software from North Star and programs written especially for this application. This latter group includes (1) a machine language program for controlling the A-D converter and for storing data on the magnetic minifloppy disk, and (2) BASIC programs for the conversion of digital voltages to absorbances, identification of peaks, integration of these peaks, subtraction of baseline area, identification of the types of amino acids corresponding to the peaks, and calculation of nanomoles of the identified amino acids.

Future anticipated modifications include simultaneous acquisition and calculation of data from two amino acid analyzers after addition of a second disk drive and more memory. This sort of system has broad application to a number of types of chromatography, including HPLC and GC, though the time scales differ somewhat. It represents a relatively modest capital investment for updating older instruments, and its components can easily be adapted to other laboratory applications if the need for quantitative chromatographic analysis is temporary or infrequent.

TEMPCAP - A SIMULATION OF THE SOIL
TEMPERATURE PROFILE USING PCAP

M. Behrooz-Lar, B. K. Huang, and H. D. Bowen
Department of Biological and
Agricultural Engineering

In: Simulation of Transient Heat Transfer in Soil Systems,
Ph.D. Thesis, M. Behrooz-Lar, NCSU, 1973.

TEMPCAP is a PCAP (Princeton Circuit Analysis Program) modified from ECAP (Electronic Circuit Analysis Program) and allows a reasonably good prediction of soil temperatures from inputs of radiation, air temperature evaporation, and soil moisture content in each layer of soil. TEMPCAP was designed for use with a PCAP model of moisture profile not yet developed that will be entitled MOISTCAP in which the total program will oscillate between TEMPCAP and MOISTCAP. Outputs are soil temperature from surface to desired depth - usually 15 cm for emergence model use. Biggest limitations is a lack of soil parameters such as heat capacity and thermal diffusivity for the many soil types over a wide range of moisture content and soil bulk density.

PLANT GROWTH SIMULATION BASED ON
NET CARBON DIOXIDE CONSUMPTION

C. S. Chang and B. K. Huang

Department of Biological and Agricultural Engineering

Trans. of the ASAE 16(4):724-727, 1973

The photosynthesis rate of a plant is affected by many factors, such as air temperature, carbon dioxide concentration and light intensity. The over-all reaction occurring in photosynthesis is the conversion of CO_2 to carbohydrate at the expense of the radiant energy in the chloroplasts of the leaves. A simulation model for predicting the growth of plant-stem diameter in terms of the net CO_2 consumption of a plant under controlled environmental conditions was studied. A relationship describing the effect of CO_2 concentration and light intensity on the CO_2 consumption rate was also presented.

Plant growth simulation model was developed and the predicted values were compared with experimental data for verification. Results indicated that the model was applicable for describing the growth of tobacco plant stem under the similar environmental conditions.

MOIST - A SIMULATION OF THE MOISTURE PROFILE
OF A BARE SOIL AFTER PLANTING

C. G. Coble, H. D. Bowen, and H. L. Kings, Jr.
Department of Biological and
Agricultural Engineering

In: Computer Simulation of a Cotton
Production Systems, ARS-S-52, 1975

MOIST is a computerized mathematical model using finite differences for predicting soil water profiles during the drying of soil. It accounts for water movement in the soil in both the liquid and vapor state and the evaporation of water to the atmosphere. Inputs are bulk density of soil for each centimeter layer down to 15 centimeters, hourly values of relative humidity, air temperature, soil temperature, and mechanical impedance. The output of the program consists of the time period, the moisture content of each level for that time period, the distance from the surface to the center of the soil layer with the moisture front and the quantity of evaporated moisture. MOIST is used as an input to EMERGE, a cotton emergence model.

A COMPUTER ALGORITHM FOR DIGITALLY FILTERING
THE SURFACE EEG TO DETECT CHRONIC, LOW LEVEL BAYGON EXPOSURE

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(M.S. Thesis Under the Direction of Dr. C. W. Suggs.)
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Pesticide exposure can represent a hazard not only to the agricultural worker but also to the average person living in an urban setting. Since removal of a person from the source of exposure is one of the first steps in treating cases of pesticide toxicity it becomes very important to be able to detect when a person has first become exposed to a pesticide. Unfortunately, there is presently no method available to screen populations for pesticide exposure. This study concerned itself with the development of a system to detect pesticide exposure not intense enough to cause overt clinical symptoms.

This system used the electroencephalogram (EEG) as an indication of pesticide exposure. Sections of the EEG were first converted to the frequency domain by the fast Fourier transform. Then the energy content of each frequency band of the input Fourier transform was reduced by an amount determined by an energy template. This template was selected from a series of templates which described the power spectra of a control group. The selection of a proper template was based upon the shape of the input EEG's power spectra. By reducing the amount of energy in the input transform, a new transform was effectively generated. This new transform was then converted back to the time domain by the fast Fourier transform. The resulting time domain signal was the filtered EEG. This process removed most of the typical control components from the EEG and thereby emphasized the differences between controls and animals exposed to pesticides. These differences, usually appearing as spikes, were used as an indication of pesticide exposure.

This procedure was then used to detect long term, low level exposure to the pesticide, Baygon. The study involved 20 female Rhesus monkeys and three different exposure levels, these being 0.1, 1.0, and 10.0 mg/kg body weight/day. The amount of spiking that was present in the filtered EEG was used as an indication of exposure. A total of 40 minutes of EEG data was analyzed and statistical analysis of the results demonstrated that this procedure was capable of statistically differentiating between exposed monkeys and controls with a confidence level of 95 percent. This system was also capable of differentiating between dosage levels with a confidence level ranging from 95 to 40 percent. These results indicated that this method was a practical means of detecting exposure.

THE IN VIVO DRIVING POINT IMPEDANCE OF THE HUMAN ULNA AND
ITS POTENTIAL IN CHARACTERIZING FRACTURES

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(M.S. Thesis Under the Direction of Dr. C. F. Abrams, Jr.)
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The large annual incidence of long bone fractures and the inadequacy of conventional methods in quantitatively determining the state of healing of such fractures has stimulated investigation in the use of mechanical vibration in the sonic range to determine the status of long bones in vivo. Information about the dynamic mechanical properties of the bone would supplement current techniques for monitoring the progress of healing and the early prediction of complications.

In order to evaluate the potential for using the vibration response of a long bone to determine its state of healing, the driving point mechanical impedance of a representative long bone, the ulna, was measured in the right and left forearms of three subjects with normal, unfractured ulnas. These measurements were taken over the frequency range of 30 Hz to 1000 Hz and employed very low peak levels of vibrational excitation (1 meter/sec² and 2 meter/sec²). From these results, comparisons of the differences were made on a statistically significant basis.

The experimental data were used to develop an anatomically motivated, distributed parameter viscoelastic beam model of the normal ulna and its surrounding tissues for the testing configuration used. The parameter values for the beam model were estimated from literature values for the properties of bone, soft tissue, etc., and were therefore physically reasonable. A predictive model for a fractured ulna was proposed by "breaking" the single beam model into two beams connected by a simple hinge and a rotary spring. When the impedance response of this model was evaluated for the special case of a fresh fracture (zero bending stiffness at the hinge), a gross differences in response were evident between the freshly fractured and the unfractured ulnar model response. On the basis of that evidence, it was concluded that the driving point impedance technique is a feasible technique (at least in theory) for evaluating the state of healing in ulnar fractures in vivo. Clinical trials are suggested to substantiate these conclusions.

A STUDY OF THE MECHANICAL PROPERTIES OF MAMMARY TISSUE AND
THE FEASIBILITY OF USING DRIVING POINT MECHANICAL IMPEDANCE
AS A TUMOR DIAGNOSTIC TECHNIQUE

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Breast cancer is most frequently detected through its palpably distinguishable mechanical properties. In an effort to develop an objective mechanical properties testing technique, quasistatic compression tests, free vibration tests, driving point mechanical impedance tests and lumped parameter modeling of foam rubber and mammary tissue were performed. Whenever comparisons between tests were possible, good agreement was found.

The quasistatic test found cancerous tumor tissue to have a compression modulus over three times as large as normal mammary stroma. Other tissues such as skin and mastitic scar tissue also had a greater compression moduli than normal mammary stroma.

In the free vibration test, transient response of tissue to an impulse was recorded. It was found that equivalent spring stiffness was directly related to the static preload on the tissue while the natural frequency and damping ratio remained constant.

Driving point mechanical impedance studies were performed on foam rubber, in vitro cow udder material, in vivo goat udders and in vivo human breasts. The in vivo tissue response was notably different from that of in vitro tissue. The response was found to be primarily a function of tissue thickness although static preload and interface area of excitation were important.

Artificial lumps of steel, aluminum and wood were inserted into foam rubber and cow udder material. A dramatic difference between "with lump" and "without lump" conditions was noted in all foam rubber tests while animal tissue only showed a notable difference for the steel lump. The larger the mass of the lump, the more pronounced was the difference. There was no success in distinguishing cystic breast lumps or mastitic udder lumps from normal tissue.

A six element lumped parameter model was fit to the observed data. It was found that the same physical model with slightly altered parameters fit both "with lump" and "without lump" systems.

Based on the results of this study, it was concluded that driving point mechanical impedance cannot be recommended as a feasible tumor detecting technique. Many questions, however, were raised and further study is suggested. The more important areas for further investigation include the frequency region above 1000 Hz and below 30 Hz, tests with better methods for surgically implanting lumps, more complex modeling, and clinical tests on women with pronounced lumps and confirmed carcinomas.

DIGITAL SIMULATION ANALYSIS OF BIOPHYSICAL SYSTEMS

B. K. Huang

Department of Biological and Agricultural Engineering

IEEE Trans. on Bio-Med., BME 19(2):128-139, 1972

Techniques of simulation analysis and dynamic analogies have become extremely important in the study of biophysical systems for their analysis, synthesis, and design. Simulation analysis constitutes a growing area of digital-computer applications, which is needed to study alternatives in the design of dynamic systems prior to the actual real-life implementation of such systems. In the simulation model, formulation is an inductive process in which the mathematical relationship between variables is hypothesized to describe the system to be studied. With the advent of computer techniques, approaches have been made to quantify the biophysical-chemical processes which occur in living systems. Everincreasing utilization of computer methods has not only strengthened the conventional analytical and experimental procedures, but has also opened up many new approaches to the study of biological and physical systems. This paper presents practical guides to the formulation, analysis, and application of computer simulation models and routines. Examples are given to illustrate techniques applied to the simulation analysis of biophysical systems using problem-oriented programming languages.

A SIMULATION MODELING OF TREE AND SHRUB GROWTH

J. Y. Lee and B. K. Huang

Department of Biological and Agricultural Engineering

Proceedings of the Sixth Annual Modeling and Simulation Conference

Vol. 6(2):825-829, 1975

Digital simulation techniques were applied to describe and predict general growth of tree and shrub dynamically. A computer program was developed to predict the number density of leaves, twigs, stems and their space distribution for a tree or shrub in a certain growth period. The simulation results were verified with observation data and trees or shrubs in different stages of growth were illustrated in two or three dimensional computer graphics.

HAND-ARM VIBRATION PART II: VIBRATIONAL RESPONSES OF THE HUMAN HAND

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Journal of Sound and Vibration 53(4), 1977

When vibration is applied to the hand in the vertical (dorsal-to-ventral) and transverse direction, the hand-arm system can be modeled by a three-mass model with each of the masses connected by a parallel spring and damper. For vibration input directed into the long axis of the forearm, the model requires an additional parallel spring and damper to connect the last mass to an infinite base. From absorbed power calculations it was determined that to minimize energy dissipation in the hand, the vibration input should be in the vertical direction and the handgrip should be as tight as convenient for frequencies below 100 Hz. Above 100 Hz the direction of input should be in the transverse direction and the handgrip should be as loose as possible. The hand, in general, was found to be a highly damped system with the damping increasing with increasing handgrip and acceleration.

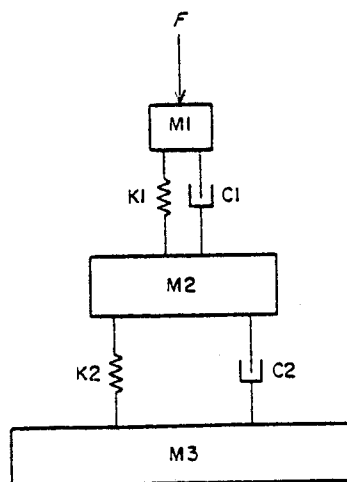


Figure 4. The model used to represent the hand-arm system for the vertical and transverse directions.

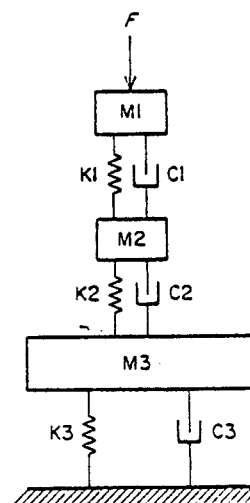


Figure 5. The model used to represent the hand-arm system for proximal-to-distal inputs.

DYNAMIC PROPERTIES OF THE HUMAN HEAD

J. B. Smith and C. W. Suggs

Department of Biological and Agricultural Engineering

Journal of Sound and Vibration 48(1), 1976

Driving point mechanical impedance measurements were used to determine the dynamic response of the human head to sinusoidal vibration in the frequency range between 30 Hz and 5000 Hz at excitation levels of 0.98 m/s^2 and 3.4 m/s^2 . Because of the low excitation levels, the weight of the head was sufficient to couple the head to the vibration source.

At 20 Hz the impedance magnitude was about 790 N-s/m but increased at approximately 6 dB/octave to a peak near 3500 N-s/m at 70-90 Hz. Between 100 Hz and 2000 Hz impedance decreased by about two orders of magnitude while the apparent mass decreased by three orders of magnitude indicating good vibration isolation at higher frequencies. The impedance response contains the information for modeling the head as a dynamic system.

The response of the head to vibration can be simulated by a two degree-of-freedom, mass-excited system consisting of a series connection of a small driving mass, a damper, a spring and damper in parallel and a large final mass. Parameter values, derived by computer techniques, suggest that the large mass represents the total head, the small mass the tissue in contact with the vibration input and the spring the skull stiffness.

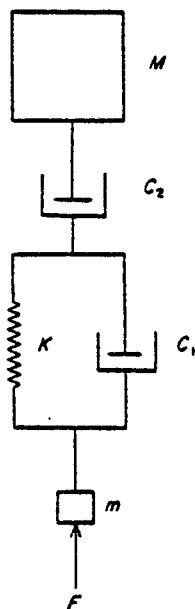


Figure 4. Dynamic model of the human head.

EMERGE: A SIMULATION OF COTTON GERMINATION
AND EMERGENCE WITH MODIFICATIONS

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Department of Biological and
Agricultural Engineering

In: Computer Simulation of a Cotton
Production System ARS-S-52, 1975

EMERGE simulates the time distribution of cotton seedling emergence. Theoretical equations that describe water absorption by seeds and elongation of the cotton hypocotyl, with accompanying logic, form the basis of the model. Parameter values for the theoretical equations and the logic were derived from experimental data and other observations obtained from emergence tests conducted under controlled environmental conditions. Parameter values in the equations are dependent functions of the soil environment. In this manner the equations reflect the effect of temperature, moisture, and physical impedance of the soil on the emerging seedlings. Inputs are hourly soil temperatures at seed level depth, average moisture content in soil layer 1/2 inch above to 1/2 inch below seed level of maximum mechanical impedance from surface to seed depth, date, depth of planting in centimeters, and germination percentages of seed between 20° to 30°C. The output is time, length of hypocotyl, emergence percentage.

The output of MOIST may be fed into EMERGE for moisture at seed depth. The output of TEMP ECAP can be used to interface with both MOIST and EMERGE. To date impedance must be measured daily - requires 5 minutes to put into program. However, a program is in development for estimating soil impedance with and without a rain.

A DISTRIBUTED PARAMETER DYNAMIC MODEL OF THE HUMAN HAND-ARM SYSTEM

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(M.S. Thesis Under the Direction of Dr. C. W. Suggs.)

Department of Biological and Agricultural Engineering

The human forearm was represented dynamically by a dual beam model over a frequency range from 30 Hz to 700 Hz. Each of the two long bones (radius and ulna) was represented as a flexural beam. Distributed stiffness, mass and damping parameters were obtained using this approach. The distributed damping parameter was included by allowing the beam stiffness parameter to be a complex quantity. Hand properties were modelled by a lumped parameter damped spring-mass system. Validity of the model was checked by experiment; its mechanical driving point impedance frequency response was compared with experimentally derived impedance data collected on the forearm. A rigid rod model and a single beam model of the forearm were rejected because of poor fit with the experimental data. It was concluded that further work is required to improve the representation of the hand at frequencies above about 700 Hz.

A distributed parameter model of the whole arm was developed by extending the model of the forearm to include the upper arm. A single beam was used to represent the humerus. The frequency response of the whole arm model was then compared with impedance data collected by a previous investigator. Above a frequency of about 700 Hz where the behavior of the hand dominated, the model response deviated from the experimental data.

PHOSPHATE UPTAKE KINETICS IN THE CHOWAN RIVER

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(M.S. Thesis Under the Direction of Dr. A. M. Witherspoon)
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Rates of phosphate uptake (P-uptake) in whole water samples were measured for the surface waters of the Chowan River, northeastern North Carolina. P-uptake measured under ambient water temperature, photosynthetically active radiation (PAR), and natural levels of DIP ranged throughout the year from a winter low of $0.001 \mu\text{M Hr}^{-1}$ to a summer high of $0.525 \mu\text{M Hr}^{-1}$.

Rate constants (k_L) ranged throughout the year from 0.0043 to 1.2350. An upstream-downstream trend of 10 - 100 X variation in k_L was observed. The annual pattern of change was correlated with changes in water temperature, DIP, and phytoplankton biomass. Approximately 35% of the variation in k_L was accounted for by its correlation with wet-weight algal biomass. Temperature effects (Q_{10}) on k_L averaged 1.92. Enrichment studies with DIP revealed that the whole water samples responded either as a single enzyme reaction or as a mixed-order reaction depending upon the sample. Instantaneous light effects on k_L were unclear. However, diel variation of k_L was observed and was correlated with changing PAR. Daily integrated C/P values ranged from 40 to 86.

Implications of these results to the nutritional status of the phytoplankton community and the phosphorus cycle in the Chowan are discussed.

A NUMERICAL STUDY OF THE COMMON NARROW-LEAVED TAXA OF
CHENOPODIUM OCCURRING IN THE WESTERN UNITED STATES

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J. F. Reynolds, Department of Botany

Brittonia 26(4):398-410, 1974

A numerical taxonomic study was conducted on the common narrow-leaved members of the genus Chenopodium that occur in the western United States. As many as six and as few as two species have been recognized. Thirty-five individual populations were used as OTU's and 35 characters were considered. The data were subjected to cluster (both the weighted-pair group method and the within-group dispersion method) and principal component analysis. The results of both analyses are in general agreement and suggest phenetic relationships that differ from current interpretations in the literature. It is concluded that C. desiccatum var. leptophylloides is much more closely related phenetically to C. atrovirens (and may not be distinct from it) than it is to C. desiccatum var. desiccatum. Chenopodium hians and C. leptophyllum appear to be phenetically distinct despite the fact that they have sometimes been viewed as conspecific. Chenopodium subglabrum is not very similar to C. leptophyllum, and should probably be treated as a separate species rather than as a variety of the latter. Populations referable to C. incognitum form a rather loose cluster that appears somewhat intermediate between populations of C. desiccatum var leptophylloides, C. atrovirens, C. hians, and C. leptophyllum.

A SIMULATION MODEL OF PRIMARY PRODUCTION AND
CARBON ALLOCATION IN THE CREOSOTE BUSH
(LARREA TRIDENTATA [DC] COV.)

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J. F. Reynolds, Department of Botany

Ecology 59(1):37-52, 1978

A preliminary simulation model of primary productivity and carbon allocation in creosotebush (Larrea tridentata [DC] Cov.) is described. The model utilizes a systems approach in which movement of assimilate within the plant is in response to changes in source-sink strengths of leaves, stems, roots, early reproductive buds, maturing reproductive buds, flowers, and fruits. Two distinct compartments are defined per organ or developmental stage to separate assimilate into a pool fraction (labile or translocatable) and a structural fraction (nonlabile). The changes in magnitude (within upper and lower limits) of a pool compartment during the course of a simulation (i.e., growth and development of the plant) are a function of the rates of maintenance respiration and growth as well as a priority scheme governing allocation of assimilates; the increases and decreases in dry weight of a structural compartment are a function of aging and the magnitude of its associated pool (which determines structural growth and physiological death).

A 1-yr simulation of a hypothetical Larrea plant shows that the model exhibits a reasonable behavior, although no validation is attempted at this stage in its development. The heuristic value of the model is illustrated in the sensitivity analysis, which shows the need for detailed knowledge of "priority" carbon movement during both vegetative and reproductive growth periods, the importance of substrate controlled respiration rates, and the need for further studies of the dynamics of labile pools in the plant.

The model has been an excellent tool in our initial attempt to integrate the voluminous information on Larrea into a complete functional description of the autecology of the species. Further refinement of this model as data from our current research and that of other investigators become available should lead us to a better understanding of the ecological role of Larrea in desert ecosystems.

VALIDATION STUDIES OF PLANT GROWTH SIMULATORS

J. F. Reynolds, Department of Botany

The objective of the proposed research is to conduct an in-depth validation of a computer simulation model of primary production and carbon allocation in the desert shrub Larrea tridentata (creosotebush). A "total validation" is proposed, i.e., validation of the model will be attempted at (1) a predictive level, and (2) a theoretical level. The predictive level validation will be accomplished by comparing model predictions to a unique historical data set collected independently of the model-building effort; various graphical and statistical goodness-of-fit tests will be used in this evaluation. The dynamics of the state variables in the model are described by random differential equations which will enable estimates to be made of means and variances of model predictions. The theoretical level validation will involve attempts to refute proposed mechanisms in the model by formulating and testing alternative hypotheses; validation at the predictive level will also serve as a test of underlying assumptions of proposed mechanisms in the model. This total validation will serve to direct our continuing modeling efforts and to help us further elucidate some of the functional mechanisms that operate in this widespread desert plant which has allowed it to become so well adapted to hot, xeric environments.

A NET CO₂ EXCHANGE MODEL FOR LARREA TRIDENTATA

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Photosynthetica 13(3), 1979

A net CO₂ exchange model for the warm desert evergreen perennial Larrea tridentata (DC) Cov. (creosotebush) was developed using the nonlinear modeling approach described by Read (1976) for the temperate deciduous tree Liriodendron tulipifera L. The approach was very successful using gas exchange measurement on environment chamber-grown Larrea transplants and results indicate that this approach may have wide applicability and versatility for photosynthesis modeling.

MODELS OF PHOTOSYNTHESIS AND PHOTOSYNTHATE
ALLOCATION IN LOBLOLLY PINE (PINUS TAEDA L.)

J. F. Reynolds, Department of Botany

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Duke University, Durham

A model of primary productivity and carbon allocation in loblolly pine (Pinus taeda L.) is being developed. This modeling activity involves: (1) the conceptual and mathematical basis of the photosynthesis and photosynthate allocation models and (2) the interfacing of these models with existing physical process models (meteorological and water-balance) to obtain a simulation of carbon dynamics in a uniform stand of loblolly pine. The forest canopy is separated into three layers to account for vertical variability in physiological processes and distinct flushes of growth characteristic of this species. Within each layer, a basic mathematical paradigm of photosynthate allocation is defined for separate age classes of axes, needles, and branch wood; for each age class of needles, photosynthesis is predicted using the Smith equation with time-varying estimates of optimum temperature, maximum CO₂ flux rate, and efficiency of light energy conversion. This approach has simplified the modeling of a complex system of sink-source balances and translocation kinetics which govern the carbon budget of this species.

SIZE-BIOMASS RELATIONSHIPS OF SEVERAL CHIHUAHUA DESERT SHRUBS

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American Midland Naturalist 94(2):451-461, 1975

Rapid, nondestructive methods are needed to quantify plant biomass dynamics. Methods known as dimension analysis can be used to establish regression relationships between plant biomass and easily obtained plant measurements. Regression analyses were used to estimate the dry weight of foliage, living and dead stems and roots from canopy area and volume for eight desert shrubs. The results show that volume and canopy area are generally suitable estimators. Regression equations developed for Larrea tridentata compare favorably with equations in similar studies in Arizona and Nevada, suggesting that our results might be applicable in other desert regions, at least for shrubs with well-defined growth forms. Other considerations when using these techniques are discussed.

PREDICTING PRIMARY PRODUCTIVITY FOR FOREST AND
DESERT ECOSYSTEM MODELS

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In: Predicting Photosynthate Production and
Use for Ecosystem Models, J. D. Hesketh and J. W. Jones (Eds.)
CRC Press, (Chapter XVIII), 1978 (in press)

One of the specific objectives of this study was to analyze the possibility of developing a single modeling framework which could be used to predict carbon allocation and biological productivity of different perennial growth forms in different ecosystems. A comparison of the application of our scheme for modeling growth in a desert shrub (Larrea tridentata) and a southeastern conifer (Pinus taeda) illustrates our approach. The generality and flexibility of the model is demonstrated by its ability to accommodate these two greatly different plant species. Additionally, the details of internal mechanisms are sufficiently adaptable to allow an interfacing with other ecosystem-level processes.

VEGETATION ON LIMESTONE AND GRANITE
IN THE MULE MOUNTAINS, ARIZONA

T. R. Wentworth
Department of Botany

Gradient analysis was employed to determine vegetation pattern in relation to environment and to compare the vegetation on limestone and granite in Mule Mountains, Cochise County, Arizona, using quantitative data obtained from 177 tenth-hectare (20 x 50 m) quadrats located over a wide range of elevation and topographic position. Direct gradient analysis revealed sequences of major community types from most mesic to most xeric positions on the mountain slopes: (1) granitic soils: pygmy conifer-oak scrub, open oak woodland, and desert grassland; (2) calcareous soils: Cercocarpus breviflorus scrub, mesic phase Chihuahuan desertscrub, and xeric phase Chihuahuan desertscrub. Calcareous bajadas to the southwest of the Mule Mountains support a highly disturbed Chihuahuan desertscrub type. An environmental scalar was developed to quantify site position along the combined complex-gradients of elevation and topographic position. Results of the scalar analysis compared favorably with indirect ordinations (including Wisconsin polar ordination, principal components analysis, and correspondence analysis) of quantitative data.

VEGETATION OF A WATERSHED IN THE SOUTHEASTERN
ESCARPMENT REGION OF THE BLUE RIDGE MOUNTAINS

T. R. Wentworth
Department of Botany

The southeastern escarpment region of the Blue Ridge Mountains has attracted the attention of botanists and ecologists since the early explorations of the eighteenth century. Pronounced relief, variation in topographic features, and a generally mild climate with unusually high precipitation create a diversity of favorable habitats for plant growth. Evolution and migration of floristic elements through the Tertiary and Quarternary Periods have endowed the region with a diverse flora having affinities to those found in many parts of the Old and New Worlds. Thus, the escarpment region has been the object of a recently renewed interest, with an emphasis on the ecology and systematics of its flora and fauna.

The information presently available provides an excellent background for an intensive, quantitative study of vegetation in an escarpment gorge. One gorge, the Thompson River watershed, has been selected for further research. Four research needs and objectives can be identified from previous work in the area: (1) the investigation of vegetation-environment relationships, (2) comparative community-type description, (3) analysis of species diversity, and (4) analysis of geographic floristic affinities. The result of this research will be the production of a monographic treatment of the gorge vegetation, useful as background information to investigators in several fields, and serving as a guide to further study. Investigation of species diversity and geographic floristic affinities also should provide useful information for evaluation of basic theory in these important research areas.

USE OF INFRARED THERMOGRAPHY IN MODEL VERIFICATION

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F. M. Richardson, Engineering Research Services Division

The investigators are using a UTI Model 900 Infrared Thermal Imaging System (a thermograph) to study embedded flow tubes analogous to blood vessels to determine the detectability of tube depth, intertube distance, relative tube sizes and effects of intratube stenoses on the surface thermal patterns. The quantification of these effects in structural models will be useful in developing procedures to identify the magnitude and location of actual circulatory abnormalities.

Also being studied is a technique for transferring thermal patterns from one surface to another and deducing the temperature profile of the first surface from that of the second. This technique has application in identifying and following deep vein thromboses and determining the thermal condition of inaccessible surfaces.

The Model 900 is capable of making non-contact measurements of local surface temperature distribution in the range of -20°C to 1000°C by scanning the IR emission (in the 8 to 14 μm range) from several hundred thousand points on the object surface. At room temperature, temperature differences of 0.2° are easily resolved. Similar devices are being used in medicine for purposes ranging from the detection of breast cancer in humans to the diagnosis of tendonitis in horses.

This instrument has a potential for use in verifying and studying biomodels in any system in which surface temperature distribution can be related to the behavior, transient or steady state, of a structural model. Modeling is not limited to thermal processes since temperature can be used as a tag or analog for mass transfer, etc.

AN IDEATIONAL PARSER

A. L. Tharp and J. F. Eastman
Department of Computer Science

Recent parsers have extended the variety and difficulty of natural language constructs recognizable by a computer. However, one shortcoming of existing parsers is that as the complexity of the sentences recognized increases, the computational complexity increases quadratically. One reason for this computational explosion is that much if not most of the control information is embedded in the parser.

A different approach, referred to as an ideational parser, is proposed. Although the design for this parser was motivated by the manner in which people might use language, it is not necessarily intended to be a model for human cognition. The control information, for the most part, is removed to the lexicon, and the words are considered operators in the formation of a mental picture rather than as operands to the parser. The parser mechanism is detailed with an example parser and a typical conversation is given in the appendix.

Two primary benefits of the ideational parser are 1) an improved, simpler control mechanism and 2) the ability to acquire new knowledge which is automatically stored in the same format as the given knowledge.

USING COMPUTERS IN A NATURAL LANGUAGE MODE FOR
ELEMENTARY EDUCATION

A. L. Tharp and W. E. Robbins
Department of Computer Science

Int. J. Man-Machine Studies 7, 1975

This paper considers the interface between an elementary school child, specially a fourth grade student, and a computerized fact retrieval system. One goal of the study was to transfer the communication burden from the user of a computerized system to the computer. Rather than training the student to use an artificial programming language as the communication medium, it was deemed preferable to attempt to use the child's own natural language. First, data was collected to determine what subset of English that natural language might be and to provide a grammar for it. After a grammar was constructed, a system was developed which would allow an elementary school child to query the system about history and geography. The implementation, based on augmented transition networks, is described.

Another goal of the study was to investigate the effect of such a system on education. For this reason, the system was tested in a classroom environment. An open classroom was chosen to allow the students a reasonable amount of freedom in using the system. In addition to learning history and geography facts, the students appeared to receive other benefits. The results of the study indicate that in certain situations, it may be possible for a computer to function as a tutor.

MODELING THE PRODUCTIVITY OF PASTURES IN THE HUMID
REGIONS (BOTH TEMPERATE AND TROPICAL) OF THE WORLD

J. C. Burns, Department of Crop Science

R. D. Mochrie, Department of Animal Science

System: This area of study would encompass the daily gain obtained per animal (subject to animal intake, forage digestibility and composition, environment and animal efficiency) and the number of animals that can be fed per unit of land area (subject to forage growth and productivity). The purpose of the model would be to predict potential animal productivity of certain forages or combinations thereof, based on expected dry matter intake, nutritive value of the forage conversion of nutrients and growth of forage or forages being considered (the latter area would require development of a plant growth model using grazing-defoliation regrowth coefficients).

Testing and Application: The usefulness of the model would be the large number of forage species (and combinations) and management schemes (grazing frequency and intensity, fertilizer variables, etc.) that could be evaluated. Those systems having the most promising potential could be examined in actual field trials. These, as well as past productivity data, would be used to verify the accuracy and precision of the model.

DEVELOPMENT OF A MODEL TO CHARACTERIZE AND PREDICT
THE INTAKE OF FORAGE BY FREE-GRAZING ANIMALS

J. C. Burns, Department of Crop Science

R. D. Mochrie, Department of Animal Science

System: The area of focus is the plant-animal interface. More specifically, the model would include animal factors (both physiological and behavioral) that alter (control) intake of fresh forage and plant factors (both chemical and anatomical) that alter animal grazing behavior. The objective of such studies would be the ultimate prediction of daily dry matter intake of animals when they are offered free choice forage in pure stands or in mixture. Specific experiments will be conducted where appropriate coefficients are lacking to permit coupling of the plant-animal segments.

Testing and Application: Development of a model would provide insight into areas where critical information is lacking and would help determine the "question" for future research. Further, development of a reliable model (either in terms of absolute intake or relative intake) would be of major importance when determining the potential of new forages as grazing species early in the development stage. When possible both stall and grazing trials will be conducted to determine the reliability (accuracy and precision) of the model.

POULTRY GROWTH MODELS

R. K. Perrin, G. F. Vocke, and M. K. Wohlgenant
Department of Economic and Business

J. B. Ward and Others
Department of Poultry Science

The immediate goal of the study would be to specify and estimate the parameters of a growth function describing growth of individual birds up to market weight. The growth rate at a specific point in time is assumed to be a function of the intake of protein and the intake of energy. These two variables are in turn assumed to be a function of two control variables; calorie content per pound of feed and protein content per pound of feed. The growth function specified should be sufficiently general to permit the phenomenon of "compensatory growth" (the growth rate in period $t + 1$ increases in compensation for a growth rate in period t which is less than the maximum possible).

The ultimate objective of the study would be to determine the profit-maximizing market weight and age of the bird and the time path of the control variables necessary to achieve that optimum.

ECONOMIC EVALUATION OF THE SHRIMP DISCARD PROBLEM
IN PAMLICO SOUND, NORTH CAROLINA

J. R. Waters, L. E. Danielson, and J. E. Easley, Jr.
Department of Economics and Business

J. of American Association of Agricultural
Economics Aug., 1978 (in review)

In North Carolina, pre-commercially sized pink shrimp are incidentally landed, killed and discarded during harvest of brown shrimp. This study analyzed the incidental catch (discard) problem and management policies to protect pink shrimp. Results showed incidental catch does not generally reduce fishermen's net incomes sufficiently to adopt a discard abatement policy.

A MODEL FOR OPTIMAL EVALUATION
OF MANUAL LIFTING TASKS

W. A. Gruver and M. B. Muth
Graduate Program in Operations Research
and Department of Electrical Engineering

M. A. Ayoub, Department of Industrial Engineering

An optimization model suitable for analysis and assessment of manual lifting tasks is derived. The lifting task is described as a function space minimization problem with nonlinear objective subject to linear and nonlinear constraints. The objective is represented in terms of the torques acting on articulation joints during the performance of the task. Model constraints are the limitations imposed by the characteristics of the human body, the task, and the work place.

Using a Ritz type discretization, the original minimization problem is converted into a finite dimensional nonlinear programming problem, which is solved by a variable metric algorithm modified by gradient projection. Examples of using the model for the analysis of typical lifts are presented and discussed.

DISTRIBUTED DIGITAL CONTROL OF MANIPULATOR SYSTEMS

W. E. Snyder and W. A. Gruver
Department of Electrical Engineering

The use of a distributed computing system employing multiple micro-processors to coordinate and control an industrial manipulator is being investigated in this project. Each joint of the manipulator is optimally controlled by a separate processor which communicates with its associated processors via a shared or global memory containing status information on all joints. Each processor is responsible for the coordination and control of only one joint. Optimal control is achieved using an algorithm based on minimum energy path control with dynamic estimation of the loading parameters (inertia, friction, gravity) of the individual joints. Servoing is done completely in joint space with each servo controller having access only to state information about the single actuator it is controlling. Each processor also monitors the functioning of the other system elements and initiates shutdown procedures in case a malfunction is detected in another part of the system. Potential biomedical application is for control of artificial limb devices.

OVIPOSITIONAL RESPONSE OF HELIOTHIS ZEA (BODDIE).
TO ITS MAJOR HOSTS IN NORTH CAROLINA

N. W. Johnson, R. E. Stinner, and R. L. Rabb
Department of Entomology

Environ. Entomol. 4:291-297, 1975

The ovipositional response of Heliothis zea (Boddie) to various phenological states of corn, tobacco, cotton, and soybeans is examined and quantified. An ovipositional preference matrix is constructed and a model for the mechanism of adult movement of female H. zea among various hosts and phenological stages is developed and validated with field data.

THE BOLL WEEVIL (COLEOPTERA: CURCULIONIDAE)
FEEDING PROCESS: A SIMULATION MODEL

J. W. Jones, J. R. Bradley, and R. E. Stinner
Department of Entomology

H. D. Bowen and R. S. Sowell
Department of Biological and Agricultural Engineering

Ecol. Modelling 1:289-302, 1975

A model is presented for predicting boll weevil, Anthonomus grandis Boheman, feeding damage to cotton. The model uses appropriate theory based on behavioral components of male and nonreproducing female boll weevils and includes the effects of (1) differential feeding site preferences, (2) previous damage to the sites, and (3) individual insect behavior extended to feeding damage caused by a population of insects. The model is sensitive to both crop and insect parameters. An example of how this model can be used in an insect-crop ecosystem simulation is offered.

FEMALE BOLL WEEVIL OVIPOSITION AND FEEDING
PROCESSES: A SIMULATION MODEL

J. W. Jones, R. E. Stinner, J. R. Bradley
and J. S. Bachelier - Department of Entomology

Environ. Entomol. 4:815-821, 1975

A model is presented for predicting the number of cotton fruit damaged per day by reproducing female boll weevils, Anthonomus grandis Boheman. The model separately considers the egg production and the oviposition processes of the female boll weevil. The oviposition process depends on the availability of eggs in the oviducts, preferential site selection, and the availability of sites. Components of behavior for individual female boll weevils are considered and expected crop damage is projected for population of insects. Data are presented and compared with simulated results and the sensitivity of the model to changes in pertinent parameters is discussed.

SIMULATION OF TEMPERATURE-DEPENDENT DEVELOPMENT
IN POPULATION DYNAMICS MODELS

R. E. Stinner and G. D. Butler, Jr.
J. S. Bacheler and C. Tuttle - Department of Entomology

Can. Ent. 107:1167-1174, 1975

The simulation of variability in temperature-dependent development is discussed. An algorithm for simulation of this variability is developed and validated under constant and variable temperature regimes for Anthonomus grandis, Trichoplusia ni, and Heliothis zea.

AN ALGORITHM FOR TEMPERATURE-DEPENDENT GROWTH RATE SIMULATION

R. E. Stinner, A. P. Gutierrez, and G. D. Butler
Department of Entomology

Can. Ent. 106:519-524, 1974

With the current advances in insect population modelling, the need for more accurate simulation of temperature-dependent growth rates has become vital. The day-degree concept, with its linear temperature-rate relationship, has not been adequate for simulation of field populations under highly variable temperature conditions. Similarly, several of the non-linear relationships proposed in the past (Janisch's catenary, parabola) have also been inadequate. All of these relationships produce large errors at temperature extremes.

This paper presents a comparison of various functions which have been used for developmental time estimation and an algorithm for a sigmoid function which can be used in simulations having either a calendar or a physiological time base. Validation of the algorithm is presented for three insect species.

EFFECTS OF CONTAGIOUS DISTRIBUTIONS OF PARASITOID EGGS PER HOST
AND OF SAMPLING VAGARIES ON NICHOLSON'S AREA OF DISCOVERY

R. E. Stinner
Department of Entomology

H. L. Lucas, Jr.
Department of Statistics, Biomathematics Program

Res. Popul. Ecol. 18:74-88, 1976

It is shown that Nicholson's "area of discovery" can be negatively related to parasite density as either a statistical "artifact" or due to an incorrect assumption of random attack, rather than as a direct result of intraspecific competition. An alternative approach to modeling parasite-host systems is presented.

POPULATION DYNAMICS OF HELIOTHIS ZEA (BODDIE)
AND H. VIRESCENS (F.) IN NORTH CAROLINA: A SIMULATION MODEL

R. E. Stinner, R. L. Rabb, and J. R. Bradley
Department of Entomology

Environ. Entomol. 3:163-168, 1974

A model is described for simulation of the population dynamics of Heliothis spp. The salient features of the model include: (1) developmental means and variances about these means nonlinearly dependent on temperature; (2) separation of the general adult pool through adult attraction to spatially and temporally variant host-plant characteristics; and (3) cannibalism as a function of larval density, age-class structure within larvae, available feeding sites, and larval spatial distribution.

Results of an initial simulation effort are also presented.

SOYBEAN UTILIZATION

L. W. Aurand
Department of Food Science

This is an AID project funded for four years and the country wherein the study is being conducted is Bolivia. The primary objective is one of introducing soybeans into the everyday diet of the native population. The overall strategy is one of bypassing the bureaucracy and working at the community and family life level. Such an effort requires the coordinated efforts of US and Bolivian counterparts. To date we have made every effort to have American experts in Bolivia on a monthly basis. We have used expertise, in the areas of medicine, public health, population, nutrition and home economics. This is necessary for the accumulation of baseline data. Now we are engaged in the preparation, evaluation and selection of promotional materials. Mathematical modeling will be involved with evaluation of cost factors, agronomic problems, etc. We are also moving toward establishment of a Bolivian food policy. This too involves a complex of inter-related problems that must be synchronized if success is to be realized. This project presently involves three of the greater University complexes: NCSU, UNC-CH, and UNC-Greensboro.

EQUATION FOR THE DYNAMIC COMPLEX UNIAXIAL COMPRESSION
MODULUS OF SPHEROIDAL SHAPED FOODS

D. D. Hamann and K. C. Diehl, Jr.
Department of Food Science

The physical properties of food materials are important in harvesting, handling, storage, processing, and quality evaluation. Of the mechanical tests available for testing intact biological materials, axial compression is very common because it is easy to perform.

Determination of the axial compression complex modulus of spheroidal shaped foods by sinusoidal direct stress-direct strain is not possible using the Hertz contact theory because the contact surface area is not all caused by the sinusoidal forcing. A static preload is normally used to hold the specimen in place and a sinusoidal forcing superimposed. Inability to use the Hertz equation in this situation is demonstrated experimentally and an alternative equation sought. Using dimensional analysis and test data for 176 specimens involving a variety of fruits and vegetables (88 ellipsoidal specimens and 88 clindrical specimens) tested at 2 Hz and 144 specimens tested at 80 Hz, the equation $|E^*| = 1.51 F / (D d_c)$ for spheroidal specimens was developed where $|E^*|$ is the absolute value of the complex modulus, F is peak to peak force, D is peak to peak displacement and d_c is the mean contact diameter (including both contact surfaces of an axially compressed spheroid). Any consistent set of units is suitable. Using this developed equation, the R^2 value for the modulus was 0.97.

BIOECONOMIC MODEL OF FOREST PRODUCTIVITY

W. L. Hafley
Department of Forestry
and Statistics

The primary objective of this project is to develop a bioeconomic model of forest productivity. The intent of the model is to describe quantitatively the influence of all factors of the forest ecosystem on the productivity of the desired crop or crops. However, it must be recognized that the major role of this modeling activity for the duration of this study will be feedback in terms of technology assessment and the identification of a framework within which an input-output decision evaluation model can be developed.

Specifically the role of this project will be:

1. To bring together existing knowledge of the dynamics of the forest system,
2. To identify areas of needed research,
3. To evaluate these research areas in terms of the sensitivity of productivity to improvements in knowledge, and
4. To order priorities for research on a cost benefit basis.

A USEFUL BIVARIATE DISTRIBUTION FOR DESCRIBING STAND
STRUCTURE OF TREE HEIGHTS AND DIAMETERS

H. T. Schreuder

USDA Forest Service, Southeastern Forest Experiment Station
Forestry Sciences Laboratory, Research Triangle Park, N. C.

W. L. Hafley

Department of Forestry and Statistics

Biometrics 33:471-478, 1977

Hafley and Schreuder (1977) have shown that the marginal S_B distribution fits diameter and height data consistently better than the Weibull, beta, gamma, lognormal, and normal distributions. The bivariate extension of the S_B distribution, the S_{BB} , is both more realistic and provides more usable information than the currently accepted approach in describing even-aged forest stand height-diameter data. The S_{BB} allows for the generation of bivariate frequencies for diameter and height, whereas the current approach only provides marginal frequencies for diameter. In addition, the S_{BB} implies a new height-diameter relationship which is comparable in fit to the most commonly used height-diameter regression model. Application of the S_{BB} to two data sets is presented.

ALLOZYMIC VARIATION AND LINKAGE
DISEQUILIBRIUM IN SOME LABORATORY
POPULATIONS OF DROSOPHILA MELANOGASTER

C. C. Laurie-Ahlberg, Department of Genetics

B. S. Weir, Department of Statistics

Nine laboratory populations of D. melanogaster were surveyed by starch gel electrophoresis for variation at 17 enzyme loci. A single fly extract could be assayed for all 17 enzymes so the data consist of 17-locus genotypes.

Pairwise linkage disequilibria were estimated from the multilocus genotypic frequencies using both BURROW'S and HILL'S methods. Large amounts of linkage disequilibrium were found, in contrast to the results reported for natural populations.

Knowledge of the approximate sizes of these populations was used to compare the observed heterozygosities and linkage disequilibria with predictions of the neutral allele hypothesis. The relatively large amount of linkage disequilibrium is consistent with the small sizes of the populations. However, the levels of heterozygosity in at least some populations suggest that some mechanism has been operating to retard the rate of decay by random drift. Several examples of significant deviation from Hardy-Weinberg frequencies and the large amount of linkage disequilibrium present in these populations indicate that a likely mechanism is selective effects associated with neutral alleles because of linkage disequilibrium with selected loci (e.g. "associative overdominance"). The results are therefore consistent with both neutralist and selectionist hypotheses but suggest the importance of considering linkage disequilibrium between neutral and selected loci when attempting to explain the dynamics of enzyme polymorphisms.

GENETIC CONSEQUENCES OF TRUNCATION SELECTION AT THE
PHENOTYPIC LEVEL IN DROSOPHILA MELANOGASTER

T. Mukai and H. E. Schaffer
Department of Genetics

C. C. Cockerham, Department of Statistics

Genetics 72:763-769, 1972

If selection operates independently on each locus, its action on the large amounts of genic variability discovered in many populations would cause excessive genetic loads compared with the actual situation. In order to accommodate selection for many genes, threshold or truncation-selection models have been proposed assuming heterozygote superiority. This paper demonstrates that several different models are equivalent under truncation selection for low heritability traits.

REPRODUCTIVE STRATEGIES FOR
PERENNIAL ORGANISMS

G. Namkoong
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Variations in allocation of effort between growth and reproduction take many forms and have strong genetic components in their control mechanisms. Constraining relationships exist between growth and reproduction and can be used in fitness functionals to derive optimum paths which maximize fitness.

Euler-Langrange equations are used to analyze the relationship between factors of the growth and reproduction functions and observable behaviour such as time to first reproduction, periodicities in reproduction, and the genetic variance in those behaviours.

COMPUTERIZED HANDLING OF PEDIGREE INFORMATION

H. E. Schaffer, Department of Genetics

Pedigree information is used in the genetic study of many higher organisms and particularly in human genetics. In many studies of experimental organisms regular breeding schemes are used, and therefore the pedigrees are in regular form, and it is often possible to indicate very simply the position of each individual in the pedigree, and to determine easily all the genetic relationships required from this information.

Another case in which the pedigree is easily represented is when the pedigree can be represented as a tree structure. It is necessary and sufficient for this monogamous case that there be no inbreeding within the pedigree represented. A tree structure can have no loops and consanguineous matings produce loops in a pedigree. (However, it is this tree structure which is commonly used to illustrate computerized handling of pedigrees, and pedigree terminology is used in discussing tree structures. Such possibilities as consanguineous marriages, or polygamy and/or polyandry -- in concurrent or serial fashion-- are ignored.)

Therefore to be of general use in human genetics, a pedigree handling scheme must be able to handle both irregularity and consanguinity within pedigrees. The mathematical structure of a pedigree which includes all possibilities is a network. This can include the loops and all other connections necessary to represent any pedigree.

A network representation has been devised which is particularly suitable for representation in a computer, and which allows computerized processing to perform many operations on pedigrees which are commonly desired in human genetics. The network representation has two different types of nodes. One type represents an individual in the pedigree, and can contain any information fields pertaining to that individual. The proper placement of these nodes is facilitated by the second node type which represents a marriage or mating. A number of pointers exist within each node, and contain all the genetic relationship information. At present the pointers used are as follows: Mating node-- husband, wife, husband's next marriage (if any), wife's next marriage (if any), first child (if any); and for the Individual's node -- parents' marriage, next sib (if any), first marriage.

A program package is being developed which implements the network described above and which allows its processing. To allow effective implementation, a computer language has been chosen which has advanced list processing features which allow a direct implementation of the desired network, and which has other features, such as unrestricted recursion, which allow processing in forms which are most natural in genetic operations. The SNOBOL4 language has been chosen as best fitting these requirements and the SPITBOL compiler is being used. The present implementation can produce a pedigree network from input consisting of one record per individual giving that individual's name and those of its parents. The primitive operations include the identification and labeling of all ancestors of an individual.

ISOZYME ALLELIC FREQUENCIES RELATED TO SELECTION
AND GENE-FLOW HYPOTHESES

H. E. Schaffer and F. M. Johnson
Department of Genetics

Genetics 77:163-168, 1974

Significant correlations between allelic frequencies and environmental variables in a number of insect species have been demonstrated by multivariate techniques. Since many environmental variables show a strong relationship to geographic location and since gene flow between populations can also produce patterns of gene frequencies which are related to the geographic location, both selection and gene-flow hypotheses are consistent with the observed correlations. The genetic variables can be corrected for geographic location and so for linear gene-flow patterns. If, after correlation, the genetic variables still show significant correlations with similarly corrected environmental variables, then these correlations are consistent with hypotheses of selection but not of gene flow. The results reported, under the assumption of linear gene flow, support hypotheses of selective action of environmental variables in the genotype-environment relationships observed.

DRIFT OR SELECTION: A STATISTICAL
TEST OF GENE FREQUENCY VARIATION OVER GENERATIONS

H. E. Schaffer, Department of Genetics

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W. W. Anderson
Department of Zoology, University of Georgia, Athens

Genetics 87:371-379, 1977

The method used by Fisher and Ford to study the spread of a gene in a natural population has been modified to analyze the variation in allele frequencies from generation to generation in a common experimental procedure. A further analysis has been developed that is more sensitive to directional trends in the allele frequency over generations, and its use in detecting the action of directional selection on gene frequency at a locus is discussed. The basic model is that gene frequency does a random walk, and so variance is a function of the number of generations (steps). The power of each of these statistical tests is calculated for a number of cases, and the tests are applied to sets of isozyme data from Drosophila pseudoobscura and Zea mays.

A TIME DEPENDENT MODEL FOR COASTAL NITRATE DISTRIBUTIONS

E. E. Hofmann and L. J. Pietrafesa
Department of Geosciences

L. P. Atkinson
Skidaway Institute of Oceanography, Savannah, Georgia

Presented at 40th Annual Meeting of
American Society of Limnology and Oceanography, Inc.

An approach to biological modelling involving the use of separation transformation theory has been developed. By use of this method, it is possible to reduce the number of independent variables in the system. The original four dimensional system (x, y, z, t) can be reduced to a vertical plane conceptual model by assuming along isobath homogeneity in the flow field as a partial function of the baroclinic flow field. Both temporally dependent and independent nitrate concentration equations are then obtained and solved by conventional approximation methods.

A time varying nitrate difference condition (ΔN) imposed at the shelf break controls the time dependence of the system (i.e., the system is allowed to feel the Gulf Stream, in an advective-diffusive sense). The time dependence of nutrient uptake by phytoplankton is the dominant biological process to which all other biological terms are related. Advection, as modified by horizontal diffusion, is the dominant physical process.

A TIME DEPENDENT MODEL OF NUTRIENT
DISTRIBUTION IN CONTINENTAL SHELF WATERS

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Department of Geosciences

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Separation transformation theory is used to obtain solutions to a time dependent, vertical plane mathematical model of nutrient distributions on a continental shelf. Terms are included to allow for prescribed advection and diffusion of nutrients. Solutions are obtained using conventional numerical techniques. Advection, modified by horizontal and vertical diffusion, is the dominant physical process controlling nutrient distribution, for the cases presented. Also the dominant biological process, which controls the time dependence of the resulting nutrient fields, is nutrient uptake by phytoplankton. Model results are compared to an upwelling event in Onslow Bay, North Carolina.

VOLUME, FREQUENCY, EFFECT AND A SPATIAL AND TEMPORAL MODEL OF
GULF STREAM INTRUSIONS INTO ONSLOW BAY, NORTH CAROLINA

E. E. Hofmann and L. J. Pietrafesa
Department of Geosciences

L. P. Atkinson, J. J. Singer, and J. O. Blanton
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Presented at 41st Annual Meeting of
American Society of Limnology and Oceanography, Inc.

Onslow Bay, North Carolina is a continental shelf area that receives little runoff and, because of shoals to the north and south, is not significantly influenced by alongshore advection. These circumstances result in a continental shelf system dominated in many respects by the adjacent western boundary current, the Gulf Stream. Intensive hydrographic sampling indicates that large volumes (ca. 50 km^3) of deep, cold, nutrient-rich Gulf Stream water intrudes into the shallow waters of Onslow Bay (volume = 420 km^3). Data from long-term current meter arrays show a dominant frequency of 5 days in the onshore/offshore velocity field. Thus we conclude that Onslow Bay can have 10% of its volume replaced every five days. Winds and shelf water densities determine the onshore extent of these intrusions. The onshore nutrient flux associated with these intrusions is orders of magnitude greater than any other nutrient source.

These intrusions have been modelled using mathematical approximation and perturbation techniques. Surface, bottom and lateral layer solutions are matched to interior water column solutions. Biological sources and sinks and suggested effects of the Gulf stream on the nutrient distribution are all included. The model results compared favorably to field data.

ESTIMATION OF NUMBERS OF EMBRYONIC
LETHAL ALLELES IN CONIFERS

J. Bishir, Department of Mathematics

Silvae Genetica 26, 1977

Controlling seed losses is a major concern in forestry, especially in tree breeding programs. One cause for seed loss is embryo abortion resulting from the matching of recessive embryonic lethal alleles after either inbreeding or cross-breeding. Our work has been concerned with developing models for the probabilities of unsound seed under various breeding schemes, and with methods for estimating the number of lethal alleles carried by a parent tree, from the observed percentages of unsound seed produced. One paper, already published (Silvae Genetica 26, 1977), deal with the case of self-pollination, while two papers in preparation deal with methods for estimating numbers of lethal alleles in both single trees and whole stands, from the results of cross-pollination. Briefly, the maximum likelihood estimators of numbers of lethal alleles are obtained by equating the observed percentages of unsound seed to the theoretical expressions for the probabilities of unsound seed, and solving the resulting equations. In practice, approximate methods must be used, but it is shown that estimates from approximate models are likely to be close to true values and that interval estimates of satisfactory precision can be obtained using sample sizes commonly reported in the literature.

PROTEIN-SURFACE INTERACTIONS, WITH APPLICATIONS TO THE DESIGN
OF ARTIFICIAL BLOOD VESSELS

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A. R. Main, Department of Biochemistry

N. Morosoff and A. Schartz
Dreyfus Laboratory, Research Triangle Institute

A major problem in the design of materials for artificial blood vessels is that many surfaces induce blood clotting. Extensive testing of materials by various researchers has shown that the degree of clotting is dependent on such surface characteristics as roughness, electric charge, and chemical make-up. Most of the results have been empirical, however, and there is little theoretical understanding of the interactions.

We have begun a project to model protein-surface interactions, with the goal of illuminating the processes that occur. Specifically, we have written a computer program to calculate the electrostatic potential between a given protein molecule and a uniformly charged plane in various orientations, and to find the orientation of lowest potential. We plan to make the model more sophisticated by allowing random roughness and non-uniform charge distributions on the surface. Our study will include models of the kinetics of reactions catalyzed by enzymes adsorbed on a surface. Laboratory experiments will be done to test our models and provide feedback to improve them.

MODELING BLUEBERRY FIRMNESS

J. Franke, Department of Mathematics

The purpose of this work is to find a feasible way to mechanically measure the firmness of blueberries. The firmer ones could then be separated from the less firm ones and sent to market. The experiment consists of bouncing the blueberry on a crystal which is used to measure the force as a function of time during impact. A differential equation is being set up which will predict the measured force. The measured force will then be used to solve for the model parameters, one of which is related to the firmness of the berry.

MATHEMATICAL ANALYSIS OF A MODEL
FOR OXYGEN TRANSPORT IN BLOOD AND TISSUE

C. V. Pao, Department of Mathematics

The inter-relationship between the substrate concentrations in blood and tissue, and the supply of oxygen to tissues from the micro-circulation can be described (under certain simplified conditions) by a mathematical model which involves a system of partial differential equations. An idealized geometrical arrangement for the capillary-tissue system is the so-called Krogh's tissue cylinder where the tissue region is considered to have a cylindrical configuration. Assume that the substrate movement in the tissue cylinder is a diffusion process, and on the inner surface of the tissue the transport of substrate is determined by the relative magnitude between the tissue and the capillary substrate concentrations. Then the substrate concentrations can be described by a coupled system of nonlinear diffusion and transport equations. Some qualitative and constructive analysis on this system of equations is being investigated. This includes (a) the well-posedness of the mathematical model, (b) the stability and instability behavior of the system, (c) a constructive method for the determination of the solution and numerical computations, and (d) the controllability of the substrate concentrations. Similar models involving enzymatic reactions using Briggs-Haldane approximations are also being investigated.

POPULATION GROWTH DESCRIBED BY A NONLINEAR
BOUNDARY VALUE PROBLEM OF PARABOLIC TYPE

C. V. Pao, Department of Mathematics

J. of Appl. Math. & Physics (ZAMP), 26, 1975

This paper treats some non-linear diffusion system arising from the population growth as well as the classical diffusion and heat conduction problem. The spatial domain in the diffusion system can be either bounded or unbounded and the boundary condition under consideration includes both Dirichlet and Neumann type conditions. It is shown under some physically reasonable conditions on the non-linear function that the initial boundary value problem has a unique bounded positive solution which can be constructed by the method of successive approximation. In some simple models, a recursion formula for the calculation of the approximation is given. In addition to the existence problem the investigation is devoted to the asymptotic behavior of the solution and the stability of a steady-state solution. Particular attention is given to a model in the population growth and the chemical diffusion system.

THE KINETICS OF DIFFUSED SUBSTANCES IN SOME BIOLOGICAL SYSTEMS

C. V. Pao, Department of Mathematics

Bulletin of Mathematical Biology 40, 1978

The purpose of this paper is to present a method for the determination of a solution for a coupled system of first order initial boundary-value problems arising from some biological systems. The physical problem is to determine the suspended and the superficial molecular concentrations of a traced substance passing through an organ containing a tangle of vessels, such as the kidney-ureter system. The approach to the problem is by successive approximation which leads to a recursion formula for the determination of the solution as well as error estimates for the approximations. The recursion formula involves only direct integration which indicates a promising possibility in obtaining numerical results by using a computer. In addition to the determination of a solution, some qualitative analysis of the solution is given. This includes the existence of a unique solution, the continuous dependency of the solution on the data, and the stability problem of a steady-state solution.

MATHEMATICAL ANALYSIS OF POSITIVE FEEDBACK IN
BIOCHEMICAL CONTROL CIRCUITS

J. F. Selgrade, Department of Mathematics

In this work, we intend to extend the analysis of Griffith's model of positive feedback to more complicated feedback terms, e.g., the Othmer-Tyson model, and obtain the same results concerning the asymptotic behavior of solutions. Also, we will add several intermediate enzymes to the model and hope to analyze the behavior of solutions to the resulting higher dimensional system of equations.

MATHEMATICAL ANALYSIS OF A CELLULAR CONTROL PROCESS
WITH POSITIVE FEEDBACK

J. F. Selgrade, Department of Mathematics

This paper studies a three dimensional system of equations with parameters proposed by J. S. Griffith to model a cellular process for control of gene expression by positive feedback. One variable represents the concentration of mRNA which codes for the production of an enzyme, the second variable. The enzyme causes the synthesis of a product; and this product, the third variable, induces the production of mRNA. The origin, which means a zero concentration for each variable, is a critical point for all parameter values. For parameter values where the positive octant contains one other critical point, we show that all nonzero solutions in that octant are positively asymptotic to this critical point. For another range of parameter values the positive octant contains two nonzero critical points, lying on a ray from the origin. We show that there is a two dimensional surface of solutions positively asymptotic to the smaller of these two critical points; all nonzero solutions in the positive octant on one side of this surface are positively asymptotic to the origin and all nonzero solutions on the other side are positively asymptotic to the larger critical point.

ASYMPTOTICS APPLIED TO A NEURAL NETWORK

J. W. Silverstein, Department of Mathematics

Biological Cybernetics 22(2):73-84, 1976

A mathematical model of neural processing is proposed which incorporates a theory for the storage of information. The model consists of a network of neurons that linearly processes incoming neural activity. The network stores the input by modifying the synaptic properties of all of its neurons. The model lends support to a distributive theory of memory using synaptic modification. The dynamics of the processing and storage are represented by a discrete system. Asymptotic analysis is applied to the system to show the learning capabilities of the network under constant input. Results are also given to predict the network's ability to learn periodic input, and input subjected to small random fluctuations.

ON THE RANDOMNESS OF EIGENVECTORS GENERATED FROM
NETWORKS WITH RANDOM TOPOLOGIES

J. W. Silverstein, Department of Mathematics

SIAM Journal on Applied Mathematics (in press)

A model for the generation of neural connections at birth led to the study of W , a random, symmetric, but very large, dimensional Euclidean space. A limit law, as the dimension increases, on the eigenvalue spectrum of W was proven, implying that realizations of W appear totally on the microscopic level and yet have identical spectral densities.

The present paper considers the eigenvectors of W . Evidence is given to support the conjecture that, contrary to the deterministic aspect of the eigenvalues, the eigenvectors behave in a completely chaotic manner, which is described in terms of the normalized uniform (Haar) measure on the group of orthogonal transformations on a finite dimensional space. The validity of the conjecture would imply a tabula rasa property on the ensemble ("species") of all realizations of W .

SPECTRAL ANALYSIS OF NETWORKS WITH RANDOM TOPOLOGIES

J. W. Silverstein and U. Grenander
Department of Mathematics

SIAM J. on Applied Mathematics 32(2):499-519, 1977

A class of neural models is introduced in which the topology of the neural network has been generated by a controlled probability model. It is shown that the resulting linear operator has a spectral measure that converges in probability to a universal one when the size of the net tends to infinity: a law of large numbers for the spectra of such operators. The analytical treatment is accompanied by computational experiments.

STATISTICAL ANALYSIS OF NEUROTRANSMITTER RELEASE

J. W. Silverstein, Department of Mathematics

The goal is to find a procedure in estimating the parameters governing the release of neurotransmitter into a synaptic junction, from postsynaptic potential (p.s.p.) data. In the past, parameter estimates were made on synaptic sites where spontaneous miniature p.s.p.'s could be recorded. But the present interest is on sites where spontaneous data cannot be obtained.

The mathematical interpretation of the random phenomena is the following: Let X_i be i.i.d. $n(\mu, \sigma^2)$ random variables and let $r = 0, 1, 2$ be $b(n, p)$. The problem is to estimate μ, σ^2, n, p from i.i.d. samples of

$$Y \equiv \begin{cases} \sum_{i=1}^r X_i & r \geq 1 \\ 0 & \text{o.w.} \end{cases}$$

Several approaches have been taken, namely the method of moments and density estimation using Fourier series. Other methods are being considered which arise out of the problem's strong connection with problems in pattern classification.

VOWEL PREPROCESSING WITH A NEURALLY BASED MODEL

J. W. Silverstein, Department of Mathematics

J. Anderson and S. Ritz
Division of Applied Mathematics, Brown University

In: Conference Record: 1977 IEEE International Committee
on Acoustics and Signal Processing, Hartford, Conn. (in press)

We assume that (1) nervous system activity is most usefully represented as the set of simultaneous individual neuron activities in a group of neurons, (2) different memory traces make use of the same synapses and (3) synapses associate two patterns of neural activity by incrementing synaptic connectivity proportional to the product of pre- and postsynaptic activity (a Hebbian rule). We extend this model by (1) introducing positive feedback of a set of neurons onto itself and (2) allowing the individual neurons to saturate. Positive feedback forces the pattern of neural activity into stable corners of a high dimensionality hypercube. The model has behavior reminiscent of 'categorical perception' in that large regions of initial neural activity will end in the same corner. We wish to demonstrate that this model can serve as an efficient pre-processor, which takes a noisy stimulus, a spoken vowel, and puts it in a noise free standard form. As a test, we used acoustic representations of nine spoken Dutch vowels. We apply the model, and show that after several thousand learning trials, input vowels, initially close together, are associated with separate stable corners.

DISTINCTIVE FEATURES, CATEGORICAL PERCEPTION, AND
PROBABILITY LEARNING: SOME APPLICATIONS OF A NEURAL MODEL

J. W. Silverstein, Department of Mathematics

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Psychological Review 84(5):413-451, 1977

A previously proposed model for memory based on neurophysiological considerations is reviewed. We assume that (a) nervous system activity is usefully represented as the set of simultaneous individual neuron activities in a group of neurons; (b) different memory traces make use of the same synapses; and (c) synapses associate two patterns of neural activity in incrementing synaptic connectivity proportionally to the product of pre-and postsynaptic activity, forming a matrix of synaptic connectivities. We extend this model by (a) introducing positive feedback of a set of neurons onto itself and (b) allowing the individual neurons to saturate. A hybrid model, partly analog and partly binary, arises. The system has certain characteristics reminiscent of analysis by distinctive features. Next, we apply the model to "categorical perception." Finally, we discuss probability learning. The model can predict overshooting, recency data, and probabilities occurring in systems with more than two events with reasonably good accuracy.

A NONLINEAR SYSTEM OF DIFFERENTIAL EQUATIONS ARISING FROM A MODEL FOR NEURAL LEARNING

J. W. Silverstein and S. L. Campbell
Department of Mathematics

It is proposed to study the nonlinear system of differential equations:

$$\dot{N} \omega = (N - \alpha I) \omega + y, \quad \dot{N} = a \omega \omega^T - bN$$
 which is a model for learning by neural networks. Here N is an $n \times n$ matrix, ω, y are $n \times 1$ vectors and α, a, b are scalar constants. The proposers intend to determine the stability behavior in order to evaluate whether the model is consistent with the particular learning theory which motivated its development. Since equilibrium values occur at singular values of N , the phase portrait cannot be obtained by classical methods.

SELECTION PRESSURES AND PLANT PATHOGENS

K. J. Leonard, Department of Plant Pathology

Ann. N. Y. Acad. Sci. 287:207-222, 1977

In many interactions of higher plants and parasitic fungi, there is a gene-for-gene relationship between specific genes for resistance in the host and genes for virulence in the parasite. A specific gene for resistance protects the host for all parasite genotypes except those with the matching gene for virulence. Avirulent genotypes (lacking specific virulence genes) of the parasite can attack only susceptible host genotypes (lacking specific resistance genes). Typically, for each specific gene for resistance in the host, there is a matching gene for virulence in the parasite that allows it to overcome that resistance. In wild populations of plant and their parasites, the alleles for resistance and susceptibility and for virulence and avirulence occur together in polymorphic systems apparently maintained by genetic feedback mechanisms. Thus, it appears that selection acts against specific genes for virulence when they are not needed and against specific genes for resistance when they do not provide protection. To account for the genetic feedback, the relative fitnesses of parasite and host genotypes in the following combinations: 1) avirulent parasite on susceptible host, 2) avirulent parasite on resistant host, 3) virulent parasite on susceptible host, and 4) virulent parasite on resistant host, can be represented as 1) 1 and 1-s, 2) 1-t and 1-c-s(1-t), 3) 1-k and 1-s(1-k), and 4) 1-k+a and 1-c-s(1-k+a), respectively, where \underline{s} = proportionate loss in reproduction of a susceptible host genotype infected with an avirulent parasite genotype, \underline{t} = suppression of parasite reproduction by effective resistance, \underline{c} = cost of resistance, \underline{k} = cost of virulence, and \underline{a} = increased suitability of a resistant host to a parasite with the matching gene for virulence as compared to the suitability of the susceptible host to the virulent genotype.

In this host-parasite system, there is a non-trivial equilibrium point where the frequency of the virulent parasite genotype is $(ts - c)/(ts + as)$ and the frequency of the resistant host genotype is $k/(a+t)$. In important plant diseases with gene-for-gene relationships, $s \gg c$ and $t \gg k$, so virulent parasite genotypes may be common even with relatively low frequencies of resistant host genotypes. For oat and wheat stem rust, \underline{k} values of 0.05 to 0.4 were determined experimentally. Unnecessary genes for virulence with $k < 0.05$ can be eliminated only very slowly from parasite populations occurring on susceptible varieties of crop plants.

INTEGRATED PEST MANAGEMENT SYSTEMS
FOR APPLES IN NORTH CAROLINA

A multi-disciplinary effort involving faculty from several departments: Turner B. Sutton, Plant Pathology; Harvey J. Gold, Statistics (Biomathematics); George C. Rock, Entomology; Herbert J. Kirk, Statistics, Don W. Hayne, Statistics; Walter A. Skroch, Horticultural Science; Larry F. Grand, Plant Pathology; Gerald A. Carlson, Economics and Business, and Mien Wann, Statistics (Biomathematics).

System analytic methods will be developed for the guidance and integration of multidisciplinary research efforts for integrated pest management in the orchard ecosystem. Emphasis will be placed on developing methods for controlling pest populations which minimize the dependency on pesticides. Specific areas of investigation include (1) the effects of habitat manipulator and toxicant application on changes in rates of pine vole reproduction, mortality, and migration; (2) the development model of the effects of pest populations, pesticide uses and other factors on yield and quality; (3) the relationship between weed populations, soil types, orchard sites and management levels as they influence tree growth and fruit quantity and quality; (4) the evaluation of models of key orchard insects and diseases under North Carolina conditions; (5) mycorrhizae relationships of apple trees as they influence tree growth and root diseases and are affected by rootstocks and pesticide application. Management models will be developed from these and other data which will serve as a basis for an advisory service.

DEVELOPMENT OF A PEANUT PRODUCTION MODEL

F. R. Cox and C. K. Martin
Department of Soil Science

J. H. Young, Department of Biological
and Agricultural Engineering

H. E. Pattee, Department of Botany, USDA

In the first stage of developing a peanut production model we are creating the growth and development phase. Inputs for predicting growth are daily radiation, maximum and minimum temperature and soil moisture tension. Daily soil moisture tension data is determined from a few direct measurements and predictions from a water model developed by C. K. Martin.

The growth model begins with an emergence function based on temperature. At emergence, and on during the season, leaf and stem weights are partitioned according to plant size. An aging function is applied to the leaf mass that affects photosynthetic efficiency.

The photosynthate produced daily is computed as a product of the aged leaf weights and a product function of variety, temperature, radiation, moisture, and shading. Net photosynthesis is then calculated by subtracting maintenance respiration. When the photosynthate is used to grow plant parts, growth respiration is accounted for according to the composition of that part.

A portion of the photosynthate is assigned to a pool that can be drawn upon during times of stress created by the fruit load. Only a fraction of a need, however, may be fulfilled on a given day. A stress function is used to predict the amount of leaf drop.

There is a priority for use of the photosynthate that follows the sequence (1) increase in pod mass and number, (2) increase in peg mass and number, (3) increase flowers, and (4) change leaf and stem mass. Maximum daily pod growth rate is temperature dependent and final pod size is related to the weight after four weeks of growth. Maximum peg growth rate is considered a constant.

The number of pods, pegs and flowers that are produced are dependent upon the amount of photosynthate available. The number of pegs capable of producing fruit may also be reduced by suboptimal moisture conditions as well as their having a maximum effective age. Flower number is dependent on photosynthate level and temperature three days prior to the observation as well as the soil moisture level for the current day.

Data have been collected from planting date, irrigation and shading studies in the field and from temperature and radiation studies in growth chambers. Types of functions and parameters in the functions were selected by a least squares procedure.

Additional information is needed to predict the time of fruit loss after maturation. After completion of this draft of the growth model it will be extended with the harvesting, curing and marketing phases as well as interacted with disease and insect submodels.

A COMPUTER SIMULATION MODEL
TO PREDICT TILLAGE EFFECTS ON SOIL TEMPERATURE

R. M. Cruse, Department of Soil Science
Ph.D. Thesis, Univ. of Minnesota, St. Paul

A physically based computer simulation model to predict tillage effects on average daily soil temperature at the 5-cm depth has been developed. Temperature predictions are a function of solar radiation absorption and soil thermal inertia. Absorption of solar radiation is sensitive to residue type, residue amount, residue age, stage of evaporation, solar radiation reflection characteristics of the soil, soil water content, soil surface random roughness, and latitude of the receiving surface. A multiple reflection model for predicting solar radiation absorption on rough soil surface was developed and used, but requires additional testing to rigidly prove or disprove its applicability. Soil thermal inertial calculations are based on a modified version of the deVries dielectric analogue approach to calculating soil thermal conductivity (deVries, 1963). Soil properties required for the model are: soil water content at the wilting point, soil bulk density, soil random roughness, initial residue dry weight, residue type, residue reflection coefficient at model initiation, soil reflection coefficient, percent quartz, percent clay minerals, and percent organic matter. Daily soil and climatic inputs required are: maximum and minimum air temperature, incoming solar radiation, soil water content at the 5-cm depth, and stage of evaporation. The model appears to adequately predict soil temperature when solar radiation can be predicted and when soil heat flow is predominately by conduction.

A MACARTHUR-WILSON MODEL OF ARCHIPELAGO SPECIES COMPOSITION

F. A. Benford

Department of Statistics, Biomathematics Program

The idea of the "equilibrium" theory of island biogeography of MacArthur and Wilson is extended to model the biogeography of species on archipelagos. The resulting model is an interesting continuous time Markov chain; the state space of this Markov chain is geometrically equivalent to the vertices of a hypercube, all legal transitions are along the edges of the hypercube, and there is a single absorbing state. The mathematics of this class of stochastic processes is developed in some detail, and these mathematical results are employed in the modeling of archipelago species composition. The model has potential applications in the fields of wildlife management, pest control, and epidemiology.

FISHER'S THEORY OF THE SEX RATIO
APPLIED TO THE SOCIAL HYMENOPTERA

F. A. Benford
Department of Statistics, Biomathematics Program

J. theor. Biol. 72:701-727, 1978

Fisher's theory of the sex ratio may be extended to the social Hymenoptera; this extension must consider the unusual genetic structure of the Hymenoptera. Queens, workers, and laying workers generally have different equilibrial sex ratios of offspring and different equilibrial ratios of investment in offspring of the two sexes; these differences are the consequence of asymmetries in the degrees of relatedness between the queen, a worker, and a laying worker to male and female offspring. The equilibrial ratios of investment for the queen, a worker, and a laying worker are derived by finding the relative expected reproductive successes of genes in males and in reproductive females.

TWO-LOCUS INBREEDING MEASURES FOR RECURRENT SELECTION

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B. S. Weir
Department of Statistics

Theor. Appl. Genet. 49:63-77, 1977

For a population undergoing recurrent selection, a method is presented for determining the average inbreeding coefficients at the end of each breeding cycle. The coefficients are derived in terms of probability that genes are identical by descent. For the one-locus case, two digametic measures are defined and employed in the derivation of a recurrence formula for the inbreeding coefficient. Two further classes of measures, trigametic and quadrigametic, are required for transition from one cycle to the previous one to allow the calculation of the inbreeding function for the two-locus case. Numerical values of the average probability of double identity by descent for populations with various imposed assumptions are listed to illustrate the effects of linkage and population size on the accrual of inbreeding and hence of homozygosity.

DIGENIC DESCENT MEASURES FOR FINITE POPULATIONS

C. Clark Cockerham and B. S. Weir
Department of Statistics

Genetical Research 30:121-147, 1977

The development of a set of two-locus descent measures is reviewed. The three digenic measures, inbreeding coefficient and parental and recombinant descent coefficients, are considered in detail. The derivations of these three in pedigrees, fixed mating systems, and random mating in monoecious or dioecious populations are given. General expressions for digenic frequencies and disequilibria functions at any time are found by applying the three digenic measures to two types of initial populations. The final or equilibrium status of the population is also given. As the inbreeding coefficient is the same as the recombinant descent coefficient in the case of complete linkage, avoidance or promotion of early inbreeding has similar effects on the two coefficients.

A STOCHASTIC MODEL FOR FACILITATED TRANSPORT
OF OXYGEN THROUGH TISSUE SLICES

T. C. Curran and H. J. Gold
Department of Statistics, Biomathematics Program

J. theor. Biol. 50:397-411, 1975

Longmuir and co-workers have reported that respiration of certain tissue slices is approximated by Michaelis-Menten kinetics. From this and other experimental findings, Longmuir proposed that a carrier is involved in tissue oxygen transport. Gold developed a deterministic model to examine this hypothesis. This report presents a stochastic model for a fixed site carrier in a more general framework that includes the stochastic counterpart to Gold's deterministic model as a special case. The kinetics of tissue oxygen to consumption predicted by the model are examined for various cases.

STABILITY OF EQUILIBRIA IN
THEORETICAL PLANT HOST-PARASITE SYSTEMS

R. J. Czocho and H. R. van der Vaart
Department of Statistics, Biomathematics Program

K. J. Leonard, Department of Plant Pathology

Phytopathology 68:971-973, 1978

In a theoretical host-parasite system with a typical gene-for-gene relationship between resistance in the host and virulence in the parasite, there is a non-trivial equilibrium point where the frequency of the resistant host genotype is $k/(a + t)$ and the frequency of the virulent parasite genotype is $(ts - c)/(ts + as)$. In this model s = reduction in host fitness caused by a parasite genotype with a fitness of 1, t = reduction of parasite fitness by effective host resistance, c = cost of resistance, k = cost of virulence, and a = specific increased suitability of a resistant host to the parasite genotype with the matching gene for virulence. In addition to the non-trivial equilibrium point which was shown to be unstable, there are 8 trivial equilibrium points which involve genotype frequencies of 1 or 0 and which are also unstable. The implication is that there must be one or more limit cycles in the system that define the pattern of genotype frequency oscillations generated by genetic feedback between host and parasite. The purpose of this research is to analyze the system and to explore the effects of various modifications in the model on the behavior of it. For example, it was shown that including in the model appropriate rates for mutations to and from resistance and virulence had little effect on the behavior of the system. Other modifications to be tested include: 1) allowing the favorability of the environment for infection to vary with some degree of randomness, 2) permitting a change from hard to soft selection in the parasite over the course of several generations of annual increase, and 3) allowing heterozygote superiority in host and/or parasite. Results of this study in comparison with what is known of the behavior of natural host-parasite systems should increase our understanding of them and provide a better basis for planning strategies for optimal use of genes for disease resistance in important crop species.

A MODEL OF VISUAL PERCEPTION USING A HOLOGRAPHIC ANALOGY
TO EXPLAIN THE PHYSIOLOGICAL INTERACTIONS

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Department of Statistics, Biomathematics Program

There are three factors that contribute to the formation of the perception of an object. These are a wavefront coming from the retinal ganglion cells, the effects of past experience, and a mechanism that correlates a sensory input to the proper past experience and causes changes in synaptic connections to occur more easily.

It is the synaptic efficiencies of the structures along the visual pathway that are the 'neural hologram' (i.e., correspond to the patterns in the photographic plate in an E-M hologram). The neural holograms are composed of circuits of functional columns along the visual pathways. The holograms are innate in mammals, but are slowly modified and sharpened by experience.

The retinal input corresponds to the reference beam that is used to reconstruct an E-M hologram. The effects of past experience are stored in the synapses that make up the hologram. The effects of past experience cause long range organizations called world models. It is postulated that the mechanism that controls attention determines the 'phase' and extent of the interaction between the retinal wavefront and the world models.

Ways to decompose the system are sought. A hierarchical structure for the visual system is proposed (cells, columns, circuits of columns, pathways, and the whole system). In addition, functions that occur in perception are picked out and the structures that support them are looked at. This approach helps to separate the various kinds of world models.

It is hoped that this model (which is not yet quantitative) can explain various types of electrode data, as well as psychophysical data like perceptual constancies and optical illusions. The practical applications might be in areas where getting information to people in ways that it can be handled and stored effectively, are important.

A number of mathematical techniques seem applicable to different aspects of this system. Transform techniques might be used in following a wavefront thru a circuit of columns. Feedback control might be applied to the interaction of circuits. Techniques for finding self-organization in dynamic systems may be used.

ELECTRONIC ASPECTS OF THE BIFUNCTIONAL CATALYSIS
OF GLUCOSE MUTAROTATION AND IMPLICATIONS
FOR ENZYME CATALYSIS

H. J. Gold

Department of Statistics, Biomathematics Program

Proc. Jerusalem Symposium on Quantum Chemistry
and Biochemistry VI, 459-471, (1974)

This paper describes results of theoretical calculations on a chemical reaction, which is a model for certain aspects of enzyme catalysis.

The generalizations for enzyme catalysis that are suggested by the study of this model reaction are:

1. Structural relations between the functional groups within the catalyst lead to electronic interactions which enhance the activity of the functional group.
2. Structural relations between catalyst and substrate allow the more efficient action of each of the functional groups and also alter the potential energy surface so as to decrease the height and width of the energy barrier.

The second effect may be further enhanced in enzyme catalysis by points of interactions between enzyme and substrate other than those directly involved in the reaction.

PATTERNS IN RELATIONSHIPS OF POLYGENIC
SYSTEMS OF OAT CULTIVARS

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C. F. Murphy
Department of Crop Science

This work is directed at the problem of selecting crosses of oat cultivars that are likely to lead to transgressive segregation. An intensive crossing program was conducted to produce as many crosses as possible among 750 plants, representing 15 lines of oats Avena sativa L. Based on data for the variances and covariances of six yield related characters for the F2 and F4 generations, several indices for "goodness-of-cross" have been calculated. They are being examined as a basis for cluster analytic classification of parental lines.

INSECT DISPERSAL AND PEST MANAGEMENT

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The life cycles of many insects include a relatively sedentary, primarily "vegetative" larval and pupal stage followed by a physiologically determined dispersal stage which culminates in oviposition on suitable host plants. Mathematical models for dispersal and host finding at the population and ecosystem levels will be formulated and studied with an eye towards application in the area of agricultural pest management. The spatial as well as temporal distribution of both insect and host populations will be considered.

THE NUMBER OF NEUTRALS ALLELES IN A FINITE POPULATION

D. R. Marshall and B. S. Weir

Department of Statistics

The distribution of allelic frequencies in finite populations is discussed for the two major models of neutral electrophoretic variation. The unique-alleles model assumes that mutations are undirected and result in new alleles while the charge-state model assumes that mutation is restricted to neighboring electrophoretic classes. Mixtures of the two models are studied, as are models with finite numbers of alleles. The allelic frequency distributions are used to provide effective and actual numbers of alleles and the use of such numbers in tests of neutral hypotheses is considered.

MAINTENANCE OF GENETIC VARIATION IN APOMICTIC PLANT
POPULATIONS. I. SINGLE LOCUS MODELS

D. R. Marshall and B. S. Weir
Department of Statistics

Heredity, 1979 (in press)

Populations undergoing selfing, outcrossing and apomixis are studied. Genotype transition equations are established which allow the properties of equilibrium populations to be discussed. Particular attention is paid to the continued maintenance of heterozygosity. It is found that apomixis leads to more restrictive conditions for the maintenance of polymorphism in species which otherwise outcross, but in species which partially or completely self, the possibility of the selective maintenance of balanced polymorphism is enhanced.

APPLICATIONS OF COMPARTMENTAL SYSTEMS

J. H. Matis

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This is an ongoing program to adapt compartmental system modeling to several specific biological systems in which it has been found very useful. These include the following three biological systems: 1) the passage of digesta in ruminants (which is envisioned to follow a compartmental model); 2) the uptake and depuration of various toxic substances in marine organisms (previously modeled by classical pharmacokinetics), and 3) survival analysis of marine organisms in heated water.

This research refines the existing compartmental models for these and other related systems and incorporates the principles of statistical parameter estimation and hypothesis testing.

STOCHASTIC MODELS OF COMPARTMENTAL SYSTEMS

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Texas A&M University, College Station

Virtually all of the current applications of and theoretical research in compartmental analysis are based on a deterministic theory. This paper, however, suggests that the "real world" of compartmental systems is stochastic and it formulates a general stochastic compartmental modeling approach. The basic thesis is that there are now many such stochastic models of compartmental systems which can and should be applied in practice. This paper presents an overview of these models and pinpoints what we believe are promising areas for future research. The research is a continuation of previous work on this topic in the following papers:

Matis, J. H. and Tolley, H. D. Compartmental models with multiple sources of stochastic variability: The one-compartment, time invariant hazard rate case. To appear in Bull. Math. Biol.

Matis, J. H. and Tolley, H. D. On the stochastic modeling of tracer kinetics. To appear in Federation Proceedings.

ON THE SOUTHERN PINE BEETLE DYNAMICAL SYSTEM

W. D. Mawby and H. J. Gold
Department of Statistics, Biomathematics Program

F. P. Hain and W. McClelland
Department of Entomology

The previous eight years have seen an epidemic surge of the Southern Pine Beetle, Dendroctonus frontalis Zimmerman, through the Southwest. This major forest pest attacks nearly all pine species. Its epidemic phase is characterized by large contiguous spots of high mortality. Its endemic phase, while as yet poorly defined, is restricted to secondary attacks and isolated single tree kills. The fuller understanding of this epidemic/endemic series is of primary importance to future prediction and control procedures.

This work is directed toward mathematically modeling this dynamic series through the direct use of North Carolina based data. There are three major emphases to our work. First is estimation. Within-tree and within-spot sampling procedures have been developed, and further work will seek to develop an aerial photographic survey technique with an associated regression estimator. Secondly, the local within-spot system is being studied. Within-tree development is well described, with our further effort to yield a general stochastic model of the dispersal system. Lastly, we approach the large scale epidemiological structure of the system. This will involve several geographical levels, and will use techniques of time-space analysis.

A MATHEMATICAL MODEL OF NORMAL GRANULOCYTE KINETICS

B. L. McFarland

(Ph.D. Thesis Under the Director of Dr. H. R. van der Vaart)

Department of Statistics, Biomathematics Program

Institute of Statistics Mimeo Series No. 1197

The purpose of this study was to determine if there is a feedback mechanism operating on the production and development of granulocytes; and if so, how the feedback mechanism operates. The maturation and development of granulocytes have been partitioned into three compartments: the mitotic compartment, the storage compartment, and the blood. Twenty per cent and 40 per cent neutropenia in the blood were achieved by causing the blood to lose approximately 20 per cent or 40 per cent of its cells. Mathematical models were developed to simulate on the computer two different feedback mechanisms. One model is designed so that release of cells from storage to the blood is dependent upon the number of cells in the blood, and the release of cells from the mitotic compartment to the storage compartment is dependent upon the number of cells in storage. The other feedback mechanism is modelled so that release of cells from the mitotic compartment to the storage compartment, and release of cells from storage to the blood depend upon the number of cells in the blood.

Results indicate that a feedback mechanism is operating on the granulocyte system. When neutropenia is simulated either feedback mechanism causes an increase of cells in the blood to near or above the steady state value within 0.2 of an hour after neutropenia is achieved. Around 5 hours after onset of neutropenia the number of blood granulocytes overshoots the steady state value and returns to normal within less than an hour after this overshoot. These simulated results are closely similar to experimental behavior of blood granulocytes after neutropenia has been achieved.

Since both models give basically the same results in the blood granulocyte pool, it is difficult, at this particular point of the study, to ascertain which feedback model better parallels the biological system.

ANALYSIS OF THE VOLTERRA MODEL

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Many systems in nature involving competition of component species are observed to display a strikingly stable oscillatory behavior in composition. These include predator-prey systems, in which the population numbers of predator species follow those of prey species of fixed, constant period, intensity, and phase lag. Such competitive behavior has been proposed as well to account for other periodic properties in biological systems, such as biological clocks and nerve conduction. The Volterra model, a system of coupled, nonlinear ordinary differential equations, has long served as a starting point both for deterministic analysis of this phenomenon and for its stochastic and simulation treatment. Although it has been shown that the model admits many stable orbits for systems consisting of even numbers of interacting species, solutions to Volterra's equation have not been discovered, even for the two species case.

Present work is concerned with application of the methods of classical statistical mechanics to the Volterra problem. We have obtained the following results: (1) closed expressions permitting evaluation of "phase integrals" (inergodic systems, the long-time averages of integrable functions of population numbers) for any stable system; (2) proof of the ergodic hypothesis for systems of two species; and (3) closed expressions for all Volterra parameters of the two-species case in terms of observable long-time population averages. These results are currently being applied (thesis: S. Ewing) in a test of the model for the remarkable Hudson Bay Company lynx-hare data, the traditional textbook example of oscillatory predator-prey behavior. Further research is in two directions. The one involves study of the stability of such systems when open to population migration in nature, with application of the formalism of thermodynamics. The other has to do with a general consideration of the criteria of "goodness-of-fit" with respect to stochastic models which predict trajectories in time, applying the methods of algebraic statistical mechanics.

Reference: "Evaluation of Phase Integrals for Volterra Systems of Arbitrary Numbers of Interacting Systems," J. Statistical Phys. 16:59-68. 1977.

MAINTENANCE OF MALE STERILITY IN PLANT POPULATIONS
III. MIXED SELFING AND RANDOM MATING

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B. S. Weir
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Heredity 35:21-29, 1975

Two models of monogenic recessive male sterility are presented, first where the male-steriles are always fully pollinated (full-fitness model) and second, where they are pollinated only to the extent that hermaphrodites are crossed (limited fitness model). Male-steriles in both models may be maintained by overdominance at the sex-control locus or by having greater ovule or seed fertility than hermaphrodites. For both models fitness of male-steriles is frequency dependent under random mating or under mixed selfing and random mating, and for the case when male-steriles are maintained only by increased fertility, expressions are derived for their equilibrium proportions and those of both hermaphrodite genotypes. Also for this latter case, fitness of male-steriles in equilibrium populations equals that of the hermaphrodites. In the full-fitness model the degree of selfing among hermaphrodites has little effect on equilibrium proportions of male-steriles, which may decline slowly, increase slowly, or remain constant with increased selfing. Except under random mating, equilibrium proportions of male-steriles are lower in the limited-fitness model and decline with increased selfing among hermaphrodites. Outcrossing rates for pollen of hermaphrodites are derived.

MAINTENANCE OF MALES AND FEMALES IN HERMAPHRODITE
POPULATIONS AND THE EVOLUTION OF DIOECY

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B. S. Weir, Department of Statistics

Evolution 30:425-441, 1976

Three models of gynodioecy and androdioecy are presented where males and females are monogenically inherited and may be maintained by having greater pollen or ovule fertility than hermaphrodites or by overdominance at the sex-control loci.

The situation where monogenic recessive gynodioecy is combined with monogenic dominant androdioecy to give a digenic model is examined in detail. Recessive gene m for male sterility and dominant gene F for female sterility result in three male, one female, two hermaphrodite and one neuter genotype. There may be overdominance at the male-sterility locus while ovules of females and pollen of males may differ in fertility from ovules or pollen of hermaphrodites.

Transition equations for genotype frequencies allow bounds to be put on phenotype frequencies and confirm that dioecy can evolve only if there is complete linkage between sterility mutants when equal proportions of MF/mf male and mf/mf female genotypes are present. Considerable selection differentials are required for evolution of dioecy, especially in more inbred populations. Numerical results indicate that even with free recombination males and females can sometimes be maintained with selection differentials which are insufficient to maintain each unisexual type in the absence of the other. Consideration of these results leads to a multilocus hypothesis for the evolution of dioecy.

LENGTH-FREQUENCIES OF LARVAL FISH AND THE LOTKA-SHARPE MODEL

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A demographic approach is being used to model length-frequency observations for larval fish, especially of spot and croaker, in the Cape Fear River Estuary. In particular, the Lotka-Sharpe age distribution model in continuous time is being used. The model is applied to yield non-stable age distributions. Ongoing work entails incorporating transport of larval fish within the estuary. Of particular concern is retention of larvae within the estuary and the use of various parts of the estuary as a nursery area. Further work calls for formulating a stochastic version of the Lotka-Sharpe model and comparing observed length-frequency data with length-frequency data generated by the model.

STOCHASTIC AND DETERMINISTIC MODELS FOR THE KINETIC
BEHAVIOR OF CERTAIN STRUCTURED ENZYME SYSTEMS I AND II

S. C. Smeach and H. J. Gold
Department of Statistics, Biomathematics Program

J. theor. Biol. 51:59-78, 1975

The usual kinetic treatments of enzyme systems involve the assumptions of large numbers of molecules in a well-mixed volume. These conditions may not be met in the micro-environment of structured (e.g., membrane-bound) enzyme systems. In such a micro-environment, the discreteness of the elementary chemical events may have to be taken into account. Differential equation formulations based on deterministic models have the ability to treat such discreteness only in some average sense.

This study is concerned with the development of stochastic models for certain prototype structured enzyme systems and the comparisons of these models with their deterministic, i.e., solution chemistry, analogs under steady state conditions. Lack of agreement between the deterministic and stochastic models is related to a measure of the nonlinearity of the system, in accord with Jensen's inequalities. Implications of these results, relative to experimental procedures are briefly discussed.

A DATA STRUCTURE FOR KNOWLEDGE REPRESENTATION
IN COMPUTATIONAL LINGUISTICS

D. A. Tang and H. J. Gold
Department of Statistics, Biomathematics Program

A. L. Tharp, Department of Computer Science

The purpose of this research is to explore the possible structures and models of human memory with a view to the application of the research results to artificial intelligence (AI), that is, making the computer "smarter" and more human-like. It is now widely accepted in AI that in order for the computer to use human languages (natural languages), not only must it know the grammar of the language, but also it must have in its memory a store of general background knowledge. How such knowledge should be represented, both in human memory, and in the computer is the focus of this research.

Human linguistic behavior can be shown to contain two complementary elements; verbal and nonverbal. Nonverbal elements are those that directly involve the motor-sensory system -- perceptive hardware, which we are all born with. These nonverbal elements serve as a common basis on which verbal elements are added for more complex and less sensory specific expressions, much like a dictionary with drawings and photographs. Taking note of the above observations, a knowledge representation system for a computer will be proposed, using a modified form of semantic networks. This representation system will have provisions for the nonverbal elements may be integrated into the system.

H. R. van der Vaart

Departments of Statistics and Mathematics, Biomathematics Program;
research interests in theoretical principles and practical applications.

A/ THEORY: Analysis of properties of mathematical models and general principles of model building.

1) Dynamics of ecosystems. Publications:

CONDITIONS FOR PERIODIC SOLUTIONS OF
VOLTERRA DIFFERENTIAL SYSTEMS

H. R. van der Vaart
Department of Statistics, Biomathematics Program
Bulletin of Mathematical Biology 40:133-160, 1978

As a contribution to the discussion of oscillatory models for interacting species, it is shown that two-species Volterra models,

$$\left\{ \begin{array}{l} \dot{x} = x(c + ax + by) \\ \dot{y} = y(\gamma + \alpha x + \beta y) \end{array} \right\},$$

can never have limit cycles, and a complete enumeration is given of (non-generic) conditions which the parameters of these models must satisfy in order that a part of the phase space be filled with a family of closed curves; sketches of phase portraits are also given. These results complement and correct older results by Bautin and by Coppel on quadratic differential systems. The paper opens with a brief discussion of some more practical aspects of the ecological application of oscillatory models.

SOME EXAMPLES OF MATHEMATICAL MODELS
FOR THE DYNAMICS OF SEVERAL-SPECIES ECOSYSTEMS

H. R. van der Vaart
Department of Statistics, Biomathematics Program

Chapter 6 (pp. 186-292) in: "Case Studies in
Applied Mathematics" (supp. by NSF), CUPM,
Mathematical Association of America, 444 pp., 1976

A didactical exposition mainly directed at college teachers in mathematics, showing how a substantial amount of basic mathematical ecosystems theory can be given to senior students in mathematics.

- 2) Relation between deterministic and stochastic models, and
between discrete and continuous models. Publication:

A COMPARATIVE INVESTIGATION OF
CERTAIN DIFFERENCE EQUATIONS AND RELATED
DIFFERENTIAL EQUATIONS: IMPLICATIONS FOR MODEL-BUILDING

H. R. van der Vaart
Department of Statistics, Biomathematics Program

Bulletin of Mathematical Biology 35:195-211, 1973

Discusses the strangeness of approximating a discrete process by a continuous one for the purpose of theory-building, then approximating the resulting continuous process by a different discrete one for computing purposes. Gives a method for finding a difference equation fitting the solutions of a differential equation and a necessary and sufficient condition for a function which determines state y at t given initial state x at t_0 , to be the solution of a differential system, or of a difference system.

3) History and didactics. Publications:

BIOMATHEMATICAL MODELS:
SOME TRIUMPHS AND SOME DEFEATS

H. R. van der Vaart
Department of Statistics, Biomathematics Program

Pp. 217-224 in: Mathematical Models in
Biological Discovery, (Eds.) D. L. Solomon and
C. Walter, Volume 13 of Lectures Notes in
Biomathematics, 240 pp., Springer, 1977

Exemplifies the difficulties that have been experienced by new
scientific developments on their way to recognition, and the contributions
made by mathematics to some of those developments.

SOME SIGNPOSTS FOR THE
EDUCATION OF SYSTEMS ECOLOGISTS

H. R. van der Vaart
Department of Statistics, Biomathematics Program

In: Vol. 5, No. 1, pp. 35-41, (New Directions in
The Analysis of Ecological Systems, Part 1),
(Ed., G. S. Innis) of the Simulation Councils
Proceedings Series; La Jolla, Calif.,
The Soc. for Computer Simulation (Simulation
Councils, Inc.), 132 pp., 1977

Discusses the problems in organizing a method of acquainting students
with multidisciplinary fields such as systems ecology, and suggests a way
of coping with these problems.

- 4) Scrutiny of the biological realism of mathematical models, seeking out and exposing the unwarranted application of models that are valid under one set of conditions, to different sets of conditions under which they are not valid. Publication:

AN EXAMPLE OF THE PERFORMANCE OF TIME SERIES
METHODS WITH RESPECT TO A KNOWN MODEL

H. R. van der Vaart
Department of Statistics, Biomathematics Program

Pp. 107-121 in: Time Series and
Ecological Processes, 1978, H. H. Shugart, Jr.
(Editor), Proceedings of SIAM-SIMS Conference
(Alta, Utah, June-July, 1977), 303 pp.

The prediction methods based on the ARIMA model for time series $X(t)$ assume that nonstationary time series can be made stationary by taking successive differences and the model the differenced data by an autoregressive moving average model. Such models are linear in the $X(t)$.

The present paper briefly explores which error structures of the time series $X(t)$ will indeed allow the error structure of the differenced series to be stationary. The paper then discusses a known nonlinear model (viz., the discrete van der Pol equation) and investigates how well ARIMA based prediction methods predict values generated by this model. It turns out that there is a complete failure to predict the trend reversal inherent in this model. This is taken as a warning against neglecting representative models in favor of linear prediction algorithms.

B/ APPLICATIONS: Analysis and identification of real biological systems.

- 1) Estimation of parameters in differential equation models.

Publication:

A METHOD OF ESTIMATING THE COEFFICIENTS IN
DIFFERENTIAL EQUATIONS FROM
TIME DISCRETE OBSERVATIONS

W. E. Bell
A. H. Robbins Co., Richmond, Va.

H. R. van der Vaart
Department of Statistics, Biomathematics Program

Institute of Statistics Mimeo Series No. 845 (1977)

This method smoothes data by spline methods and then estimates parameters from the non-integrated equations by linear methods. Potential application to tracer data and to pharmacokinetic problems.

- 2) Use of Fourier series for the analysis of biological systems.

Publication:

CONDITIONS UNDER WHICH A NUMBER OF SINUSOIDS
MAY BE INSTANTANEOUSLY IN PHASE

V. F. Gallucci
Center for Quantitative Science in Forestry,
Fisheries and Wildlife, Univ. of Washington, Seattle

H. R. van der Vaart
Department of Statistics, Biomathematics Program

Phys Med. Biol. 21:117-127, 1976.

Investigates a subproblem that came up in the study of Fourier analysis as a model, e.g., in the areas of acoustic and neurophysiology.

3) Tracer kinetics. Publication:

THE STUDY OF GRANULOCYTE KINETICS
BY MATHEMATICAL ANALYSIS OF DNA LABELLINGW. M. O'Fallon
Mayo Clinic, Rochester, Minn.R. I. Walker
UNC Medical School, Chapel HillH. R. van der Vaart
Department of Statistics, Biomathematics ProgramActa Biotheoretica 20:95-124, 1971

Elaborate non-linear model for radioactive labelling of granulocyte DNA, explaining observed specific activity of granulocytes in the circulating blood as a function of time.

QUANTITATIVE RESPONSE OF PLANT TO AIR POLLUTANTS

M. Wann

Department of Statistics, Biomathematics Program

W. W. Heck, Department of Botany

(A cooperative project between USDA-SEA and NCAES)

The physiological processes leading to visual leaf injury for plants exposed to air pollutants may consist of a series of consecutive steps. In the early stage, pollutant molecules may react with biomolecules and/or change the environment of cellular compartments (such as pH). These processes may lead to metabolic alteration and ultimately, to degenerative alterations of cells (cell death) which produces the visually observable injury. However, some of the physiological lesions may be reversible or bypassed.

A mathematical model based on the above considerations is proposed to quantify the dose (concentration) - response (visual lesions) relationship. Three parameters are identified in the model. One parameter provides a measure of damage rate if the repair or bypassing mechanism is inoperative. The second parameter determines the relative importance of damage and repair (or bypassing) processes in a given plant type. The third parameter relates to the change of repair ability with concentration.

A DYNAMIC MODEL FOR PLANT GROWTH:
A SIMULATION OF DRY MATTER ACCUMULATION FOR TOBACCO

M. Wann and H. L. Lucas, Jr.
Department of Statistics, Biomathematics Program

C. D. Raper, Jr., Department of Soil Science

Photosynthetica 12(2):127-136, 1978

A set of nonlinear, ordinary differential equations has been used to construct a dynamic model for simulation of the vegetative growth phase of plants. The model describes growth subject to variations in ambient temperature and photosynthetically active radiance. Dry matter accumulation in leaves, stem, and roots is the aspect of growth considered. For each class of organ, the model specifies compartments for soluble carbohydrate pool, young tissue that is capable of active growth, mature tissue that is incapable of active growth, but capable of normal physiological functioning, growth respiration, and respiration not associated with growth. Major simplifying assumptions for the present model are that water and mineral nutrients are not at growth limiting levels, only prevailing temperature effects on relevant physiological processes are modeled, and only energy flow through the plant system is considered. The conservation law is adhered to for energy. A condition of the model is that photosynthesis is the sole source for the carbohydrate pool in leaves. A portion of the carbohydrate reserves in leaves is translocated as the source of the stem pool and a portion of the reserve in the stem is translocated as the source of the root pool. All parameters in the model have been adjusted to simulate the growth of tobacco (Nicotiana glauca L.) exclusively with data from experimentation in controlled environment rooms for which all environmental conditions have been precisely identified. The predictive capability of the model is tested by a simulation of the dry matter production achieved by tobacco in a separate experiment conducted in air-conditioned greenhouses.

A DYNAMIC MODEL FOR PLANT GROWTH:
ADAPTATION FOR SIMULATION OF DRY MATTER ACCUMULATION
DURING VEGETATIVE GROWTH OF SOYBEANS

M. Wann

Department of Statistics, Biomathematics Program

C. D. Raper, Jr., Department of Soil Science

A dynamic model for vegetative plant growth has been constructed with a set of nonlinear, ordinary differential equations. The model accepts photosynthetically active radiance (PAR) between 400 and 700 nm wavelengths as input and predicts quantitatively the partitioning of photosynthate of leaves, stems, and roots over a normal range of temperatures. The parameter values for the model which were not measured were estimated with data from an experiment in controlled-environment rooms. A determinate cultivar of soybean (Glycine max. (L.) Merrill 'Ransom') was grown at day/night temperatures of 18/14, 22/18, 26/22, 30/26, and 34/30 C; PAR of 75.0 $\mu\text{Einstein cm}^{-2}\text{sec}^{-1}$ during a 9-hour light period; and CO_2 concentrations of 400 $\mu\text{l liter}^{-1}$. An interruption in the middle of the dark period by incandescent lamps was used to prevent floral induction. Plants from all treatments were sampled at approximately 2-day intervals for measurement of total leaf area and dry weights of leaves, stems, and roots.

A comparison of calculated and measured dry weights for soybean plants demonstrated that the model, which previously had been adjusted for simulation of growth for tobacco (Nicotiana tabacum L.), is capable of describing growth of soybeans. Only minor modification of functional forms and parameter values were required for adaptation of the model for simulation of soybeans.

A DYNAMIC MODEL FOR PLANT GROWTH: A SIMULATION OF DRY
MATTER PRODUCTION FOR SNAP BEANS UNDER AIR POLLUTION STRESS

M. Wann

Department of Statistics, Biomathematics Program

H. H. Rogers and W. W. Heck

Department of Botany

(A cooperative project between USDA-SEA and NCAES)

One consequence of air pollution caused visual injury in leaves is the reduction of photosynthetic surface area. This can affect photosynthetic capability and therefore plant growth. A dynamic model, which has previously been utilized to describe growth of tobacco and soybeans, is being adopted to study quantitative effects of leaf injury on snap bean growth. This model will simulate dry matter production and distribution among plant parts (leaves, stems and roots) for snap beans in controlled growth chambers. The model will provide a tool to investigate snap bean growth response under air pollution stress in various environmental conditions (i.e., temperature, light, relative humidity).

TESTING FOR SELECTIVE NEUTRALITY OF
ELECTROPHORETICALLY DETECTABLE PROTEIN POLYMORPHISMS

B. S. Weir, Department of Statistics

A. H. D. Brown and D. R. Marshall
CSIRO, Canberra, Australia

Genetics 84:639-659, 1976

Here we formulate a test of whether polymorphisms detected by electrophoresis are in accordance with the stepwise, or charge-state, model of mutation in finite populations in the absence of selection. First, estimates of the model parameters are derived. Then the remaining deviation is tested under the null hypothesis of neutrality. We applied the test to Ayala and Tracey's data on 27 allozymic loci in six populations of Drosophila willistoni. About one-quarter of polymorphic loci showed significant departure from the neutral theory predictions in virtually all populations. A further quarter showed significant departure in some populations. The remaining data showed an acceptable fit to the charge state model. A predominating mode of selection was selection against alleles associated with extreme electrophoretic mobilities. The advantageous properties and the difficulties of the procedure are discussed.

TWO-LOCUS THEORY IN QUANTITATIVE GENETICS

B. S. Weir and C. Clark Cockerham
Department of Statistics

Proceedings of the International Conference in Quantitative Genetics
(Eds.) E. Pollak, O. Kempthorne, T. B. Bailey
Iowa State University Press, pp. 247-269, 1977

The consideration of the effects of two or more loci on quantitative traits goes back at least as far as Fisher's 1918 paper. Fisher introduced the concept of epistasis whereby genes at different loci act in a dependent fashion. Apart from epistasis there are the complications of linkage and linkage disequilibrium for pairs of loci, and a comprehensive theory should also take account of inbreeding.

When we introduced our four-gene descent measures (Cockerham and Weir, 1973), we remarked that they could be used to provide means and variances for a two-locus quantitative model of gene effects. Such expressions are derived here, and the problem of determining the covariance of relatives is discussed.

While the expressions, especially that for the mean, do offer some insight into the effects of the various dependencies, they also illustrate our belief that exact treatments of completely general situations are unlikely to be of great use in quantitative genetics. An adequate approximation treatment is needed.

TESTING HYPOTHESES ABOUT LINKAGE DISEQUILIBRIUM
WITH MULTIPLE ALLELES

B. S. Weir and C. Clark Cockerham
Department of Statistics

Genetics 88:633-642, 1978

For loci with multiple alleles, hypotheses about linkage disequilibrium may be tested on the complete set of gametic data, or on various collapsed sets of data. Collapsing data into a few alleles at each locus can change the power of the tests, as implied in a recent paper by Zouros, Golding and Mackay (1977). We show that the nature of such changes can be found from properties of the noncentral chi-square distribution, and that the magnitude and direction of these changes depend on the levels of linkage disequilibria, allelic frequencies and degrees of freedom.

A GENERAL ANALYSIS OF RESOURCE ALLOCATION
BY COMPETING INDIVIDUALS

L. A. Real, Department of Zoology

Theor. Pop. Biol. 8:1-11, 1975

The analysis presented in this paper is constructed to determine the pattern of resource allocations among competing individuals of the same and/or different species in some defined habitat. Competing individuals have at their disposal various activities which can be run at different intensities and consume or produce resources in the habitat linearly. The linearity of resource utilization restricts the analysis to exploitative competition. Each resource is assigned values representing the reproductive gain and reproductive cost to the organism incurred while utilizing the resource. The organisms attempt to choose the amounts and kinds of resources which maximize the total reproductive gain. Resource utilization is restricted by the availability of resources in the habitat, the patterns of consumption associated with the activities of the individuals, and the demand for the individual resources (fixed through competition pressure) of the habitat. It is proved that under these restrictions a competitive equilibrium exists where resources are utilized so as to maximize individual reproductive gain and that this equilibrium generates the most efficient utilization of the resources of that habitat. The selection of a diet subject to nutritional requirements is given as an example of possible applications of this approach. The assumptions and restrictions associated with this technique of analysis are discussed.

THE KINETICS OF FUNCTIONAL RESPONSE

L. A. Real, Department of Zoology

American Naturalist 111:289-290, 1977

Holling's Type II functional-response relationship is presented, and the formulations expressing the underlying organismal interactions which might generate such a relation are generalized into the Type III response typical of predators showing learning behavior. An equation derived through an analogy with allosteric enzyme kinetics is given which will account for both Type II and Type III responses. The response behavior can be explained by three parameters: maximal feeding rate (\underline{F}); an affinity constant (\underline{G}) related to handling times, capture efficiencies, etc.; and the number of encounters (\underline{n}) a predator must have with a prey item before becoming maximally efficient at utilizing the prey item as a resource. A discussion follows on the biological processes which result in shifts from Type II to Type III functional responses. Most of the learning processes involve changes in predator behavior associated with increasing encounters with prey, thus supporting parameter \underline{n} as a major determinant in shifting the functional response. Three hypotheses concerning the values parameters \underline{F} , \underline{G} , and \underline{n} will assume under different ecological situations are posited: (1) food preferences will be reflected in an increase in resource-utilization efficiency (\underline{F}) and affinity (\underline{G}) and a decrease in values of \underline{n} encounters; (2) a size ordering of the predators will result in shifts up in the resource-utilization efficiency (\underline{F}) and affinity (\underline{G}); while (3) increasing habitat complexity will generate decreases in \underline{n} and \underline{F} .

UNCERTAINTY AND THE DIVERSIFICATION OF BEHAVIOR.

L. A. Real, Department of Zoology

American Naturalist (In press)

I have shown how a maximum principle for evolutionary processes based solely upon mean fitness of behaviors may, under certain circumstances, be misrepresentative and misleading in the analysis of biological systems. Many of the misrepresentations can be corrected by including variance of fitness associated with environmental uncertainty and variability, in the structure of the maximum principle. There are many ways of incorporating this variance into a mathematical model. I have chosen to depict the modified maximum principle as a discounted function of expected fitness, where the discount is a function of the variance in fitness between behaviors. Such a function under no uncertainty reverts to the simpler mean maxim. Including uncertainty generally results in evolutionary strategies consisting of sets of diverse behaviors whose resulting fitnesses show negative covariance. Under certainty, organisms can specialize showing only single types of behavior.

Supporting evidence has been gathered from different areas of ecology and evolutionary biology. The model appears to be consistent with what we believe to be the consequences of uncertainty in sexual processes, herbivory and pollination systems. Future research will, hopefully, demonstrate the general applicability of this approach.

ECOLOGICAL DETERMINANTS OF FUNCTIONAL RESPONSE

L. A. Real, Department of Zoology

Ecology (In press)

Experimentally derived functional response curves for Peromyscus maniculatus preying upon European pine sawfly cocoons and wheat seeds are analyzed according to a general formula representing both hyperbolic and sigmoidal responses. The response curves were constructed under varying preferabilities of alternate prey and varying degrees of spatial contagion. The important parameter values discussed are the maximum rate of feeding (F); an affinity constant (G) equal to the density of resource for which feeding is half maximal; and n , a parameter associated with the amount of "learning" being exhibited by the predators. It is shown that when a low palatability alternate food is present the predator will increase both the total utilization (F) and the affinity (G) for the test food item being monitored, but show little change in the degree of learning (n). On the other hand, when foods are changed from randomly dispersed to clumped in the habitat, the predators increase their total resource utilization (F) but decrease their learning (n) and affinity (G). The results are discussed in terms of the effect the ecological changes produce in the general behavior of the organism.

A COMPUTER PROGRAM FOR THE ANALYSES OF CARBOHYDRATES
SEPARATED BY GAS CHROMATOGRAPHY

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Gas chromatography has proved valuable in the estimation of the carbohydrate content of biological materials including glycoproteins. Calculation of the amount of these components involves measuring peak areas by one of several methods including planimetry, width x height at half height or by employing electronic integrators are the most reliable. However, when a system contains multiple peaks, calculations of concentrations can prove time consuming. Such calculations can be rapidly accommodated through the use of computer programs.

While there are many published programs for the analysis of biological components, each investigators' applications are significantly different to warrant the writing of programs which fit the individual investigators' experimental design. In our laboratory, a program has been devised that will identify and analyze unknown sets of data in which carbohydrates isolated from hog gastric mucosa have been chromatographed.

Carbohydrates were chromatographed and the data obtained was given in retention time (seconds) and area counts under each peak. Seventeen sugar and/or derivatives were used. Retention times, peak area of the individual sugars, concentration, area of the internal standard in the mixture were used. Molecular weights and slope factors were also dimensioned. The intent of this program is to identify and analyze each chromatographed peak based on predefined dimensions. By imputing time and area, representing each unidentified peak in a mixture, several calculations can be performed, including slope factor, concentration factor and concentration of the internal standard.

The program is set up to continuously scan the information fed into it (area, retention times, and temperature). Arrange retention times and retention temperatures of known standards were used to set retention boundaries between which elution times and temperatures of known sugars would fall. If an unknown sugar in a mixture would fall within a given boundary, the data is analyzed and the program prints the names of the unknown sugar, the retention time, the area under the peak, the concentration in micromoles and in milligrams, the percent micromolar and milligram concentrations, the relative retention time (to the internal standard), the relative area, and the relative micromolar and milligram concentrations. If a retention time and temperature did not fall within predefined boundaries, the computer will only print the sugar was unknown and then continue in the do loop until each data card was read and the program finished.

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