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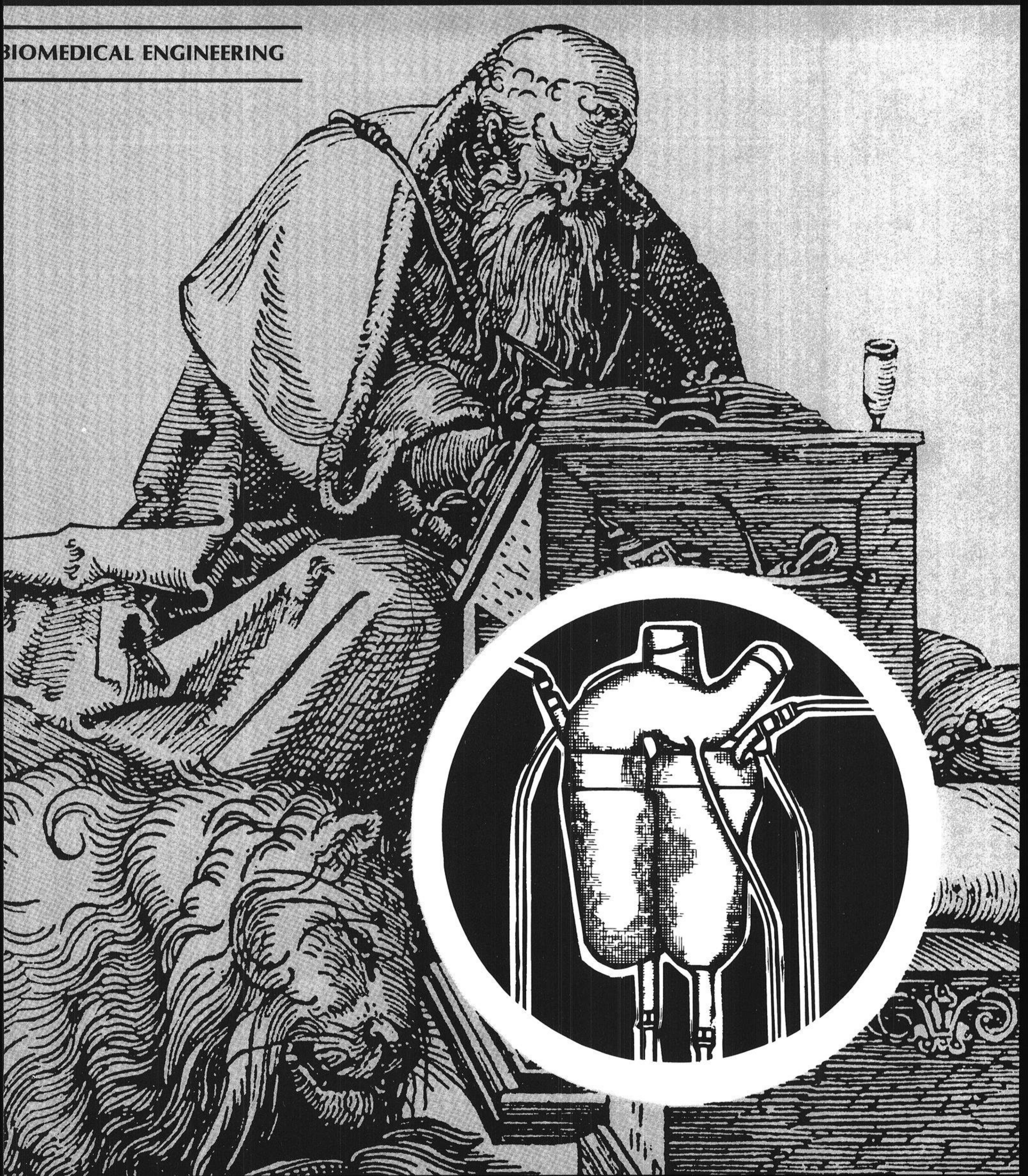
wisconsin engineer

BIOMEDICAL ENGINEERING



"The concern for man and his destiny must always be the chief interest of all technical effort. Never forget it among your diagrams and equations."

Albert Einstein

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Titanium Bones

by Fred Schuhle

When grandmother broke her hip six years ago, an operation was performed joining the broken piece back to the rest of the bone. But she was back in the hospital a few years later because the repair job wasn't holding up too well. Now some techniques have been developed that may change all that.

When part of a bone must be replaced, chances are that the replacement is solid, either plastic or cast metal, since the replacement piece must be as strong as bone. But at the University of Wisconsin Medical School in Madison, Dr. Andrew A. McBeath has come up with a new technique using powdered metal to make "implants," as replaced portions of bones are called.

The substance used is powdered titanium, a hard, light metal that is also used to strengthen steel. Titanium is frequently used in medical processes because it is very compatable with the human body. Elements and chemicals within the body can carry out their functions nearly as well when titanium is used as an implant material; better than when other metals are used.

In the powdered form, titanium is useless as a substitute for something as hard as a bone, obviously. It must be made into something more substantial. So a rubber mold is made of the section of bone to be replaced; usually a portion of a joint. In a hip, the mold would be made of the "ball," or top portion of the upper-leg bone.

The powdered titanium is then hydraulically compressed in the mold and "fired" in a special oven, much the same way as pottery is fired in a kiln. When it comes out, the implant is hard and about as strong as the bone it is to replace.

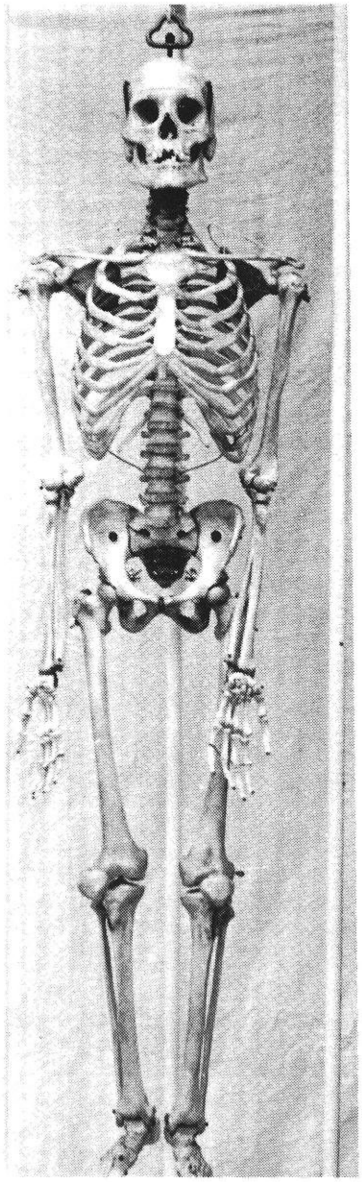
Now to the natural bone left in the body. The place where the implant is to be attached to the remaining piece is called the interface. The material used in any implant is important here, too. Some less successful implant materials do not adhere firmly; others loosen with age and wear, and "migrate" or shift around on the bone surface to which they were supposed to be attached.

Dr. McBeath thinks this problem may be solved with the titanium implants, with the use of a polymer (like a plastic) grouting compound, much like the plaster you might use to repair a crack in the wall. The titanium affixes itself well to this sticky substance, and does not move around too much.

Once the bone in the body is prepared and the interface is ready, the implant may be attached. And once this joining is complete, some additional benefits of porous titanium implants become important. Since the hardened titanium implant is porous, it can absorb some moisture, like natural bone, and can bend somewhat. Much like a dry sponge can bend; not as much as a wet sponge, but more than a piece of metal the same size and shape. This "porosity" also means the implant will wear the same way as the bone does - if they are going to bend and "deform" with use, at least the implant will bend the same way as the bone to which it is attached. Smooth metal implants cannot bend at all, and often wear differently than the bones to which they are attached, causing further problems.

But the most exciting advantage of these porous titanium implants is that, along the interface, the bone actually grows into the small "pores" in the metal, which it could not do with a smooth, metal or plastic surface.

Not only is there better adhesion but actual growth is possible. If such an operation were to be performed on a young child, presumably that bone could grow and surround the metal implant as the child grew up and the bones got bigger. The inorganic base and growing bone is more flexible than a solid implant that would remain the same size, since the bone cells could not grow into it.



Grandmother

A titanium powder implant is also encouraging because it has about the same elastic and damping capacities to absorb blows, bend a little, and stop movement as does natural bone. This helps to further reduce wear and tear on the implanted piece at the interface.

Although surgery has been done exclusively on animals thus far, the techniques may become more widespread, including human surgery, in the future. The experiments with this material began three years ago in cooperation with Joel Hirshorn in the Mineral and Metalurgical Department of the College of Engineering at Madison.

Grandmother's hip is now doing fine. It took her to the ocean, for the first time in her 85 years, last summer. WE

AUTOMATED MEDICINE

An Interview with Dr. John W. Cameron

Ultrasound is used to "see" into the body much like x-rays can.

Interview by Don Johnson

Dr. John W. Cameron is director of the Biomedical Engineering Center at the University of Wisconsin-Madison. He has been a professor of radiology and physics there since 1958, conducting research in quantitative diagnostic radiology, bone mineral and body composition measurements in vivo, radiation dosimetry involving thermoluminescence, physical aspects of nuclear medicine, and applications of computers in medicine. Dr. Cameron is a consultant to the Atomic Energy Commission in Washington, to the International Atomic Energy Commission in Vienna, and to the NASA Manned Spacecraft Center in Houston.

Q: Would you please define the terms bioengineering and biomedical engineering?

Cameron: I like the term biomedical engineering. Bioengineering is engineering referring to any engineering that has to do with biology. The department of agriculture is bioengineering. How to design a manure carrier, or a barn, could be bioengineering. It is so broad a term we have to define various areas of it.

Biomedical engineering is the application of physical science to diagnose and treat sick people, such as designing better X-ray equipment and finding new ways to get information from the body such as measuring bone mineral content and measuring radiation in the body.

This is clinical engineering to make it clear that we are interested in patients themselves. Not to criticize other fields, but I am primarily interested in patients and what we can do for them now—not in the next decade.

Q: What is the status of biomedical engineering in the University's curriculum?

Cameron: There is an MS program in biomedical engineering, and we hope to offer a PhD in a few years after the MS is firmly established. Just a few undergrad courses are currently being offered.

We started as a biomedical engineering committee. It is now a center. We feel we could be more effective as a center than as a committee. (The University) should have a biomedical engineering department either in medical school alone or in the medical and engineering schools.

Q: Computers can now monitor a

patient's vital bodily functions and collect data. Can they administer medication?

Cameron: Computers are used to monitor a patient's condition and to see subtle changes more quickly than humans. I don't know of any cirucmstances where they administer drugs yet. A very small computer like a pocket computer attached to a skin flap could control insulin injections for diabetics and act as an artificial pancreas.

Q: Are hospitals moving toward common use of computers?

Cameron: In any system there is great inertia to change. The medical profession has more inertia than any other profession I know. It would be chaotic, though, if they tried everything that came along.

Q: Can malpractice suits be raised in a case of mistaken diagnosis by computer?

Cameron: Who would get sued, the computer or the physician? Computers are used in calculating optimum distribution of radiation in treatment of cancer patients, and if an error is made the physicist and the therapist in charge could both be sued. Engineers can be sued for malpractice can't they?

Q: How much radiation can a patient absorb before it becomes harmful?

Cameron: How many cigarettes can you smoke, and how much alcohol can you drink before it becomes harmful? How fast can you drive before it becomes dangerous?

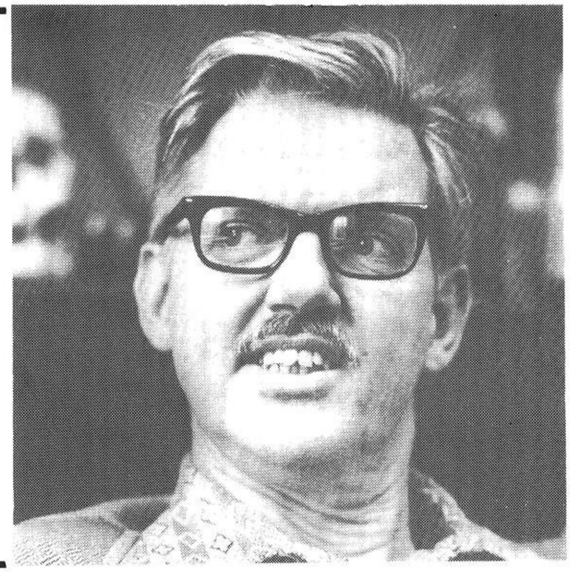
Q: How much radiation is absorbed from the average X-ray?

Cameron: I dressed up an old unit called the Roentgen Area Product (RAP) which is the product of the amount of radiation times the area of the body it is hitting. Twenty RAPs per year is normal for natural radiation absorption. A chest X-ray is less than one RAP, and usually a pelvic is five RAPs.

Q: Is it possible to tell if people are receiving more radiation today than they did 25 years ago?

Cameron: In general there has been an increase in the amount of radiation absorbed by humans in the last 25 years. This raises other questions facing biomedical engineering. Radiation to patients from diagnostic X-ray procedures could be reduced by ten without

"To be ultimately useful they must work in medical centers. Medical engineers on a campus miles always are not effective."



any loss of information. X-ray films are by far the greatest users of our silver and by 1980 we will have a desparate need of silver. Another area in medical engineering is replacing that standard film. I would predict in a couple of decades the present, large X-ray will be an artifact. Magnetic tapes, videotapes and videodiscs will be used instead. We can use those now in radiology. Often progress in medical engineering comes from developments in other areas — computers, TV and nuclear physics.

If medical engineers are to be ultimately useful they must work in medical centers. Medical engineers on a campus miles away are not effective. They are not useless, but they certainly are not aware of the day to day problems in the clinical situation.

Q: Ultrasound is now being used to see into the body with high frequency sound waves. Could it be possible that there is a limit to how much ultrasound can be used on a human body, just as there is with X-rays?

Cameron: There is, but we haven't been able to determine the level yet. So far no damage has been done by ultrasound for diagnostic purposes. This is one of the research topics being considered at the cellular level.

Therapy levels of ultrasound can be used to warm up and destroy tissues, somewhat like infrared high energy. Ultrasound is being used routinely in diagnostic work with a disease which affects balance. It's especially helpful in pregnancies because of a smaller danger, and it gives more information than an X-ray.

Q: Isn't it possible that undetectable vibrations caused by high frequency sound waves might cause some cellular and tissue damage?

Cameron: It's a matter of engineering whether ultrasound can be harmful. If it goes high enough and if you put enough energy in, it may cause other damage— mechanical damage — independent of the heat.

Q: You have developed techniques for detecting bone mineral loss and resulting bone weakening. Could this lead to techniques of strenthening bone structure, like tempering steel?

Cameron: Probably not. But if you have a way to measure things you could find a way in which to probably improve them. Doing something dramatic is unrealistic. You might be able to stimulate better bones by getting more exercise. If you can strengthen muscles by exercise, you may be able to apply this idea to bones. After a year and a half of study with elderly people, it was found that those who did special exercises showed better bone strength than those who did not.

Q: Is there a general age at which bone mineral loss increases and the skeleton begins to weaken?

Cameron: Bone strength begins to deteriorate in women around the age of 40. It goes down about ten per cent per decade or one per cent per year. It happens on an individual basis, of course, but there is a general loss around 40, just before menapause. Men show noticeable weakening around 50 or 60. Women have many more broken hips, and the problem is much more crucial for women since they have weaker bones in the sense that there is less bone to begin with. There are many more hunchbacked women than men.

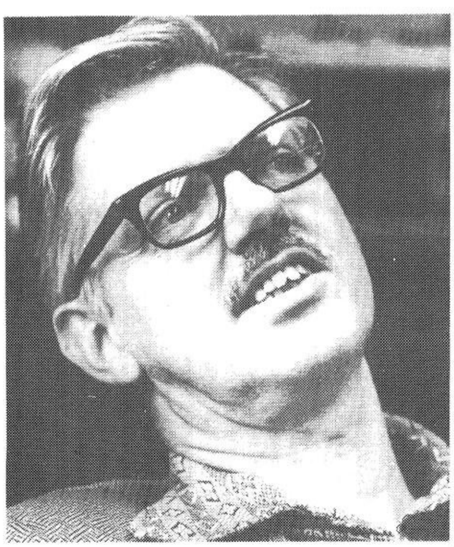
Q: Would the bones of a malnutritioned child be more breakable than those of a well-fed child?

Cameron: I don't think anyone has proven it but I would certainly expect so. A study of eskimo children vs. mainland American children showed they were the same, but I don't know how their nutrition was. There will be some more studies conducted next summer in South America.

Q: A television show has been aired called "The Million Dollar Man", in which a human is supposedly half man-half machine. Is this a possibility, or perhaps, a probability of tomorrow?

Cameron: You could make an analogy with an old song from the thirties about the girl . . . After the ball Maggie took out her glass eye, stood her peg leg in the corner, and corked up her bottle of dye.

It's an old idea to use artificial parts for the human body. Modern hearing aids date back to the ear trumpet. Eyeglasses were replaced by contact lenses and later these gave way to the new soft contact lenses. In the future we may be able to remold the eye to focus the image on the retina so we won't have to use eyeglasses or contact lenses to correct vision.



There is a great deal of research being done in the field of artificial hearts. We are a few decades away from using artificial internal organs, because we still must contend with rejection of artificial and foreign parts.

I suppose if you combine enough of these you could have an artificial man. It does not appeal to me, but if I were short a leg, I would want the best one available. Getting a set of legs that can perform like the originals is an extremely difficult job. Research is now in progress to train the artificial limb to conform with the brain's instructions rather than trying to train the mind on how to make the limb operate. So we are making progress.

Q: If it is possible to capuslize the accomplishments of science, what do you believe is the greatest new insight medicine has achieved through an engineering approach to the human body?

Cameron: I think the area of microelectronics and integrated circuitry have produced a lot and they will do a lot more in the future. If a physician wanted one he could have a miniature computer to help him in his work. I may be giving the field premature credit, but a lot of the information we get is through electronic means. This also affects the analysis of medical data such as an X-ray that takes a picture at optimum conditions through self-adjustment.

Q: Do you have any particular points about biomedical engineering you feel people should know about?

Cameron: There is a major philosophical point. We have to educate our medical students to be aware and familiar with medical engineering and its capabilities. Few students are aware of them. We must convince the young doctor of the new advancements and advantages of computers. We are not going to convince the old ones that computers are going to help them.

"There is a good share of the medical profession not in favor of keeping someone alive if the quality of life is low."

Q: Medicine's goal is to prolong life under all circumstances . . .

Cameron: I think you are mistaken. There is a good share of the medical profession not in favor of keeping someone alive if the quality of life is low. For the average person this is a very good goal. But there is this other factor. Do you want to suffer on?

Many patients chose, and the doctor goes along with them, on a mode of dying, which has more dignity. Generally you will want to prolong life, but you should say to prolong a long, useful life.

Q: That is what I was leading up to. We have the technical capability for prolonging "life", or rather forestalling death, in many cases of hopeless comas, severe brain damage, and terminal illness. Some patients linger on in agony. Do you see this as a moral obligation to practice euthanasia? To allow a patient to die peacefully through omission of treatment?

Cameron: I think this is a distinction. Euthanasia is physically speeding up death rather than letting illness take its course. You may withhold oxygen on one hand, but you should not play an active role in terminating life.

All professions working with humans have moral obligations including medical engineers. They certainly would have more dramatic moral obligations than an engineer who is designing a new gear for a machine. There are ethical questions when a patient dies. This idea of social conscience has been demonstrated in electrical safety devices to protect patients, which is a moral obligation. Whether you are an engineer or not you have moral opinions partly formed by your heritage — by a combination of cultural and theologic implications. It's a personal thing that gets into metaphysics. WE

Research Advances In Bio-Medical Engineering

Students Design Auto-Com

In the past two years, a team of 16 University of Wisconsin Madison students have developed a device to help handicapped persons communicate. This device, known as the Auto-Com, consists of a smooth, flat board with letters, numbers, and punctuation figures printed on it. Beneath the board is a sensing system that is activated by a magnet contained in a handpiece manipulated by the handicapped person.

By pointing the handpiece over a character, the figure is reproduced on a portable TV screen. Only minimal pointing skills are needed to communicate; the Auto-Com responds even to hesitate movements of the handpiece. The unit also may be used with a typewriter instead of the screen.

The research team, consisting of engineering, journalism, psychology, special education, communication disorders, and speech therapy students, is headed by Greg C. Vanderheiden, Appleton. It was organized as the Cerebral Palsy Communication Group, with experiments conducted in the College of Engineering.

This past fall, it received a National Science Foundation grant of $84,000 to continue development of their project.

During the one-year grant period, the team will work to improve the design of the device, and to produce a final model that can be manufactured and made available at modest cost to schools, institutions, and the estimated 10,000 persons unable to speak or write in this country.

This is the second NSF award to the group. Last summer it received $16,340 under the foundation's Student-Originated Studies Program. NSF sees the project as an educational experience for the students and an opportunity to apply technology to an educational need.

Currently being designed is a mount so the board can be placed on the arms of a wheelchair and used as a lapboard when not in use. The students also hope to develop an Auto-Com with more portability, using small battery-operated transmitters mounted inside the board to transmit signals up to 200 feet to the output devices, the controller, and the TV screen or typewriter.

For even more portability, the students are working on a model that has a miniature printer built inside the board and is battery-operated. This would produce copy like a ticker tape.

The Auto-Com: "Even the severely handicapped can now communicate freely." (Courtesy, UW News)

Stresses and Strains in Bones

By Robert Ebisch
UW Science Writer

Ali Seireg's rats are running a one-legged race against weak bones and joint conditions.

Seireg, a mechanical engineer at the University of Wisconsin-Madison, is studying effects of stress on bone mineral content, the role of muscle fatigue in fracture, and the causes of wear in joints.

Seireg's rats are strapped like tiny bicyclists on a device that makes one leg pedal in two-second cycles against a force roughly equivalent to the rat's body weight while holding the other leg still. Thus changes due to exercise can be seen by comparison of the legs.

Analyzing the bones of rats subjected to the exercise programs, Seireg found that frequency and magnitude of stress applied to the leg changes bone size and mineral content, and therefore strength.

"It's well known that you can make any muscle stronger by exercising it," Seireg points out. "We're now starting to realize the importance of exercise to bone strength as well."

But the strength of the bone itself isn't the whole story. Seireg has also measured how the frequency of an applied load will affect how much of a load is needed to break a bone.

"The muscles and the bone work together," he continues. "Soldiers on long hikes often get what is called 'march fatigue,' which involves cracks in the leg bones, because the muscles get too tired to provide adequate support."

An overload of exercise also leads to damage in the joints. Using an electron microscope and medical school facilities to survey wear and tear on cartilage, Seireg studied the different levels of surface damage that occur.

One problem is that, like bones, cartilage increases in mineral content when it is under stress. "Cartilage is just a bone that hasn't been fully calcified," Seireg explains, "and as such it is elastic enough to distribute stress evenly in the joint. But as exercise calcifies the cartilage, the joint stiffens and the stress distribution becomes uneven, making the cartilage corrode faster."

Another reason why cartilage becomes worn is the breakdown of sinovial fluid, the lubricant in joints. "With too much exercise the body cannot rejuvenate the sinovial fluid fast enough," says Seireg. "As the fluid breaks down like overheated crankcase oil the temperature in the joint rises.

"Joint temperature may actually prove a good tool for measuring damage in living animal joints," he predicts. "This and the other techniques we have developed provide a tool for testing drugs and methods of treatment to avoid arthritis that comes from stress."

Chemical Battery For Pacemaker Developed

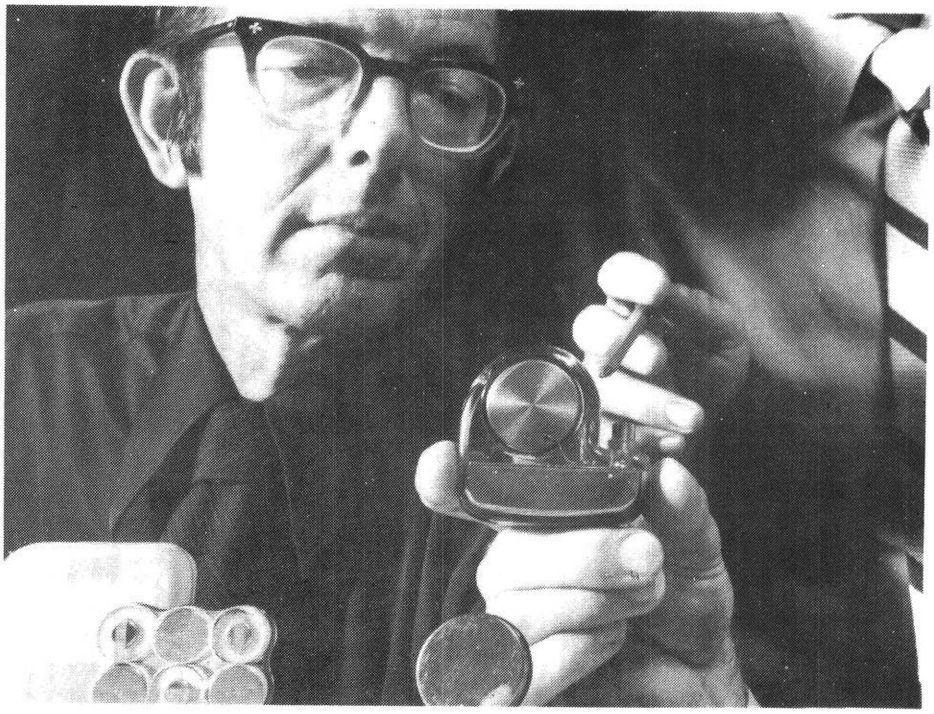
Chemical batteries for heart pacemakers with a life expectancy of 10 years, as long as nuclear pacemakers are e xpected to last, are being tested at the General Electric Research and Development Center. The GE batteries will cost less than nuclear ones, according to Dr. Arthur M. Bueche, GE's vice president for research and development, who said that chemical batteries ultimately will be the answer to long-life heart power devices.

The new chemical batteries are now being tested in animals in GE's Medical Systems Business Division, Milwaukee, Wis. Human implants are planned within two years.

A pacemaker is inserted into the patient's body and connected to the heart by electrode wires. It delivers electrical impulses that force the heart to contract, thus regulating its rhythm.

Dr Bueche said that "a new long-life electro-chemical power source would completely eliminate any hazard associated with the radioactivity of nuclear batteries and, at the same time, would greatly extend the intervals between replacement surgery for users of chemically powered pacemakers."

The new sodium-bromine battery is the size of five stacked 50-cent pieces and weighs about an ounce. It consists of a bromine cathode, a sodium-amalgam anode and a beta alumina ceramic electrolyte. Unlike the liquid electrolyte in conventional batteries, the solid ceramic prevents contact between the reactive materials. Thus it, eliminates self-discharge and cell shorting that reduces the life of today's chemical batteries. GE experts say that shelf life of new cells is virtually unlimited.



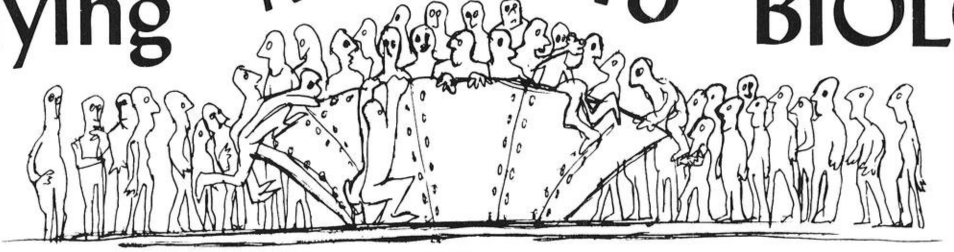
A General Electric Researcher compares pacemaker containing the new chemical battery with a conventional pacemaker (left).

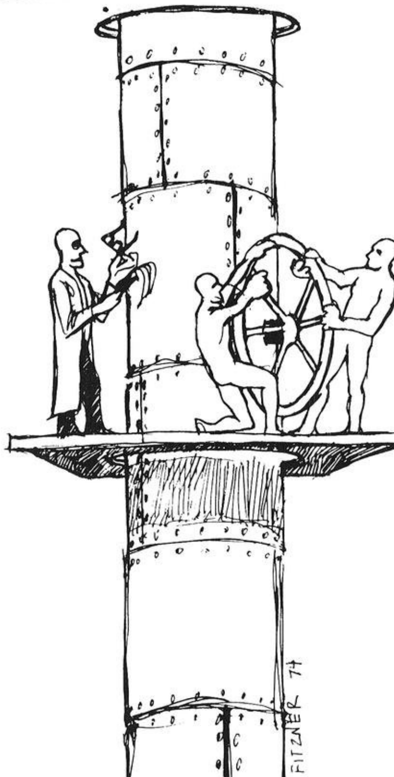
The new batteries produce 3.6 volts, nearly three times that of the mercury-zinc cells, and can store up to 170 watt-hours of energy per pound, or 15 watt-hours per cubic inch. Today's mercury-zinc pacemaker batteries store only 50 watt-hours a pound, which is eight watt-hours a cubic inch.

An estimated 50,000 to 60,000 persons in the United States now use conventional battery-powered pacemakers. Another 25,000 persons are expected to be added to that list. The new sodium-bromine battery will improve both the safety and function of heart pace-makers. WE

by Bob Friedman and Tom Peterson

Applying MATH To BIOLOGY





Applied mathematics of the type engineers have been using for years has recently been applied to biological systems with much efficacy. The application of sets of simultaneous differential equations for ecological studies was originally presented in 1925 but remained relatively dormant until just recently when biologists realized the importance of considering each organism not as a unique entity, but as part of a total system including the environment and inter-relationships with other organisms.

Engineering mathematics and biology may appear at first to be a strange marriage, for biology in the past has been considered a non-quantitative science. Perhaps the reason for this has been more pragmatic than intentional; biological systems which at first appear relatively simple, in fact are rather mathematically complex for biologists, with only a cursory background in mathematics, to deal with. The engineer, with a rigid background in applied mathematics, is in an excellent position to augment the biologist's qualitative field knowledge.

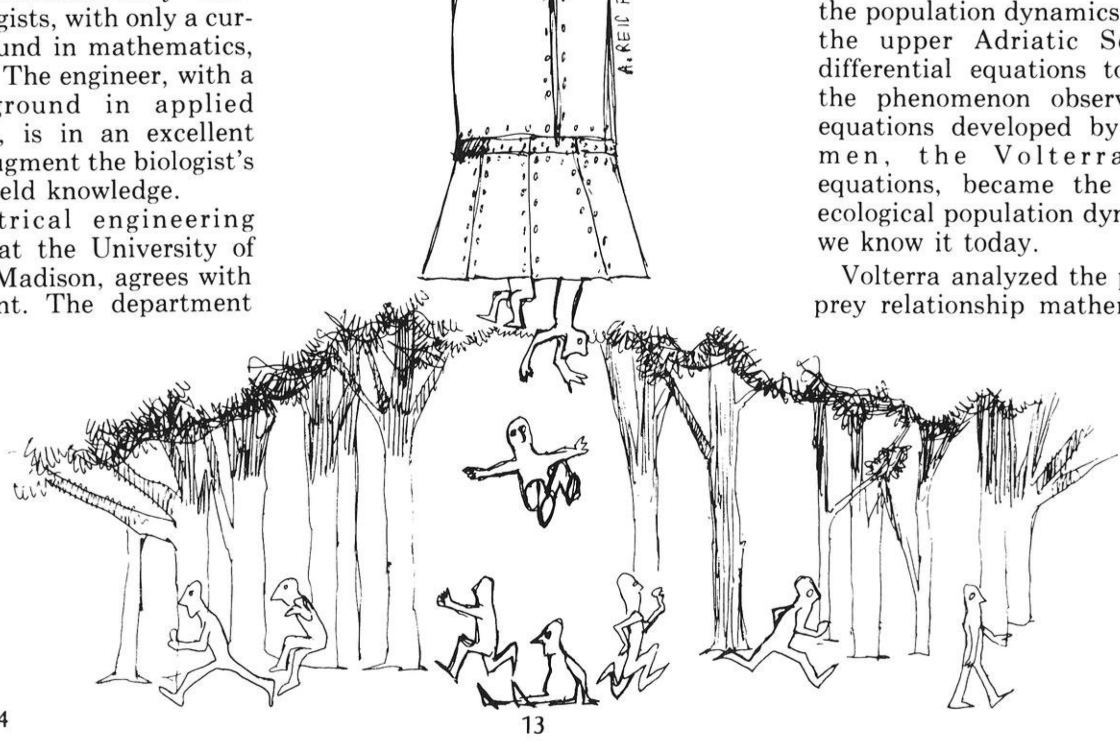
The electrical engineering department at the University of Wisconsin - Madison, agrees with this viewpoint. The department offers a course each spring which deals with the application of engineering mathematics to biological, ecological, and socio-economic systems.

Presented in this article are some of the topics considered in this course, with a historical introduction to the first realization of the advantages of dealing with biological systems mathematically as well as some examples found in nature which are well described by this technique.

By 1925, the applicability of the calculus developed for classical physics to biological problems was stated by Alfred J. Lotka. In his monumental work, *Elements of Physical Biology,* questions of evolution, growth of organisms, energetics, and population dynamics were investigated in mathematical terms.

At approximately the same time, Vito Volterra investigated the population dynamics of fish in the upper Adriatic Sea using differential equations to explain the phenomenon observed. The equations developed by the two men, the Volterra-Lotka equations, became the basis of ecological population dynamics as we know it today.

Volterra analyzed the predator-prey relationship mathematically



in the following way: let the population of species 1 be N_1 and the population of species 2 be N_2. If species 2 did not exist, N_1 would increase exponentially. Every generation by some factor, ξ_1. For instance if $\xi=2$, every generation is twice the size of the previous one. This can be written as $\frac{dN_1}{dt}=\xi_1 N_1$. Similarly, if species 1 did not exist, N_2 would decrease exponentially by a factor ξ_1 due to the absence of food. Thus we have $\frac{dN_2}{dt}=-\xi_2 N_2$. But species 2 maintains itself by feeding on species 1 and the population of species 1 is held in equilibrium by this process. If predation is proportional to the probability of encounters of the different species, then the growth rate of species 2 and the loss of species 1 due to predation may be proportional to the probability of encounters of the different species, and then the growth rate of species 2 and the loss of species 1 due to predation may be proportional to $N_1 \cdot N_2$. Thus we have $\frac{dN_1}{dt}=\xi_1 N_1 - \delta_1 N_1 N_2$ and $\frac{dN_2}{dt}=-\xi_2 N2 + \delta_2 N_1 N_2$ where δ_1 and δ_2 relate the loss and gain of species 1 and 2, respectively, to the probability of predation. In this system of two differential equations relating N_1 and N_2, the predator reaches both its peak and minimum slightly later than the prey.

These equations can be altered to more closely approximate conditions found in nature. A more accurate representation of N_1 growing without the existence of N_2 might be exponential growth followed by the leveling off due to a finite 'carrying capacity' of the environment. Organisms can increase their population indefinitely, but will be limited by the available food and space. A 'Verhulst correction' may be added so that $\frac{dN_1}{dt}=\xi_1 N_1$ becomes $\frac{dN_1}{dt}=\xi_1 N_1 \left(1-\frac{N_1}{\theta_1}\right)$ where θ_1 is the carrying capacity of the environment for species 1. The system of equations is then:

$$\frac{dN_1}{dt}=\xi N_1\left(1-\frac{N_1}{\theta_1}\right)-\delta_1 N_1 N_2 \text{ and } \frac{dN_2}{dt}=-\xi N_2+\delta_1 N_1 N_2.$$

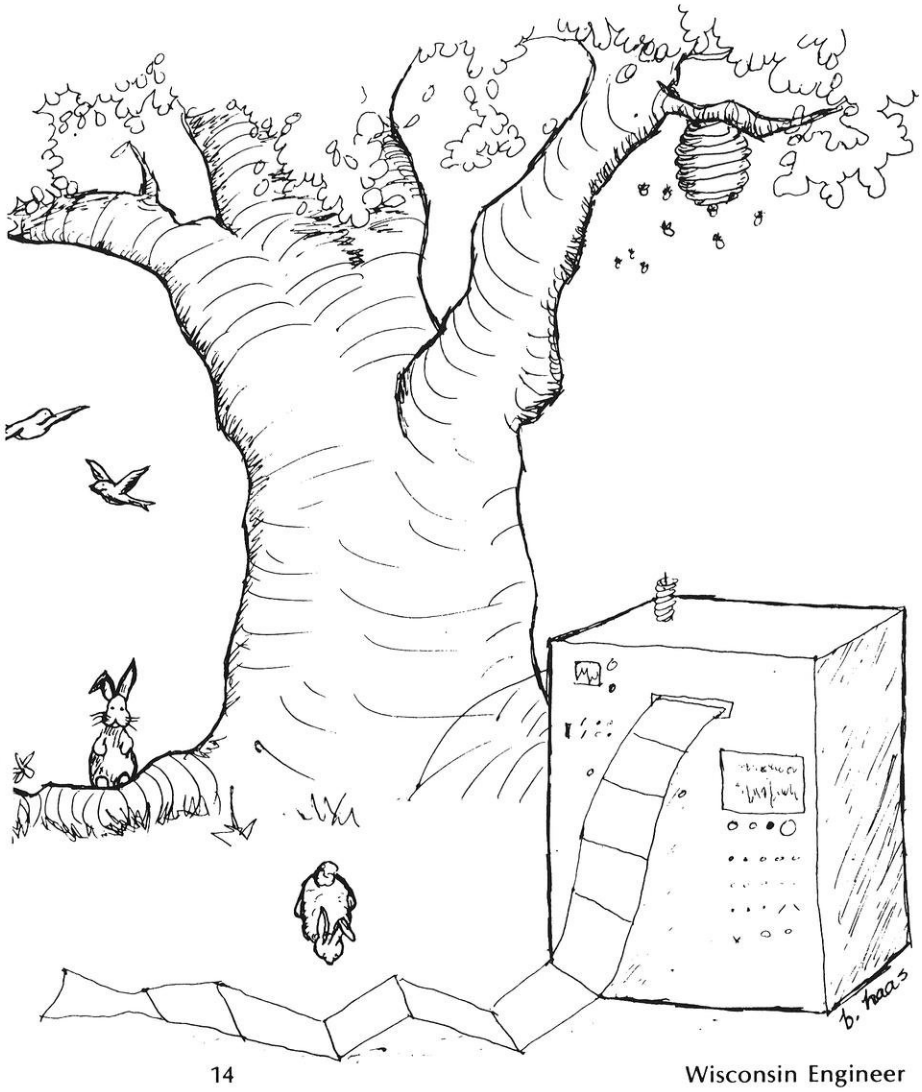
The result of the Verhulst term is to dampen the oscillations of a two species system.

The predator-prey interaction described by Volterra and Lotka is not the only way biological organisms affect each other. Two species may compete for the same food supply, sunlight, or habitat. In 1934, a Russian biologist, G.F. Gause formulated what is generally known as the Gause model of interspecific competition. From this insight, modern ecologists have evolved the theory of the ecological niche . . . no two species can exist in the same place with identical food and habitat requirements. When species do have the same requirements, the stronger outcompetes the weak species and the weaker species eventually dies. If the two species have only weak competition they may coexist, but usually to the detriment of both.

Volterra was the first to consider competition as a special case of the predator-prey equations, but it was Gause who realized the full implications and biological importance of the competition relationship. Nor did Gause satisfy himself with a purely theoretical formulation as he said in *The Struggle for Existence,* "No mathematical theories can be accepted by biologists without a most careful experimental verification."

Gause proceeded to design the first extensive corroboration of the mathematical theory first using yeast cells and later more complex organisms, protozoa. His work showed the applicability of the Volterra-Lotka formulation and led him to understand and remedy some of the defects in the purely theoretical approach.

One modification Gause made of the Volterra-Lotka equations involves the $N_1 N_2$ term (consider two species again). He experimentally determined that the amount of predation on species 1 by species 2 is more nearly proportional to $N_2\sqrt{N_1}$ than $N_2 \cdot N_1$



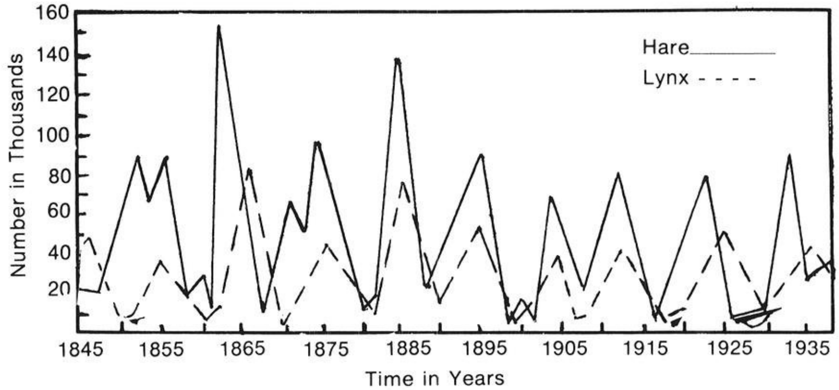


Figure 1
Population density variations of the snowshoe hare and the lynx

Also on the basis of experimental data, Gause concluded that if the population of the predators is large, and prey exist, the $-\xi_2 N_2$ factor representing death of predators is negligible. With these alterations the two species Volterra-Lotka equations become $\frac{dN_1}{dt} = \xi_1 N_1 - \delta_1 N_2 \sqrt{N_1}$ and $\frac{dN_2}{dt} = \delta_2 N_2 \sqrt{N_1}$. Gause then found that the curves predicted by these equations fit the observations on the micro organisms *Paramecium* and *Didinium*.

Analysis of these equations yields four possibilities. In case 1, species 1 has some competitive advantage, so it always wins. Similarly in case 2, species 2 always dominates. In case 3, whichever population is largest to begin with wins. In case 4, the species coexist.

Biologists have noted that two species may interact with each other in nine different ways, and the predator-prey and competition models presented above may aptly describe all the possible interrelationships between two species.

There are three ways the stronger may affect the weaker and three ways the weaker may affect the stronger or nine permutations in all; each combination has been given a name by biologists. Predation is the case where the stronger species has a detrimental affect on the survival of the weaker and the weaker species is required for the growth of the stronger. If the roles of the two species are reversed, the relationship is then called parasitism.

Six of the possible relationships between two species are forms of the classical concept of competition described by Gause. The species may interact negatively with each other, they may be unaffected by the other, or they may exist in a relationship favorable to the survival of both species. A classic example of the latter occurs in lichens, a combination of fungi and algae. Both components may be cultured separately in a laboratory, but when found in nature the interdependance of the algae and fungi effectively enables the two to function as a single organism, unlike either of its components alone, which can survive harsh environmental conditions.

After presenting the mathematical theory behind the Volterra-Lotka equations, one is probably wondering how accurately they describe natural ecosystems and certainly what use they may have. Figure (1) is a graph of the population hare and its natural predator, the lynx (a northern wildcat). Notice that a large population of hare leads to a rapid growth in the numbers of lynx, a subsequent reduction in the hare population, and finally the decline of the lynx population whence the cycle begins anew.

A very practical use of the Volterra-Lotka equations, and quite striking in its predictions, involves the control of agricultural pests by either insecticides or natural predators. Volterra indicated that if an environmental factor affects both species, the prey is more likely to survive than the predator. Huffaker and Kennett (1956) performed laboratory experiments to determine an effective control over cyclamen-mites which were damaging the strawberry crops in California. Their studies indicated that using a natural predator mite to control the harmful cyclamen-mite was more effective than repeated applications of the insecticide parathion.

C. S. Holling (1966) has correctly indicated that the Volterra-Lotka equations consider only the "rate of successful search" and the "time exposed" components of the predator-prey interactions. Using difference equations-based computer programs, Holling has introduced such factors as the hunger frequencies of the predator and inhibition mechanisms of the prey. A similar approach is by K.E.F. Watt (1964). Watt has tried to design an ideal control mechanism for the spruce budworm in the coniferous forests of British Columbia.

Using predators, parasites, pathogens and insecticides as control possibilities, Watt compared the longevity, spatial effects, rate of spread, and population equilibrium level of the pest due to each of the control mechanisms. As one can readily see, the Volterra-Lotka approach is very definitely useful in solving some of the environmental problems facing us today.

The Gause competition model, as well as the Volterra-Lotka model, has been proven helpful in understanding population interactions. In the original experiments performed by Gause using paramecia we notice a characteristic sigmoid growth for each species alone, and the resultant extinction of one species when the two are placed in competition. This corresponds to case 1 explained above. Case 4 of the equations is also found in nature, as discussed by Harper and Clatworthy (1963). Two species of clover were grown separately and in mixed

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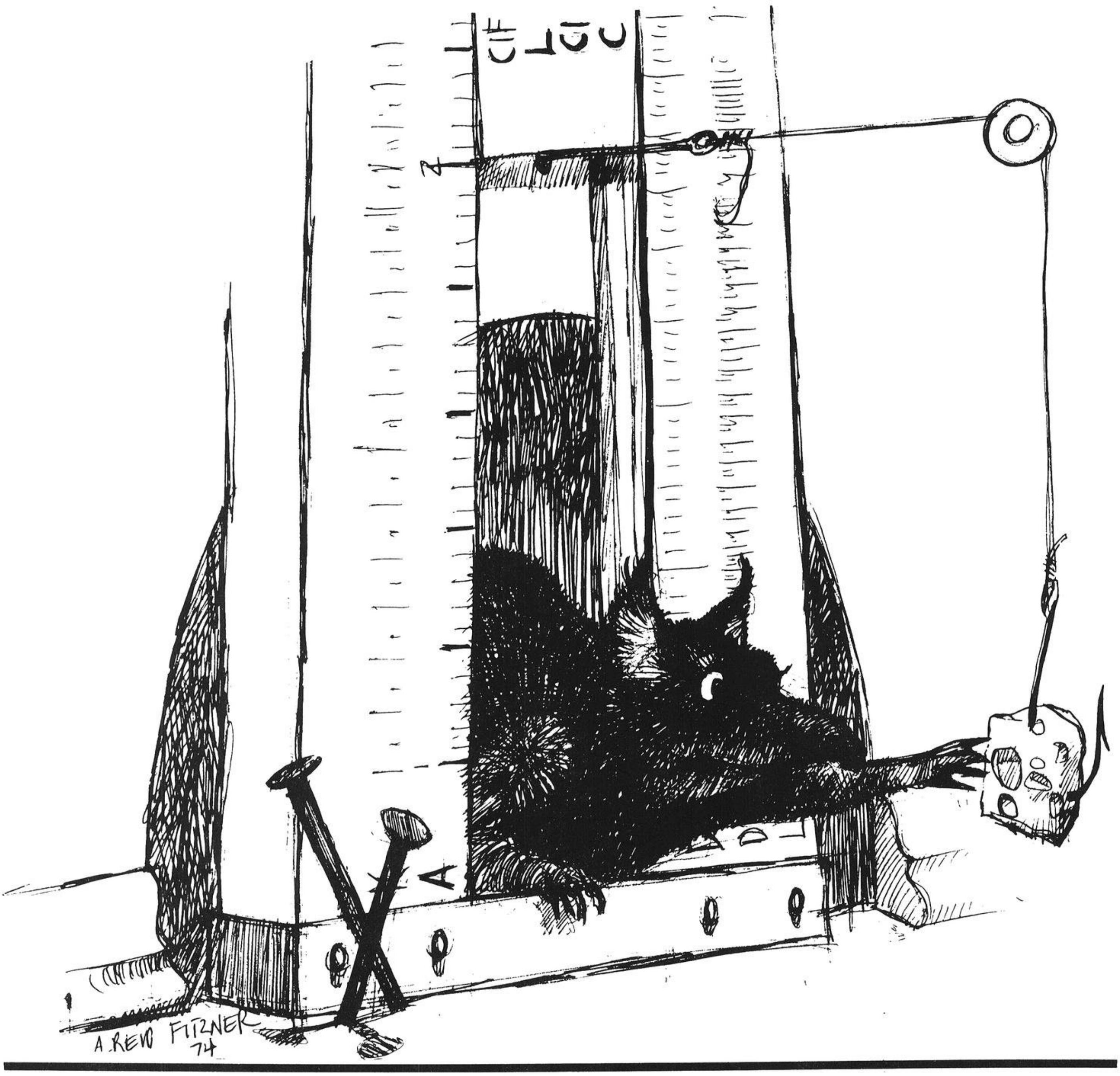

swards, where they decreased, but co-existed.

Neyman, Park and Scott (1958) expanded the deterministic Gausian model to include statistical variation. They hypothesize that there is a zone of indeterminate conclusion where either of two species of flour beetles may outcompete the other. These experiments indicate that there is statistical variation which results in an indeterminate region rather than a single line separating the domination of either one species or the other.

The kind of mathematical modeling that has been described in this article is being applied to other problems besides biological species interactions. For instance, biophysicists are presently using this approach to further understanding of the interactions of neural systems. Excitatory and inhibitory neurons are considered separate "species" which interact in a similar fashion to biological organisms in an ecosystem.

In fact, several researchers have logically expanded this technique from the original considerations of fish in the Adriatic Sea and yeast in cultures to the socio-economic dynamics of the entire earth. Jay Forrester's *World Dynamics* and the Club of Rome's *Limits to Growth* are two examples of modeling the interactions between human population growth, natural resource availability, agricultural production, pollution, and economics to predict the dynamics of the quality of life in years to come.

The Institute for Environmental Studies on the Madison campus is dealing with these questions on both world and regional scales. The technique of using coupled differential equations to describe dynamic interactions of total systems is being applied in both large and small scale approaches and offers much promise in helping solve ecological and environmental problems. WE

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[1] All powermeasurements taken at 120 volts/60 cycles, 8 ohms, 20Hz-20kHz, all channels driven simultaneously.
[2] Manufacturer's suggested list price which may be higher in some areas.

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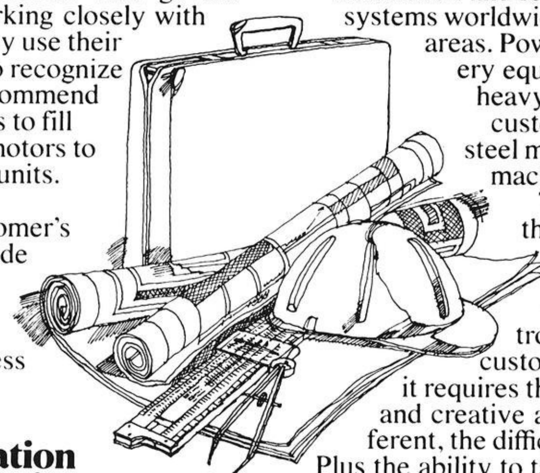

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Application engineers are technical experts who work closely with the sales engineer and the customers' engineers. Their job is to analyze special problems and equipment needs of customers, then determine the optimum GE products or systems to meet them. There are two kinds of application engineers. The first works out of a sales operation and is adept at applying a wide variety of products to create a "system" that meets the customers' needs. The second works in a product manufacturing department and is a specialist at applying the products of that one department. Both must have in-depth knowledge of the customers' technical needs. They often consult with product planners and other marketing personnel to suggest ideas for new or modified products.

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Field engineers at GE plan and supervise the installation and service of large equipment systems worldwide in two main customer areas. Power generation and delivery equipment for utilities. And heavy apparatus for industrial customers such as paper and steel mills, chemical plants and machine tool manufacturers. They specialize in either the mechanical/nuclear or electrical/electronic areas. Since field engineers are often called to troubleshoot and correct a customer equipment problem, it requires the technical competence and creative ability to handle the different, the difficult and the unexpected. Plus the ability to take charge, lead people, and make independent, on-the-spot decisions.

Product Planning

Product planning is a marketing function. Product planners make sure a product line offers what customers need at competitive prices. They determine the need for a new or modified product, product availability, market size, cost structure, profitability, specifications and distribution channels. To do this, they work with market researchers, application and sales engineers, finance experts, marketing management, plus design and manufacturing engineers. Their engineering background is a big plus. This work requires self-starters who can coordinate a project and sell their ideas to management.

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