WHAT MAKES YOU THINK YOUR SOLUTION IS CORRECT?!

Breathes there a simulation man who hasn't been bothered by this? If not put by others, the question will probably arise from his own sense of integrity.* Well, we're going to get together the afternoon of Thursday, 16 April to kick this question around a bit. How do we know our solutions are correct? Of course no one questions the fact that they are correct. We just want to talk about how we know. How do you know?!

Come to the Computer Research Corporation plant at 3348 West El Segundo, in Hawthorne, (between Prairie and Crenshaw) at one o'clock. We will visit their plant and have a first-hand opportunity to examine and discuss some of their products, and then we will get down to the subject of Verification of Solutions of Simulation Problems, i.e., CHECKING TECHNIQUES.

Lots and Lots of Helipots!

Or as Lee Cahn said, "No matter what kind of computer you've got, you're sure to be using a Helipot."

To scorn the corn, we will say seriously that the visit to the Helipot plant was both interesting and informative. We were particularly interested in the automatic winding machines and the multi-tapping of multi-tapped pots. This latter operation is done by particularly talented young ladies, some of whom seemed to have more on the ball than the tap! Anyway, when a pot is to be tapped, the approximate location is calculated and a hole drilled in the case. The exact turn is determined by accurate resistance measurements and the tapping wire inserted by the operator, working with the aid of a binocular microscope. The wiper of the potentiomotor is moved exactly under the turn that is to be tapped, and when the meters indicate a minimum resistance between it and the tapping wire, a foot pedal is touched and a capacitance welder does the rest. Sounds easy, but our host told us that he once tried all day and made only three successful welds. The young ladies, I am told, are able to do about 190!

There are, of course, other things of interest which contribute to the popularity of Helipots. But the automatic winding machines, including the little toroid winder, and the pot-tapping gals will be the things we'll remember.

* This brings up a subject beyond the scope of this paper. Perhaps we should make it the subject of a future meeting!
Notes on the Meeting of 12 March 1953

The Beckman Instrument Company was host to the Simulation Council meeting in Pasadena on 12 March. The announced subject was Systems Design, but as usual many aspects of Simulation were discussed. Lee Cahn opened by telling about the concepts that led to design of the EASE computer. He drew a diagram on the board to indicate the interrelationship of accuracy, convenience, and cost. On the subject of accuracy he suggested that if each of four components in a simple problem were to be accurate to one percent it would not be reasonable to say that the solution contained 4% error; the probable error is nearer the square root of the sum of the squares. Lee pointed out that if 5% components can be used, substantial savings may result, and that conversely the cost increases disproportionately if .015 components are specified, i.e., there is sort of a flat between 1.0 and 0.15.

Lee said that at Lockheed they buy pots without specification, calibrate and label them. This might keep a desk calculator occupied for some time to get scaling factors, but it seemed to work.

Lee next spoke of dynamic accuracy. "At the low end of the spectrum, we have this cussedness of inanimate matter known as zero drift." When they check a number of their uncompensated amplifiers and average the absolute values, they find drifts in the order of .06 millivolts. He considers this bad only when integrating the difference of very large quantities, and not then if the loop is closed, as it usually is in simulation problems. Olds of Inyokern pointed out that this would only be true if there were an odd number of amplifiers. Lee replied that if there were an even number, other things would happen which would negate the whole solution.

Mallinckrodt of Ralph Parsons asked Lee if anyone had measured the spectrum of this drift of unstabilized amplifiers. John Burke of JPL said they had, but that there are different characteristics with integrators and summers. With a specific integrator, they have found the spectrum to be between zero and a 1000th of a cycle per second. The spectra of adders have humps, one at 60 and one at 120 cps, and frequencies of a 100th to a 1000th of a cycle.

Lee said that when their integrators are run as straight amplifiers, they will drift about 2 millivolts in 5 minutes. This is contrasted to the Bureau of Standards figures for a chopper-stabilized amplifier of about 0.1 millivolts. Lee suggested that the only difference between stabilized and unstabilized amplifiers is the length of time you can compute with a given error. Dow Abrams asked Lee what would happen if he wanted to repeat a run with 0.6 mV. error. Lee explained that correcting the drift did not require a readjustment between each run, but simply using the reset button. In answer to a question by Bill Sedlacek of NAMC, Lee explained that the drift rate was pretty constant within ± 20%

Burke objected to Cahn's procedure of using the average of the absolute values of the drift rate, saying that they used to have a sign over their computers saying "What makes you think this answer is right?" You must know that the amplifier will never drift more than so much.

Jack Mallinckrodt suggested that the spectrum analysis John Burke mentioned would be interesting, because certain circuits exhibit preferential gain.
Lee - "If you are operating at 10% of full scale with a 15 instrument, you actually have only a 10% instrument."

Dov said that repeatability might be a better reason for using more accurate components than absolute accuracy.

Lee recommends evaluating a computer component by component rather than on the basis of its overall accuracy in the solution of a particular problem. He suggests inaccuracy of the computer might be considered as an extension of the inaccuracy of the input data. (What do readers think?)

Rick Anderson says that in a complicated problem, even if you know the absolute accuracy of individual components, it does not help in determining the overall accuracy. He claims that the only way the large-scale computers can determine what their accuracy is, is to compute a sample problem on a digital computer. Lee answered that this depends on whether you are an engineer or a mathematician.

Dr. Brock of Consolidated Engineering pointed out that Professor Murray of Columbia University has worked out the relationship of the error in the individual components to that in the overall solution. The really tough job is to determine the individual errors of the components. Using check solutions is OK for that particular solution, but questions are raised when you begin to vary parameters.

Hallinicrodt objected to allowing errors in analog computers simply because some things are difficult to measure accurately; the computers are also used for such things as the solution of geometric problems and Maxwell's equations.

Dr. Brock stated that errors from a computer are more serious than errors in measurement because they are a function of the problem itself, which might cause very large errors in the result.

Lee replied that this is also true of the hardware that you are simulating.

Burke - "The simulator in the imperfect form with drift and error does not represent the system."

Lee - "Let me hit it once more. The errors in the computer propagate in the same way as errors in the complete system."

Dov insisted that you can maintain confidence only to the extent that you can repeat solutions.

TO BE CONTINUED IN NEXT MONTH'S THRILLING EPISODE - DON'T MISS IT!

Lee suggested a formula to give a figure of merit for computers which he has found handy. $T_L f_H = R$, when $T_L$ is the longest time of computing, $f_H$ is the highest frequency the computer can handle, and $R$ is the relative figure of merit.

When Olds asked if this didn't ignore the fundamental difference between open and closed loop calculating, it precipitated quite a discussion by Hallinicrodt, Anderson, Olds, and assembly about the frequency spectrum of the drift and other errors. Hallinicrodt compared an unbalance of any magnitude at the beginning of a problem to an error in initial conditions. Lee thinks that if we are only interested in dynamic solutions, all of these fine points can go hang.
Stan Rogers said he liked Lee Cahn's attempt to analyze a computer by its component parts.

Lee summed up by saying accuracy is a function of the computer, of the problem, how you scaled it, and how you programmed it. Lee figures that the Cal Tech equipment has an R of about 50 resulting from a frequency of about 1000 cycles, and a time of about 40 milliseconds. The Philbrick computer he found to have an R of 4. (Any comment, Philbrick?) The absolute time scale is of interest only for real time simulation, and when there are many runs to be made. All of these factors made Beckman decide on a computer where cost was kept low by using electronic multipliers and electronic function generators to improve $f_n$ at the expense of $T_l$ in order to throw out the chopper stabilizer and its attendant complication. They compromised the accuracy-convenience aspect in favor of low cost, assuming that users would be willing to take extra calibrating precautions for the small percentage of problems requiring extreme accuracy.

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Dick Baum next discussed Lee's points of accuracy, convenience, and cost with respect to GEEDA. Goodyear wanted the highest accuracy possible with good convenience, and let the price fall where it would. Because they do not know how their computers will be used, they can only increase accuracy by using accurate components, which will allow operation in real time. They were also interested in portability. Dick told a little of the history of the Goodyear computer, and showed how these considerations led to the chopper-stabilized L3. To make Lee Cahn's R larger, they have tended more and more to all-electronic rather than partially electronic and partially servo components. They have also tended to give more and more latitude to the user as to how he connects his equipment, as exemplified by their having provisions for external reference voltage and bringing out all grid and relay loads.

Dov Abramis told of the development of the Convair-Pomona computer, saying that it was started in San Diego by Stan Rogers. They were not so interested in absolute accuracy as repeatability.

Considering patching as a primary source of error, they tried to make correct patching easy. Next they attacked reliability and stability of components, which made the components very expensive. Dov believes you probably have to go farther in this direction than appears necessary for accuracy alone.

Next they devoted their attention to tracing errors. Tours of the whole country indicated that the Rand Company in Santa Monica was probably the most progressive in attacking the problem of repeatability, by making it easy for the operator to check, and by using more reliable components. They use the IBM system to make patchboards as easily detachable as possible and contacts as reliable as possible. Dov will show their adaptation when the Simulation Council meets at Convair-Pomona in May.

Stan, Dov, and Company also wanted to be able to take any component out of the system without unpaching. They therefore brought all amplifier grids out to the patchboard, so that they can put in a standard signal and compare it with the output, thereby checking the gain of the amplifier. They also provide two separate bus systems so that certain loops of complicated problems may be checked separately by plugging them into one bus system while the rest of the problem is on the other. As a further aid to trouble-shooting a switch was provided to reverse the signs of all the initial conditions of a problem, which should not change the solution. They are also able to plug one patchboard into any of eight stations.
on their consoles, which should give the same solution. How many installations in the country could do this?

Dov was also concerned with whether they should stick to one type of equipment or, if not, what types they should get and how they could combine them into one system. RCA had decided to custom build all of the system from scratch. "OK for half a million dollars!" Convair, however, was concerned with delivery dates and varying the vendors to get comparisons of products. At Pomona they have three types, Reeves and Electronic Associates amplifiers, and Goodyear multipliers. In San Diego they have these same three types, also some Beckman amplifiers.

Dov then indicated that problems might arise from combining equipment of different "R'ss". Seems they test their amplifiers by bringing the grids and outputs to a stepping switch. Fearing trouble, they tried this with Reeves amplifiers 1½ years ago when they placed their order. At that time the expected bandwidth of the Electronic Associates amplifiers was only about twice that of Reeves, but when delivered they had bandwidths 10 to 100 times as wide. This is fine for Electronic Associates, who are contemplating coaxial patchboards and no stepping switch, but Dov got a 5% A.C. oscillation of his entire console! Difference of ½% here makes it difficult to apply the same kind of testing.

Rick asked about how Abramis intended to handle the convenience problem when it comes to adjusting 700 pots, to which Dov replied that he hoped to show the Electronic Associates remotely set pots when the Simulation Council visits Pomona in May. Kalbfell has delivered a similar type to Convair–San Diego, which is already working. Pots will be set against a Leeds & Northrup voltage divider to better than 0.01%, i.e., 10 millivolts.

Dov believes large installations may require further breakdown of Lee's three factors, for instance cost should be broken down to compare investment vs. running cost. Complication of running a 200 amplifier 700 pot installation on large high-priority problems during the first shift, and 4 or 5 smaller low-priority problems during subsequent shifts, relates convenience directly to cost.

There followed such a discussion of preventive maintenance that Lee Cahn suggested making it the subject of a future meeting. Dov said that at their former installation they arbitrarily replaced six amplifiers every day and very carefully checked those that were removed. This decreased their down time to about 1/5 of what it had been and paid for six spares (about 10% of installed number) in a short time. The "test" position obtained through use of the previously mentioned stepping switch performs the same function on the new installation, removing the amplifiers electrically rather than physically. They also have 5% spares for physical replacement, and have their precision resistors in fuse clips for easy test and replacement. Dov also suggested a number of separate power supplies. (They have no choice because of different makes of equipment.)

Bill Sedlacek of NAITO asked what the criteria were when amplifiers were removed for test. Dov replied that if the gain was down, they would replace tubes or do whatever was necessary to bring it back. Bill asked if this did not introduce the initial failure of tubes. Dov answered there was no use putting in a new tube; tubes should be replaced with properly aged ones. Bill asked if records of tube reliability were kept. Rand has done so. Convair's records are not good, but they intend to keep good records in the future. Once Convair replaced 2 of the 6SL7 input tubes with 5691 or 92S— the red type tube. For some reason which he does not understand, the replacement tubes were found to be worse.

Burke says JPL had an experience similar to Convair's. Because of time wasted trying to locate trouble when something went out during operation, figures showed
from 25% to 30% outage time before institution of preventive maintenance. Afterwards outage time went down to 5%. Stan Rogers commented that some down time is caused by personnel error, when things which just don't seem possible do happen, such as people not familiar with electronics sticking a connector in the wrong hole. Dick Baum got a laugh by observing that people who are familiar with electronics sometimes do this. Stan said they are considering rigging up an alarm system so that when anybody draws too much current, a large gong will ring over his head, telling everybody "who done it!"

Lee Cahn stated that if there is a certain probability than an element will fail and you have N elements, then the probability of a failure is N times as great. If you have 20 amplifiers with 5% down time, 200 amplifiers would then have 50% down time and you would be out of business. This makes a very definite difference between moderate and large size installations. Dov agreed, and added that there should be another factor in R for large installations.

McLeod asked Burke about his system at JPL. John said he would first like to answer the February Newsletter question about MIT's multiplier. There are two of which he has knowledge, the strain gage voice coil one mentioned in the Newsletter, which impresses a 400-cycle voltage across an unbonded strain gage stressed mechanically by the voice coil. It is supposed to be good to approximately 0.1% statically and between 0.1 and 0.2% up to 20 cycles.

In answer to Dick Baum's question, John said that it did not have to be demodulated because it works in their 400-cycle flight simulator system.

John then told of a more interesting multiplier wherein a special electron gun throws a one-inch spot of uniform electron density on a target on the end of a cathode ray tube. The target is separated electrically into four sectors by the vertical and horizontal axes. Circuitry subtracts electrons collected by the upper left and lower right sectors from those collected by the other two sectors, so that when the spot is in the center there is no output. However, reference to a diagram will show that if the spot is displaced in the x direction a distance x, and in the y direction a distance y, there will be an area 2x times 2y which is not compensated by areas of the spot remaining in other sectors. Therefore the output of the circuit will be f(xy). Accuracies within 2% for frequencies up to 50 K.C. are claimed for the first and only model built.

John then defined a simulator as an analog system working in real time which may or may not include parts of the system under test. He feels that a simulator has three main functions. (1) It can be used for original system design and setting up criteria for the design of certain components; (2) Actual components can be inserted and the simulator used to represent the remainder of the system; (3) It can be used for final checkout.

In order to make simulation as easy as possible on the people doing the analysis, the simulator must be made as complicated as possible. Complicated loading devices are required, but the critical item in most missile simulators is the flight table. The design is most difficult, and usually requires about a "megabuck" to complete. MIT, Reeves and two or three others have built tables, and there are a number now being developed. WADC, Bendix, NASA-Corona, NAIRC, and others are working on this problem.

John's version of specs for a universal flight table:
Roll velocity of 100 rad./sec.
Yaw and pitch velocity of 20 rad./sec.
Roll acceleration of 1500 rad./sec.$^2$
Yaw and pitch acceleration of 500 rad./sec.$^2$
Roll response to 200 cps
Yaw-Pitch response to 100 cps
Continuous rotation on each axis
20 minutes continuous operation
Pay load of 25 lbs. minimum - should be 100 lbs.

Anyone want to build this table?

Olds says these specs are strong arguments for filling the sky with hardware!

Burke feels the need for only one or two large simulating facilities in this country - for use of the military and others. Most companies and universities should have small-scale simulators - perhaps with only one degree of freedom to handle one axis at a time. If more effort were put into mathematical analysis, most problems could be solved so that the computer could solve one degree of freedom at a time; many complete missile systems have been accurately designed using single axis tables. Only tables JPL has in the simulator lab are 5 single axis ones. Dr. Bennett at Hughes has studied air-to-air missiles with a relatively small amount of equipment. He isolated reasonably small parts of the problem, solved them, and deduced from that how the system would work.

Many people are talking about using digital elements in simulation. JPL wanted to use their analog computer, but certain problems required solutions to 0.1%, so the answers were masked by computer errors. A digital multiplier might do the job. There are other reasons for using digital equipment. It might yield lower complexity in certain cases, such as generating pure time delay. Or function generation may be accomplished more cheaply with less equipment.

Lee Cahn said that North American Downey has used interesting method on trajectory. Using calculus of variations on equations of motion to derive equations of error, they have an inherently more accurate method. With a 5% computer they will have only 5% of the error they would normally get.

Burke - "I like this; in this way you get by with less complicated equipment."

Rod Face Department

John Burke tells us that we were mistaken in saying that he was using digital multiplication in his analog setup at JPL. Apparently they are only planning to do so, and he attributes the plans to his co-workers. (Are you being gracious or cautious, John?)

Also apologies for misspelling Mr. Landsame's name; giving the wrong address for Kalbfell Laboratories, which should have been Post Office Box 1578, 1090 Morena Boulevard, San Diego 10; and calling Rawley McCoy of Reeves "Raleigh", as in Sir Walter.

Subscriptions to the Newsletter

To subscribe to the Newsletter, send a check or money order payable to the Simulation Council, Post Office Box 731, Camarillo, California. The price is $6.00, to cover a one-year subscription.
Paper from the IRE Seventh Regional Conference at Albuquerque

B. J. Carr loaned us his copy of the New Mexico College of Agriculture and Mechanic Arts report, "An Electronic Integral Equation Resolver", on which his Conference talk was based. This report, on which he collaborated with R. E. Chlemacker, L. E. Gough, E. C. Davis, and J. S. Arnold, describes a computer which, although primarily designed for solving equations relating distant microwave antenna field patterns to the electronic field distribution at the antenna aperture, was also designed to be adaptable to other similar problems.

The computer embodies three single variable function generators and one "two variable" function generator, all of the masked cathode ray tube type described by A. B. Macnee in his thesis for the Doctor of Science degree at MIT, 1948, "An Electronic Differential Analyzer". In the two variable function generator the length of the sweep is the second variable. (This is not exactly what we had in mind when we discussed bivarint and other function generators at the December Simulation Council meeting.)

The computer also uses an adder similar to that described in the Macnee paper, and a multiplier of the type developed at Cal Tech and reported by B.N. Locanthi in his paper "A High-speed Multiplier for Analog Computers". The multiplier uses multiple modulation of an r.f. carrier of approximately 450 kc. There is also an integrating amplifier which is similar to the adder, with the resistor replaced by a capacitor. Solutions are displayed on an oscilloscope at a rate of 1000 cps.

Our Project That Needs Attention!

You were introduced to our "Project That Needs Attention" in last month's Newsletter. Now we are yelling — for help! Most people complain that they get too much advice on such matters, but we are asking for it. Printed below in their entirety are Dick Baum's "Suggested Specifications for Electronic Multiplier". Others have helped with suggestions, but they are all covered by Dick's thorough job. Perhaps he is too thorough. (Is this possible?) Anyway, here's what we would like for you to do. If you have a multiplier, see how much information you can fill in on Dick's form, tear it off and send it to us. If your answers are qualitative rather than quantitative, or if you wish to qualify your quantitative answers, please do so. They will be considered accordingly.

If you are a user, give the make and model of your equipment; the manufacturer would like to know your opinion. If you are afraid this may break up a beautiful friendship, remain anonymous, but do give us the straight dope.

If you are a producer of multipliers, this is your opportunity to cover the simulation field with the good word if you think you've got something, or to make rebuttal if some stupid users have shown they don't know how to use fine instruments!

If you built your own multiplier, we are particularly anxious to hear from you. Perhaps you've got something. We must conclude from Simulation Council discussions to date, that the completely satisfactory analog multiplier, if it exists, is yet to be dragged out into the open.

Here are Dick's specs, folks. Let's have at 'em!
Suggested Specifications for Electronic Multiplier

I. For Basic Unit Producing Output $x \cdot y$

A. Input and Output Circuits
   1. Voltage range and input impedance for each channel
   2. Voltage range and output impedance of output circuit

B. Static Accuracy
   1. Maximum error for any combination of $x$ and $y$
   2. Plot of error vs. $x$ for $y = 0$
   3. Plot of error vs. $y$ for $x = 0$
   4. Maximum and average rates of drift for $x = y = 0$
   5. Maximum and average rates of drift for $x$ and $y$ at full-scale value

C. Frequency Characteristics
   1. Plot of amplitude and phase shift vs. frequency for $x = A \sin \omega t$
      and $y = 0$ (and for $y = A \sin \omega t$ and $x = 0$ if the two input channels
      differ significantly). If the shape of the curves is a function of
      $A$, a family of curves for different values of $A$ should be given.
      For T. D. multipliers, the frequency range should include the repeti-
      tion frequency and for repetitive multipliers (such as the Philbrick)
      the range should extend two decades above and below the repetitive
      frequency.
   2. Maximum output ripple magnitude and frequency

D. Controls
   1. Number of panel controls
   2. Number of chassis controls
   3. Frequency of adjustment of each control in order to maintain stated
      accuracies

E. Miscellaneous
   1. Number of tubes and/or transistors employed
   2. Power requirements
   3. Auxiliary calibrating equipment required
   4. Test Equipment required for servicing
5. Guarantee and service policy of manufacturer
6. Spares furnished by manufacturer
7. Temperature rise above ambient at surface of the chassis

II. For Basic Unit Producing Output \( \frac{X}{U} \)

A. All of Part I for \( U = U_{\text{max}} \).

B. Voltage range and input impedance for \( U \) input channel
   (including any restrictions on \( \frac{X}{U} \) or \( \frac{Y}{U} \) )

C. Plot of maximum error vs. \( U \) for \( x \) and \( y \) at full-scale values

D. Plots of amplitude and phase shift vs. frequency for \( x = A \sin \omega t \),
   \( y = 0 \), and \( U = U_1 \), \( U = U_2 \), \( U = U_3 \), etc. for values of \( U \) including the
   useful range of the variable \( U \). Repeat with \( y = A \sin \omega t \) and \( x = 0 \).

E. Plot of output ripple amplitude and frequency vs. \( U \).

Make and model of Multiplier, if commercial product. Otherwise, generic type
such as "Electronic time division", "Servo potentiometer", etc. and designer.

Comments and qualifying remarks:

(Continue on back if necessary)