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MIT
Differential Analyzer

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

DEPARTMENT OF ELECTRICAL ENGINEERING

CAMBRIDGE A. MASS.

December 17, 1937

Mr. George W. Gray
The Rockefeller Foundation
49 West 49th Street,
New York

Dear Mr. Gray:

I am returning the draft of your article on the new Differential Analyzer which you sent me for review. It is an extremely interesting treatment of the project and you are to be congratulated on assimilating so much detailed information in such a short time.

Unfortunately, Dr. Bush had to be away and in order to return this to you in time to meet your publication date, I had to do so without showing it to him. However, Dr. Compton reviewed it and was quite pleased with it, and I feel that Dr. Bush will be also when he sees it. I have made a copy to show him when he returns. I have indicated a few suggestions on pages three and four. In one case I corrected your statement so that it would agree with the facts. We have nothing to do with the data obtained by cosmic ray counters as far as our work on the Differential Analyzer is concerned. The machine deals entirely with the theoretical treatment of the problem. The experimental data enters the picture only when we wish to compare such data with the results of theoretical study to see if the results agree.

There is only one other matter which might be corrected. At the bottom of page two, you speak of "solving mathematical problems involving six variable quantities". Again at the bottom of page three, you speak of "mathematical problems involving more than six variables". On the next to the last paragraph on page four, you again speak of "18 variables". I am afraid that I did not get across to you clearly the significance of the number of integrator units which you have interpreted to mean the number of variables which the machine can handle. Mathematically, your interpretation is not correct, although it will probably make little or no difference to the layman. However, we may as well try to get it right. The number of integrators used in a problem does not indicate the number of variables occurring because, for example, we may very easily have a problem involving only two variables but requiring a dozen integrators for its solution. The number of integrators in the machine does indicate the complexity of the equation which the machine is able to solve because any complex equation can be broken down into a set of simpler equations for which a large number of integrators is required. The integrator does not handle a "variable"; it performs the process of integration and the

complexity of a differential equation can be measured by the number of integrating processes which must be carried out. I hope I have thrown some illumination on this matter for you. It is a difficult point to express without the use of mathematical idioms and I hope you can do a better job on it than I have.

Very truly yours,

S H Caldwell

SHC:W

S. H. Caldwell

P.S. It is not very important that the last point be corrected at all, if you have any difficulty with it.

SHC.

Grants from the Foundation:

$85,000 to Massachusetts Institute of Technology

A ROOMFUL OF BRAINS

A new building now under construction at the Massachusetts Institute of Technology will contain many interesting interior arrangements, some spacious, others compact, all modern, of reinforced concrete. Unique among them is a massive rectangular room designed to house a marvelous machine.

The machine is called by the technicians a "differential analyzer", but perhaps laymen will continue to picture it as an electro-mechanical brain. It is a brain that must be rated in tons rather than in ounces, so the architects have specified for its room a floor stronger than that of any other of the hundreds of shops, laboratories, and halls of Technology's exceptionally massive group of buildings. In order to carry safely the thirty-ton machine, the floor is designed to bear a load of more than an eighth of a ton to the square foot.

Just as the blood stream pours energy into the human brain housed within its skull bone, so will electrical currents carry energy into this metal brain housed within its room of concrete. There are thousands of tiny electromagnets to be actuated, dozens of motors to be spun into rotation, and all under the control of lightning-quick amplifiers embodying, among other devices, 1,300 vacuum tubes. Merely to heat the filaments and other electrodes of these vacuum tubes requires 20,000 watts of electricity, and the total power crowding into the narrow room is 100,000 watts. It would be sufficient to light 2,000 ordinary incandescent lamps.

The concentration of so much electrical energy within a closed space measuring sixty feet in length and twenty-four feet in width has created

a problem in air conditioning, since the heat of the vacuum tubes and other electrified parts would soon warm the interior to unbearable temperatures. So a system of ventilation has been devised, admitting air at one end of the room and withdrawing it at the other. Although the air enters at 70° F. and the forced ventilation draws it off so rapidly that the average air particle spends only a few minutes in the room, the emerging air will register around 105° F.

But items of weight, power requirements, and temperature are only the grosser and more obvious details of this intricately complex and impressively ingenious machine. In effect, it is a mathematical robot, an electrically driven automaton which has been fashioned not merely to relieve human brains of the drudgery of difficult calculation and analysis, but actually to attack and solve mathematical problems which are beyond the reach of mental solution.

Something of the significance of the robot may be suggested if we compare it with existing facilities. For the apparatus now under construction is not novel in its purpose. It is only the latest development in a distinguished sequence of mathematical aids originated at the Massachusetts Institute of Technology by Professor Vannevar Bush and his associates. Indeed it is doubtful if the Trustees would have received a recommendation of this project in 1936, if there had not already been in operation at M. I. T. a machine, a differential analyzer of a more primitive type, which had demonstrated its usefulness in many practical ways.

The completion of this earlier machine was announced in 1931 by Dr. Bush. It is capable of solving mathematical problems involving six variable quantities. Soon after the announcement, problems began to pour in from other universities, research centers, engineering firms, and industrial companies.

Another is to be built at Cambridge Univ (Eng).

Duplicates of the machine were installed at the University of Pennsylvania, the United States Army Proving Grounds in Maryland, the Astrophysical Institute of Oslo, and the University of Manchester, England. Still the demand for its analytic service continues to increase, and in the six years the M. I. T. apparatus has been a powerful aid in the mastery of many practical problems of engineering and industry as well as of more erudite problems of physics, chemistry, and cosmology.

It has been employed several weeks at a time, for example, analyzing the complicated ~~data~~ behavior of cosmic rays as they ~~are recorded by automatic detectors at various places on the Earth's surface and at various heights of the atmosphere.~~ arrive from outer space and come under the influence of the earth's magnetic field. The problem was to determine and plot the effect of terrestrial magnetism on these mysterious messengers from outer space. When you remember that the Earth is in continual rotation, that it is perpetually revolving round the Sun at a velocity which changes from day to day, that the intensity of the Earth's magnetic field is nowhere constant but varies with latitude, and is subject to periodic fluctuations, you recognize in this cosmic ray phenomenon a capital example of the sort of problem which involves what the mathematician calls "variables". It is possible to write an equation or a series of equations - "differential equations", they are called - which embodies these changing quantities, but it is extremely difficult to solve the equations by paper-and-pencil computation. By means of Dr. Bush's machine these cosmic ray data have been elucidated - and if the apparatus had not been available, it is doubtful if the data would yet have emerged from their raw state.

Powerful as it is, the machine built in 1931 has limitations. Engineers and scientists are confronted with many mathematical problems involving more than six variables. Moreover the old machine is wholly mechanical

in its operation, requiring the manual setting of gears and other connections for each problem, and often days are required to adjust the mechanism for a task which, once the setting is accomplished, it is able to complete in an hour or perhaps in only a few minutes. In handling the cosmic ray data, for example, the attendance of five persons was required for thirty weeks, entailing a payroll of more than $100 a week.

These preliminary delays and costly personal attendance are reduced to a low minimum by the new machine. It requires only <u>one attendant</u>, and its setting will be accomplished automatically by an electric system.

(unless multiple operation requires another man)

To submit a problem to the new analyzer, you need only to punch certain holes in a card, and place this card in the receptor end of the machine. Nimble electrons will swiftly and surely do the rest. Seventy electrical "masters" will marshall into instant service ninety electrical "slaves", relays will click, wheels will whirr, and in a few minutes the solution will be delivered as a numerical result.

The new machine will be able to care for eighteen variables (to compare with six in the old apparatus), and is so constructed that its capacity may be increased to thirty. Not only will it be able to solve more complex problems than the present machine, but it will do these more difficult jobs in less time and with at least tenfold gain in precision.

A visit to Cambridge in December showed the construction to be well advanced. As rapidly as parts are machined and assembled they are being stored in convenient classifications, and when the concrete room is finished next September there is assurance that the mathematical robot will be ready to move in. But even so, the thing is so intricate, it involves such miles of delicate wiring, such a complexity of parts and hook-ups, that nearly a year will be required to install it.