Emergency Simulation of the Duties of the President of the United States

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I. INTRODUCTION

A TECHNICAL problem is arising in our democratic government which engineers and mathematicians are equipped to assist in solving. The problem is how to approach making the kind of decision the President is called upon to make if missiles are detected on their way toward the United States. The number of facts on which a decision should be based appears to be increasing. The length of time in which to make the decision appears to be getting shorter.

Dr. Isador Rabi described the problem in a speech given in December, 1957.[1]

> Hydrogen bombs are going to be deployed at bases around the world under the control of many groups of persons. If an oncoming ICBM were detected 5000 miles away there might be time to intercept it with weapons not yet developed. But there will not be time to wake up the President to ask what to do, to call a meeting of the cabinet.

Facing a question that has not been mentioned before in the literature of computer engineering, we should give great consideration to method. I propose that as we approach each part of the problem we first describe it in the language most appropriate for the topic. Then let us attempt to translate this statement into computer and control terminology. Third, let us inquire to what extent an improved system can be built out of a combination of human beings and electronic equipment or electronic equipment alone.

The work of three men is the precedent for the attempt, in this paper, to describe human beings, human relations, and man-machine relations in terms of computer and control engineering. One is Dr. Warren McCulloch, a psychiatrist now at M.I.T., who is describing the human nervous system in this manner. One of his early papers was, "The Brain as a Computing Machine."[2] One of his more recent is on the design of reliable circuits out of unreliable components,[3] giving one answer to the question of why the brain is as reliable as it is. The second man to supply precedent is Dr. Karl Deutsch, a political scientist now at Yale. He came to wide attention with the publication of a book explaining nationalism in terms of communication engineering.[4] The third is Jay W. Forrester who is now simulating business and economic systems by computer programs. He described his approach in, "Industrial Dynamics—A Major Breakthrough for Decision Makers."[5] Prior to undertaking this he directed the development of the SAGE computer. I quote these three men extensively.

This paper was written during evenings, weekends, and holidays. The opinions expressed are mine or those whom I quote, and not necessarily those of my employer.

II. THE PROBLEM

We appear to be approaching an era of violence. The two major powers are manufacturing weapons to kill millions of people. They can be fired by the push of a button or by the signal from a computer. Many may soon be hidden so that they cannot be destroyed by bombing. As these weapons are built, installed, and connected to remote controls, the probability that one will be fired will rise rapidly, and the probability of a salvo to wipe out a nation will also rise, although more slowly.

The problem that engineers need to consider requires them to design controls that operate within limits. They must so arm the United States that another country considering an attack will know that it will receive a violent attack in return. Such armament is called deterrent power. On the other hand, they need to be concerned that building up deterrent power by the United States will lead to building up deterrent power by another country. This interaction is regenerative and leads to a rising probability of destruction of both sides.

The need for deterrent power was presented by Albert Wohlstetter in an article entitled, "The Delicate Balance of Terror."[6] Wohlstetter is an economist for the Rand Corporation, a private nonprofit research corporation working on aspects of national defense and survival. He states that:

> We must expect a vast increase in the weight of attack which the Soviets can deliver with little warning, and the growth of a significant Russian capability for an essentially warningless attack. . . . What can be said, then, as to whether general war is unlikely? Would not a general nuclear war mean "extinction" for the aggressor

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[1] R. K. Plumb, "New weapons peril U. S. life, Rabi says," *New York Times*, vol. 107, pp. 1, 10; January 1, 1958.

[2] W. S. McCulloch, "The brain as a computing machine," *Trans. AIEE*, vol. 6, pp. 492–497; June, 1949.

[3] W. S. McCulloch, "Stable, reliable and flexible nets of unreliable formal neurons," Res. Lab. of Electronics, M.I.T., Cambridge, Mass., Quart. Prog. Rep., pp. 118–129; October, 1958.

[4] K. W. Deutsch, "Nationalism and Social Communication," John Wiley and Sons, New York, N. Y.; 1953.

[5] J. W. Forrester, "Industrial dynamics—a major break-through for decision makers," *Harvard Business Rev.*, vol. 36; July–August, 1958.

[6] A. Wohlstetter, "The delicate balance of terror," *Foreign Affairs*, vol. 37, pp. 217, 222; January, 1959.

Data Input	Data Processors	Output
Radars →	BMEWS and SAGE Computers → Dept. of Defense ↘	
		The President → Decision and Action
Reports from Overseas →	Dept. of State ↗	

Fig. 1—Examples of channels in the man-machine system for making emergency decisions.

> as well as the defender? "Extinction" is a state that badly needs analysis. Russian casualties in World War II were more than 20,000,000. Yet Russia recovered extremely well from this catastrophe. There are several quite plausible circumstances in the future when the Russians might be quite confident of being able to limit damage to considerably less than this number—if they make sensible strategic choices and we do not. On the other hand, the risks of not striking might at some juncture appear very great to the Soviets, involving, for example, disastrous defeat in peripheral war, loss of key satellites with danger of war spreading—possibly to Russia itself—or fear of attack by ourselves.[6]

Wohlstetter concludes that our ability to strike back in spite of attack should make a foreign country's aggression less likely. This is deterrence. It consists of two parts: first, the weapons, and second, the ability to reach a decision to use them.

In arming against Russia, the United States is making a move which may be followed by more arming on the part of the Russians. This is positive feedback. It should be replaced by negative feedback of the kind to be described in the next section.

Let us return now to the problem, namely, how to approach making the kind of decision the President is called upon to make if missiles are detected on their way toward the United States. Dr. Karl Deutsch who has studied this problem suggests breaking it down into the following parts:[7]

1) Broaden the base of facts which lead to a decision.
2) Improve the reliability of the logic and computation used in processing these facts.
3) Shorten the time for making the decision.

Let us apply Dr. Deutsch's analysis to a rough diagram of the man-machine system now used for making emergency decisions. (See Fig. 1.) The upper input illustrates electronic channels; the lower, written reports. The many other inputs have been purposely omitted. Data flow from these inputs through a stage of data processing before they enter the State and Defense Departments. In the executive departments, the new data are correlated with data stored in the files and memories of the personnel. They report to the President and they may recommend action. The President usually chooses between alternatives presented to him. If there is time he will consult with the National Security Council before deciding.

[7] K. W. Deutsch, private communication; February 21, 1959.

We can plot on this diagram the three improvements recommended by Dr. Deutsch. To broaden the facts on which a decision is based, there needs to be a greater input of data. In addition, there need to be better ways of tapping the facts stored in the executive departments. To improve the reliability of logic and computation requires improved data processors. To shorten the time requires an increase in speed of the entire decision-making system.

Pursuit of these three improvements can take us a long way toward a solution of our problem. To go further requires that we look closely first at the human being who holds the office of President, then at the biological computer which learns, remembers, and makes decisions. Delving into these biological mechanisms will allow us to examine possible simulators of memory, ability to learn, and ability to make decisions.

III. History of our Decision-Making System

We have now described the problem this paper considers, in language appropriate to the problem. We began to convert this description to computer language when we made the simplified diagram of the system (Fig. 1) and observed that this is a man-machine system. To progress further in making a description in computer and control terminology, we need to go back to the origins of this man-machine system.

Perhaps by accident, the history of man-machine systems has never been told as a whole. To read present texts on the subject one might be led to believe that man-machine systems are not much more than a hundred years old. Yet books are a kind of machine. Their parts move with respect to one another. Moreover, as a human being reads words in a book, he is letting these words program the biological computer in his head.

Thus, a society that lives by rules written in books is a man-machine system. It has been evolving for 5000 years, from the days when men first wrote on stones and clay blocks to the present when recorded knowledge fills vast libraries. The evolutionary process has been carried forward by inventive people who created new systems when the need arose for them.

Benjamin Franklin might be called the first engineer to apply himself to the design of the American system. We know Franklin for his inventive work in the realms of electricity and heat. He discovered the identity of lightning and electricity and advanced the theory, still valid, that electricity is of two kinds, "positive" and "negative." He invented the lightning rod, a heating system for American homes, and the lending library. In 1754, he started work on the American system of government.[8] The colonies were then threatened by the French and the Indians. The British government called a congress at Albany in the hope of getting the colonies to cooperate in raising troops and funds. Franklin, representing Pennsylvania, drafted the plan which the congress adopted, although the colonies did not.

Franklin's plan, redrafted twenty years later, became the Articles of Confederation, which were the system specifications for the first American government. When a more elaborate system was required, Franklin participated in the writing of the present Constitution.

James Madison was the leading designer this time. Unlike Franklin, he had specialized in the design and operation of governmental systems. He had helped to set up the state government of Virginia. He had served in Congress and observed the weaknesses of the Articles of Confederation. When the prospect arose of writing a Constitution he wrote out a proposal for it.

Adopted in 1789, the Constitution has grown since then by amendments and interpretation by courts. Congress has passed laws and administrators have made rules to carry out the laws. These rules are the programs which public officials pledge that their internal computers will obey.

The system devised by Franklin, Madison, and the other founding fathers is diagrammed in Figs. 2–4. Lines represent information flow. Fig. 2 suggests that each Congressman is ideally part of several feedback loops. The people in a congressional district elect him, then demand action of him. His action may be to participate in writing a new law or in opposing a proposed law. One feedback loop consists of reports by newspapers, radio, and TV. In another loop, the law is carried out by someone appointed by the President. Either the reports shown in the first loop or the impact of the law itself on wages, prices, and other interests of people shown in the second loop, may cause them to change their demand on their Congressman. If he acts to their satisfaction, they usually re-elect him.

The election of the President occurs in another loop which takes four years to traverse. Formation of the Constitution occurs in still another loop with the longest time period of all. Fig. 3 shows the same loops as Fig. 2, but now all of Congress and the whole electorate are represented. The whole body of law enacted by Congress is shown as a block at the center. To it is attached a small block below it, representing the newly enacted law.

A Congressman is also part of feedback loops that include very much larger groups of people than a congressional district. Such groups might be the automobile industry, the United States, or mankind. To show these feedback loops would require a very much more intricate drawing than Fig. 3. The number of these additional feedback loops and the quantity of people that they involve are a measure of the breadth of interests and the statesmanship of a Congressman.

Fig. 4 shows the response that the system was designed to make to an offensive incident or series of incidents by another nation. The incidents bore on the electorate or on special interest groups among the electorate who demanded action from Congress and the President. When a "threshold of tolerance" was crossed, Congress declared war and the President carried out the war through his secretaries of War and Navy. In practice, the incidents may have affected the owners and editors of mass media of communication so that they demanded action from Congress and the President. Or the incidents might come more fully to the attention of the executive than the public and thus the threshold of tolerance of the President would be crossed before that of the public and he would press Congress to a greater degree. This happened from 1939 to 1941.

Germany under Hitler, Russia then and today, lack the free flow of information and feedback controls of the kind described above. They are less stable in their relations with other nations. For example, a treaty, being a law, is part of the feedback control system of the United States. A treaty made by a dictatorship is observed or not as the dictator sees fit.

A system like that devised for the United States could be devised for the entire world and provide stability in that area also. The man part of the system needs to be educated for its task. The machine part needs to be capable of greater speed and reliability than the original system designed for the United States.

IV. Changes to the Decision-Making System, 1950 to 1959

We have described in computer and control terminology the system that operated to repel an attack up to 1950. Let us now look at the changes that have been made in the present decade. Steps have been taken in each of the three directions that we considered desirable in Section II.

Fig. 1 showed the pattern of response that has been taking shape since 1950. Congress is no longer part of the loop of response. In January, 1955, Congress

> handed to the President the power to defend Quemoy and Matsu if he likes, and to use atomic weapons there at his discretion. . . . The pattern is now clear; in the Middle East, as in the Far East, Congress has left it to the President to fight or retreat as he sees fit.[9]

[8] H. C. Hockett, "Political and Social Growth of the United States, 1492–1852," The Macmillan Co., New York, N. Y., pp. 188, 189, 247, 286; 1935.

[9] J. Reston, "War-making power; Quemoy crisis shows how control passed from Congress to President," *New York Times*, vol. 107, p. 4; September 4, 1958.

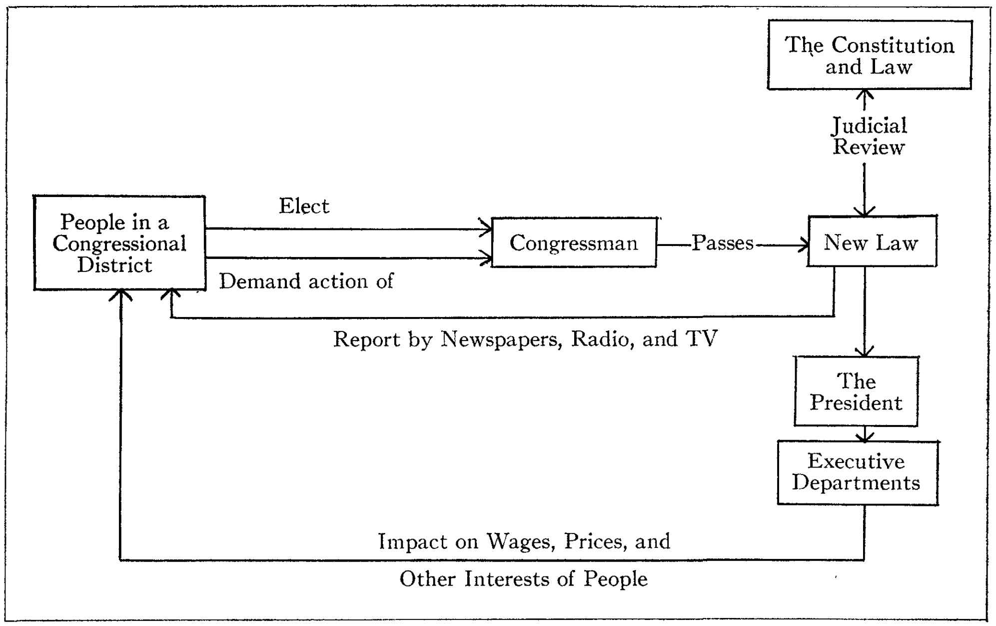

Fig. 2—Congressman in feedback loops.

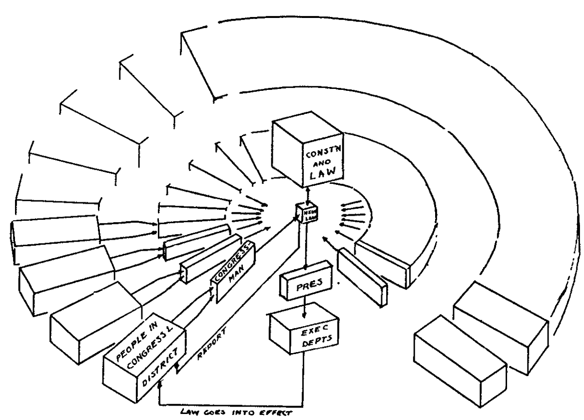

Fig. 3—Simplified block diagram of the United States Government.

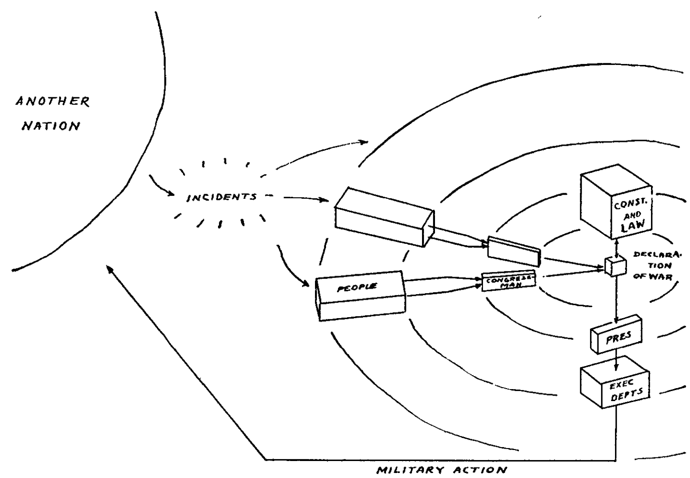

Fig. 4—Response of the United States to an attack, 1789–1950.

This act of Congress formalized the practice begun by President Truman at the outbreak of the Korean Conflict in 1950. This practice has served to shorten the time for making the decision, but I question if it has increased the reliability of the decision. The older system requiring debate in Congress and across the nation brought more minds to bear on the problem.

The flow of facts into the decision-making system has been increased and speeded by two unique electronic systems, SAGE (Semi-Automatic Ground Environment) and BMEWS (Ballistic Missile Early Warning System).

Fig. 5 shows the contents of the upper half of the diagram of Fig. 1 arranged in pictorial fashion. For simplicity, it shows only the part of the system where data are detected and moved at electronic speeds. The flow of reports from overseas to the State Department is assumed to be present but not shown. SAGE computers with radars above them are shown in the inner ring. BMEWS computers with radars above them are

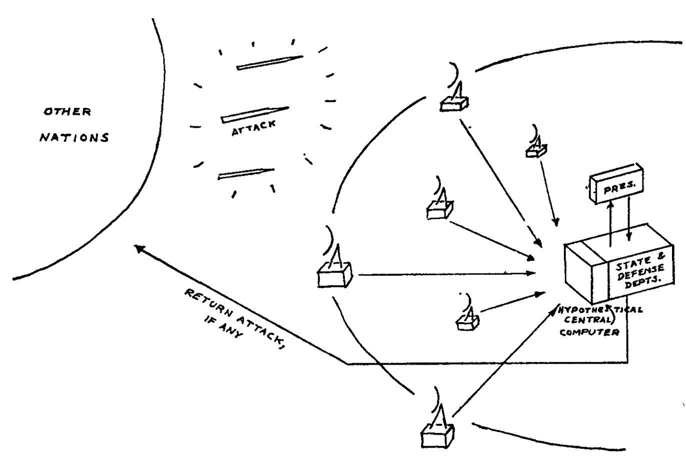

Fig. 5—Hypothetical response of the United States to an attack in the present and near future. (The flow of reports from overseas to the State Department is assumed but not shown.)

shown in the outer ring. Their signals are shown entering a hypothetical central computer which organizes them for presentation to personnel in the Defense Department. These people merge the new data with pertinent data from their own memories or their files. Then they make selections from these merged data to compose reports and make recommendations to the President.

The SAGE and BMEWS systems are part of the improvement to the decision-making process that we seek. They broaden the base of facts on which a decision would be made. Let us examine those systems in more detail.

Sage is a gigantic man-machine system whose radars watch the sky over the United States and feed information into the largest computers so far mass-produced.[10–15] At each of about 30 "direction centers" in the United States, a 75,000-instruction program runs continuously to process the data and display them on large scopes. Fig. 6 shows a typical computer center. Fig. 7 shows this center being fed by information from radars at the left and giving out information to planes and missiles at the right. A tie is shown at the top to higher headquarters and at the bottom to an adjacent direction center.

Fig. 8 shows the point at which the SAGE computer gives up its data to a man who then makes a decision. Here an Air Force officer, looking at a displayed map on which approaching enemy planes are shown, orders planes or missiles to intercept them. The SAGE computer carries out his order by directing the plane or missile to the target.

In 1960 a system is scheduled to go into operation which will inspect in a similar fashion the air space between the United States and other countries. This is the Ballistic Missile Early Warning System (BMEWS) whose radars have a range of 3000 miles.[16] The radar returns will be interpreted by a computer to discover whether each object seen moving at high speed is a meteor, a satellite, or an ICBM. As in the SAGE system, the conclusions reached could be used to generate a display, send a message, or fire an interceptor missile. But it can also do more than SAGE. By tracing the trajectory of a missile, BMEWS can determine where it

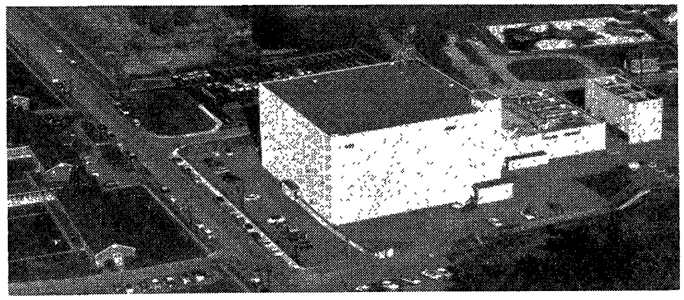

Fig. 6—A SAGE direction center building. (Photograph by Lincoln Laboratory, M.I.T.)

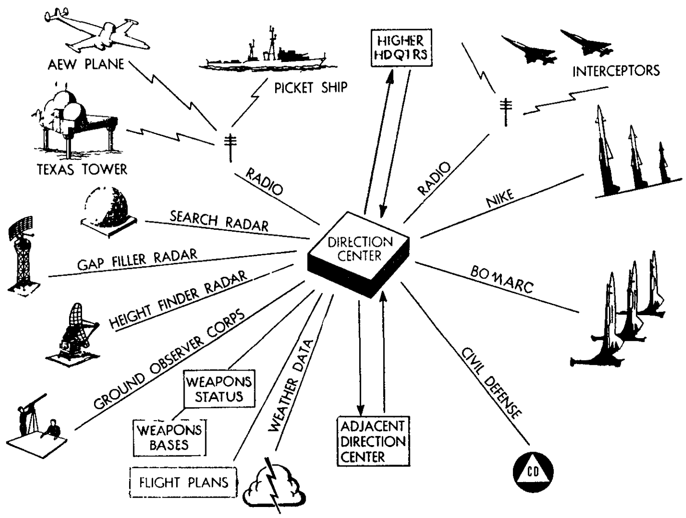

Fig. 7—Inputs to SAGE direction center are from radars at left, weather stations and commercial planes below. Outputs are to planes, missiles, adjacent direction centers, and higher headquarters. (Drawing by Lincoln Laboratory, M.I.T.)

Fig. 8—Air Force officer ordering interception of enemy plane or missile. (Photograph by Lincoln Laboratory, M.I.T.)

came from; then, assuming the missile takes no evasive action at a later stage, BMEWS can predict where the missile is likely to go. The prediction may make it possible to destroy the missile in the air. The estimate of where the missile came from can be the basis for a decision to retaliate.

[10] R. R. Everett, C. A. Zraket, and H. D. Bennington, "SAGE, a data processing system for air defense," *Proc. EJCC*, pp. 148–155; December, 1957.

[11] W. A. Ogletree, H. W. Taylor, E. W. Veitch, and J. Wylon, "AN/FST-2 processing for SAGE," *Proc. EJCC*, pp. 156–160; December, 1957.

[12] R. R. Vance, L. G. Dooley, and C. W. Diss, "Operation of the SAGE duplex computers," *Proc. EJCC*, pp. 160–163; December, 1957.

[13] M. M. Astrahan, B. Housman, J. F. Jacobs, R. P. Mayer, and W. H. Thomas, "The logical design of the digital computer for the SAGE system," *IBM J. Res. Dev.*, vol. 1; January, 1957.

[14] H. D. Bennington, "Production of large computer programs," *Proc. Symp. on Adv. Prog. Methods for Digital Computers*, ONR Symp. Rep. ACR-15; June 2, 1956.

[15] D. R. Israel, "Simulation in large digital control systems," presented at the Natl. Simulation Conf., Houston, Texas; April, 1956.

[16] "The ICBM's: danger—and deterrents," *Newsweek*, vol. 52, pp. 56–57; December 22, 1958.

Congress' response to the threat of nuclear attack has been to increase the effectiveness of the President and at the same time weaken the feedback loops of which the President is a part. This has reduced the sensitivity of the control system to public demands and restraints. It appears that attention should be given to providing new control loops to replace those that have been weakened or removed. But first let us give our full attention to the problems of the President.

V. Problems of the President in an Emergency

The following are two situations that he might have to face.

Fig. 9 shows country *A* (aggressor) launching an attack on country *N* (nonaggressor) intended to both destroy it and prevent it from retaliating. Let us assume that the deterrent power of country *N* is its ability to launch missiles. It appears that in the immediate future, the majority of launching sites are likely to be known, with the result that a retaliatory attack by missiles can be made only if it is started before the original attack arrives. There are several "ifs" here and if they are all to be satisfied, speed of decision is very important. However, when the retaliatory power is hidden, as we are led to believe it will be in a few years, great speed will not necessarily be needed. A reliable decision requiring days if necessary appears far more important, lest an error be made.

However, a circumstance that would demand speed of decision arises when the President's life is threatened by an approaching missile. He has two alternatives: to order a retaliatory attack on a suspected country, or to wait, knowing that if he is destroyed someone else may order the retaliatory attack. Needed is fast processing of data that give him a reliable basis for decision in the time he has available.

As we approach closer to an examination of the duties of the President, let us consider what Dr. Deutsch believes a data-processing system can and cannot do today:[7]

1) Compute trade-offs (if I do this, then what?).
   a) What might be the effect of each of our actions on the civilians in this country?
   b) What will be the effect of each of our actions on the capabilities of the attacking countries?
   c) What will be the effect on third countries?
2) Prepare estimates of the over-all effect of an action.
3) Make recommendations to the President.

No computer today has the learning capacity of an individual, much less that of a community. Computers should facilitate human and community learning by evaluating and cross-checking relevant data. Progress consists of putting more and more of the information-handling burden on the mechanical and electronic equipment and leaving an ever-smaller amount of ever-higher decisions to the human agent.[7]

But suppose the human agent does not respond because he is asleep, as Dr. Rabi suggested, or for some other reason. It is the obligation of computer engineers and programmers to inquire what they can do to supplement the President. The American people may not

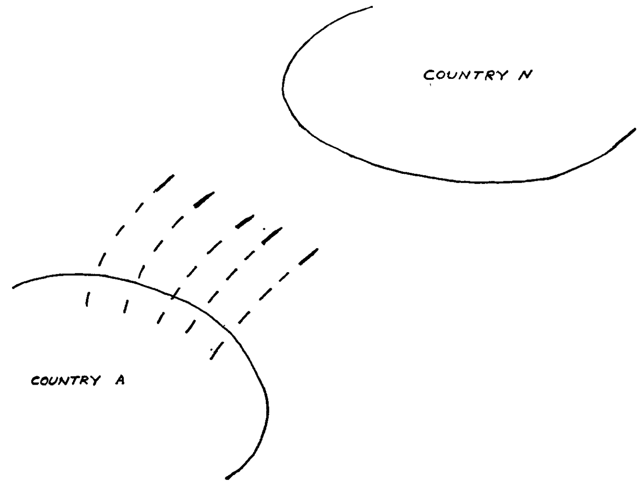

Fig. 9—Country *A* launching an attack on country *N*.

accept what they propose. But proposals should be made periodically and in greater detail as more techniques become available.

To that end a description will be made first of the emergency duties of the President, then of the qualities that led to his selection by the American people. These two descriptions can be regarded as part of the specifications of a simulator. With these specifications before us we will then inquire how far engineers have progressed toward the emergency simulation of the duties of the President.

VI. The Duties and the Qualities of a President

The President's task in the problem we are considering is to order or not to order the military to act. He is there to make sure that the military are effectors, not decision points. For example, in an international crisis, military men get poised, ready to use their weapons. The President, on the other hand, will act the way his personality dictates.

All that we ask of a President is that he be his best self. We mean by this that we ask him to apply to a major decision the traits that he demonstrated before taking office. Yet all of us have our ups and downs. There is always the possibility that a quick decision will be required when the President is not at his best. A system to back up the President, therefore, is being considered.

If such a system were to win the acceptance of the American people it would need some of the qualities of a President. What are some of these?

To avoid the mental images of actual Presidents, let us refer to the President for the moment as a system—a very elaborate biological system. This system is put into its key position by a process whose first milestone is nomination at a national convention. It is then tested for three to four months in a kind of trial presidency during which it is presented with the problems of the President and called upon to declare what decisions it would make if it were the President. During this same time, the system is watched by reporters and TV: How does it treat its wife, its children, its friends? What are its beliefs? Does it get angry easily? During this testing period, an image is built up in the minds of the voters. The image is one of a predictable system, to the extent that the voter has made observations. On election day, at the end of this test period, voters choose between two or more systems.

Looking more closely at a system, we observe that what interests the voters most—or what we think should interest them most—is its information-processing subsystem. This is a network of switching and storage elements. Of the 30 million million cells that comprise a human system about one tenth make up its information-processing or nervous subsystem.

Dr. McCulloch calls this subsystem a "biological computer."[17] Feeding information into it are the senses of sight, hearing, touch, taste, smell, and acceleration. It contains three kinds of memory, a means of learning, and a means of making decisions. It appears that a system to simulate (see the Appendix) the duties of the President will require the following properties of biological computers:

1) Memory
2) Ability to learn
3) Ability to make decisions.

In the following three sections we briefly describe and evaluate the steps that the computer engineering profession has taken toward simulation of the duties of the President. These efforts are for other purposes, but they serve this purpose.

VII. Simulation of Human Memory

By computer memory we mean both the static storage and the continuously running program that up-dates this storage and presents alternatives for decision. Let us look at the memories in both SAGE and in Industrial Dynamics Research programs at M.I.T.

From the data received by its radars, a SAGE computer can predict the course of each aircraft in the airspace which it is monitoring. It can predict the points at which interception can be made by aircraft taking off from different airfields. An Air Force officer, watching the two predictions plotted on a scope, can select an aircraft to make an interception. This action is illustrated in Fig. 8.

Just as the SAGE computer contains a model of moving aircraft, so an Industrial Dynamics program contains the model of a company. In a diagram of a typical model,[18] a solid line represents the flow of goods from the factory to the warehouse, to the retailer, and finally to the customer. Dashed lines represent the flow of information from the customer to the retailer and all the way back to the factory. Numbers in the lines indicate the length of delays. Where a flow of goods and a flow of information touch, a decision is made.

Forrester's diagram represents a more advanced form of analysis than that shown in Figs. 3–5. The analysis itself consists of difference equations.

> The following (typical) equation tells how to calculate the level of *U*nfilled *O*rders at (the) *R*etail (end of the business) at time K:
>
> $$UOR_K = UOR_J + DT(RRR_{JK} - SSR_{JK}).$$
>
> This equation tells us that the unfilled orders at retail at time, K, are equal to the unfilled orders at retail at the previous time, J, plus the inflow minus the overflow.[18]

The inflow is the product of a time interval DT and a rate, RRR, that holds from times J to K. The outflow is the product of the same time interval and another rate, SSR. Each equation is evaluated independently, using the results from the previous evaluation of all the equations. (See the Appendix.)

While the simulator of the President would require facts and figures bearing on current issues, its memory of environment can be approximate. Industrial dynamics models could serve this purpose. The model described above was intended to bring understanding of one company to its factory manager or corporation executive. Models of the groups of companies that make up an industry would be useful to the simulator of a President. Models of the United States government, its allies, and its adversaries would be necessary.

VIII. Ability to Learn

The present system for making emergency decisions is one that learns. The biological computers in the system learn by changing, or increasing, the storage in their memories. The system as a whole learns in several ways, one of which is illustrated in Fig. 3. Here trials and errors are recorded in the memories of human beings and lead to new rules.

The first method of learning we shall consider for the simulator is continual reprogramming. Dr. Richard C. Clippinger suggests:[19]

> It will probably be necessary for the governmental simulator to operate in parallel with the President for a considerable time in order to learn. Computer learning is similar to the successive reprogramming of a complicated process by means of more and more efficient programs, drawing intelligently on more and more past experience. Probably the longer it has been in operation the more efficient it will be, that is, the more it can accomplish in a few microseconds.

[17] W. S. McCulloch, "Reliability of Biological Computers," lecture, University of Pittsburgh, Pittsburgh, Pa.; May 10, 1957. (Unpublished.)

[18] J. W. Forrester, "Formulating Quantitative Models of Dynamic Behavior of Industrial and Economic Systems, Part I," Industrial Dynamics Res., School of Industrial Management, M.I.T., Cambridge, Mass., Memo. D-16, pp. 8, 30, 31; April 5, 1958.

[19] Private communication, October 19, 1958.

The SAGE system learns in the manner described by Dr. Clippinger. A staff of programmers at the System Development Corporation in Santa Monica, Calif., attends the system and incorporates what is learned in an improved program.[14] To "get back into" a program of 75,000 instructions requires careful documentation augmented by computer methods for changing the program. The need to rework increasingly large programs is an incentive for the second method of computer learning we are considering here—heuristic programming or "artificial intelligence."

Dr. John McCarthy describes artificial intelligence:[20]

> These programs all use trial-and-error learning. A criterion for an acceptable solution is known. Then the machine "searches" a group of potential solutions for one answer that meets the criterion . . . . Unfortunately the groups or classes of potential solutions of interesting problems are too large to be examined one at a time by any conceivable computer.
>
> Therefore, we must devise methods called heuristics for replacing the search of the class of potential solutions by a number of searches of much smaller groups. It is in these heuristics that the intelligence, if any, lies.

Programs written by Newell, Shaw, and Simon have proved theorems of logic[21] and played chess, each with increasing skill. A program written by Gelertner and Rochester containing the theorems and heuristics taught in a high-school geometry class has done the homework and taken the examinations of that class.[22]

But each of these programs handles only a limited range of problems. To extend the range we need to tie together a learning system with many storing systems. Each of us needs only to look in a mirror to see a system that does all these things and, in addition, makes decisions of the kind described in the next section. Examination of this system is instructive. Its elaborate transducers facilitate learning. These transducers include the eyes, ears, sense of touch, and inertia-sensitive inner ears. For each transducer there is a corresponding part of the biological computer where information is processed before it is stored. Thus the transducers are not only detectors, they are filters, switching incoming information toward its place of storage. Furthermore, they are adjustable filters. When you are looking for something, you have tuned your detectors to find that thing and ignore other things. Searching for a red ribbon in your bureau drawer, you tune your eyes to search for red and need only make a yes or no decision about each thing you see.

The radars of the SAGE system report only targets moving at a speed greater than a certain amount. However, the filter here is not adjusted by the computer. Moreover, radars "see" with very coarse resolution. Great sums of money have gone into the development of radar. There has yet to be a comparable effort at developing a high-resolution system with adjustable filtering to enable an electronic system to "see" the objects that human beings not only see but think about most of their waking hours.

In the absence of its own inputs, the simulator will have to take in the form of punched cards or electric signals the observations of those who do have these inputs. Lacking a filtering system, it will have to use the classifications of events made by these observers. The classification can determine what heuristics and what part of the memory are to be employed.

IX. Ability To Make Decisions

Decisions can be made by computer programs according to predetermined rules. To run these rules *and* memory of the kind developed by Industrial Research *and*, possibly, a learning routine would make a slow simulator. Speed can be obtained by imitating the human decision system.

The decision-making apparatus in the human system is the reticular formation. It is the core of the brain stem. It is about as big around as a cigarette and about two inches long. Each of the several thousand large cells in this formation:

> receives signals from almost every source in the human body, coded in pulse-interval modulation to convey whence the signal came from and what happened there . . . . The reticular formation decides what he ought to do, what he should heed, how vigilant he ought to be and whether he has time for that idle fancy that inspires his future action.[23]

The method by which the several thousand large cells of this formation reach a decision is similar to that used by a battle fleet.

> Every ship of any size or consequence receives information from the others and sweeps the sky for hundreds of miles and the water for tens of miles with its own sense organs. In war games and in action, the actual control passes from minute to minute from ship to ship, according to which knot of communication has then the crucial information to commit the fleet to action . . . . It is a redundancy of potential command, wherein knowledge constitutes authority.

In the reticular formation, each cell is like a ship of this battle fleet, able to take command when the information it has received is accepted, by all of the several thousand large cells, as that most requiring attention.

Having spent much of his life mapping the nervous systems of monkeys and men, Dr. McCulloch is now studying the nerve connections of the human reticular formation. Every one of the several thousand large cells in this formation is connected to nearly every other. In addition, every one of these cells receives signals from

[20] J. McCarthy, "Getting closer to machines that think," *New York Herald-Tribune*, Engineering News Supplement; May 24, 1959.

[21] A. Newell, J. C. Shaw, and H. A. Simon, "Empirical explorations of the logic theory machine, a case study in heuristic," *Proc., WJCC*, pp. 218–230; February, 1957.

[22] H. L. Gelertner and N. Rochester, "Intelligent behavior in problem-solving machines," *IBM J. Res. Dev.*, vol. 2, pp. 336–345; October, 1958.

[23] W. S. McCulloch, "Where is fancy bred," Bi-Centennial Conf. on Experimental Psychiatry sponsored by the Western Psychiatric Institute and Clinic, Dept. of Psychiatry, University of Pittsburgh School of Medicine, Pittsburgh, Pa.; March 5, 1959.

some of the afferent cells of the body and from some of the cells of the cerebral cortex. This much can be determined from dissection. What cannot be determined this way is how each cell influences every other.

Fortunately, much is known about how the reticular formation performs. From this knowledge, McCulloch is considering a possible logical diagram showing how its neurons may affect each other. The resulting design can be implemented by artificial neurons such as those being built by Jerome Lettvin.[24]

Could the logical design also be implemented by a programmed computer? A small part of it could. Each neuron can be represented by storage registers containing the neuron threshold, the state of the neuron after the last cycle of excitation and inhibition, and the nature of the connections to other neurons. To simulate all of the interconnections in the clock time of the brain would require the processing of at least 1000(!) instructions in 0.1 second.

An assembly of artificial neurons is called a parallel computer, meaning that all logical operations are occurring at the same time instead of sequentially, as in a programmed computer. For the present, parallel logic is a goal to work towards while using programmed logic.

X. When Should the Simulator Be Used?

A programmed simulator, although slow, can render a service now by providing an operating model of the environment of the President, by demonstrating how new rules may be learned, and by demonstrating how rules may be applied to make decisions. Starting as a guide to decision-makers, a simulator could be gradually improved until it might be able to make decisions on its own. It would be for Congress, the President, and the American people to decide if the simulator should be allowed to do this.

Three measures will be suggested as aids in deciding when a simulator should be used in this way. One measure is the extent of internal restraint. As Dr. Deutsch puts it:

> For any large . . . memory system, the specific content of all combinations that might become dominant . . . cannot be predicted. The possibilities are too numerous as to what combinations might arise in a human mind, or in any computer . . . remotely comparable. Hence we fear entrusting political control to any one human mind, or to any small committee, even though we trust them as being human personalities . . . who share the unspoken and unstated values and inhibitions of our culture and religion.
>
> An electronic machine (at present) can include in its memory, at best, only those rules of law, morality and religion that have been stated explicitly in words. . . . These . . . rules a computer would then apply with terrible literal-mindedness. It might become the electronic embodiment of the letter that kills, rather than of the spirit that gives life.

[24] J. Y. Lettvin, "Nerve Models," Res. Lab. of Electronics, M.I.T., Cambridge, Mass., pp. 178–179; January 15, 1959. In the diagram, the unlabelled diode at the left is the excitatory input; that at the right, the inhibitory input. The wiper of the potentiometer determines the threshold.

Limitations of computers, when recognized by engineers, appear to stimulate efforts to overcome the limitations. This gives direction to the development of new techniques of memory, ability to learn, ability to make decisions and the additional categories mentioned by Dr. Deutsch.

A further challenge from him should be quoted:

> To build into a computer the properties of perceptiveness, tolerance of ambiguity, mercy and spirituality—that is, perceptiveness toward second-order and higher-order patterns of preferences—would require capabilities far in excess of those available at present. So long as such vastly greater capabilities have not been developed, computers can aid human judgment but cannot safely replace it.

The second measure we shall consider is the extent and sensitivity of feedback control such as that in Fig. 3. If we find difficulty in trusting one human mind, we shall have greater difficulty in trusting a simulator. However, a control network is possible consisting of many simulators. Given authority to act, a decision would be made by a majority of those simulators that had not been destroyed by attack or sabotage. Each would simulate the duties of a Congressman or group of Congressmen. As Dr. Clippinger has suggested for a simulator of the President,[19] each should be operated in parallel with the one it is simulating so as to:

> . . . (a) learn, (b) demonstrate to Congress and the President that it is worthy of their respect and faith for at least a limited period, (c) provide time to educate and persuade the people of this democratic country that it should be used.

Such a network could have feedback controls as extensive as Congress itself, at least during trial periods.

The third measure of when a simulator should be used is the measure of the emergency when, if Congress, the President, and the American people have previously approved, the simulator would be permitted to act. Seeking this measure takes us back to the question raised by Dr. Rabi. In accord with that, two conditions would make the use of a simulator desirable. One condition is imminence of destruction such as a 90 per cent probability that 5,000,000 people will be killed, a 9 per cent probability that 50,000,000 people will be killed, or any of the equivalent probabilities. The other condition is the inability of the President to respond.

Equipment with extraordinary reliability is needed to determine both of these conditions. The estimate of probable deaths would need to be made by a computer that has both information about approaching missiles and models of population. The President's ability to respond in a predetermined time could be determined by interrogating him, by requiring him to report periodically, or by some other method.

The desired reliability should be obtained either by operating computers in parallel, which is done in the SAGE system, or by applying the theory of building reliable circuits out of unreliable components.[3] The latter requires the kind of parallel logic described in the last section with interconnections and thresholds so selected that the failure or erratic behavior of one or more elements will not affect the output.

Appendix

Definition of Simulation

The word "simulation" is used in this paper in its modern technical sense:[25]

> ... to assume the appearance of, ... without any intention to deceive. I refer to its use in the field of mechanical-electronic computation. Here the procedure is to simulate physical or mental processes in setting up a problem which is then given to a computer to solve.[25]

The Industrial Dynamics Research program at M.I.T. uses the words "make a model of" in the place of "simulate." The model in this case is a set of equations. These M.I.T. people save the word simulate to describe the evaluation of these equations, one at a time, for a given set of input conditions. They solve the equations at time intervals which are short compared to the shortest delay intervals of the system being modeled. They are thus simulating simultaneous solution.

In this paper "simulate" is given the meaning of the first paragraph above. Simulation here is intended to achieve a "quality" equal to or excelling the performance of the human being to be simulated, for the periods when it is given his responsibility. The "quality" of performance is a composite of breadth of facts which lead to a decision, reliability of the logic and computation used in processing these facts, speed, and human considerations. A simulator might attain acceptable quality by excelling in some of these considerations while falling short in others.

[25] J. C. Warner, "The fine art of simulation," *Carnegie Alumnus*, Carnegie Inst. of Tech., Pittsburgh, Pa.; 1959.

Can Computers Help Solve Society's Problems?

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Introduction

THE advent of large-scale computers gave new impetus to mechanizing the handling of tremendous quantities of data. It also indicated the possibility of carrying out many ventures of social significance which are now completely impractical. It is hard to see an important social revolution in the first, *per se*. Automatic billing of telephone subscribers or mechanization of clerical activities, for example, is only substitution of machine for manual activities. This has been going on continuously since the beginning of the industrial revolution. Exciting prospects emerge when one considers fields characterized by enormous amounts of data together with complicated intertwining causal relationships buried under statistical blur.

The present paper considers a few of very many possibilities. They were chosen mainly because one might expect them some day to have enormous impact, both on the individual and on society. The first group bears on the weather and on economic planning and policy, the second on various questions of public health, and the third on "the proper study of mankind," man himself. They are tentative groupings with no pretense to completeness or profundity. It is believed, however, that they make some general statements plausible. These are that modern computer and data handling techniques may

1) lead to making our economic system more productive, and to smoothing cycles of inflation and deflation, or employment, and of farm income;

2) revolutionize our ideas of public health, and make the world a more wholesome dwelling place;

3) revolutionize our knowledge of ourselves, our abilities, susceptibilities, mental, physical and genetic constitution, as well as diagnostic and preventive medicine.

We believe it is the responsibility of the computer engineer and scientist to point out such potentialities, to acquaint specialists in many fields with what computers can do, to collaborate with them in applying computer techniques to those fields, to keep research foundations and government agencies aware of areas worthy of support, to keep administrators, policy makers, and legislators informed and advised, and thereby to assist in the formulation of sound public policies.

In the discussion below, military, industrial, and scientific applications are very largely neglected. This is

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