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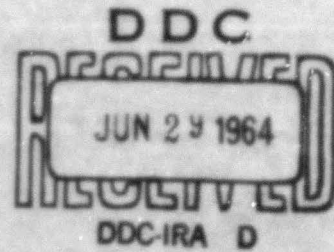
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MAGIC, MATHEMATICS and MYSTERY

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Of all the bumps on the human head that fascinate the phrenologist, curiosity is reputed to be the most developed. And it is unquestionably true that there is much to be curious about in this world; the rain and the wind, the thunder and the lightning, the change of seasons and the growth of crops, sleep and illness, birth and death, all of these natural events which intrigue and interest us as much as they did our remote picture-painting, myth-making ancestors.

These primitives, as well as the tribes that today inhabit the primitive areas of the earth, explained natural phenomena in terms of magic and religion. These were generous religions, endowed with a multiplicity of gods and devils, demons and spirits. There are gods of the sun and of the lightning, the demons who possess the ill, the devils who kill the cattle, destroy the crops, and cause the death of loved ones. Let us not, however, in this discussion look down in too supercilious a fashion upon these beliefs and concepts of different cultures. Some of our most cherished concepts will appear equally amusing and naive to the cultures of five thousand years hence.

The important point we wish to make is that in these early explanations in religious and supernatural terms, we see the beginning of the concept of a unifying scientific explanation. In a recognition of

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the regularity of the forces of nature, we observe a groping towards the concept of natural laws. Each breath of wind is a manifestation of the same power by the Wind God; each jagged lightning bolt comes from the Thunderer, Zeus or Thor; each spring represented the same triumph of fertility over wintry barrenness.

There is a further factor, the matter of control. Magic provided a systematic means for man dominating his environment. Through the intervention of the medicine man, the high priest, or the shaman, by way of personal prayers, offerings, and sacrifices, the individual and the society could exert their influence over the gods and devils. If the crops were failing, the earth required a blood sacrifice, to ensure victory in war, prayers and promises of the sacrifice of prisoners would suffice. Threats and promises, flattery and humility, all were invoked.

It is rather amusing to identify religion as the first science, at a time when Science appears on its way to becoming not only the latest and most fashionable religion, but also the ultimate religion.

What we object to, or should object to, in the invocation of magical explanations and supernatural causes, is the luxury of the situation. The abundance of gods and devils, spirits and gremlins, the ability to create even more of them when necessary, is somehow an affront to our intellectual asceticism. There are too many of them and they don't appear to obey any simple rules and regulations.

Electricity, and certainly gravitation, are as magical in their properties as any soothsayer or haruspex would possibly wish. But we can explain a very large number of occurrences and effects in terms of a few quite simple causes and assumptions. Science certainly does not profess to explain everything. Somewhere, the explanation must cease. All theories at some point become phenomenological, just as all dictionaries must become circular somewhere. How, for example, do we contemplate an "explanation" of infinite

space or infinite time, or of finite space or finite time, for that matter? How do we propose to "explain" the existence of anything at all?

We do, however, expect to reduce the set of unexplained phenomena over time, and to simplify and unite the various conceptual schemes which have been proposed.

The constant battle (in which some are volunteers, and some are drafted) of the scientific method, the rational approach, against fuzziness, dogmatism, superstition and stupidity, has in its clash and clangor obscured the fact that science makes its own strenuous demands on belief. But there is a vast difference in the two types of belief.

Probably the only way to make precise this gulf between what we can call the medieval attitude and the rational attitude is by introducing arguments based upon a Russell theory of types.

Science has systematic ways of making statements, of making statements about statements, and so on. We possess techniques for testing and verifying statements, for constructing theories and for discarding theories, and even for modifying and adapting viewpoints. There are built-in safeguards against the usual weaknesses of human psychology that express themselves in bigotry, fanaticism, stand-pattism and fear of anything new or unknown.

All of this is quite different from the attitudes found typically and habitually among the spiritualists and astrologers, the advocates of telepathy and extrasensory perception, and occultists and cultists in general. Science, for example, does not proudly assert that the greater the paradox, the greater the truth.

It is perhaps well at this point to emphasize that science is relative, not absolute. By this we mean that contemporary science very carefully picks and chooses the areas in which it wishes to compete. The success of science as a whole, as well as success in

individual fields, depends crucially upon choosing the appropriate problems. Even more, we must agree very carefully upon what we mean by a problem and what we mean by a solution. We shall return to this discussion below in a different context.

A corollary of the foregoing is that it is not sufficient to describe the scientist as one motivated solely by love of knowledge. He is driven by his curiosity as an antidote to boredom. This is the real and ultimate enemy of the overdeveloped brain of the human. It is not knowledge, therefore, that attracts, but certain types and aspects of knowledge.

There are many facts available at the present time, and their number is increasing in rather an absurd fashion. There are new chemical compounds, additional insect species, particular and not so particular applications of Lyapunov's second method, expensive and extensive trans-uranic elements, stellar maps, and so on and so on. Some of these are useful, and most are not. Since, however, at this stage of science, we don't know how to sort out the two kinds, we must hedge and collect them all.

The collection and cataloguing of facts do not, however, constitute our principal goals in science. Our objective is to understand the basic patterns of the world. In essence, theories are mnemonic devices for keeping in mind large bodies of data and the descriptions of complex systems.

Thus, we remember formulas such as $F = ma$, or $u_{xx} + u_{yy} + u_{zz} + \phi(x, y, z)u = 0$. The tremendous contribution of a Newton or a Schrodinger lies in the unification provided by a simple formula. How unified a theory of scientific phenomena can one obtain? Since we know so little at this point in time, it is not clear what we mean by the question or an answer. These matters are quite subjective and are best left for cocktail parties.

The language of science is mathematics, for a variety of reasons which we shall not enter into. This places a burden, often intolerable, upon mathematics itself, which is in its native habitat an art form. Naturally, this argument like most arguments, can be inverted. One can say (and it has been said) that mathematics exists solely as a handmaiden of the sciences, and that it is intolerable that some should attempt to make it an art form.

This kind of debate pervades the world of culture; we meet it in art, in music and in literature. Does the artist have a responsibility to communicate (whatever that means), or do these fields exist merely to give pleasure to the creative spirit? We shall carefully avoid these abstract questions which breed so much real emotion. It is, nonetheless, worth pointing out, as a parting shot, that almost all of the best in pure mathematics is the result of investigations initiated in the study of physical phenomena. Who was it who said, "They did not know history and thereby condemned themselves to repeating it"?

Let us turn now to a discussion of some of the consequences of the inordinate and unexpected success of the mathematical method in the physical sciences. As pointed out previously, it is, of course, a matter of choosing the area carefully.

In celestial mechanics, we see the flowering of the effort. The ability of Newtonian techniques to predict the behavior of the planets, the moons, the comets and the tides is uncanny. I have been told that the great French mathematicians, Laplace and Lagrange, could not believe that the observed complicated celestial behavior could be predicted using such simple equations as those deduced from Newton's laws of motion. The more detailed their examination of special cases, the more amazing the agreement.

Successes of this spectacular nature lead naturally to further successes. Mathematical formalism was applied to other

areas of science, science was applied to other areas of life. By the end of the eighteenth century and the beginning of the nineteenth century, it was earnestly believed that mankind, in the scientific method, had at last found the key to happiness on earth. The philosopher's stone was merely a set of syllogisms.

Even by the end of the nineteenth century, this ardent belief in salvation through science had weakened considerably. The barbarism of the two world wars, and particularly the fact that Germany, the most educated of nations, was so instrumental in precipitating the holocausts, cast considerable doubt on the thesis that rationality alone was sufficient. It became increasingly clear that whereas we could easily dispense with the supernatural aspects of religion, we could not do without the moral aspects.

Nonetheless, the scientific method, combined with the mathematical method, continued to play a major role in diminishing the influence of traditional superstition. Not enough, of course, to prevent the appearance of a column on astrology, that Chaldean "science", in almost every major newspaper, nor to prevent new superstitions based on the new religion from arising.

The Constitution that rather explicitly prohibits any intimate connection between the state and the conventional religions is, unfortunately, silent on the subject of Science. We now see Big Science as the new official American state religion. We have our Crusades, our High Priests, our Sacred Language, and even our human sacrifices — the Astronauts.

Science has invaded and pervaded every aspect of our life. So much so, that a number of well-meaning people rather mournfully assert that science has destroyed romanticism. Modern life — so the complaint continues — is not as romantic, or happy, or fulfilling as Victorian, Elizabethan, Renaissance, Medieval, etc., existence. Oh, for the Peace and Tranquility of the nineteenth, eighteenth, . . . , twelfth century.

Let us not bother to dissect and demolish these laments. It is sufficient to contemplate a world without dentists and doctors, without novocaine and anesthetics, antibiotics or sanitation, and a world filled with religious warfare and superstitious fear, a world where poverty was a hereditary disease with no cure in sight.

Turning back to the subject of Romanticism, let us agree that this, whatever it is, is essential for human happiness. Two important aspects are mystery and challenge. As a matter of fact, these are today two of the major arguments advanced on behalf of space travel and linear accelerators. Don't we want to know what's on Venus? Don't we want to discover some more strange particles? Isn't the fact that the mountain is there a sufficient motivation for climbing it?

All of this ties together with our previous discussion, since it shows that the problem of choosing problems is a real one and a serious one. What are our goals, what should they be? How do we propose to achieve them, and do we care that much?

This type of question is of particular importance to those of us engaged in the study of control theory. We know that the choice of the criterion function plays a dominant role in the determination of optimal policies.

I start then with a very simple premise: The most important things on earth are human beings. It follows then that all activities, and certainly all major activities consuming appreciable fractions of the GNP, must be evaluated in terms of their influence upon the health, wealth, welfare and happiness of humans.

Frequently, the reaction to this statement is that it is a very selfish one. Of course it is — and what is wrong with that? It is rather sad to see how the scientific intellectuals have contorted themselves in this connection. As mentioned above, using the concepts of science, they have proudly freed themselves from the

enforced asceticism of the desert and the medieval ages. They have rudely renounced the idea that life on earth is a pit stop on the way to heaven, and they insist that we focus on this world. But, they proudly assert, not on the human aspects! The stars, the interior of the nucleus, the bottom of the sea, all of this they accept as mostly worthy of the attention of the most brilliant and creative minds in our society. Science si, humanity no!

Thus they have renounced one asceticism for another, and a far more dangerous one at that. Spend 20-30-40 billion dollars on space travel, spend one billion dollars on a linear accelerator. Do you dare to ask why? It is for the Glory of Science, and that is sufficient answer.

This is, of course, an absurd argument, but it requires some care in the answering. We pointed out before that the scientist is not primarily interested in human welfare. His curiosity bump may be well developed, but there need not be any overflow into social conscience. We cannot expect him to roll bandages at the local hospital, and we do not want him to.

What we do wish to demonstrate is that the major problems that concern humanity are more exciting, more challenging and more mysterious than those currently occupying so many scientists — and consuming so many tax dollars. Why not optimize then? Why not, indeed?

What then are the major areas for research which possess the desired challenges? There is general agreement that the fields of biology and medicine are the new frontiers of science. This is of particular import to those of us interested in control theory.

The reason for this is that in the biomedical area, control problems are paramount. Although it is true that we wish to understand, it is far more true that we wish to put this understanding to immediate use. Perhaps it is here that we see the real reason for

the decline of the supernatural in favor of the natural. Prayers and magic have not fared well in connection with control processes. Warts and migraine headaches can occasionally be disposed of by means of panaceas and incantations, but cancer, heart disease, hearing difficulties and broken legs require scientific precision.

Unfortunately, the major control problems of medicine are several orders of magnitude more difficult in every possible way than those which we encounter in engineering and applied mathematics in general. The fundamental challenge is that of obtaining partial control now on the basis of our present partial understanding. Furthermore, it is a question of combining theoretical and experimental investigations in one vast adaptive control process. This is the situation we face in attempting to study cancer, nervous disorders, mental illness and other major medical phenomena.

For those then who insist upon challenge and mystery, who pride themselves on tackling only the most difficult problems of their times, we offer the puzzles of the reproductive capacity of the single cell, the memory, or memories, of the brain, the operation of the nervous system, and, on a much less precise plane, the explanation of intelligence and creativity. Observe that these are all problems within the domain of control theory. Furthermore, any hint towards their solution would have tremendous impact not only upon the biomedical field, and the control field, but also upon all of the remaining part of the scientific world, and indeed upon all of the world.

Also in the control field are the problems of prosthetics, covering such items as hearing aids, eyeglasses, artificial limbs and artificial kidneys. All of these represent attempts to remedy the cruel caprices of probability distributions in the replication of the human.

For the first time in history, the alleviation and cure of the ills and afflictions of mankind are within the realm of the possible.

Through the application of control theory, we can, if we wish, help the blind to see again, the deaf to hear, the crippled to walk. We can rejuvenate the old and guarantee a full and happy life for the infant. We can make the deserts bloom and we can end the tyranny of hunger throughout the world.

What direction will our civilization take? Will it continue to squander our resources and sacrifice our brains to Big Science or will it allow the human use of human beings? It is the people in this audience who will decide. I hope that you will make the correct choice, and I believe that you will.