BIONICS

1 INTRODUCTION

The term "Bionics" will in all likelihood come a little strange to many readers; it is in fact a word coined only some years back to describe a science concerned with the possibilities of constructing automata modelled upon real life biological examples.

In fact Bionics springs from a more all embracing title, that of Cybernetics. The late mathematician Norbert Wiener suggested the word cybernetics in about 1948 as a name for the science of control and communication in animals and machines. Cybernetics is involved with and finds its origins in as varied disciplines as philosophy, physiology, psychology, electronics, mathematics, and logic.

Bionics, then, relates to just a small fraction of the field of cybernetics, as does say television to the compass of electronics. We already have some examples of bionics in our midst: such devices as iron lungs, artificial limbs, and kidneys, are typical. However, bionics is lately concentrating its efforts more upon artificial intelligence and machines which have the ability to adapt themselves to their environment.

The concept that it might be possible to construct a machine which demonstrated a degree of intelligence, was developed from the notion that animals (including humans) are essentially complicated machines. Thus, if the *modus operandi* could be established for a biological brain, then it would not be unreasonable to suppose that the same type of principles might be replicated mechanically—better still electronically.

This to a degree is what bionics sets out to accomplish, although in the coming series of articles the term is used in a somewhat modified context. The idea of this series will be to present a number of challenging and often unusual applications of electronics—particular stress being laid on "home brewed" automata. There will be times during the series when we shall consider quite daring possibilities for these automata and the author makes no excuse for their inclusion, for it is of his opinion that some of the concepts may well stimulate further research on the part of the constructor.

This is an "experimental" series of articles and as such will not include detailed constructional information. The series is, however, a forerunner to a number of constructional projects it is hoped to publish later. Perhaps it need hardly be said that the more venturesome experimenter need not wait for these detailed designs, but can proceed straightaway to apply in a practical manner the information presented in this new series.

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The design and construction of electronic "animals" or machines with artificial intelligence

In nearly every one of us there is a latent desire to create. Not only to create, but to create something unique. It is therefore not surprising that since time immemorial man has made numerous (relatively unsuccessful) attempts to devise machines that might imitate himself.

Probably one of the first examples we can find is the lever; not in fact an actual imitation of man, but a device that could aid his physical strength. As time continued, so he produced more and more powerful "muscle amplifiers" (this is, after all what they are), and so if we stop to consider say a huge jib crane capable of lifting some tons, the amplification factor involved may well be in the order of several million. No mean feat, for a man!

AMPLIFICATION OF MENTAL ENERGY

The foregoing examples serve to indicate the "stepping stones" from which man began his attempts to synthesise certain characteristics of himself and other animals. It was not long, however, before it occurred to him that if *muscular* energy could be amplified, so indeed the same should apply to *mental* energy, and so we have the abacus or bead board which certain Asiatic countries are still using with great success.

With the advent of electronics it was at once realised that more rapid and yet more powerful machines could be built; and so we see the giant abaci of today: we call them computers. When electronic computers came into existence the popular press of course tended to over glamourise the machines' capabilities using such anthropomorphic terminology as "brains", "thought", etc. What the press lost sight of was that a basic digital computer however powerful or rapid, is still none-the-less a rather more sophisticated version of a mechanical desk calculator.

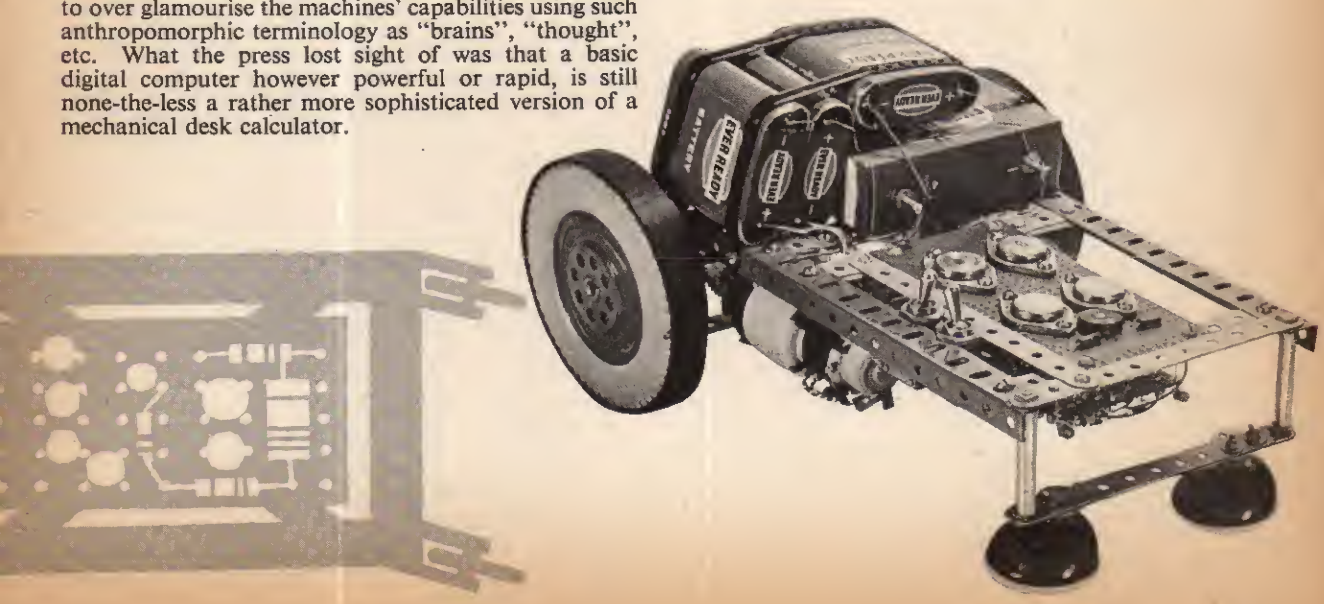
THOUGHT AND LEARNING PROCESSES

Unfortunately, although thought is a very intimate part of us we remain, ironically enough, unable to specify exactly what it is. However, we can say what it is not, and in no wise does any characteristic of a computer (save perhaps memory) qualify the right to be called a thought process. Before a computer can operate at all on the complex mathematics that it must handle, a programme often taking months to prepare and containing very precise orders, must accompany any calculation. If this were not enough, the computer must have all its instructions written in machine language.

It was not until about two decades ago, that man even began to "scratch the surface" of what appear to be the underlying principles of "thought" and learning processes. Although little is still understood, it is now possible to synthesise certain characteristics of the biological brain, albeit crudely, by applying the wealth of electronic principles we now have at our elbow. It is with this in mind, and with the almost limitless possibilities that it suggests that we shall discuss, and even construct, artefacts which will have "memory" and the ability to "learn".

MOBILE BREADBOARD

However, prior to considering rather more exotic devices, from a practical point of view it is a pre-requisite that we design and build some type of mobile breadboard



upon which we can perform modifications and "surgery". This then will be our first consideration, and at this stage an initial glance at Fig. 1.1 will reveal the main structure and "muscles" of the electronic animal.

Generally speaking, those of us whose interests lie in electronics rarely claim a similar zeal for the field of mechanics. In bionics this state of affairs can be a real handicap, because there are all too often times when a particular item just does not exist and one has no alternative but to fabricate. However, most of the mechanical problems can be largely solved by the use of Meccano, which readily lends itself to adaptation and "grafting". In addition, Meccano produce "ready-made" drive gearboxes which can either be used in conjunction with one of their motors, or a motor of the constructor's choice.

As will be seen from Fig. 1.1, the breadboard is basically of rigid box construction, cross members being incorporated to reduce possible twist along the length and increase its strength. The choice of chassis size was very much an arbitrary one; but in fact, providing readers maintain the general format it may be constructed to personal preference.

GEARBOX AND WHEELS

The original model was shod with plastic tracks, but as these are frequently difficult to come by we have chosen separately driven wheels for the device given here. The motor gearbox units are mounted at the rear end of the chassis, and drive power is transmitted via final bevel gears to the road wheels. The forward end of the chassis is supported by a pair of castors; one at each corner. This was found necessary, since a single castor introduced excessive chassis twist.

The "muscles" selected to power our model are a pair of Meccano E15R motor gearbox units, but in fact any reliable equivalent would do just as well provided that the overall gear ratio is kept lower than 160 : 1. Any higher ratio would tend to make the "animal" rather intractable, and apart from anything else accurate observation would become impossible.

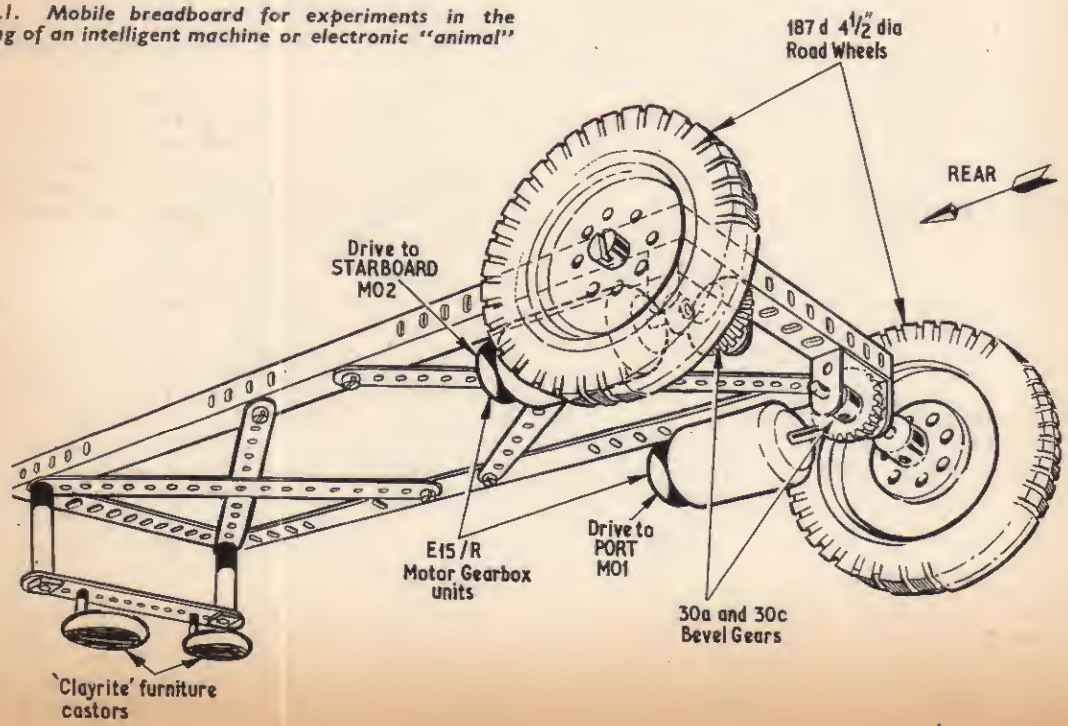
There are, of course, two fundamental methods for controlling the motors: relays and power transistors. As variable (analogue) control of the motors was often required, relays were rejected at an early stage in favour of power transistors. The use of transistors involves somewhat more complex circuit arrangements, but in view of their inexpensiveness and ability to provide more sophisticated control, extra time taken in building the equipment is adequately rewarded.

"MUSCLE" CONTROL CIRCUITS

The "muscle control" circuits are shown in Fig. 1.2. At the risk of causing some slight confusion the right and left hand side motors have been referred to respectively as Port and Starboard—the reason becomes obvious upon reflection because the right hand motor will cause the "animal" to move to port, and vice-versa. Motor Mo1 is therefore Port and Mo2 Starboard: together they drive the animal in forward or reverse directions.

Alternative steering and drive arrangements of course are possible, but owing to various problems that will be apparent as we progress, the present scheme will be retained. In any case there are unlikely to be any actual biological examples which utilise separate steering and motive systems; indeed, steering is usually a function of motivation. In our model steering is achieved as an integral part of the drive functions.

Fig. 1.1. Mobile breadboard for experiments in the building of an intelligent machine or electronic "animal"



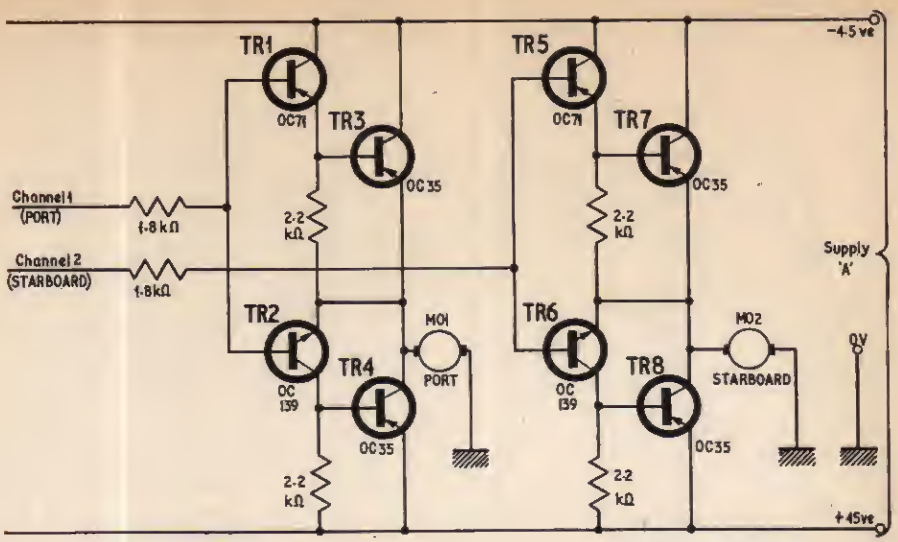


Fig. 1.2. "Muscle control" circuits for a simple electronic animal

TWO CHANNELS

Control over the motors is brought about through two separate channels which can provide facilities for operation in rate of response, scansion, and direction modes. Each channel consists of complementary emitter follower type configurations of *pnp-pnp* and *npn-npn* Darlington pairs. It is essential to ensure that the drive transistors have low leakage, otherwise there will be a pronounced tendency for the motors to rotate even when the inputs are grounded.

Prior to connecting the motors into the muscle control circuit, attention must be paid to establish correct polarity. With a negative input at each channel, TR1 and TR5 will conduct causing their associated power transistors TR3 and TR7 to drive up, thereby bringing Mo1 and Mo2 into operation: these inputs should cause forward rotation of the motors. Reverse rotation results from application of positive inputs, when TR2 or TR6 will conduct to drive up TR4 or TR8.

PRACTICAL POINTERS

All circuits can be built on Veroboard. No difficulties should be experienced in drilling the holes to take mounting bolts for the power transistors. The power transistors for each channel are located side by side and take up very little space; no heat sink being required as even maximum current demands are fairly small.

ANIMAL PSYCHOLOGY AND BEHAVIOURAL THEORY

Up till now, and for quite valid reasons, we have considered only the basic muscle control circuits. Having built and installed them, we shall now be able to concentrate our energies upon somewhat more creative lines.

As discussed previously, we shall consider the feasibility of synthesising electronically certain very limited aspects of memory and learning: these will be eventually incorporated within our mobile breadboard. It is simple enough to build an animal that will react to light and this will be discussed, but before attempting these projects it would at this stage be prudent to re-discover certain basic facts about animal psychology and behavioural theory.

Ostensibly, the problem we are facing appears simple enough: all that seems necessary is to arrange for a design procedure which will fit in with our concept of what a biological animal's psychology is. But then we don't really know completely, even if we examine it. The minute an animal is confronted with the unnatural conditions of a laboratory its responses tend to be artificial. Often, animals are bred in the laboratory, and behavioural tests with these are frequently even more sterile because they have never known a normal environment. On the other hand if an animal is within its normal environment we cannot easily examine it.

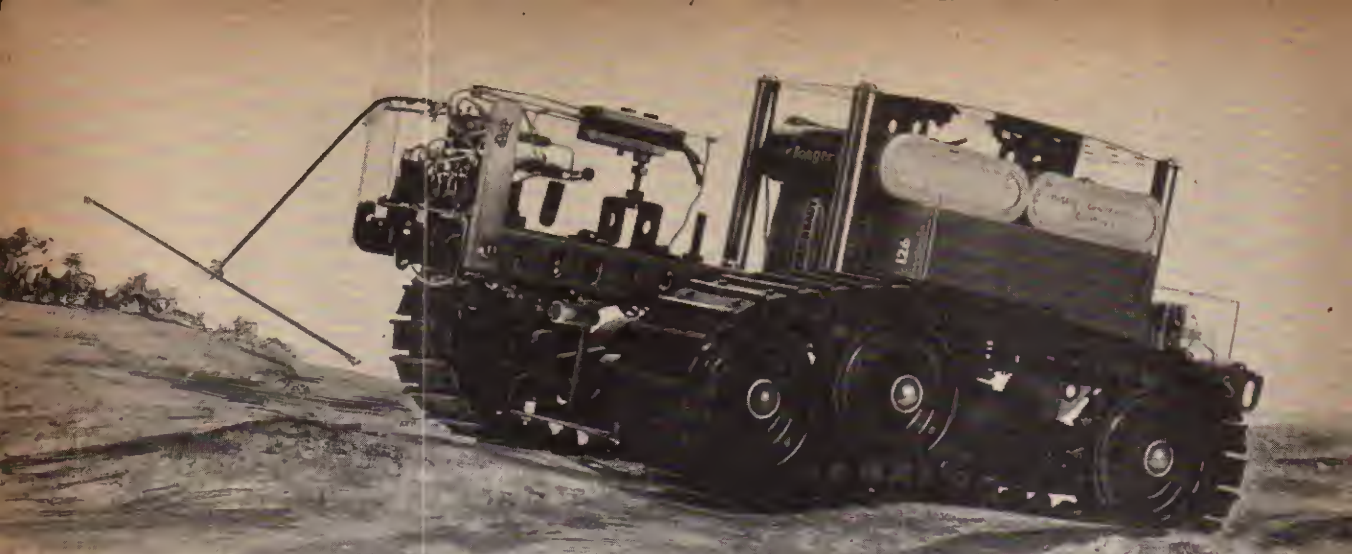
It is gratifying to discover that in our quest for information there are some short cuts that may be taken, so we can, as a cliché suggests "stand on the shoulders of giants". One of these "giants", Pavlov in fact, has already done a lot of ground work for us and it is to a large extent from this and other classical data that we shall draw our inspiration.

BLACK BOX ANALYSIS

In experiments designed to assess the reasons behind certain animal behaviours, "black box" principles have been used. This amounts to qualifying the animal and its brain as an unknown quantity and placing this in a hypothetical box with inputs and outputs. The notion being that if we have known inputs and measurable outputs, a relationship might be established between them which will tell us about the contents of the "box".

This method in principle is a good one, and probably the only one we can safely utilise, because any direct attempts to evaluate the brain and its peripheral equipment by way of surgery necessarily interfere with the animal's behaviour.

However, the black box analysis is not without certain pitfalls. One obvious difficulty is that no matter how many different inputs we apply, there may still remain further modes of response that the animal can produce; thus never giving us a complete look inside the "box".



Another problem arises from the fact that animals often produce responses from what seem to be a whole repertoire of possible actions; it is therefore sometimes impossible to be specific about outputs.

At present then, for our purposes at least, we must be content to base our reasoning along the lines of well tested and easily reproducible features of behaviour. Even then, actual design work must needs be largely based on experiment.

CONDITIONED REFLEX

One aspect of animal behaviour which should show us some rewards upon synthesis, is the conditioned reflex.

Reflexes, or more correctly reflex responses, are due to stimuli exciting certain sensory organs: they may for example be the result of light shone into the eyes, or a touch applied to some area upon the skin. These stimuli having excited a receptor cause nerve impulses to pass along the various neural pathways to the reasoning part of the brain, or cortex. Here they may interact with other types of sensory information either produced simultaneously or stored at some time in the past.

Now the reflex that concerns us is a special condition occurring as a result of the former variety, the conditioned reflex—let us call it R_c. To understand what it is and how it may be evoked, we must hearken back to Pavlov's early experiments.

Pavlov, who performed the conditioning experiments with hungry dogs, used food as a basic drive—this we shall call the "specific" stimulus S_s. The amount of saliva produced upon application of S_s was then measured. When the animals became hungry again, a further stimulus was included which would not normally cause salivation; this was a "neutral" stimulus in the form of sound, i.e. a bell. This we shall designate S_n.

Pavlov found that if S_n was applied shortly before S_s, and the combination repeated a few times, S_n would eventually produce salivation in the same way that S_s did. Hence the animals had *learnt* that the sound of the bell meant food. The neutral stimulus S_n had thus been conditioned to the specific stimulus S_s and so the result of applying S_n at future times was to elicit a conditioned reflex.

There are two important factors to remember if we require the stimulus combination to be successful in producing a conditioned reflex. Firstly S_n should occur *before* S_s *not after*; the reader will appreciate that there is little point in sounding the dinner gong after the meal has been eaten! The second fact is that assuming S_n occurs before S_s, it must be *just* before, or else it will be of no significance. Otherwise it would be rather like announcing lunch, two hours before it was served!

INHIBITION

So far, so good! But we have only considered the excitation mode of conditioning. What if we continue the application of S_n without the reinforcement of S_s? That is, ring the bell without feeding the animal.

The effect of course can be virtually predicted; the bell no longer signifies the coming of food, and so the conditioned reflex is inhibited. The animal therefore no longer responds to S_n. This state of affairs is generally referred to as extinction.

However, an interesting fact emerges from inhibition of this kind, in that it too can be inhibited. One easy way to bring R_c back is to re-establish the reinforcement (S_s).

There are more unexpected ways too: assume we take the case of a dog which, say yesterday, had its conditioned response extinguished. If today we re-apply S_n, back comes the conditioned response as strong as before; even more surprising is the fact that no matter how many times R_c is extinguished it will always re-appear. This "recovery" or disinhibition as it is called, seems to be the result of the inhibition placed upon R_c dissipating with time.

DISTRACTING STIMULI

Disinhibition can occur in an even more striking way, a way which in fact caused Pavlov no end of problems from quite a different point of view. During his experiments there were times when he found it difficult, often impossible, to condition the animals—and it was not long before he realised the cause.

Most of the experiments were conducted in an environment where the ambient noise level was relatively high, resulting in distracting stimuli which either inhibited the conditioning, or caused irrelevant conditioned responses. These strong "external" stimuli whilst inhibiting excitation, will also remove inhibition. Hence, if R_c has been extinguished it can be recalled by the simple expedient of introducing a powerful external stimulus.

With the conditioned reflex mentioned earlier, we considered only two kinds of stimuli. Of course, virtually any stimulus combination could be used, and as we proceed with the design of our electronic "animal" so its need to deal with more and more combinations (some of them quite unusual) will increase.

Next month: "Muscle" control and reflex response.