Chapter 5: Logic

At this point we are ready to make a fundamental discovery. We have gathered evidence for what I would like to call the "law of uphill analysis and downhill invention." What I mean is this. It is pleasurable and easy to create little machines that do certain tricks. It is also quite easy to observe the full repertoire of behavior of these machines-even if it goes beyond what we had originally planned, as it often does. But it is much more difficult to start from the outside and to try to guess internal structure just from the observation of behavior. It is actually impossible in theory to determine exactly what the hidden mechanism is without opening the box, since there are always many different mechanisms with identical behavior. Quite apart from this, analysis is more difficult than invention in the sense in which, generally, induction takes more time to perform than deduction: in induction one has tosearch for the way, whereas in deduction one follows a straightforward path.

A psychological consequence of this is the following: when we analyze a mechanism, we tend to overestimate its complexity. In the uphill process of analysis, a given degree of complexity offers more resistance to the workings of our mind than it would if we encountered it downhill, in the process of invention. We have already seen this happen when the observer of Vehicle 4b conjectured that the vehicle does some thinking before it reaches a decision, suggesting complicated internal processes where in reality there was nothing but a threshold device waiting for sufficient activation. The patterns of behavior described in the vehicles of type 4a undoubtedly suggest much more complicated machinery than that which was actually used in designing them.

We may now take pleasure in this and create simple "brains" for our vehicles, which will indeed (as experience shows) tax the mind of even the most playful analyst. All we have to do is introduce special elements, called threshold devices, which will be either interposed between sensors and motors or connected to each other in complexes that receive some input from the sensors and give some output to the motors.

The individual threshold device is of the simplest sort: it gives no output if its input line carries a signal below the threshold, and it gives full output beyond the threshold. We will also use another variety giving output all the time unless the input carries a signal above the threshold. Each of these devices is fitted with a knob which may be turned to set the threshold, so that the input would become effective with one, two, or any specified number of input activation units. (The word threshold of course implies that, for a given threshold value, any input stronger than the one specified would also be effective.)

We are not limited to the types of connections through which the threshold devices activate each other. We can also use another kind, call them "inhibitory," which counteract the activation that comes from other sources (figure 9).

A diagram of a structure

Description automatically generated with medium confidence

In order to make a brain out of threshold devices, we may connect them together one to one, or many to one, or one to many, or many to one and one to many, in whichever way we like. When you are designing brains, it is important for you to know that in one of these threshold devices the output does not appear immediately upon activation of the input, but only after a short delay, say one tenth of a second. During this time the gadget performs its little calculation, which consists of comparing the quantity of its activation with its threshold.

You can already guess some of the things that a vehicle fitted with this sort of brain can do, but you will still be surprised when you see it in action. The vehicle may sit there for hours and then suddenly stir when it sights an olive green vehicle that buzzes at a certain frequency and never moves faster than 5cm/sec. Since our brand 5 vehicle is not interested in any other vehicles, you might say that the olive green vehicle is its special friend. You will have to conclude that Vehicle 5 has something like proper nouns in his mind, NAMES that refer to very particular objects, like James, Calcutta, or Jupiter.

But Vehicle 5 can do much more than that. It can count (figure I0). It may associate only with groups of four vehicles, not more and not less, to make a party of five. Or it may visit every tenth source it encounters on its way. Or it may turn away from a vehicle whose number of sensors is a multiple of seven, implying that such vehicles bring bad luck. In some way, it seems to operate with NUMBERS.

If you fit such a vehicle with a very large number of shrewdly connected threshold devices, you may get it to play a passable game of chess. Or you may make it solve puzzles in LOGIC or prove theorems in euclidean geometry. You realize what I am driving at: with enough threshold devices it can do anything a computer can do, and computers can be made to do almost everything.

A diagram of a circuit

Description automatically generated

But where is the memory, some of you will ask, realizing that most of the activities of a digital computer consist of putting data into memory, taking the data out again to perform some calculation, putting the results back into the memory, and so forth. The answer: there is room for memory in a network of threshold devices, if it is large enough. Imagine a threshold device connected to a sensor for red light. When it is activated by the red light, it activates another threshold device which in turn is connected back to the first device. Once a red light is sighted, the two devices will activate one another forever. Take a wire from the output of one of the two threshold devices and connect it to a bell: the ringing of the bell then signals the fact that at some time in the past this particular vehicle sailed in the vicinity of a source of red light.

This is an elementary sort of MEMORY. It is not difficult to understand how out of such elementary memory stores (consisting of reciprocally connected threshold devices) complex memories can be synthesized, with the possibility of storing extremely complex events. But there is a limit to the quantity of facts the vehicle can store this way. For instance, when storing numbers, if the vehicle has a bank of ten elementary memory devices, it cannot fit any number that has more than ten digits (in binary notation), since each elementary device can at most remember one digit by being active or inactive ("one bit of information").

There is a trick that can be used by our brand 5 vehicles to overcome the intrinsic limitation of their storage capacity. Imagine a vehicle involved in a calculation in which numbers occur that are much larger than the number of parts in the vehicle's own interior. You might think that such a task would be forever beyond the comprehension of that particular vehicle. Not so if we employ the following strategy. Let's transfer our vehicle to a large, sandy beach. The vehicle can crawl on the beach, leaving marks in the sand indicating the succession of digits in the large numbers that emerge from its calculations. Then it can crawl back, following its own track, to read off the digits and put them back into the calculation.

The vehicle is never able to comprehend these large numbers at any one moment. But using itself as an instrument in a larger scheme involving the environment, and partly directed by it, it ends up with the correct result. (Of course, to be on the safe side, we must suppose that the sandy surface has no limits.) If you want a concrete example, think of the vehicle calculating the difference (small enough for it to comprehend) between two large numbers, which it can produce but not comprehend. It will produce one number by leaving marks on its way along the beach. It will produce the other number on its way back. And then it will measure the difference by counting the number of marks that are in default or in excess of the first number.

Later on, we will learn how to incorporate into a vehicle something quite analogous to the sand outside, and almost as boundless in its capacity.