A Measure of Machine Intelligence

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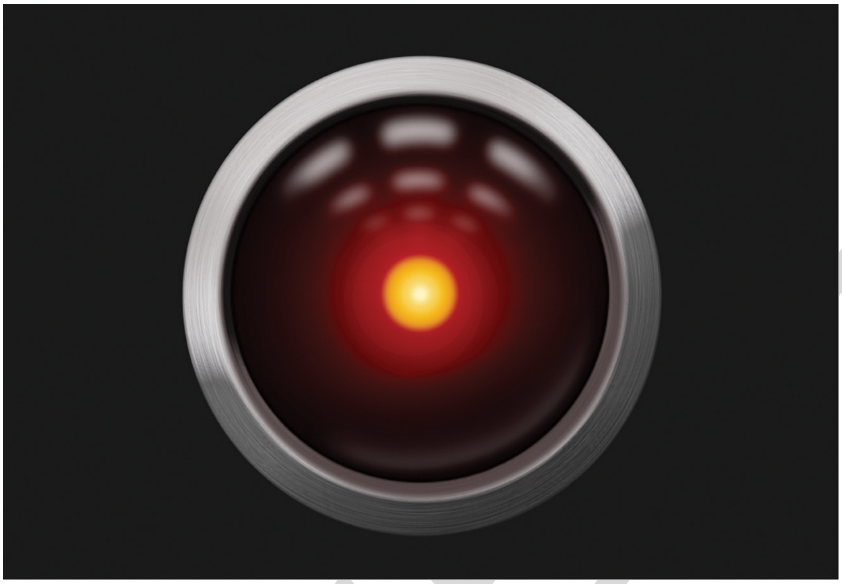

There are two "wisdoms" from my undergraduate days that I have had reason to recall on many occasions. The first came from the lips of an engineering academic with a long and distinguished career in industry. His words still ring in my ears today: "Mr. Cochrane, while it is acceptable for the mathematicians, physicists, and theorists to declare that there is no solution, we in engineering enjoy no such luxury. We always have to find a solution." The second came from a mathematician, again with years of industrial experience. Quite prophetically, he said: "Before you even start a problem, it is worth thinking what form the answer might be, and what would be reasonable."

As my career and technology has progressed, the ethos and necessity of these maxims have grown ever stronger. For sure the world has become a far more complex and faster moving place. So when faced with a recent engineering dilemma that involved the quantification and comparison of "intelligent systems" I found myself alone and without books or published papers to consult.

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At a modest estimate, there are over 120 published definitions of intelligence penned by philosophers and theorists. Unfortunately, none of them provide any real understanding, enlightenment, or one iota of quantification. Worse, the long established IQ measure by Alfred Binet (1904) is both a flawed concept and a singularly unhelpful idea in this instance. The limitations of the approach were detailed by Binet, but then ignored by those eager to apply the IQ concept in its full simplicity and meaningless authority.

A more engineering-based, and commonly used, system comparison technique is to count the number of processors and interconnections, and then multiply the two to create a single figure of merit. This too seems far too simplistic to be meaningful and certainly does not reflect any notion of intelligence. In fact, estimates of machine intelligence growth on this basis would suggest Hal 9000 should be alive and well at this time, but clearly he is not.

What should I do? The problem lay before me, the clock was ticking, a solution needed, and excuses held no value. I decided to go back to basics, real life experiences, signal theory, and thermodynamics. Cutting to the chase, the argument developed went along the following lines.

1) Slime moulds, jellyfish, etc., exhibit intelligent behavior without a distinct memory or processor unit. They have "directly wired" input sensors

and output actuators. Of course, a proviso here is that we exclude the delay between sensing and reacting as a distinct memory function, and the sensor actuator as a one-bit processor on the basis of being so minimal as to be insignificant. In effect, this is a good engineering approximation based on the processing power and memory capabilities of far bigger and more complex machines and organic systems.

2) Mainly, our machines have memory and processing maintained as distinct and separate entities, but this is seldom so in organic systems where there are overlaps and shared functionality. But again, this assumption of separation is true, and will suffice, for the class of machines being considered. I make this distinction because the immediate temptation is to apply this as a general model to organic life, and while not entirely inapplicable, this limitation should be born in mind.

3) While intelligent behavior is possible without memory or processor and simple sensors and actuators alone can furnish that facility, conversely, systems cannot exhibit intelligence without an input sensory system or output actuators. This was recently writ large by a series of experiments on human subjects. Place a fully able human in an MRI scanner, ask then to close their eyes and imagine they are playing tennis, and their brain lights up. Now repeat that experiment with comatose patients of many years and the same result is often evident.So these poor victims have an input mechanism that is functional, but no means of communicating with the outside world. To the casual observer, and until very recently to the medical profession, they have appeared brain dead, mere inanimate entities, living and breathing, but nonfunctional.

4) Our final observation is that all forms of intelligence we have encountered to date invoke state changes in their own, and/or other, environments. A comparison of such change can be an expansion or compression of the quantity of the information in the original input. For example, the answer to the question "why is the sky blue" would contain a far more words and some diagrams, while the reply to "do we know why the sky is blue" would be a simple yes.

At this point, it seemed entirely reasonable to assume an entropic measure able to account for the reduction or increase in the system information or state change, before and after the application of intelligence. Therefore, we begin by defining a measure of comparative intelligence as

$$\begin{aligned}\text{Comparative Intelligence} &= \text{the change in entropy}\\ &= \boldsymbol{I_c}\\ &= \mathrm{MOD}\{\mathcal{E}_i - \mathcal{E}_o\}\end{aligned}$$

where $\mathcal{E}_i$ is the input or starting entropy, and $\mathcal{E}_o$ is the output or completion entropy. We take the modulus value here as we are using the "state change" as our measure. Entropy $\mathcal{E}$ is the amount of information to *exactly* define systems state.

For the purpose of a comparative measure, it was possible to skirt around the complex operations of the sensor, actuator, processing, and memory functions by applying "weighting values" denoted as: $\mathcal{S}$ = sensor, $\mathcal{A}$ = actuator, $\mathcal{P}$ = processor, and $\mathcal{M}$ = memory.

Using entropic change as the defining property of intelligence, a reasonably general formula for simple machines resulted from a combination of analysis and adjustment to meet practical system limitations as follows:

$$\boldsymbol{I_c} = K\log_2[1 + \mathcal{AS}(1 + \mathcal{PM})].$$

We can now observe and immediately confirm two essential properties.

1) With zero processor and/or memory power intelligence is still possible.

2) With zero sensor and/or actuator power intelligence is impossible

These properties are consistent with our life experience and experiment findings (3 above). And a further observation that flies in the face of the conventional wisdom of those that worry about "the singularity" of the machines taking over because the outsmart us is that the speed of intelligence growth is logarithmic and not linear.

So, if we see 1000-fold increase in the product of processing and memory ($\mathcal{PM}$) power, then by virtue of the $\log_2$ function, intelligence only increases by some tenfold. Hence, a full 1 000 000 increase in $\mathcal{PM}$ sees intelligence grow by a factor of 20 times. This is far slower than previously assumed and goes some way to explain the widening gap between prediction, expectation, and reality.

A further important observation at this point is the fact that the sensors and actuators have largely been neglected as components of intelligence. From the above formula, it is clear that they play a really important part in the fundamental intelligence of anything. Interestingly, this fact has been observed in other disciplines but not directly linked to the whole; and perhaps more critically, sophisticated sensors have only recently emerged as "key capability" components in robotics, artificial intelligence, and control systems.

What does all this mean? With the arrival of a myriad of sensor components and their rapid deployment on the periphery of networks, the internet, and robotic, large and small systems, we are really much closer to achieving truly intelligent entities than ever before.

So if this is only a matter of when, and not if, then there is only one questions left to ask: Will we be smart enough to recognize a new intelligence when it erupts on the internet or within some complex system? ■

AUTHOR QUERY

No query.