Knowledge, its hierarchy and its direction

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“The purpose of life is to obtain knowledge, use it to live as satisfactorily as possible, and pass it on with improvements and modifications to the next generation.” The interpretation of these words may be subjective, yet this is what all living organisms—from bacteria to human beings—do in their life time. Evolution points out the direction in biological systems for acquiring, processing and communicating information. Comparison with the computers we design illustrates the hierarchical architecture of information processing. We are now in a position to make the underlying principles mathematically precise, and to exploit them as far as the laws of physics permit. That will decide which questions are relevant to the future of life and which are not.

I. INTRODUCTION

The topic of this workshop, concerning cognition and consciousness, is such that it is hard to avoid philosophical overtones, and I shall make no attempt to do that. But underneath all that I am going to say, I am a physicist, and that will show through in my presentation.

I am going to talk about knowledge—its structure, manifestations and implications, as we have interpreted them over the ages. Let me begin by showing you an instructive example, which is a video of a white blood cell (neutrophil) chasing a bacterium [1]. This process of phagocytosis progresses from physical sensation to decision to action. Both the neutrophil and the bacterium could not have done what they did without a certain sense of awareness of their surroundings and who they themselves are. If you watch closely, you will even observe an instance when the neutrophil makes a choice between which of the two detected bacteria to go after.

Now consider the hierarchical levels of experience analysed in the traditional Indian philosophy, and summarised in Table I. The levels progress from inductive to deductive to abductive logic, and neutral to objective to subjective view of reality. With a little bit of thought, we can surmise that phagocytosis exhibits all these seven stages of experience, and the stages are not independent but closely tied together. Acquired knowledge, ranging from immediate sensation to the memory based on prior experiences (going all the way back to what is written in the genes), is at the heart of this process.

To what extent can we understand the interlinking of the hierarchical structure, in this simple example? That will be at the root of how we interpret knowledge and consciousness.

II. THE MEANING OF LIFE

What is the answer to the ultimate question of life, the universe and everything?

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according to the Hitchhiker’s Guide to the Galaxy [2]. That is anticlimactic, and was meant to be a parody, but is there really a better answer to such a question? All our philosophical enquiries frequently come down to our view of ourselves: Why are we here? What is so special about us? What is our future? And so on. Science does have something to say about such an anthropocentric outlook!

Let us look at our location in space. The universe has billions of galaxies, each with billions of stars and a similar number of planets orbiting the stars in the habitable zone. Our sun is an average star occupying a non-descript place in our galaxy (called the Milky Way or अकाशगंगा). On the scale of a printed picture page of our galaxy, the sun would be smaller than an atom. Clearly there is nothing special about the position of our earth in the universe.

Next look at our location in time. The universe is approximately 13.7 billion years old. In the beginning, it was an extremely tiny, dense and hot ball of elementary particles (no atoms). Atoms formed as the universe expanded and cooled. Our sun is about 4.5 billion years old; it is not a first generation star. Life on earth appeared around 3.8 billion years ago. Human beings (Homo sapiens) appeared on earth around 100,000 years ago. If the age of the universe is scaled to a day, human existence on earth would be for less than a second. It is hard to find anything special about the time of our appearance on the earth either.

Let us broaden our viewpoint and look life itself as a whole. The universe has billions of planets that can support life. Single celled life forms outnumber and outweigh(1) multi-cellular ones, and are ubiquitous. For complex living organisms on earth, average lifetime of a species is about 4 million years. Most living cells seldom last more than a month or so. Individual components of cells are constantly renewed. There isn’t a single bit of any of us (not even a molecule) that was a part of us nine years ago! The atoms in each DNA strand get knocked off and replaced, in a continuous jostling with other molecules, ten thousand times a day [3]. There is hardly anything of permanence even for all of life.

So what meaning can be extracted from all this?Atoms are fantastically indestructible as far as life is concerned; they just get rearranged in different ways. Each of us would have a billion atoms that once belonged to the Buddha, or Genghis Khan, or Isaac Newton—may be an exciting or may be a sobering realisation! It is not the atoms themselves but their arrangement, which carries biochemical information. Life is fundamentally a non-equilibrium process. Living organisms evolve, even as the atoms keep on shuffling. To put it in the language of computer science:

Hardware is recycled, while software is improved!

It is the accumulated software, stored in various types of memories, that provides the identity to an individual.
TABLE I: Hierarchical levels of experience, their level of operation, and the questions they address, according to traditional Indian philosophy.

<table>
<thead>
<tr>
<th>Mode of experience</th>
<th>Level of operation</th>
<th>Question to be answered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bodily sensation</td>
<td>Body (मार्गीत)</td>
<td>What is happening?</td>
</tr>
<tr>
<td>Sensory perception</td>
<td>Senses (आरोग्य)</td>
<td>What is this?</td>
</tr>
<tr>
<td>Perceptual conception</td>
<td>Outer mind (सत्ता)</td>
<td>How come this?</td>
</tr>
<tr>
<td>Conceptual reasoning</td>
<td>Intellect (वृद्धि)</td>
<td>Why this and not that?</td>
</tr>
<tr>
<td>Reasoned judgement</td>
<td>Inner mind (चिन्ता)</td>
<td>What is its meaning or purpose?</td>
</tr>
<tr>
<td>Judged action</td>
<td>The ego (अहंकार)</td>
<td>What ought to be done?</td>
</tr>
<tr>
<td>Acted realisation</td>
<td>The self (आत्मन्)</td>
<td>Who am I?</td>
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</tbody>
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III. EVOLUTION: DIRECTION VS. GOAL

As keenly observed by Theodosius Dobzhansky, "Nothing in biology makes sense except in the light of evolution" [4]. Over billions of years, biological evolution has experimented with a wide range of physical systems for acquiring, processing, selecting and communicating information. In this history, evolution has been dominated by changes at the genotype level, and selection at the phenotype level. We carry two lasting signatures of this evolution: (a) all living organisms begin life as a single cell, and (b) the genome is inherited as a read-only-memory.

In Table 2, I have described the development of systems for conveying information as living organisms evolved. The process has not stopped, and its continuation hardly requires any persuasion. Look at the number of gadgets that we were not born with but we have become accustomed to carry: spectacles, pens, watches, mobile phones. It is easily noticed that evolution has progressively discovered more and more sophisticated mechanisms, which expand our range of knowledge acquisition and communication. In this natural selection,

- Communication range expands in space and time.
- Physical contact reduces.
- Abstraction increases and succinct languages arise.
- Complex translation machinery develops.
- Cooperation gradually replaces competition.

Here also we observe that the various systems involved are interlinked in a hierarchical fashion.

There is a lesson in this pattern. Environmental hazards exist at all scales, and knowledge helps overcome these hazards. As a result, the increasing reach of knowledge has become the driving force behind "survival of the fittest". It provides the direction for evolution, even when the goal is unclear.

Indeed, direction is needed to go forward, but goal is not! The bacteria existing billions of years ago had no clue whether they will evolve into tall trees, fearsome dinosaurs or smart human beings, and we can only guess what living organisms may turn into in future. Evolution has followed a bottom-up approach. That can be fully self-contained, as long as direction is available at every step.

On the other hand, many of our queries arise from a top-down approach. A typical situation would involve finding the direction for a specific goal, which is a non-trivial exercise. Is that the correct strategy for deciding our actions, or a waste of effort and cause for misery? (Note that the dynamics is local in physics, and the space-time range of exploration is always finite, while global constraints provide conservation laws.) The fact that we are better off concentrating on the direction of action, without worrying much about the final result, is forcefully expressed in the following ancient wisdom:

कर्मण्यवाधिकारणे मा फलू न कर्मचारन
—भगवद्गीता ३.७३

Thy right is to work only, but never to its fruits.

IV. LIVING ORGANISMS VS. COMPUTERS

With increasing reach of knowledge, human beings have become capable of asking (not necessarily answering) more and more elaborate questions. To put that in perspective, let us compare the hierarchical processing of information in living organisms and in computers. We have a good understanding of what goes on inside computers because we know the basic principles that we have used to design them.

We use the terminology where data represent a particular realisation of the physical system among its many possible states, information is the fungible abstract mathematical property obtained by detaching all physical attributes of the data, and knowledge is the practical outcome obtained by adding appropriate interpretation to the abstract information.

Table 3 illustrates how in the hierarchical structure of information processing, translation machinery (e.g. compilers) maps high level instructions to low level executable tasks.
Subjective, varied and abstract higher levels are irrevocably tied to objective, limited and physical lower levels. Both top-down (↓) or bottom-up (↑) designs, indicating where the fundamental programme is written, are possible. Obviously, genetic approach is bottom-up, while conscious effort is top-down.

Bottom-up construction can make programmable devices, e.g. the fertilized egg knows how to produce a brain without knowing what will be stored in it. Top-down feedback can select and modify the rules, e.g. we can select stem cells and alter the genes towards a specific goal. But neither can work without an understanding of all the intervening levels. As far as life itself is concerned, there is little doubt about what came first; “how to learn” has always been more more important than “what to learn”. But we can now look at alternatives.

V. ARTIFICIAL INTELLIGENCE VS. LIFE

Evolution works by generating a variety of possibilities, and then selecting appropriate ones from them. They do not have to be restricted respectively to genotype and phenotype stages only. In programmable devices, the corresponding features are “imagination (↑)” and “feedback (↓)”. (Their successful combination allowed Deep Blue to beat Garry Kasparov in chess.) Let us consider what they involve.

In imaginative exploration, memory (pattern recognition based on past history) has a crucial role. In generation of new possibilities, random random choices are convenient at small scale, while mix-up of established features is efficient at large scale. Selective feedback reduces choices and focuses progress. Clever amplification/suppression can specify priorities, deciding what to retain and what to forget. Clarity is increased by digital punctuation of analogue processes.

We are now using these ideas to build intelligent devices. But let us turn the attention back to ourselves. In our experiences, children are good at imagination. At that stage, the brain is more programmable, although the failure rate is higher. On the other hand, adults are good at feedback. The brain becomes more filled with memory, and that offers higher security in selecting tasks. Both imagination and feedback are essential for progress. But a balance has to be struck between the two, because too much exploration is wasteful and excessive feedback hinders exploration. When the computers get too cluttered, we save the important stuff, then wipe the slate clean and start all over again. Life’s answer to the same conundrum is similar: The cycle of life and death “reboots” the system. Contributions of children and adults then alternate.

It is worth noting that every level of knowledge in the hierarchy (see Table 2) has a role to play, and it can be tinkered with using appropriate methods. The changes can be permanent, provided one can control the translation machinery between the levels. Development of higher levels of knowledge communication, not just the genetic one, illustrates that life has grasped this fact. It can be observed that the capability to pass on knowledge influences life expectancy: For primitive living organisms, reproduction is usually the last stage of life, some advanced ones live longer to take care of their children, and a few (like us) live even longer to look after their grandchildren.

Our efforts to build increasingly powerful and versatile computers have taught us a lot about acquisition, processing and communication of knowledge. It is no longer an exercise of trial and error, but it is a problem of systematic design. It is not unrealistic to say that we are now in a position to figure out the whole machinery of life, and to exploit it as far as the laws of physics permit.

VI. CONCLUSION

According to Gödel’s theorem, any consistent axiomatic system allowing recursion cannot be complete, i.e. it will contain precise but unprovable statements. The well-known example is the “halting problem”, where a universal computer is unable to determine whether a given programme will halt or loop indefinitely. Life is complex enough to make certain questions about goals unanswerable. Fortunately, questions about directions can always be answered, and that is sufficient for progress. Indeed, all the instructions contained in the genetic machinery are about directions and not about goals.

Thus life’s exploration of knowledge will continue, with the hierarchical structure and memory playing indispensable roles, and pointless questions getting discarded along the way. Let me then end with an invocation for peace (शांतिमन्त्र):

...तमसो मा व्याहतिमय... Lead me from darkness to light.