Intelligence - consider this and respond!

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Abstract. Regarding intelligence as a 'considered response' phenomenon is the key notion that is presented in this paper. Applied to human-level intelligence, it seems to be a useful definition that can lend clarity to the following related aspects as well: mind, self/I, awareness, self-awareness, consciousness, sentience, thoughts and feelings, free will, perception, attention, cognition, expectation, prediction, learning. Also, embodiment is argued to be an essential component of an AGI's agent architecture, in order for it to attain grounded cognition, a sense of self and social learning - via direct physical experience and mental processes, all based on considered response.

Keywords: AGI, Artificial General Intelligence, Artificial Intelligence, evolution, adaptation, intelligence, response, embodiment.

1 Introduction

AI is a venerable field, quite broad in scope, ambitious, and, over 60 years old, [1], [2], [3]. Even at the 1956 Dartmouth Conference that 'birthed' AI [4], there was not an agreed upon definition of intelligence; instead, the program description included this: 'The study is to proceed on the basis of the conjecture that every aspect of learning or any other feature of intelligence can in principle be so precisely described that a machine can be made to simulate it.'

A formal lack of definition has meant that the field diverged in its goal, scope, techniques - today we are the benefactors of rich set of these, and lately, a handful of techniques (based on Deep Learning, a subset of Machine Learning, a subset of AI) have begun transforming societies worldwide. Nevertheless, the achieving of human-level intelligence and beyond, generally termed AGI, has elusively and tantalizingly remained beyond reach thus far.

In this paper, we make a modest attempt at reframing the notion of 'intelligence', to make it be applicable to the diversity of it in the natural world - this is in contrast with the more common descriptions that pertain mostly to human-level intelligence (eg. involving logical reasoning, planning, problem-solving, natural language, etc.) on which AI has been focused.

In turn, this lets us provide working definitions of associated concepts such as consciousness, perception etc., which have also not been mainstream AI topics.

Embodiment, which has been largely ignored by AI for the most part, is considered in light of the proposed intelligence reframing, as an essential aspect that could lead to AGI.

2 Postulates on intelligence and related phenomena

The following 15 items (axioms) are presented, without proof or even strong evidence/argument; nevertheless, taken together, they do provide a unifying view of a variety of terms that are used in AI, cognitive science and philosophy. The idea is to be able to use them for constructing biologically-inspired AGIs; the descriptions for the items are rooted in biological (higher animal) existence - obtained from observing others (including animals), wide-ranging study of existing literature (involving neurological studies), and old-fashioned self-examination. In addition, they do seem to be useful launch points for BICA-AGI-related discussions. Here are the items:

- **Intelligence:** all form of **intelligence is considered response** (often referred to as C→R, or simply, 'CR', in what follows). For instance, intelligence is a situated agent's considered response to its environment. The considerations are viewed as **processes**, whose **responses** constitute intelligence. The rest of the items that follow (except for the last one) are described in terms of consideration processes and/or responses, and apply primarily to higher-level (animal-like) intelligence.
- **Mind:** the mind constitutes a collection of independent, interacting **processes** that carry out consideration tasks.
- **Self/I:** the 'self' is a privileged, meta ('higher') level **process** which (learns over time that it) 'owns' the rest of the processes as well as owning the body+brain in which it resides - the owner is the 'self', the 'self' is the owner.
- **Awareness:** the 'self' process just **responding** that is 'ready'/'on' [but not 'for' anything in particular], is 'awareness'.
- **Self-awareness:** the 'self' process **responding** to (acknowledging) itself is 'self awareness' - 'I exist'.
- **Consciousness:** the 'self' process **responding** to (being aware of, ie. considering and acknowledging) sensation is said to be 'conscious'.
- **Thoughts and feelings:** thoughts and feelings are **responses** - of consideration processes that usually involve access to memory (in which is stored the agent's ongoing life experiences, skills, facts and more). In the brain, both thoughts and feelings are manifested as electrical activity (occurring in neural populations), or chemical activity (via neurotransmitters); feelings can also trigger, or be triggered by, physical responses which we term 'emotions'.
- **Sentience:** the 'self' process considering and acknowledging its feelings is said to be 'sentient' - it is a subjective **response**
- **Free will:** the 'self' process considering a situation and creating response choices, being aware of those choices (ie. considering, acknowledging them) and picking one of them as its **response**, is said to exercise 'free will'. Free will is somewhat of an illusion - it seems to exist, given the lack of predictability on an agent's part,

from the points of view of other agents (since they do not have access to the free-will-exhibiting agent's consideration processes and memory contents).

- **Perception:** perception is the **process** of considering sensory data (which involves more than merely labeling it), using prior knowledge and experience stored in memory, in order to subjectively interpret it.
- **Attention:** attention involves selective consideration/**processing**, by the self, of whatever is salient at the moment, within the agent and/or its environment; attention (focus/concentration) is how the self exerts control over ongoing CR processes - attention strength can vary, and attention can be split.
- **Cognition:** these are the **processes** underlying various forms of consideration.
- **Expectation:** expectation is an internal **response**, to a consideration process that involves perception of the environment (which can include an agent's own body), and subsequent matching against an internal, subjective model of the world. The agent's considerations and/or responses are adjusted to minimize mismatches - this is often the goal of intelligent behavior.
- **Prediction:** given its personal 'version' of the world and the current state of it to consider, the brain is constantly predicting the next state - it is also a **response**. Prediction and expectation are often conflated, but it useful to look at prediction as a lower-level consideration process, which feeds into the expectation process (which can involve cognition in addition).
- **Learning:** learning is an ongoing accumulation in memory, for the most part (with corrections and deletions as well), of what to consider, and how (and where pertinent, why), for the purposes of responding. Learning is augmented by 'experience' - it consists of not only objective knowledge about the world, but also, personal (subjective) aspects such as skills and capabilities, beliefs, habits, etc.

In summary: in order that higher level, (eg. human-like) intelligence can be exhibited, evolutionary adaptation has resulted in an electrochemical processor (brain), which, coupled with the body it is housed in, can consider and respond to externally and internally generated inputs, via a set of ongoing, interacting 'CR' processes that make use of, and contribute to, accumulated experience - mediated by the self when necessary.

3 Discussion

In the following subsections, we are going to consider what can follow from the 'considered response' notion, aspects of human intelligence, and a case for embodiment.

3.1 Intelligence - a continuum of responses

A wide variety of definitions for intelligence exists, but almost all are focused on higher level brain processes such as reasoning and problem-solving. For example, after collecting more than 70 definitions, Shane and Hutter summarize them like so: 'intelligence measures an agent's ability to achieve goals in a wide range of environments' [5].

The diversity of intelligence in the natural world (including simple reactive creatures, swarm intelligence that emerges in collections of bees, termites [6], fish, and birds [7], alien-like octopus brain 'wiring', animals and birds with a wide range of sensing, capabilities and behaviors, and of course, humans) suggests that there is a common underlying principle, one that is simple, elegant, and extremely widely applicable, and is likely tied to evolution! It is such reasoning that leads us to the following realization: intelligence is a biological phenomenon tied to evolutionary adaptation, meant to aid an agent survive and reproduce in its environment by interacting with it appropriately - it is one of considered response.

To make an analogy with computation, consideration is equivalent to executing a function or process, whose algorithm handles inputs, possibly accesses additional stored data in memory, and returns (responds with) a result - consideration is the processing, and response is the result.

The notion of intelligence being a response, helps us place it in the following response continuum, based on structure-property consideration.

Simply put, structures, from the microscopic to human level to cosmic level, organic and inorganic, exhibit ('respond with') phenomena on account of their spatial and temporal arrangements, under conditions external to the structures. This can sometimes result in new structures that display phenomena appropriate to them, and this process of structure+phenomena creation could continue.

For example, molecules in ice vibrate when heated, eventually turning into liquid water - a different structure which undergoes its own phenomenon (flowing); sand dunes form wave patterns in response to wind, which then result in sound production on account of the periodicity - structures exhibiting phenomena could result, as a response, in further structures that exhibit their own phenomena. Not only can the formation of the Milky Way, the solar system and the Earth be considered responses (to universe-scale matter, long and short range forces, space, time and energy), so can the origin of life itself, on our planet: given ideal conditions that exist here, primordial carbonaceous structures must have undergone phenomena that resulted in life-bearing forms that exhibit the phenomena of survival and reproduction!

The continued evolution of simple life into multi-cellular organisms, sea creatures, and land dwellers, and their underlying adaptations are of course, responses to environmental factors, guided by an unseen hand as it were. In this scheme, intelligence becomes another type of response, exhibited by a variety of biological structures in a variety of ways, for purposes of survival and reproduction. More generally, life can be regarded as being comprised of evolved structures and processes that involve information, energy and matter based interactions with their environment, for purposes of survival and reproduction; the information-processing ('considered response') aspect is what can be termed intelligence. In this view, intelligence is seen as a requisite component of all forms of life.

In plants, intelligence is manifested in the design of their immobile structure - strong roots, thick leaves, thorns, bright flowers, etc. In lower animals, the structures that exhibit reactive intelligence are their simple nervous systems. In collective animal colonies (ants, termites, bees, birds, fish... as noted above), the evolved design response seems to be a two-stage one - evolution of simple actions to be performed us-

ing simple brains, which are able to result in global ('emergent') behavior, which could be considered to be the response of a colony-level, self-organized structure. In addition, mimicry, camouflage, aposematism, symbiosis, stygmergy... can all be seen as intelligence-related design responses in form or the other, meant to aid the predator, prey, individual or the colony.

Moving on to higher animals including humans, the intelligent response by the individual stems from a more developed brain (and better co-evolved bodies) that can form memories, develop complex skills, develop communication, etc.

In all cases, it is structures that exhibit specific phenomena, which we regard as their response, intelligent or otherwise - note that we only attribute intelligence to specific biological structures designed (evolved) chiefly for survival and reproduction.

3.2 Human intelligence

Now we look at how the notion of considered response can shed light on the complex phenomenon that is human (and other higher animal's) intelligence.
Fig. 3.1 shows what consideration and response might look like, in a human brain.

Consideration produces as response the following: thoughts, feelings (physically manifested as emotions), and actions (including vocalizations (which encompass verbalizations)).

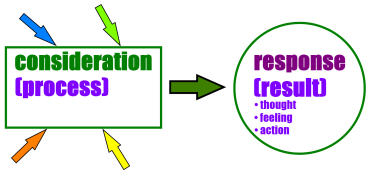

Figure 3.1. Consideration and response.

The consideration process gets as its inputs, sensations from the environment (which includes the agent's own body), contents retrieved from long term memory, as well as responses from other ongoing and prior considerations. These operate in a continuous, parallel, interacting, shared-memory fashion (where they retrieve as well as write to long term memory, and working memory) - this is precisely what gives rise to the complexity of human thought, feeling and action (including language). This is illustrated in Figure 3.2 below.

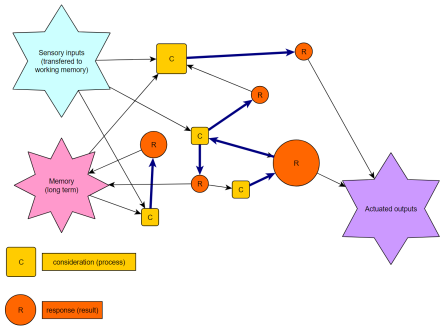

Figure 3.2. Interacting CR processes.

3.3 Embodiment - a necessity for human-level AI

An AGI agent without a body (virtual or physical) is, for all practical purposes, a 'brain in a jar'. We note that in nature, given all the biological diversity, there is not a single example of such an entity - brains are always housed in bodies, in exchange for which they help nurture and protect the body in numerous ways (depending on the complexity of the organism). The only disembodied being is one worshiped by billions, an omnipotent, omnipresent and omniscient God!

An AGI brain does not always need to be housed in a AGI body - but the point is that it would need a body, in order to attain certain characteristics that are otherwise unattainable. Let us confine our discussion to a human-like AGI, although the ideas and lessons should transfer to lesser forms (simpler AGIs) as well.

A body provides a brain, the following advantages:

- separation from the environment - when the torso moves, so does the brain, creating a sense of ownership and situatedness
- identity - the body parts are controllable by the brain (thanks to the integrated, matched 'wiring' that enables this; in humans, this starts at birth, in fact in the womb during late stages of pregnancy) - this, is conjunction with social conditioning (eg. a mother using a baby's name repeatedly), helps develop a sense of self
- 'grounding', via direct physical experience - from being able to pick up light, small things (but not big, heavy ones) and rolling down a slope, to learning the passage of time to stereopsis to being able to tilt the head and view the world sideways, etc., the experience and knowledge gained is subjective, first-hand and incremental
- agency - this is a big advantage; the agent does not need to rely on another, to carry out possible actions, instead, the agent can just do them on its own (also, this facility of direct first-person-oriented action cannot be compensated by a disembodied agent having available to it, rich multi-sensory 'data' from the world - this is about active engagement with the environment, only possible via a physical form)
- agency also leads to the development of 'free will' - "I can control what I can or will not do"
- theory of mind - "looking at your actions, I can tell you are like (or not like) me"

- empathy - “I see you howling in pain after you fell, I know how you feel, I fell in the exact same spot earlier and it hurt"
- social/imitation learning - thanks to mirror neurons, a kid would be able to imitate (gracelessly at first, till reinforcement learning kicks in) her pre-school teacher's hokey-pokey dance routine; same goes for language - understanding words by associating them with things (nouns), actions (verbs) and qualities (adjectives) become trivial when these are shown, told, read to, overheard etc.
- model-free learning - experiencing the world first, then being able to fill in the reasoning (eg for why a rainbow forms, or why metal gets hot, etc.)
- number sense, grouping, abstraction etc. - by using tangible objects and having features subtracted (or singled out) verbally and by demonstration, the brain is able to grasp underlying concepts that are abstract and non-immediate, such as opposites, colors, groups, hierarchies, numbers, etc. (pre-school board books are a testament to this) - this offers the brain a way to learn to create and use symbols, from within

As is evident from the above list, a human AGI without a body is bound to be, for all practical purposes, a disembodied ‘zombie’ of sorts, lacking genuine understanding of the world (with its myriad forms, natural phenomena, beauty, etc.) including its human inhabitants, their motivations, habits, customs, behavior, etc., the agent would need to fake all these. To put it differently, a disembodied agent is forever left ungrounded, reduced to deriving meaning from symbols and/or data that the agent did not develop or gather first-hand.

As discussed earlier, an embodied AGI architecture needs to be ‘matched’ in body and brain - the brain architecture needs to be designed in such a way that it is integrated into the body so as to provide optimal control of the body, monitor and regulate it well, and obtain appropriate sensory inputs from it. Further, the body+brain would need to be designed so as to function optimally in the environment which they will inhabit.

As for a human-level AGI brain architecture, we need a design that involves continuously running, interacting, consideration-response processes that draw from two shared memory stores - a short-term working memory one (for processing sensory inputs, ie. perception, and details related to current processing), and a long-term memory that houses accumulated experiences, memories of events, semantic information, thoughts, feelings, etc. (Fig. 3.3):

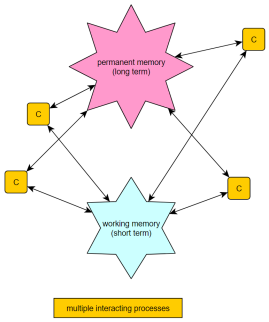

Figure 3.3. Use of long and short term memories, by CR processes.

As shown earlier, the responses that are generated can serve as inputs for further considering and responding, and results of such interactions can be stored away as memories for future consideration. All this makes for a rich web of memory store that would comprise of an ever-changing mix of content and procedural knowledge, thoughts, feelings and experiences. Further, these items are hypothesized to be stored as key:value associations, connected together in the form of deeply and richly linked, flexibly indexed hypergraphs for efficient retrieval by ongoing CR processes.

We can use '**4E/6EXP**' to mnemonically describe human-level brain function. As for '**4E**', the brain is '**e**'mbodied (situated in a suitably co-evolved body), '**e**'mbedded (in the environment, via the body), '**e**'xtended (where it makes uses of the environment for some of its consideration processes), and '**e**'nacted (its primary purpose is to support body functioning). The '**6EXP**' aspects are as follows. Fig. 3.4 shows how we can consider human intelligence as comprising three components, as it relates to a suitably embodied agent negotiating its world: a memory store that contains an agent's ongoing, accumulated '**exp**'erience for future use; 'regular' CR processes that interact among themselves and with short-term memory as they access and possibly modify the memory store, during routine, day-to-day '**exp**'eriencing; a supervising/'self'/"meta-CR"/owner/'**exp**'eriencer process that directs the regular CR processes when necessary - for conscious attention, imagining, simulating, planning, problem-solving, reasoning - thereby exerting explicit control over the agent's responses. The stored experience and knowledge, coupled with ongoing experiencing, lets the brain '**exp**'lain away its reality, '**exp**'ect (anticipate/predict) what is about to happen, and let the agent '**exp**'ress itself (respond) via thoughts, feelings, words and deeds.

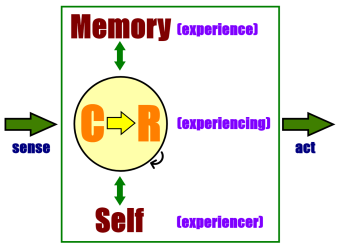

Figure 3.4. Experience-oriented aspects of human intelligence.

Any form of AI will be limited in its CR, unless it is embodied in a way that permits subjective and active first-hand exploration that provides for direct physical experience, interaction with other similar agents, remembering and recalling experiences, continuous learning and growing (mentally and even physically). In the absence of directly gained '3D' knowledge of the world (which includes forms, patterns, a variety of phenomena, events, experiences of different places, etc.), abduction (ie. the 'frame' problem of generating hypotheses or justifying existing ones) will remain a difficult issue, because there is simply no way for the system to know what is 'beyond' (even if combined with semantic knowledge graphs, which will help avoid the problem somewhat, but will not entirely eliminate it). **A suitably paired (brain,body) embodiment that is also matched to its environment, is key to 'fluid' intelligence (C → R) that can continue to grow and adapt** - in short, the expe-

riences, experiencing, and experiencer depicted in Figure 3.4, all need to be body-oriented.

In sharp contrast to standard AI, AGI architectures tend to be more biologically-based, with the presumption that a biological underpinning helps them have advantages similar to biological beings including humans. A variety of AGI architectures are documented in Samsonovich [8] and kept up-to-date at the associated website [9]; see [10] for recent work on humanoid robots. Research is underway to imbue AGI agents created using architectures we just noted, with characteristics such as consciousness, self knowledge, ethics, empathy, episodic memory, emotions [11], creativity [12], etc. This is a promising area of research, going forward - if the goal of AI is to imitate (and possibly surpass) human intelligence, a good functional basis for it would be the brain, considered alongside the body in which it is housed. Depending on the architecture, the C in these systems would include episodic and semantic memory, stored experiences, and inputs from sensors and receptors; R would include thoughts, feelings, vocalizations and other actuations (even possibly including creative pursuits such as art and music). Again, embodiment is likely to be a key requirement in such implementations.

We briefly note the following: in general, to create embodied agents, we have two choices - we could use physical robots, as was done by Goertzel [13], or we could use virtual agents, as advocated in [14], and possibly create embodiments of the virtual versions later.

4 Conclusions

The ‘intelligence as considered response’ notion proposed in this paper, seems uniformly applicable to a variety of intelligence(s), from reactive to distributed to enactive human-level - differences between them stemming from what is considered and how, and what the response is.

Applied to human-level AI, it also helps reinforce viewing biological intelligence as an evolutionary adaptation phenomenon, where an agent's brain that has co-evolved along with the body, helps the agent survive and reproduce (in a broader sense, negotiate its environment), by carrying out ongoing considering and responding, with or without active involvement of the self. The ‘consideration as a process’ idea helps provide working descriptions of several other terms (such as awareness, thought...) which have been rather difficult to be conceptualized in a simple and implementable manner.

To achieve human-level AI, a strong case is made for embodiment - this would provide agency, which in turn would help create a sense of self (and prove invaluable in multiple other crucial aspects related to learning, mentioned earlier). The embodied agent's direct physical experience would provide it grounded, ongoing, actively and subjectively acquired meaning of the world ('experience'); this experience is used in considering and responding (actively guided and directed by the self, when necessary) - in short, to exhibit intelligence.

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