Open-Ended Intelligence
On the Role of Individuation in AGI

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Abstract. We offer a novel theoretical approach to AGI. Starting with a brief introduction of the current conceptual approach, our critique exposes limitations in the ontological roots of the concept of intelligence. We propose a paradigm shift from intelligence perceived as a competence of individual agents defined in relation to an *a priori* given problem or a goal, to intelligence perceived as a formative process of self-organization by which intelligent agents are individuated. We call this process *Open-ended intelligence*. This paradigmatic shift significantly extends the concept of intelligence beyond its current definitions and overcomes the difficulties exposed in the critique. Open-ended intelligence is developed as an abstraction of the process of cognitive development so its application can be extended to general agents and systems. We show how open-ended intelligence can be framed in terms of a distributed, self-organizing scalable network of interacting elements.

Keywords: Intelligence · Cognition · Individuation · Assemblage · Self-organization · Sense-making · Coordination · Enaction · Fluid-identity

1 Introduction

The field of "narrow" artificial intelligence (AI) that focuses on goal-specific kinds of intelligence such as speech recognition, text comprehension, visual pattern recognition, robotic motion, etc. has known quite a few impressive breakthroughs lately. The highly competent AI agents developed today rely mostly on vast networks of artificial neurons inspired by biological brains and their competences begin to rival those of humans. The field of Artificial General Intelligence (AGI) is much more ambitious in comparison. It aims to distill the principles of intelligence that operate independently of a specific problem domain or a predefined context and utilize these principles to synthesize machines capable of performing any intellectual task a human being is capable of and eventually go beyond that. The goal of this paper is to examine, from a theoretical perspective, the conceptual foundations of intelligence and their emergence in the dynamics

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of distributed, disparate, interconnected structures. In a nutshell, the term *open-ended intelligence* is used to describe intelligence as a process of bringing forth a world of objects and their relations, or in other words, a continuous process of sense-making.

2 What Is Intelligence? Definition and Critique

Intelligence has many definitions in diverse disciplines. The most comprehensive collection of definitions of intelligence to date can be found in [1]. In the AGI community, a widely accepted definition of General Intelligence is: "The ability to achieve complex goals in complex environments" [2]. We refer to this kind of intelligence as *Goal-oriented Intelligence (GOI)*. Generally speaking, Goal-oriented Intelligence is a measure of an agent's competence to match actions to observations such that it will achieve optimal rewards in a variety of environments.

The goal-oriented approach to defining intelligence is based on a few presumptions: (a) a sharp agent-environment distinction; (b) well defined interactions; (c) the environment is observer independent and *a priori* given; (d) goal driven rewards, and (e) the agent's computational capacities. While strongly appealing to common sense and framing the concept of intelligence in a reasonable and pragmatic manner, these presumptions limit the generality of the concept in at least three profound ways: (a) they overlook processes of agent-environment differentiation and boundary formation; (b) they overlook processes of goal and value formation – intelligence never starts with solving a problem but much earlier in the formation of the problematic situation, and (c) they disregard environments of multiple intelligent interacting agents (i.e. reflexivity) with no *a priori* definite set of goals or knowledge of other agents' goals. In short, the current definition of intelligence covers only a well determined kind of intelligence but neglects the more profound and difficult to define process of the *emergence* of intelligent behaviors. The difficulty lies in the *a priori* assumptions one is willing to give up. The less assumptions one initially commits to, the more difficult it is to make the concept concrete and formal. It seems however that there is something missing in our understanding of intelligence. Wittgenstein stated that "Whereof one cannot speak clearly, thereof one must be silent." Yet, babies are speaking, whereof, initially, nothing they say can be said to be clear, and still they do! If they would have followed Wittgenstein's view, they would never learn to speak. On the same token we should ask what is intelligence *prior* to anything *intelligible*?

To answer this question, we need to reexamine the roots of the concept of intelligence. Our thinking about the concept seems to be constrained by the ontological elements that shape conventional thinking. These elements constitute a so called *image of thought* and place implicit limits on any concept [3, pp. 129–168]. In our case this image involves a few *a priori* givens: an agent, a formed environment and certain relations between them. By going beyond our conventional image of thought, we can reduce to the minimum the presumptions that constrain the concept of intelligence. This is how we arrive at the

concept of *Open-ended Intelligence (OEI)*. Open-ended Intelligence precedes the well characterized concept of Goal-oriented Intelligence (GOI), it makes fewer presumptions and therefore is *fundamentally more general*. To develop the idea of open-ended intelligence we begin by introducing an alternative image of thought.

3 The Theory of Individuation

The conventional image of thought is ontologically grounded in elements called *Individuals*. Individuals are unambiguously defined by their properties (Aristotle's principle of the excluded middle). We represent and understand the world by identifying individuals and relations among them. Everything starts and ends with individuals. The genesis of individuals is merely the manner by which one individual transitions into another. Stable individual entities are primary; change is secondary.

The theory of individuation is an ontological paradigm shift developed by Gilbert Simondon [4–6]. Instead of positing individuals as the primary ontological elements, it posits as primary the process of their becoming i.e. their individuation. Individuation is a primal formative process whereas boundaries and distinctions arise without assuming any individual(s) that precede(s) them. The theory's point of departure is that individuals are merely temporarily stable phases within a continuous process of transformation. Individuals are always pregnant with not yet actualized and not yet known potentialities and tensions that may determine their future states.

Individuation always takes place under certain conditions which characterize it as a process.

Metastability – The individuation of a system involves the system moving among multiple attractors. Additionally, individuation involves possible transformations of the system's state-space, e.g. changes in the number of involved state variables and their relations which in turn dynamically modifies the landscape of attractors, their shape, relative location, dimensionality, etc. Individuation takes place as long as the system has not reached a final stability exhausting all its potential for change. But final stability does not exist, it is merely an idealization because no actual situation is permanent.

Intensity – The motion of individuation is driven by intensive differences, or in short, intensities. Intensity is a general term for differences that drive structural and state changes in a system. Intensities are always context specific and depend on the nature of the system e.g. temperature or pressure differences, chemical concentration, economic wealth, psychological needs, distribution of populations in an ecology etc. All these can be generalized under the broad concept of *preindividual* which precedes the individual and may drive future transformation.

Incompatibility – Incompatibility is the situation where a set of interacting elements pose to each other problems that prompt resolution. The *problematic situation* is unstable, non-organized, and lacks coordinated interactions. It does not give itself to systematic representation therefore is difficult to address by

any conventional method. Importantly, situations of incompatibility bring forth intensities that drive processes of individuation. An extreme case of problematic situations is termed *disparity* where elements initially lack any common ground. In principle, every process of individuation starts from disparity; in such cases, individuation must also mean the emergence of a system of coordinating signals.

If we consider the interactions among a collection of initially incompatible agents, the outcome of interactions is unique and unpredictable; it does not follow any systemic development. Prior to, and in the course of the actual interaction, the outcome is said to be *determinable but not yet determined*. Determination which is at the core of individuation, necessitates the actual localized and contextualized interaction where the participating agents reciprocally determine behavioral and structural aspects of each other. Individuation proceeds as a sequence of progressive co-determinations i.e. a sequence of operations O_i on structures S_j [7, pp. 14–15]:

$$O_1 \rightarrow S_1 \rightarrow O_2 \rightarrow S_2 \rightarrow O_3 \rightarrow \ldots$$

Every intermediate step is a partial resolution of incompatibility: Each structure constrains the operations that can immediately follow; each operation constrains the possible transformations of the current structure.

3.1 Assemblages

Assemblages are networks of interacting heterogeneous individuals that have established partial compatibility among them [8,9]. Assemblages possess an intrinsic though metastable individuality; an individuality that does not depend on an external observer but only on the relations that have been stabilized among their elements. Individuals as assemblages are characterized by: (a) identifying properties – that define them as the individuals that they are, and (b) capacities to interact – to affect and be affected by other elements. While the individual's properties are more or less stable and independent, the set of its interactive capacities is open and inexhaustible. It depends only on the actual and contingent relations that an individual forms with other individuals. Since there is no limit to the number and kind of relations, the set of capacities to interact is open-ended and non-deterministic. What becomes determined in the course of individuation are the actual interactive capacities. This is why the actual interaction is necessary for the determination and why the resulting relations cannot be predicted. Good examples for assemblages are cyborgian entities: individual biological organs that are considered parts of an irreducible whole, can be taken out and replaced by artificial organs such as bionic limbs, artificial kidneys, hearts, joints, retinas etc., to form cyborgian assemblages. The important difference between an assemblage and an organic whole is that while in organic wholes the components are entirely defined by their interrelations, the components of an assemblage, while forming together a greater individual, keep their own individuality too.

3.2 A New Conceptual Approach to Intelligence

In our attempt to extend the scope of the definition of intelligence to be open-ended, we base our approach to intelligence on the new image of thought where individuals are replaced with *individuation* as the primary ontological construct. For this we give up: (a) the clear boundaries and distinctions between agent and environment; (b) the implied observations and actions that are made possible by such boundaries and distinctions; and finally (c) definite goals with their associated mapping of rewards. It might seem that there is nothing left to build upon. If there are no prior distinctions, how is one to make sense out of a non-sense situation where no agents or objects can be identified to begin with? The conceptual leap that needs to be taken here is that while the concept of Goal-oriented Intelligence answers the question"what does it mean *to be* intelligent?", the concept of Open-ended Intelligence focuses on a prior question: "what does it mean *to become* intelligent?". The process of becoming intelligent can be understood as the sense-making that precedes clear distinctions and goals and brings those forth. Comparing the two kinds of intelligence, GOI assumes definite boundaries, definite goals and definite capacities, while OEI works with fluid boundaries, progressively determined goals and capacities and considers situations which are metastable and problematic.

4 Intelligence, Cognition, Sense-Making

Natural evolution can be considered as the most prominent example of OEI. Organisms interacting in their environments are undeniably intelligent; but their intelligence is only apparent as an already individuated product of an evolutionary process. From a philosophical perspective, general systems whether natural like galaxies, stars, weather systems etc., or artificial such as machines, wars, corporations, AI agents etc. are individuals that manifest an intrinsic and identifiable systemic behavior that could in many cases be considered as rudimentary intelligent featuring self-sustained boundaries, cybernetic control, reflexivity, adaptation and more. We are not interested in such consolidated manifestations of intelligence but rather in their individuation. Our thesis is that the formative processes that bring forth individuals, are manifesting Open-ended Intelligence (OEI). In the following, we draw the lines that connect OEI to the individuation of cognition and cognitive systems.

Cognition in its broadest sense, is a complex activity that involves agents operating in their environments. Cognition can be understood as an on-going problem solving activity where problems are situational and rarely formally represented. The roots of cognition therefore is in problematic situations that require resolution through action. Still the question remains how do agents, environments and their dynamic problematic relations that facilitate cognitive activity emerge? The answer can be given in terms *sense-making*. Sense-making is the bringing forth of a world of distinctions, objects and entities and the relations among them. Even primary distinctions such as 'objective – subjective' or 'physical – mental' are part of sense-making. We understand sense-making as

the individuation of cognition itself. It precedes the existence of already individuated autonomous cognitive agents and is actually a necessary condition to their becoming. This approach is based on the enactive theory of cognition [10,11]. The theory asserts cognition to be an ongoing formative process, sensible and meaningful (value related), taking place in the co-determining interactions of agent and environment. It regards sense-making as the primary activity of cognition, whereas the word enactive means *actively bringing forth*. Clearly, the enactive theory of cognition naturally accommodates the idea of individuation. Still there is a major difference between enactive cognition and OEI. The principle underlying enactive cognition is the generation and sustenance of an identity (an individual) by forming operational closures. As such it requires that a stable individual cognitive agency must precede the sense-making activity. OEI sees in sense-making the individuation of cognition itself and as such *preceding* the existence of individuated identities and is actually a necessary condition to their emergence. Additionally, OEI is not biased towards the conservation of any identity; both integration and disintegration play a significant role.

To summarize, Open-ended Intelligence in the context of cognition is the bringing forth of a complex world via the activity of sense-making. The concept of sense-making captures two distinct meanings: cognition as a concrete individuated capacity (intrinsic to individuals), and *the individuation of cognition* as a process intrinsic to cognition itself. The latter corresponds to the acquisition of novel cognitive capacities i.e., intelligence expansion; it generalizes the concept of cognitive development beyond its conventional psychological context [12].

5 A Framework for Open-Ended Intelligence

5.1 Structure

We consider an heterogeneous and diverse population of interacting individual agents. Each agent is characterized by defining properties and capacities to affect and be affected that depend on contingent interactions. In 'Heterogeneous' we mean a population with various sets of properties and capacities and in 'diverse' we mean a variability in the expression of properties or capacities. The formation of new individuals within such populations is the core of the framework. Populations of individuals have a stratified architecture where each stratum provides the "raw material" for the stratum immediately above it. New individuals are assemblages – sets of "raw material" agents that established recurrent and coherent interactions among themselves. Every stratum is a unique field of individuation whereas individuation takes place in parallel at all strata simultaneously, and where the nature of interactions facilitating the process is unique per stratum. For example, individuation taking place at the neuronal level is unlike the individuation of complex goals, behaviors and plans at the level of individual minds, and is unlike the individuation of social organizations constituted of human agents and artifacts. The hierarchical relation of assemblages unfolds recursively both upwards and downwards where each level

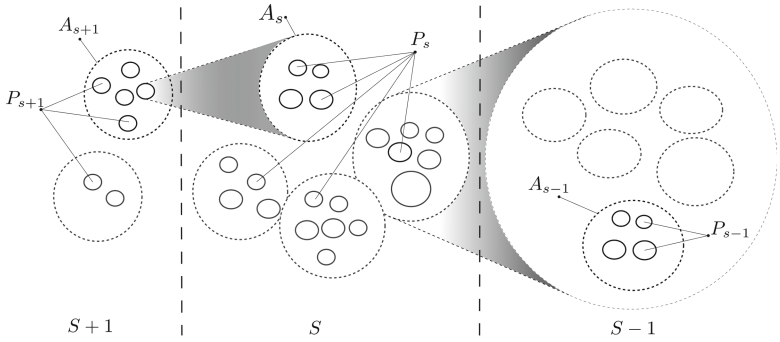

Fig. 1. Relationship between strata: Solid circles denote the individual agents at any stratum. Dashed lined circles denote assemblages at any stratum.

is the substratum of the level above it. There is no end in principle, to the possible expansion of Open-ended Intelligence via the emergence of new strata of individuation. Figure 1 illustrates the general characteristics of the structure.

5.2 The Unfoldment of Individuation

Actual sense-making is a continuous process of integration and disintegration of assemblages taking place in a distributed network of agents and their interactions. There is no *a priori* subject who 'makes sense'. Both subjects and objects, agents and their environments co-emerge in the course of sense-making. Based on the general characteristics of the formed assemblages, three phases of individuation can be distinguished: (*a*) Preindividual boundary formation (*b*) Fluid identities (*c*) Fully formed individuals (identities). In the preindividual phase, boundaries arise due to the non-uniformity of affective interactions within the population. Groups of agents that contingently affect each other more strongly or frequently than they are affected by the rest of the agents in the population, tend to clamp together and form a boundary that distinguishes them from the rest of the population that becomes their respective environment. The non-uniformity of affective interactions can be quantified in terms of *information integration*, a concept developed by Tononi [13]. The information integration $I(P)$ of a set of interacting agents is a relative measure of how strongly their states have become mutually correlated in comparison to their correlation with the rest of the population.

On the other extreme, a fully formed individual (identity) is generated as a network of interdependent agents become operationally closed – the conditions necessary for the existence of each component agent critically depend on the interactions with other agents in the network. For an identity to become stable, the state transitions and interactions of component agents must become recurrent by that allowing the continuity of the closure. Importantly, stable identities arising from strict operational closures are mere idealizations and are always temporary. Our tendency to see the world in terms of stable identities is

itself only an individuated habit subject to frequent changes that we overlook. This brings us to the concept of *fluid identities* – the most interesting phase of individuation.

The three phases of sense-making form *a continuum of change* spanning from ultimate disparity (disorder) to highly organized cognitive individuals. The preindividual phase is characterized by a majority of contingent interactions over coordinated and regular ones. The operational closures that form identities are characterized by a majority of coordinated regular interactions over contingent ones. Fluid identities form a thick borderline between these phases with more or less balanced proportions of coordinated and contingent interactions. Fluid identities are volatile entities whose defining characteristics change across relatively short periods of time but without losing their overall distinctiveness in the long term. A fluid individual as an assemblage may lose or gain components in the course of its interactions. Some of these interactions may bring forth an identity that did not exist before, others may disrupt an existing identity, and yet others may gradually replace one set of properties with another. From the perspective of Open-ended Intelligence fluid identities are where new sense objects arise out of non-sense and in association with other previously established sense objects. We argue that fluid identities are the rule rather the exception and it is in their dynamics that intelligence expands.

5.3 Compatibility, Complexity and OEI

The nature of Open-ended Intelligence is associated with the resolution of problematic situations. The concept of compatibility distinguishes between organized and disorganized relations in both structural and dynamic terms. Disparate agents will be perceived by each other as sources of noise; no correlated or coordinated exchange of signals takes place. Note that collections of disparate agents do not constitute systems as yet. A system arises from a collection of agents only when some degree of compatibility is achieved between its member elements. Systems may have a more compact formal descriptions because compatibility means a degree of regularity, similarity and recursion in structure and dynamics. Here, the information integration function $I(P)$ mentioned above is an approximation to the degree of compatibility. Yet, compatibility thus conceived cannot be the only factor necessary to qualify intelligence. A system with a highly compressed description would mean that its components are so highly correlated that it becomes redundant in terms of its properties and capacities. Therefore, a second factor called *operational complexity* ($OC(P)$) is needed [14]. Qualitatively, the operational complexity of a group of agents P is the degree to which their global state is differentiated, i.e., how many distinct behaviors it can globally present. A disparate collection of agents achieves maximum distinctiveness but is not interesting in terms of intelligence as maximal $OC(P)$ indicates no boundary formation and no significant correlations between agents. In contrast, a redundant assemblage with a single fixed inner state achieves maximum compatibility but indicates no interesting behavior. An approximate measure of

Open-ended Intelligence can be achieved by considering a balanced combination of both compatibility $I(P)$ and distinctiveness $OC(P)$.

5.4 Coordination

To achieve compatibility, agents must *coordinate* their interactions. Coordinated agents affect each other in a non-random manner but still maintain a relevant degree of distinctiveness in their milieu. Distinctiveness here means that an agent's behavior is not redundant and cannot be entirely given in terms of other agents' behaviors. Open-ended Intelligence can therefore be associated with the coordination achieved by initially disparate groups of agents in the course of their interactions. Consequently, mechanisms of coordination are foundational to our framework and to the understanding of how intelligence is realized as a process.

Generally, we define coordination as the reciprocal regulation of behavior given in terms of exchanging matter, energy or information among interacting agents, or, between an agent and its environment. In the latter case, the very distinction of agent – environment already involves a basic level of coordination. Technically, agents can overcome their initial incompatibility and become coordinated by constraining their own or each others' set of possible behaviors as well as their connectivity. The mutual modification of behavior requires direct or indirect feedback among agents. Therefore, the underlying individuating processes that progressively achieve coordination can be understood in cybernetic terms. These are mutually selective processes distributed over populations of interacting agents. They 'explore' and spontaneously 'discover' novel coordinated interactions among themselves. A new sense consolidates however only when such 'discovered' coordinated interactions become recurrent i.e.'forming a habit'. It is important to note that the tendency towards the formation of recurrent patterns of interactions is not given. It is itself an outcome of ongoing individuation.

The regulation of interactions whether by constraining the topology of connections or the actual behavior of the interacting agents can be considered a *meta-capacity* of agents because they not only affect and are affected by other agents but also *regulate* the manner by which they affect and are affected. This is considered a defining property of cognitive systems [10, p. 39]. The regulation is not designed and not globally driven. Instead, it gradually emerges in the course of interactions that are at least initially contingent.

6 Conclusion

We go beyond the goal-oriented approach to intelligence and lay down philosophical and theoretical foundations to how intelligent systems such as brains, whole organisms, social entities and other organizations individuate. We do that by identifying a generalized concept of sense-making in cognitive systems with individuation. By that we shift the focus of investigation from intelligent agents

as individual products to Open-ended Intelligence – the process of their individuation. Open-ended Intelligence is a process where a distributed population of interacting heterogeneous agents achieves progressively higher levels of coordination – the local resolution of disparities by means of reciprocal determination that brings forth new individuals in the form of integrated assemblages that spontaneously differentiate from their surrounding milieu. Open-ended Intelligence manifests all around us and at many scales; primarily in the evolution of life, in the phylogenetic and ontogenetic organization of brains, in life-long cognitive development and sense-making and in the self-organization of complex systems from slime molds, fungi, and bee hives to human sociotechnological entities.

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