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Z*-numbers: Augmented Z-numbers for machine-subjectivity representation

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ABSTRACT

Envisaging a futuristic environment of man–machine and machine–machine synergy, this article documents our research on the augmented Z-numbers, the Z*-numbers, for machine-perception encapsulation. The Z*-numbers have been envisioned as operands of endogenous machine-mind processes underlying bespoke comprehension of the real world. Besides information-*certainty*, as in a Z-number, a Z*-number incorporates *context*, *time* and *affects* as essential factors of subjectivity representation. We have proposed: (a) definitions for *certainty* and *affect* parameters—arising out of socio-cultural influences on machine-knowledge, (b) a Z*-number based rudimentary procedure for natural-language comprehension emulation, and (c) primitive perception-operators for 'machine-mentalese' simulation using Z*-number information-equivalents. Our work draws from non-symbolic theories of cognition and 'mindfulness', human-mind processes—studied through behavioral experiments, and theories of the 'self' and 'qualia'. The article includes detailed discussions of these experiments and consequent insights, analysis of a theoretical run-through of the defined procedure, and correspondence-studies between the Z*-number paradigm and philosophies of the self. Our research raises questions on cognitive biases and autogenous mind-processes that highlight crucial practical challenges in the current realization of a synthetic-mind. All ideas herein aim to contribute to studies on the 'self' and its machine-embodiment for the synthesis of an empathetic machine-mind.

1. Introduction

"… the brain is a machine and a computer – everything in classical neurology is correct. but our mental processes, which constitute our being and life, are not just abstract and mechanical, but personal, as well – and, as such, involve not just classifying and categorizing, but continual judging and feeling also."—[75]

"You cannot see what I see because you see what you see. You cannot know what I know because you know what you know. What I see and what I know cannot be added to what you see and what you know because they are not of the same kind. Neither can it replace what you see and what you know, because that would be to replace you yourself."—Douglas Adams, *Mostly Harmless*.

"Human behavior flows from three main sources: desire, emotion, and knowledge."—Plato

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A cognitive system must think, improve by learning, adapt to the environment, and find structure in massive amounts of ambiguous, noisy real-world and domain knowledge. Such systems are intuitive, possess commonsense reasoning abilities, curiosity, the urge to improvise and learn from experiences (self-induced as well as arising out of interactions with others). The hallmark of an empathetic cognitive system lies in its ability to acknowledge 'first' person perspectives to a situation and others' views to it as well. A rational mind is aware of its self-ideals and biases, and is consequently receptive to new ways of thinking. Each of these points hints the presence of a framework of the 'self'—the elements that define the 'personality' of the system—underlying bespoke interpretations of the real-world. This article is a treatise on our endeavors toward the construction of the machine-self in a 'mindful' cognitive machine.

Coined in 2011, Zadeh's Z-numbers [97] were a significant contribution to the intelligent-systems design initiative. These constructs sought to juxtapose the objective and the subjective components of natural language expressions toward enhanced natural language understanding. This paradigm focused on precisiating the *certainty* of information—a parameter of machine-subjectivity—in a natural language expression to support effective decision-making. Alieva et al. [2] document a comprehensive summary on the work done on Z-numbers, since its inception. Banerjee et al. [10,11,58] present detailed analyses of the pros and challenges of this paradigm, in the context of natural language understanding.

Aiming at identifying other factors of subjective information recall, we performed a number of behavioral experiments on human subjects (as has been detailed out in Section 4.1). These studies not only depict belief (*certainty*) in information, but also the *context* of discourse, and *affect*s—bound by *time* (retrospective, present or prospective projections of the 'self')—as essential factors of subjective information recall.

The Z*-numbers, defined in this article, augment the basic Z-numbers with these other parameters of bespoke information recall. Intuitively, all of the Z*-numbers parameters are essential to the extraction of qualia (or raw affects) [98] from real world scenarios, reflect non-symbolic theories [53] of cognition and support grounded [13] mental representations of the real world for a machine-mind.

Besides extension of the basic Z-numbers, envisioning a future of man–machine and machine–machine symbiosis [39,44], our major contribution lies in the consideration of socio-cultural impact [72,74] on machine-knowledge, and its influence on the endogenous arousal of beliefs and affects in a synthetic mind. The article outlines steps of a basic effective procedure and primitive perception-operators that utilize the Z*-numbers as tokens of 'machine-mentalese [62]' (or internal computations) toward personalized natural language comprehension.

The article includes descriptions of the behavioral experiments we performed, consequent insights into real-world comprehension and a theoretical run-through the Z*-number based procedure. Philosophical correlates to our concepts have been analyzed through correspondence studies with theories (Freud [25], Minsky [51,52], Damasio [16,17] and Ramachandran [63–66]) on the 'self' and 'qualia'. Our work aims to contribute to the synthesis of the machine-self and self-consciousness en route to the construction of an empathetic, rational artificial-mind. Crucial research questions—on subtle endogenous brain processes and cognitive biases [9,27,86]—answers to which should assist autonomous-mind design initiatives [69,89], have been highlighted as well.

The studies described herein, are a part of a series of our endeavors toward the design on a machine-mind, drawing from Minsky's 'society of mind [51]' theory. The Z*-numbers serve as operands in the processes particular to the self-reflective and self-conscious layers of thinking.

The article begins with Section 2 highlighting theories (basic Z-numbers, constituents of the 'self', and key elements of our machine-mind architecture for natural language or real world comprehension) influencing our ideas, followed by a detailed discussion of the Z*-numbers (Sections 3), and descriptions of experiments performed, consequent observations and issues of practical concern (Section 4).

2. Theory

This section presents a general outline of the theories that support our ideas. Following a description of the basic Z-number theory, we move on to an elucidation on theories of the 'self'—underlining all that a cognizant machine-self needs to accomplish.

2.1. Z-numbers

Voluntary actions involve decision-making based on information. Thus, greater the reliability of the information better is the decision made. The Z-numbers [97] aim at encapsulating the reliability or the confidence in the information conveyed by natural language statements.

Based on the concepts in [37,91–96], the Z-number is a manifestation of level-2 Computing With Words (CWW) [48] [i.e., the precisiation of entire natural language statements instead of just the component adjectives and adverbs]. Consequently, if it were possible to simulate the endogenous arousal of 'belief' or 'affect' on information, the Z-numbers would prove to be an effective means of representations of machine-subjectivity.

Given a natural language statement, Y, the 'Z-number' of Y is a 2-tuple $Z = <A, B>$, where A is the restriction (constraint) on the values of X (a real-valued uncertain variable, interpreted as the subject of Y) and B is a measure of the reliability (certainty) of A. Typically, A and B are expressed as words or clauses, and are both fuzzy numbers. Some examples of Z-numbers are:

(i) Y_1 = It takes me about half an hour to reach point A.
Therefore, X = Time to reach point A, and Z = <about half an hour, usually>.

(ii) Y_2 = This book is an absolute cracker.
Therefore, X = Quality of the book, and Z = <cracker, absolutely> => <excellent, definitely>.

Understandably, *A* is context-dependent while *B* summarizes the certainty or belief in the applicability of *A* given *X* within the purview of the context of *Y*. The value of *B* may be explicitly or implicitly quoted in *Y*.

The ordered 3-tuple <*X*, *A*, *B*> is referred to as a 'Z-valuation'. A Z-valuation is equivalent to an assignment statement '*X* is <A, B>'. As for example: The Z-valuation of Y_2 is <Quality of the book, excellent, definitely> implying that [Quality of the book] is <excellent, definitely>.

A collection of Z-valuations is referred to as 'Z-information' and is the stimulus to a decision-making process.

Preliminary rules of Z-number computations [97] are:

(i) For the purpose of computation, the values of *A* and *B* need to be precisiated through association with membership functions, μ_A, μ_B respectively.
(ii) *X* and *A* together define a random event in *R*, and the probability of this event, *p*, may be expressed as:

$$p = \int_R \mu_A(u)\, p_X(u)\, du \tag{1}$$

Where, *u* is a real-valued generic value of *X* and p_X is the underlying (hidden) probability density of *X*.
(iii) The Z-valuation <*X, A, B*> is viewed as a generalized constraint on *X*, and is defined by:

$$\begin{aligned} &\text{Probability } (X \text{ is } A) \text{ is } B \\ &\text{or,} \quad p = \textstyle\int_R \mu_A(u)\, p_X(u)\, du \text{ is } B \end{aligned} \tag{2}$$

Eq. (2) is mathematically equivalent to the expression:

$$\begin{aligned} &p = \mu_B\left(\textstyle\int_R \mu_A(u)\, p_X(u)\, du\right) \\ &\text{subject to,} \quad \textstyle\int_R p_X(u)\, du = 1 \end{aligned} \tag{3}$$

The philosophy of the Z-number is reminiscent of the quantum model of the mind in [88], where, the uncertainty on a hypothesis (*subject* and *value* association as per the Z-number terminology) is represented by probability density and confidence (or *certainty*) values.

Features of interest of this paradigm are: (a) it supports precisiation of natural language sentences (for example: Example (ii) in the discussion above is inherently exclamatory), (b) allows grouping statements into context-sensitive granules of information—mimicking natural data-compression and subsequent data-comprehension by the human brain, (c) evaluation of parameter *B* initiates integration of affective computing and CWW, and (d) Z-valuations provide succinct summaries of the objective (parameters *X*, *A*) and subjective (parameter *B*) information in a sentence.

Despite the advantages, the primary challenges in the implementation of the Z-numbers lie in the representation of meanings of natural language elements in some form of machine-language, and the emulation of endogenous arousal of certainty values, qualia [98] and subsequent metacognition. Refer to [10,58] for a detailed analysis of the practical advantages and issues related to the Z-numbers, and suggestions to the resolution of the latter. Alieva et al. [2] highlight recent work done on Z-numbers.

This article elucidates on our endeavors in extending the philosophy toward the formalization of a complete model of a sentient, comprehending machine-mind.

2.2. Properties of the self

> *"Self-consciousness, i.e. the ability to observe some of one's own mental processes, is essential for full intelligence"*—McCarthy in [46]

Philosophers view the consciousness problem through abstract questions on qualia and their relationship to the self. Going by McCarthy's quote above, consideration of concepts of qualia and the self are essential for the synthesis of true artificial intelligence.

This section is divided into sub-sections, each entitled by the name of a philosopher and highlights key points of their theories on the self and qualia. We do not intend to debate on the correctness or completeness of these theories, but rather to present equipotential elements across a number of view-points that have influenced our work.

• ***Marvin Minsky***

We were drawn to the notion of the design of the machine-self by the above quote and Marvin Minsky's theories of the Society of Mind [51] and Emotion Machine [52]. In these, he visualizes the mind as a society of co-operating functional modules that work across six levels of contemplation or thinking (abstraction and sequential jugglery of symbols [63])—beginning with intuition, right up to self-conscious affects. Fig. 1 is an illustration of the layers of the mind and their functions. The structure is reminiscent of Dennett's 'Tower of Intelligence' [18] and the Walterian forms by Winfield [90].

The purpose of the research described in this article is to suggest a foundation for the emulation for the two upper layers of Minsky's model of the mind.

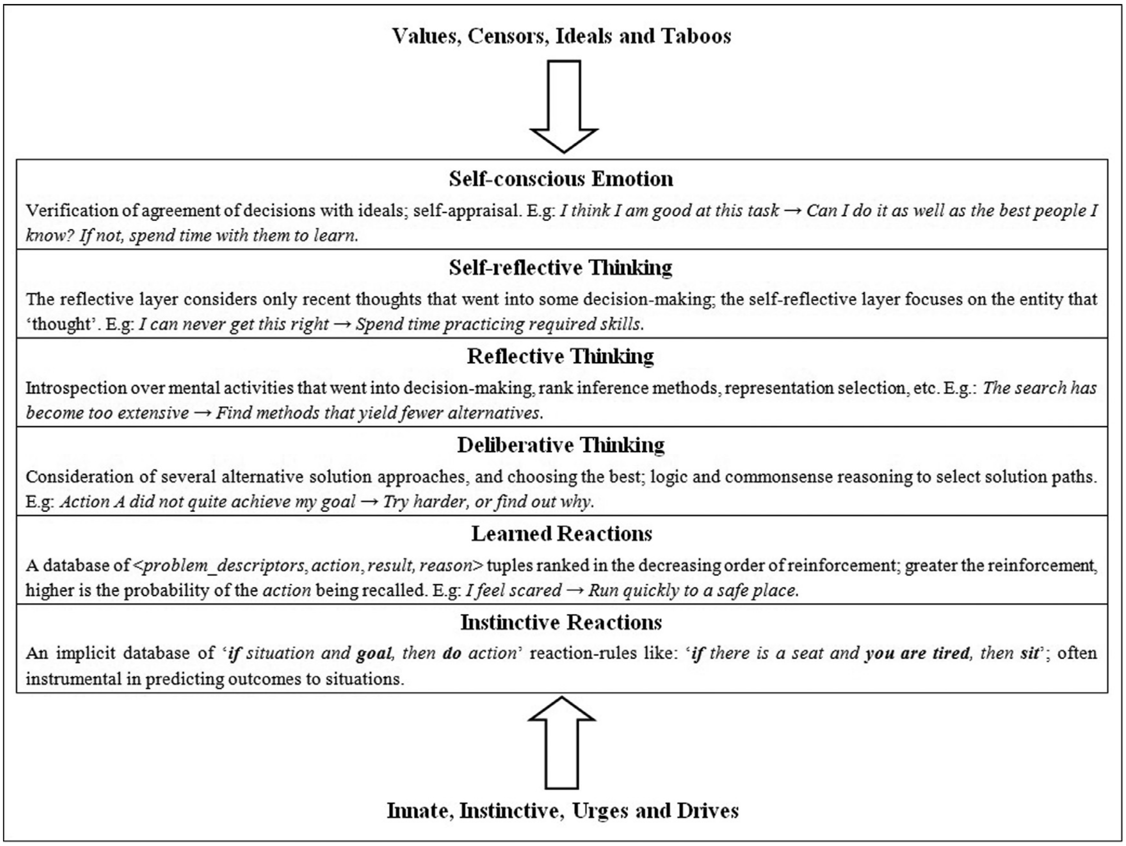


Fig. 1. The layers of the mind and their functions—Minsky [52].

• ***Sigmund Freud***

The earliest views on the layered structure of the mind and the self or personality were probably propagated by Freud in [25]. According to him, both the mind and the self can be divided into three different levels.

The levels of the mind are:

Conscious: Comprising all that we are aware of, and can think and talk about rationally. A part of this includes memories (or preconscious), which are not always part of consciousness, but can be instantaneously retrieved and brought into awareness.

Preconscious: The part of the mind that represents ordinary (or procedural) memory. While we are consciously unaware of this information at any given time, its elements are effortlessly brought into consciousness on requirement.

Unconscious: A reservoir of affects, thoughts, urges, instincts and memories external to our conscious awareness, which surreptitiously influences behaviors and experiences.

The layers of the self are:

Id: The 'Id' is what we are born with. It is based on our "pleasure principle" which strives for immediate gratification. The id is oblivious to reality and the needs of anyone else; often harboring on the verge of socially unacceptable behavior.

Ego: As the child interacts with the world, the second factor of the 'self'—the 'Ego' begins to develop. It is based on the "reality principle" which judges pros and cons of an action, to Id's impulses, before deciding to act upon or abandon it. These impulses can mostly be satisfied through delayed gratification.

Superego: By the age of five, the third stage—the 'Superego' develops. It dictates our conscience and develops due to the moral and cultural restraints placed on us by our environment (attachment figure endowment [51]).

Freud visualized all of the above as an iceberg (Fig. 2), in which only the tip rises above the surface of conscious awareness, the ego and superego operate across all the levels of consciousness, while the id remains mired in the dark recesses of the unconscious mind.

• ***Antonio Damasio***

In [16], Damasio defines feelings or qualia as "mental experiences of body states", which arise as the brain interprets emotions (physical states arising from the body's responses to external stimuli). E.g. If I am threatened, I 'experience' fear, and 'feel' horror.

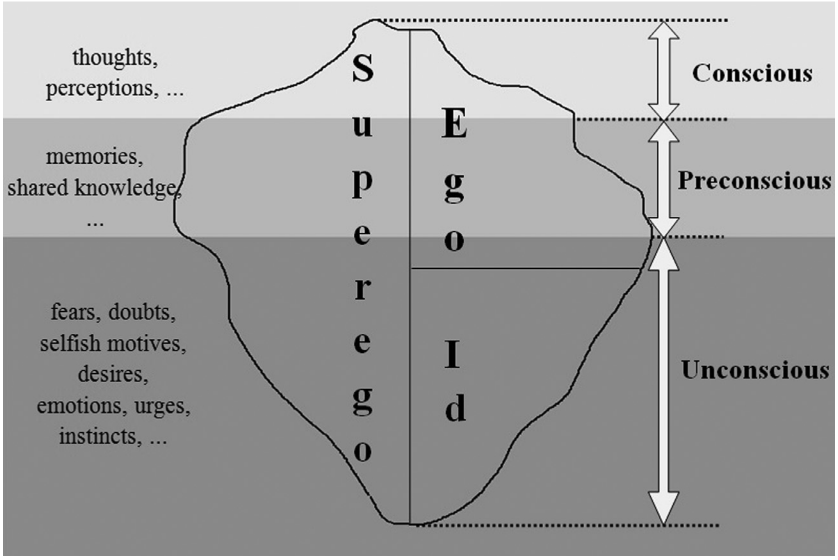


Fig. 2. The 'Iceberg Metaphor'—Freud's vision of the mind [54].

First stage: the protoself

- The protoself is a neural description of relatively stable aspects of the organism
- The main product of the protoself is spontaneous feelings of the living body (primordial feelings)

Second stage: the core self

- A pulse of core self is generated when the protoself is modified by an interaction between the organism and an object and when, as a result, the images of the object are also modified
- The modified images of object and organism are momentarily linked in a coherent pattern
- The relation between organism and object is described in a narrative sequence of images, some of which are feelings

Third stage: the autobiographical self

- The autobiographical self occurs when objects in one's biography generate pulses of core self that are, subsequently, momentarily linked in a large-scale coherent pattern

Fig. 3. Three stages of self—Damasio [17].

He suggests that consciousness emerges from emotions and feelings; the mind begins at the level of feeling and when we feel we begin to have a mind and a self.

In [17] he hypothesizes the construction of a conscious mind and in turn the 'self', in the following terms:

(i) An awake mind is rendered conscious by generating a 'self' process.
(ii) The 'self' is built through the stages depicted in Fig. 3.
(iii) The stages of the 'self' are constructed in synchronized brain workspaces.

The self represents individual life-regulating mechanisms, and it motivates the cognitive capability of the conscious human mind. A self-aware computational-mind, thus encodes: (a) components evolving out of actions, and (b) elements arising out of the system's perspective (feelings or qualia) on those actions.

Note: Damasio uses 'images' to refer to data in all sensory modalities. Images represent "objects-to-be-known" in the conscious mind. They pertain to any object or action being processed in the brain, objects present in the immediate environment or being recalled, concrete and abstract information.

• ***V. Ramachandran***

In [63], Ramachandran states,

> *"… self and qualia are two sides of the same coin. You can't have free-floating sensations of qualia with no one to experience it and you can't have a self completely devoid of sensory experiences, memories or emotions."*

Qualia (singular 'quale') refer to the introspectively accessible, phenomenal aspects of our mental lives [98]. These are the 'raw feels' of conscious experience: the painfulness of pain, the blueness of blue, the loudness of a sound, the feeling of delight, etc. They give human conscious experience its particular subjective character.

> *"The sensation of color cannot be accounted for the physicist's objective picture of the light-waves. Could the physiologist account for it, if he had fuller knowledge than he has of the processes in the retina and the nervous processes set up by them in the optical nerve bundles and in the brain? I do not think so."*—[76]

Ramachandran observes in [63,65] that basic sensory representations (S) use qualia to enable economical higher order metarepresentations to emphasize important aspects of S and create subsequent representative tokens. Internal computations on these tokens formulate hypotheses of all possible (remote or even absurd) interpretations of S. This phenomenon of abstraction and symbol-jugglery is 'thinking'.

(***Note:*** The subtle similarity between the purpose of the Z-numbers and qualia, i.e., metarepresentations of events for decision-making.) Refer to [98] for a comprehensive discussion on qualia and [64] for the laws of qualia.

The characteristics of the self, as is enlisted by Ramachandran in [63,65,66] are as follows. These perceptions are in sync with those of Minsky's in [52] and Damasio's in [17]:

Continuity: The sense of an unbroken thread running through the whole fabric of one's life; being able to engage in seamless bidirectional mental "time travel"—from early childhood-to-projecting oneself in the future, and vice-versa.

Unity or self-coherence: All our diverse sensory experiences and various (often contradictory) goals, memories, emotions, actions, beliefs and awareness cohere to form a single individual.

Embodiment or ownership: Being anchored to our bodies—a vivid sense of different body parts occupying space—the body image.

Privacy: Our qualia and mental life are our own, unobservable by others. We can empathize with our colleague's pain but cannot literally experience his pain.

Social embedding: The self is closely linked to other brains; almost all emotions—pride, vanity, ambition, love, fear, mercy, angry, humility, etc.—are immaterial in a social vacuum.

Sense of agency: Free will [31], being in charge of our own actions and destinies, and engage in counterfactual thinking [28,71].

Reflection or self-awareness: Being aware or conscious of someone else being conscious of "me" (the top-two layers of Minsky's model in Fig. 1).

Refer to [23,55] for observations on the different kinds of minds or selves and [77] for an insight on the hard problem of consciousness.

The following section presents key features of a conceptualized architecture of a sentient, natural language understanding machine-mind [11,12], based on Minsky's theories of the mind [51,52]. The primary focus of this article is on supporting the Self (**Se**) module of the framework that is responsible for the emulation of the machine-self and subjectivity.

2.3. A machine-mind architecture for real-world comprehension [11,12]

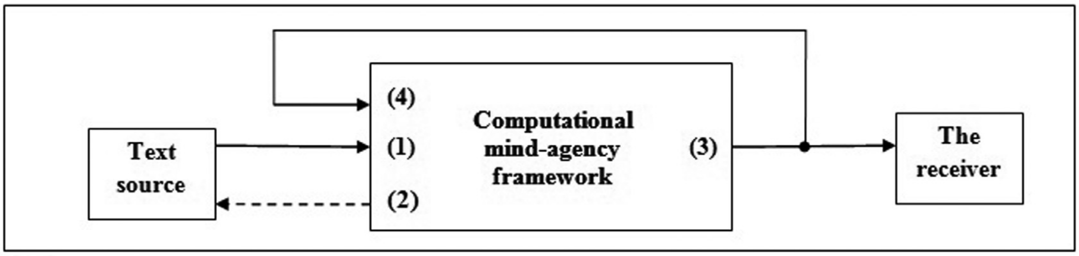
> *We think about the world in all the ways we experience it- we think in sound, we think visually, we think aesthetically, we think in abstract terms, we think in movement*—Sir Ken Robinson

A computational-mind typically iterates [4,29,66] through the following steps, using multi-modal sensory inputs, and knowledge about the real-world and the problem domain, to produce granules of comprehension. Fig. 4 outlines the incremental-developmental mechanism of comprehension followed by a machine-mind:

Prediction: Causally relate the present to past experiences and visualize future actions on the basis of intuition, common-sense, reinforced learning and reflection.

Visualization: Conjure mind-images (real or intentional [36]) depicting people, places, events, etc., from natural language components.

Connection: Build inter-domain associations, and existing and new knowledge.



Index –

(1) – Input to the system = the text-elements.

(2) – **Vision** might be instructed, by the **Deducer,** to re-read sections of the current text-source.

(3) – Output of the system = a granule of comprehension = deep-semantics (cross-contextual information associations) + reflections + emotions + new-knowledge + updated old-knowledge.

(4) – Granules of comprehension, produced at time (t_i), are re-introduced into the system along with the current text-inputs at time (t_{i+1}). The elements along the feed-back path influence the current comprehension – set the context of interpretation, facilitate anaphora/cataphora resolution, etc.

At time (t_1), when the input to the system is the first text-element of the current session, values in the feedback path symbolize the state of the computational mind – cognitive biases arising out of comprehension processes handled in the recent past. Ideally, the system is robust and is able to override these exogenous influences during the course of current processing activities.

Fig. 4. Black-box representation of the incremental-developmental strategy of comprehension emulated by our computational-mind framework [11,12]. [Vision and Deducer are mind-agencies of the framework.]

Table 1
Functionality-based correspondence between the enumerated computational mind-agencies and cerebral cortex regions [12].

Lobe	Parts/Functions of the lobe in relation to language understanding	Framework agencies
Occipital	Processes visual information	**V**
Frontal	*Broca's area* (syntax and morphology analysis)	**Sy**
	Self definition, attention, social behavior	**Sf**
	Reasoning, judgment, strategic thinking	**Re**, **Cr**, **Su**
Parietal	*Angular gyrus* (language and number processing, spatial cognition, memory retrieval, attention mediation and metaphor comprehension [67,68])	**Se**, **Sf**, **Su**, **Re**, **Cr**
Temporal	*Wernicke's area* (semantic resolution)	**Se**
	Amygdala (affective processing and memory consolidation)	**Sf**, **Su**
	Hippocampus (storage and consolidation of semantic and episodic memories)	**Su**
	Basal Ganglia (reinforcement learning, procedural memory—priming and automatic behaviors or habits, eye movements [35] and cognition [82])	**Sf**, **Su**, **Re**
	Recognition	**Re**

Question and **Clarification:** Reflect upon and test strength, completeness, correctness and relevance of knowledge associations; re-organization and rectification of associations.

Evaluation: Test coherence between perception granules formed for the current processing event, measure relevance and prune insignificant granules; attach notions of subjectivity or 'self consciousness' (emotions, degrees of interest, summarize, biases, etc.).

The basic components of a machine-mind framework for real-world comprehension are:

• ***Agencies [51] or Functional modules***

The functional modules in a computational-mind are categorized into **super-agencies**, each representing a complex cognitive functionality like 'reasoning' or 'processing', and **sub-agencies**. A super-agency comprises a cluster of sub-agencies that work in health and harmony to achieve the super-agency functionality. Sub-agencies are built of agents [51], each simulating an atomic sub-process of the sub-agency purpose. Fig. 5 is a pictorial representation of such a mind-agency framework, and Table 1 summarizes the functional analogy between the mind-agencies and human brain-constructs. The super-agencies and constituent sub-agencies in a computational-mind are:

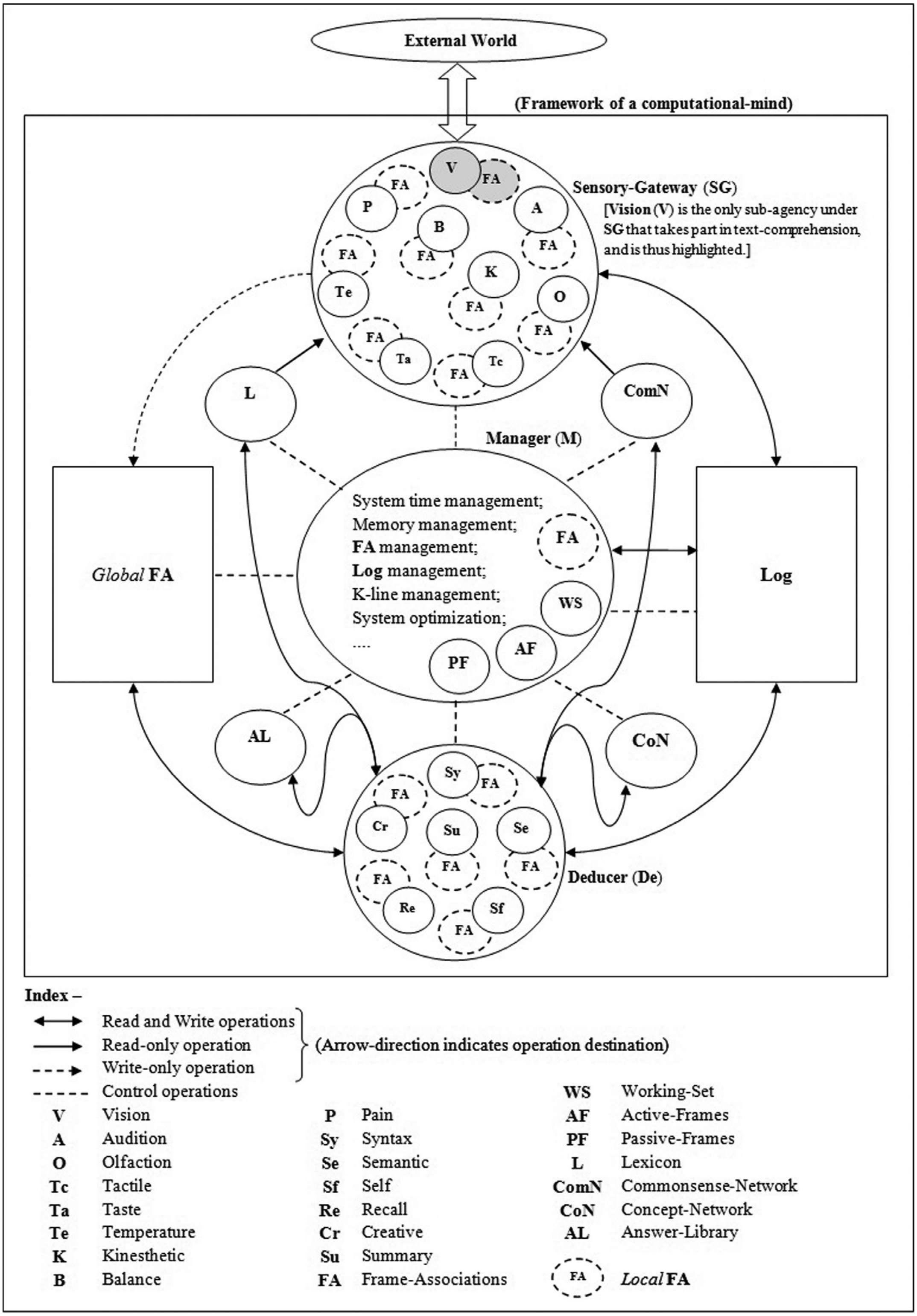


Fig. 5. Macro-components (agencies and memory constructs) of the machine-mind framework [11,12].

Sensory_Gateway (**SG**): Receiver of sensory information, based on the modality of which, sub-agencies [*Vision* (**V**), *Audition* (**A**), *Olfaction* (**O**), *Tactile* (**Tc**), *Taste* (**Ta**), *Balance* (**B**) [70], *Temperature* (**Te**) [70], *Pain* (**P**) [70] and *Kinesthetic* (**K**) [70]] activate other framework components for further processing. **SG** transports system results to the external world as well.

Deducer (**De**): The 'brain' of the system; is responsible for the emulation of each of the aforementioned comprehension processes. It receives outputs (data) of **SG** to formulate units (or frames) of comprehension—utilizing syntax and semantic analysis mechanisms, relevance-evaluation, affect-extraction, comprehension-evaluation and error-handling processes; and sends out instructions (activation, re-evaluation, error signals, inhibition) to other super-agencies. The sub-agencies of **De** are:

Syntax (**Sy**): Syntax-resolution.

Semantic (**Se**): Semantic-resolution.

Self (**Sf**): Flavors comprehension with components (affects, biases, ideals, etc.) of the system self; activates 'multi-realm [52]' thinking.

Recall (**Re**): Thin-slices a problem into sub-problems, maps them to memories which facilitate processing in the current context.

Creative (**Cr**): Projects and suggests solutions for 'new' problems; the hub of reflection, imagination, creativity and system IQ [95].

Summary (**Su**): Measures distance between the current state of the system and the projected goal through relevance, affect and comprehension progression evaluation; summary results can activate or inhibit agencies; consolidates memories.

Manager (**M**): The global administrator of the system; runs in the background and is responsible for self-activation of functions (system-time management, memory handling, process synchronization, job scheduling, etc.) that support other agencies; is accountable for continual self-evaluation of system processes and subsequent updating toward optimal (cost effective and robust) system performance.

• ***Memory constructs***

The *long-term* memory stores of knowledge, supporting functioning of the machine-mind agencies, are:

Lexicon (**L**): System vocabulary (words, phrases, idioms) and their meanings encoded in machine 'understandable' form—either precise machine-language statements or multi-modal implications (sounds, images and metaphors).

Answer-Library (**AL**): Resource of <*solution_strategy, result, reasons*> for <*context_parameters*, *problem*> tuples.

Concept-Network (**CoN**): Hypergraph of inter-contextual data associations; are formed consciously or unconsciously but retrieved consciously.

Commonsense-Network (**ComN**): Network of networks of commonsense and intuitive (automatic) behaviors; are retrieved unconsciously; elements of **L**, **CoN** and **AL** are incorporated into **ComN** after prolonged periods of reinforcement.

The basic *working-memory* data-structures are as follows; these are referenced by every agency and support deliberative and reflective functions:

Log: An online global record of time-stamped agency-activity entries; indicates instantaneous state of the system, analyzing which agencies may be autogenously or exogenously activated, intelligent backtracking [81] initiated, error signals generated, etc.; is the basis of system-reflection.

Frame-Associations (**FA**): A blackboard or scratchpad for data (frame [50]) manipulations during the process of understanding; is categorized into *global* and *local* (per sub-agency). All recollections are placed in the *global* **FA** space, while relevant portions of the *global* **FA** are transferred into *local* **FA** for deliberations by sub-agencies before globally 'advocating (a <*problem*, *solution*, *reason*> tuple)' knowledge manipulation processes through **Log**; sub-agencies can share components or all of its *local* **FA** with other agencies; globally approved suggestions (by **Su**) are implemented in the *global* **FA** which translate into updating of long-term memory components.

The *system memory-management* constructs, used by **M**, are:

Working-Set (**WS**): Set of pointers to frame-networks (in **FA**) being referenced within a narrow time-window (of the order of seconds).

Active-Frames (**AF**): Set of pointers to frame-networks (in **FA**) being referenced within a broad time-window (of the order of minutes); is the superset of **WS**.

Passive-Frames (**PF**): Set of pointers to frame-networks (in **FA**), that were in **AF** but were pruned due to irrelevance or lack of use; these frames remain available during the entire span of the processing of the current language sample for quick 'on-demand' placement into **FA** for re-processing.

Refer to [11,12] for details on the working principle, properties and projected execution results of this architecture.

> *"The real drive to understand the self comes not from the need to develop treatments, but from a deep-seated urge to understand ourselves. Once self-awareness emerged through evolution, it was inevitable that an organism would ask, 'Who am I?'"*—[65]

Integrating the salient concepts of the self and the synthetic-mind structure, the issues of practical interest at this juncture are as follows. These questions occur as a recurrent theme through this article:

(i) How are we to simulate the endogenous arousal of qualia?
(ii) *"A single unified self is something we (humans) create – not something we are given."*—[28].
How will an artificial mind construct and represent its sense of self and self-consciousness?
(iii) Would the machine-mind ever question itself, "Who or what am I"?

An important aspect of consciousness is that we see with our eyes and also feel ourselves seeing with our eyes, i.e., we have a 'viewpoint' or a perspective of the mind—and it is this that we wish to emulate. Studies in this article attempt the elucidation of a paradigm—inspired by the Z-numbers [97]—that should serve as qualia-encapsulating tokens of subjective information representation for machine-mentalese [62]. Section 3 describes this paradigm. The artifacts proposed therein aim to serve as placeholders of elements of machine-subjectivity, facilitating the synthesis of the Self (**Se**) sub-agency of the machine-mind architecture (described in Section 2.3).

3. Proposed work

> *"Without consciousness – that is, a mind endowed with subjectivity – you would have no way of knowing that you exist, let alone know who you are and what you think. Had subjectivity not begun… in living creatures far simpler than we are, memory and reasoning are not likely to have expanded in the prodigious way they did, and the evolutionary road for language and the elaborate human version of consciousness we now possess would not have paved…. Had subjectivity not made its radical appearance, there would have been no knowing and no one to take notice, and consequently there would have been no history of what creatures did through the ages, no culture at all… a conscious mind arises when a self process is added onto a basic mind process."*—[17]

> *"…whether 'intelligence' is simply a technological system that is sufficiently complex to correctly answer a series of questions, that a slightly more complex biological system (us) has arbitrarily decided, constitutes a measurement of what thinking requires. It seems inevitable that at some point, we'll have to say that true intelligence is feeling as well as thinking…"*—[1]

Classic symbolic theories [53] of cognition visualize the human brain as an information processing machine, operating on amodal mental representations of the world. Such mental depictions are construed out of abstract symbols, devoid of sensorimotor experiences of the physical world. These theories of knowledge representation postulate an objective view of the world.

Non-symbolic theories [53] of cognition, however, draw focus away from the mind as a universal Turing Machine and promulgate the view that cognition relies on the experiences of the whole organism in its constant interactions with the environment. Mental representations of information—abstract or concrete—are grounded [13], i.e. encode specific parameters of the physical world that complement internal representations. The structures defined in this article are based on the non-symbolic theory of cognition. These structures also draw from the principles of 'mindfulness' where understanding affects is the key to social synergy, empathy and contemplative behavior.

Mental simulation, i.e., the re-enactment of perceptual, motor, and introspective states acquired during interactions with the world, is another feature of non-symbolic cognition. Simulation potentiates future actions by making predictions founded on past experiences. Simulated knowledge is grounded, multimodal, and integrated within the brain's sensory and motor architecture. Though based on offline multimodal data, simulation is actuated in the "here and now" of cognitive processing.

Parameters simulated during knowledge retrieval represent the organism's embodied experiences. These parameters depict [53]: (a) Tropism: the objective organization of the physical world, and (b) Situatedness: the given context in which the knowledge is retrieved; contexts are subjective and are subsets of the environment perceived relevant to the agent's goals and actions; contexts may be physical, social, introspective, etc. Mental simulations constitute "mentalese [62]", and engaging in mentalese—across all the layers in Fig. 1—to hypothesize every possible interpretation of an event is the hallmark of "thinking".

Simulated representations are functions of: (a) defining features of world-specific, body-specific, and context-specific components, (b) hierarchical relationship between them, and (c) their specific instantiations in relation to the distinction between online (simulated) and offline (stored) representations. The parameters representing the machine-self, outlined in this section, pertain to element (a) in a machine-mind.

Our objective for embarking on enumerating factors of the machine-self, drawing from theories highlighted in Section 2.2 and non-symbolic cognition, is to devise an empathetic system capable of formulating novel, bespoke interpretations of natural language. This is envisioned to facilitate man–machine symbiosis—aids for the elderly and children, differential diagnosers, etc. The structures named here are our initial endeavors in the journey of design of a "complete intelligent machine" as envisioned by Turing [84,85] and McCarthy [46].

3.1. Definition of Z^*-numbers

Drawing from the ability of the basic Z-numbers to summarize the objective and subjective information in a sentence, the Z^*-number attempts to extend the definition to include other crucial parameters of subjectivity.

Given a natural language simple sentence, Y, on a subject X, the 'Z^*-number' of Y is a 5-tuple $Z = <T, C, A, B, AG>$,

Where, T is the time—a combination of the present, retrospective or prospective moments,

C is the context, in which Y was used,

A is the value of X = the predicate of Y = instantiation (or, restriction on the values) of X given C and T, *B* is a measure of the reliability or certainty—represented as adjectives, adverbs or adverbial phrases—of *A* given *C*, *X* and *T*, and

AG stands for the affect group—a set of ordered triples of (affect, affect-strength, affect-valence [41])—arising on account of the mind-transactions triggered by the instantiation of *X* given *C* and *T*; multiple ordered triples in an *AG* for *Y* represents "mixed feelings [17]" arising out of "mixed emotions"; enumerated in [19] by Ekman, the basic affects are 'happy', 'sad', 'fear', 'surprise' and 'disgust'; default affect-strength = 0; affect-strength is typically depicted as adjectives, adverbs or adverbial phrases representing degrees of strength (very, strongly, a little, etc.); default affect-valence = positive; affect-valence ∈ {+, -}.

A, *B* and the elements of *AG* are perception-based fuzzy numbers. [*AG* is conceptually similar to spectral fuzzy numbers [57].]

Some examples of Z*-numbers are:

(i) Y_1 = I have an R.K. Narayan in my hands.

X = what do I have in my hands? => what am I reading presently? [as R.K. Narayan is an 'author']
T = {retrospective, present} = {recent past, now}
C = {my current read, personal memories and reviews of R.K. Narayan's works}
A = an R.K. Narayan => a book by R.K. Narayan
B = definitely ← implied value for certainty in Y_1
AG = {(happy, high, +)} ← intuitively, a result of internal processing in the order of:

$$\begin{aligned}&\sum[(\text{Pleasant personal experiences of reading R.K. Narayan } \mathbf{OR} \text{ Recall positive reviews of}\\&\quad \text{R.K. Narayan's works by attachment figures}) + \text{general frame of mind at } T]\\&\text{where, } \mathbf{OR} \Rightarrow \text{ the logical OR operator, and}\\&\quad \text{attachment figures } [51, 52] = \text{ set of acquaintances who influence judgements.}\end{aligned} \tag{4}$$

Thus, the Z*-number of $Y_1 = Z_1$ = <{recent past, now}, my current read, a book by R.K. Narayan, definitely, {(happy, very, +)}>.

(ii) Y_2 = It takes me about an hour to reach point A!
X = time it takes me to reach point A
T = {retrospective, present} = {over some days, today}
C = {average travel time to point A, general road conditions, less travel time today}
A = an hour
B = about => usually ← explicit value for certainty in Y_2
AG = {(Surprise, very, +), (Disgust, high, -)} ← a result of internal processing in the order of:

$$\left[\sum(\text{previous tedious travel experiences to point A}) \gg \text{the relatively easier experience today}\right] \tag{5}$$

Thus, the Z*-number of $Y_2 = Z_2$ = <{over some days, today}, {average travel time to point A, general road conditions, travel time today}, an hour, usually, {(surprise, very, +), (disgust, high, -)}>.
Had the situation been of the following description,

C = {average travel time to point A, general road conditions, longer travel time today}, then
AG = {(surprise, very, –), (disgust, high, -)} ← a result of internal processing in the order of:

$$\left[\sum(\text{previous tedious travel experiences to point A} + \text{excruciating experience today})\right] \tag{6}$$

Accordingly, the Z*-number of $Y_2 = Z_2$ = <{over some days, today}, {average travel time to point A, general road conditions, travel time today}, an hour, usually, {(surprise, very, –), (disgust, high, -)}>.

The ordered 6-tuple <*X*, *T*, *C*, *A*, *B*, *AG*> is referred to as a 'Z*-valuation'. A Z*-valuation is equivalent to an assignment statement '*X* is <*A*, *B*> (arousing *AG*) given *T* and *C*'. As for example: The Z-valuation of Y_2 is < time it takes me to reach point A, {over some days, today}, {average travel time to point A, general road conditions, travel time today}, an hour, usually, {(surprise, very, +), (disgust, high, -)}>.
Set of Z*-valuations for a particular event (*E*) denotes the 'Z*-information' for *E* and is the stimulus to related decision-making processes.

• ***Preliminary rules of Z*-number computations are:***

(i) For the purpose of computation, the values of *A*, *B* and *AG* require to be precisiated through context-sensitive membership functions, μ_A, μ_B, μ_{AG} respectively, where the context is defined by parameters that capture descriptions of the external world (event under consideration) and internal system conditions.
(ii) μ_{AG} uses as operands the polarity and weights of the affects constituting *AG*. The sub-affects of *AG* are fuzzy numbers as well, and their strengths are precisiated by membership functions.

(iii) X and A together define a random event given (T, C) in R, and the probability (p) of this event, may be expressed as:

$$p = \int_R \mu_A(u) p_X(u) du \tag{7}$$

Where, given (T, C), u is a real-valued generic value of X and p_X is the underlying (hidden) probability density of X.

(iv) *"Emotions and beliefs are both mental states. They share certain qualities and they can be distinguished in terms of other attributes but, like all mental states, they are closely intertwined. Mental states evoke other mental states and together they form such an intricate web that distinctions can become blurred. Yet, both emotions and beliefs can be characterized with sufficient clarity… Emotions can be defined as states that comprise feelings, physiological changes, expressive behavior, and inclinations to act. Beliefs can be defined as states that link a person or group or object or concept with one or more attributes, and this is held by the believer to be true."*—[26]

"The correlation between beliefs and emotions is yet to be clearly determined."—[59]

The Z*-valuation $< X, T, C, A, B, AG >$ is viewed as a generalized constraint on X, and is defined by:

$$\begin{aligned} &\text{Probability } (X \text{ is } A) \text{ is } (B *^C AG) \text{ given } (T, C) \\ &\text{or,} \quad p = \int_R \mu_A(u) p_X(u) du \text{ is } \left(B *^C AG\right) \end{aligned} \tag{8}$$

Where, $(*^C)$ denotes a complex operation involving B and the constituent affects in AG to agglomerate the mutual roles of belief and emotions in decision-making. It refers to the system's "feelings", as is described by Damasio in [16,17]. The formalization of $*^C$**,** stresses on the need for careful analyses of the covariance and correlation of beliefs and emotions in everyday decision-making, and is one of our future tasks.

Eq. (8) is mathematically equivalent to the expression:

$$\begin{aligned} &p = \mu_{B\_AG}\left(\int_R \mu_A(u) p_X(u) du\right) \\ &\text{subject to,} \quad \mu_{B\_AG} = \left(\mu_B *^C \mu_{AG}\right) \text{ and } \int_R p_X(u) du = 1 \text{ and } (T, C) \end{aligned} \tag{9}$$

• ***Significance and properties of the Z*-number parameters:***

(i) Our conceptualization of the Z*-numbers is based on its use in the emulation of machine-understanding of natural language or real-world events.
(ii) Z*-number parameters are typically instantiated as words or clauses—satisfying the 'cannot define' rationale [93,96] of CWW-application for sentence precisiation. These values could either be explicitly mentioned in Y, or implied in the deep-semantics of Y.
(iii) Z*-information sets for sentences, for a given C and T, form concept granules.
(iv) A Z*-valuation summarizes the objective and subjective percepts of a simple sentence. While B and AG are thoroughly subjective, and X thoroughly objective, A, C and T straddle both perspectives.
(v) Z*-information sets can be envisioned as the operands of machine-mind processing and consequently instrumental in the emulation of machine-self consciousness.
(vi) The Z*-numbers typically depict ensembles of information in the *working-memory* and *system-memory* constructs (described in Section 2.3). These are distinct from generic codes of information in the *long-term* stores of the machine-mind architecture (analogous to different data-types—images, sounds, smells, etc.—active in multi-modal thinking, while the brain has generic neural correlates for data irrespective of modality).
(vii) *"Without it (time), there would be no planning, no building, no culture; without an imagined picture of the future, our civilization would not exist… Mental time travel may indeed be the cognitive rudder that allows our brains to navigate the river of time."*—[21]

Referring to Ramachandran's note of the properties of the self (in Section 2.2), Zimbardo's observations in [100] and the formation of autobiographical memories [60]—the Time (T) parameter is crucial to the sense of the unified-self and reflective-self representations within the system-mind. This parameter lends dynamicity to the paradigm.

(viii) *"Perception is always relative – never absolute – is always dependent on the surrounding context"* – [66].

"…we perceive by engagement, rather than by passive receptivity,… the reason why we often recall contexts rather than just isolated things." – [17]

Besides the observations in Section 2.2 on the importance of the context (C) in comprehension, the following case studies highlight its practical implications:

(a) **Case 1**—The same expression being used in different contexts:-
- She caught on (*understand*) to what was being said.
- The trend of wearing palazzos has caught on (*become popular*).
- The kakapos were caught on (*captured on*) film.

Table 2
Correspondence between Z*-number parameters and definitions of the self.

Philosophy	Views	Supporting elements of the Z*-number paradigm
Sigmund Freud	Id	Emulation of artificial 'instinct'—endogenously generated as $<$*Context* (*C*), *Time* (*T*), *Certainty* (*B*), *Affect* (*AG*)$>$ tuples
	Ego Superego	Networks of $<$*Context* (*C*), *Time* (*T*), *Certainty* (*B*), *Affect* (*AG*)$>$ in the system's memory—generated endogenously and through interactions with the real-world and fellow systems
Marvin Minsky	Self-reflective thinking	Equivalent to Freud's definition of *Ego*
	Self-conscious emotion	Equivalent to Freud's definition of *Superego*
Antonio Damasio	Protoself	Equivalent to Freud's definition of *Id*
	Core self	*Id* + *Ego* + *Superego*; Each Z*-number for an event (*E*) is an instance of the core self
	Autobiographical self	*Id* + *Ego* + *Superego*; Z*-information for *E*
V. Ramachandran	Continuity Unity or self-coherence Embodiment or ownership	Equivalent to Damasio's definition of *Autobiographical self*
	Privacy Social embedding Sense of agency Reflection or self-awareness	Equivalent to Damasio's definition of *Core self*

(b) **Case 2** – Different expressions being used in the same context:-

- This car cost me an arm and a leg.
- This car cost me the Earth.
- This car cost me a pretty penny.

$\Rightarrow$ This car is very expensive.

(ix) *T* and *C* facilitate anaphora and cataphora resolution, and possibly serve as essential parameters of the Winograd Schema [43] for MIQ [95] evaluation.
(x) *A* is dependent on *T* and *C* for sentences activated in the mind as mentalese [62], for some event (*E*) and subject (*X*).
(xi) In [38], Kahneman shows that memories of events are dominated by experiences and consequent feelings—at their peak (for positive events), the nadir (for negative events), and at the very end. The duration is inconsequential, but the affect-strength is the determining factor. Thus, justifying the inclusion of *AG* as an essential Z*-number parameter.
(xii) Damasio, in [17], describes the role of somatic markers or affects as information importance graders.
  (a) *B*, and *AG* are dependent on *X*, *A*, *C* and *T*, and represent the system's emotional self.
  (b) *B* summarizes the certainty or belief in the applicability of *A* given *X* within the purview of *C* and. *AG* denotes the emotions or affects activated autogenously by the event.
  (c) *B* and *AG* are results of experiences, anticipations, commonsense, intuition, and are thus representatives of subjectivity or qualia. These parameters act as somatic markers and index system memories in terms of the affects they evoke. They can be generated online (during current processing) or offline (during reflections or contemplations), and are subject to modifications over time. (Section 3.2—describes our work on the basis of endogenous certainty and affect values, and Section 4 describes certain behavioral experiments we conducted to study the practical significance of these parameters).
(xiii) The conjunction of *C* and *AG* supports the differentiation between senses of the same expression. E.g. the statement—"This book is a cracker!"—could mean either of:
  (a) This book is actually an excellent work of literature.
  (b) This book is *actually* disappointing, i.e. the above statement is made in sarcasm.
(xiv) Table 2 summarizes our analyses of correspondence between the enumerated parameters of the Z*-numbers and perspectives of the self described in Section 2.2. The coverage of the philosophies adjudges this paradigm theoretically capable of delineating the machine-self and machine-subjectivity. Section 4.3 describes a theoretical exercise depicting this paradigm as simulating machine-mentalese [62].

Note: The definition of the Z*-number, applies to simple sentences. We reason that through decomposition of complex or compound sentences (*S*) into their simple sentence constituents (*S*'), translation of *S*' into their Z*-number equivalents and subsequent union of these component results as per connectives used in *S*, it should be possible to encode any natural language sentence into its Z*-number equivalent (similar predictions were made in [10,58] while discussing the scope of Zadeh's Z-numbers).

The operators defined in Section 3.4 use Z*-valuations of sentences (either externally sourced or arising in the machine-mind) as parameters to simulate comprehension processes. Section 4 describes experiments, results and discussions on the theoretical and practical connotations of the paradigm.

The following section is dedicated to a discussion on essential computational factors of endogenous machine-certainty and machine-affects, drawing inspiration from the human-model.

3.2. The social machine: Foundations of machine-certainty (B) and machine-affects (AG)

"As we navigate our lives, we normally allow ourselves to be guided by impressions and feeling, and the confidence we have in our intuitive beliefs and preferences"—[38]

"The brain is an extraordinarily plastic biological system that is in a state of dynamic equilibrium with the external world"—[65]

"Belief is not monolithic; it exists in many layers ..."—[65]

Cognitive anthropology [14] treats the mind as a cultural phenomenon. The way people move, talk and gesture—their facial expressions, posture and speech—contribute to formation of impressions about them and most of our judgments depend on these expressive behaviors [3]. We attach a sense of purpose, choice or free will onto our interactions with fellow social beings and accordingly apply and derive social and self-conscious emotions from their actions [65]. Studies in [15,78] further demonstrate the positive role of enriched environments in neurogenesis in the human brain.

Considering the implications of the above, a sentient intelligent machine-mind—engaging in man–machine interactions for symbiotic purposes—should be gaining knowledge through interactions with itself (self-reflections, contemplations, and realizations) as well as other systems or human users. The subjective properties of knowledge acquired through acquaintances with the self and others—the degree of correctness or strength of certainty of the information and associated affects—depends on the system's impressions of the knowledge source.

- ***Parameters of 'knowledge by acquaintance [72,74]'***

"We can learn from the discoveries of earlier generations just because... loving caregivers invest in teaching us. It isn't just that without mothering, human would lack nurturing, warmth, and emotional security. They would also lack culture, history, morality, science and literature"—[28]

Assuming the system as capable of identifying itself in the first-person ('I', 'me', 'my'), relating to its intuitive emotions and associated qualia, and categorizing acquaintances into attachment figures [51,52] or else and forming impressions of them, this section attempts at elucidating the factors that influence the *certainty* (B) and *affects* (AG) factors of information.

We have here some basic computational definitions of quantification of subjective properties of knowledge gained through social interactions with the self and others for a sentient machine-mind. These definitions modulate values of parameters B and AG in the Z^*-number equivalent of some information. All formulae are with respect to the first-person perspective of the machine-mind.

The parameters defined here, in conjunction with the memory constructs defined in Section 2.3, result in the emulation of all three categories ('what', 'how' and 'by acquaintance') [72,74] of knowledge by a computational-mind. This conceptual ability is the key novelty of our design. Fig. 6 summarizes the flow of data through the parameter formulations.

Behavioral experiments (described in Section 4) depict the self as the highest ranking attachment figure, influencing information recall. This undoubtedly has to do with the reinforcement of knowledge based on hands-on experiences, contemplative cross-domain knowledge associations and realizations, and internalization [73] of extrinsic motivators.

Framing our understanding (highlighted in the preceding paragraphs) and heuristics arising out of introspections into their computational equivalents (in bold), we have:

For a *context*,

an atomic *event* ϵ *context* where, *event* = particular <*subject*, *value*> tuple for *context*, and

context takes into consideration some *time* perspective—a combination of retrospective, present and prospective moments.

$$\boldsymbol{att\_figure} \in \{Self, Others\} = \text{an attachment figure } [51, 52] \tag{10}$$

where,

Self = the *protoself* or the system-self, leading to instinctive behavior, self-reflections and self-conscious activities.

Others = set of known figures (people or personified systems) = family, friends, teachers, acquaintances on the fly, etc. who profoundly impact our comprehension of the real world.

$$\boldsymbol{core\_self}(context, event) \in \left\{Self\text{'s instinctive responses to }(context, event), Others'\text{ responses to }(context, event)\right\} \tag{11}$$

$$\boldsymbol{autobiographical\_self}\ (context, event) = \sum core\_self(context, event) \tag{12}$$

$$\boldsymbol{belief}(att\_figure) = \text{generic degree of belief } on\ att\_figure;\ belief \in [0, 1] \tag{13}$$

This value is, objectively, proportional to the average correctness or pragmatism and stability of *att_figure*'s responses or suggestions to arbitrary situations [30], over a considerable time frame. (As is evident from the quote on belief at the start of this section, there definitely are other parameters, subjective mostly, influencing *belief*(*att_figure*), but we refrain from a discussion

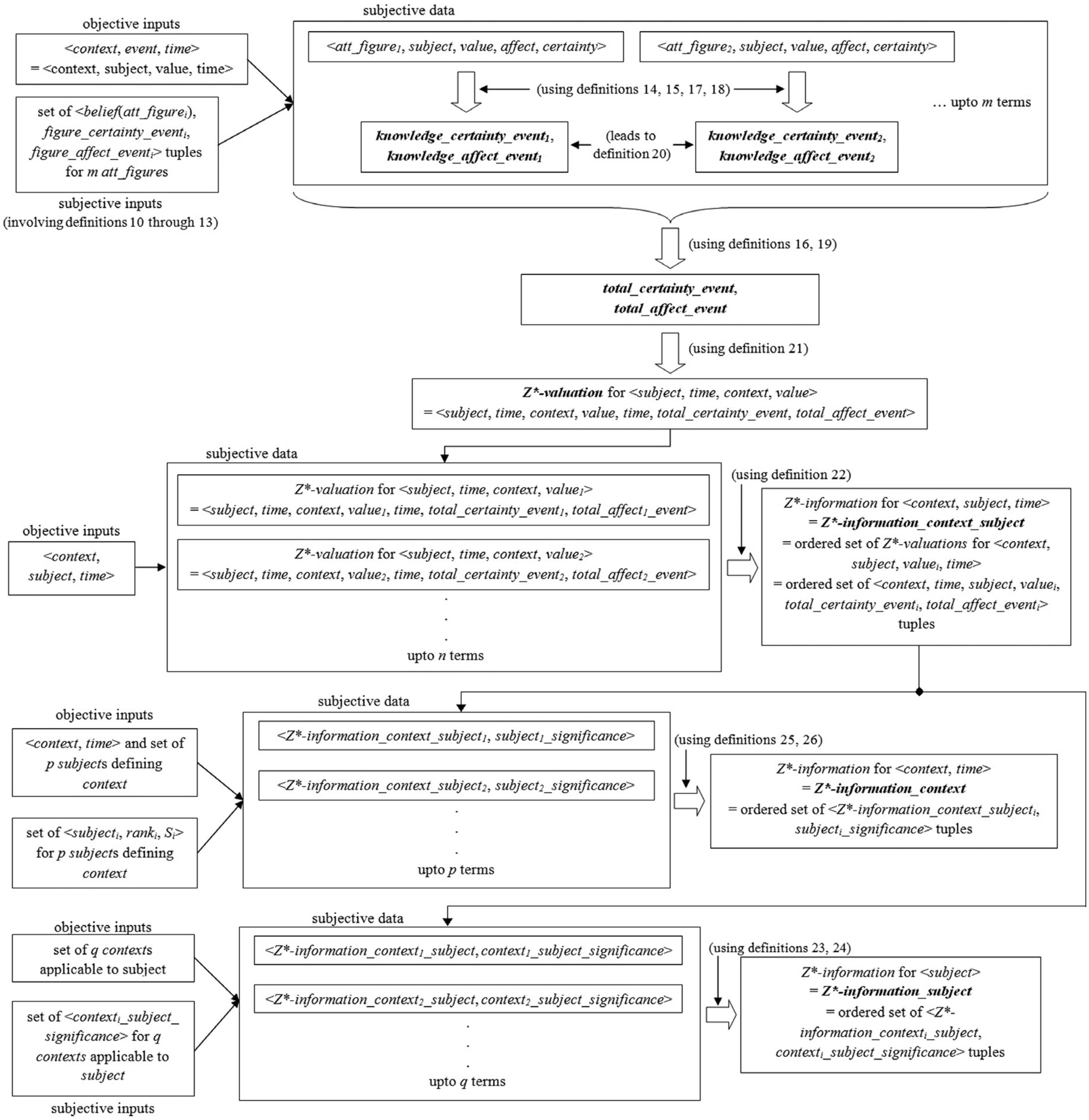


Fig. 6. Block-diagram of the flow of subjective and objective information across a machine-mind for the creation of Z-information tokens.

on them in this article.)

$$\begin{aligned}
&\boldsymbol{knowledge_certainty_event}(att_figure,\ event_information,\ figure_context_certainty)\\
&\quad = \text{a measure of my perception of } att_figure\text{'s forte in } event\\
&\quad = \text{the confidence I attach to } att_figure\text{'s response to } event\\
&\quad = \sum_{i=1}^{n} (event_information_certainty * figure_context_certainty)
\end{aligned} \tag{14}$$

where,

att_figure = source of information on *event* within *context*
event_information = the <*subject, value, certainty, affect*> component sourced from *att_figure* for *event,* where,
  certainty = conviction in *att_figure*'s conveyance of *event*, and
  affect = emotion of *att_figure* for *event*, and

event_information_certainty = *certainty* component of the *event_information* tuple

$$
\begin{aligned}
figure\_context\_certainty &= \text{subjective rating of strength of knowledge of } att\_figure \text{ on } context \\
&= \left(\begin{array}{l}\text{average correctness of } att\_figure's \text{ responses to any arbitrary} \\ event \in context * \text{my perception of } att\_figure's \text{ capability of relating to } context \\ \text{based on its/his personal history (occupation, habits, personality} \ldots)\end{array}\right)
\end{aligned} \tag{15}
$$

$$
\begin{aligned}
&\boldsymbol{total\_certainty\_event}(attach\_figures) \\
&\quad = \text{my certainty of } (context,\ event) \text{ information arising out of interactions with } attach\_figures \\
&\quad = \text{weighted average of all } knowledge\_certainty\_event \text{ information sourced from } attach\_figures \\
&\quad = \frac{\sum_{i=1}^{m} (knowledge\_certainty\_event_i * belief(att\_figure_i))}{\sum_{i=1}^{m} belief(att\_figure_i)}
\end{aligned} \tag{16}
$$

where,

attach_figures = set of all *att_figures* contributing to knowledge on *event*, |*attach_figures*| = *m*, (*m* is a positive integer ≥ 1)
$att\_figure_i = i^{th}$ *att_figure* in *attach_figures*
$knowledge\_certainty\_event_i = knowedge\_certainty\_event(att\_figure_i,\ event\_information_i,\ figure\_context\_certainty_i)$ [using Eq. (14)]
$event\_information_i$ = the <*subject, value, certainty, affect*> component sourced from att_figure_i for *event*
$figure\_context\_certainty_i$ = subjective rating of strength of knowledge of att_figure_i on *context* [using Eq. (15)]
$belief(att\_figure_i)$ = generic degree of belief on att_figure_i [using Eq. (13)]

$$
\begin{aligned}
&\boldsymbol{knowledge\_affect\_event}(att\_figure,\ event\_information,\ figure\_context\_affect) \\
&\quad = \text{a measure of my perception of } att\_figure's \text{ affect for } event \\
&\quad => \text{ viewing event from } att\_figure's \text{ perspective or empathizing with } att\_figure \\
&\quad = \sum_{i=1}^{n} (event\_information\_affect * figure\_context\_affect)
\end{aligned} \tag{17}
$$

where,

att_figure = source of information on *event* within *context*
event_information = the <*subject, value, certainty, affect*> component sourced from *att_figure* for *event*, where,
  certainty = conviction in *att_figure*'s conveyance of <*concept*>, and
  affect = emotion of *att_figure* for <*concept*>
event_information_affect = *affect* component of the *event_information* tuple

$$
\begin{aligned}
figure\_context\_affect &= \text{subjective rating of } att\_figure's \text{ affect for } context \\
&= (\text{average affect of } att\_figure \text{ for any arbitrary } event \in context * my \text{ perception of} \\
&\quad att\_figure's \text{ capability of relating to } context \text{ based on its/his personal history} \\
&\quad (\text{occupation, habits, personality} \ldots))
\end{aligned} \tag{18}
$$

$$
\begin{aligned}
&\boldsymbol{total\_affect\_event}(attach\_figures) \\
&\quad = \text{my affect for } (context,\ event) \text{ information arising out of interactions with } attach\_figures \\
&\quad = \text{weighted average of all } knowledge\_affect\_event \text{ information sourced from } attach\_figures \\
&\quad = \frac{\sum_{i=1}^{m} (knowledge\_affect\_event_i * belief(att\_figure_i))}{\sum_{i=1}^{m} belief(att\_figure_i)}
\end{aligned} \tag{19}
$$

where,

attach_figures = set of all *att_figures* contributing to knowledge on *event*, |*attach_figures*| = *m*, (*m* is a positive integer ≥ 1)
$att\_figure_i = i^{th}$ *att_figure* in *attach_figures*
$knowledge\_affect\_event_i = knowedge\_affect\_event(att\_figure_i, event\_information_i, figure\_context\_affect_i)$ [using Eq. (17)]
$event\_information_i$ = the <*subject, value, certainty, affect*> component sourced from att_figure_i for *event*
$figure\_context\_affect_i$ = subjective rating of *att_figure*'s affect for *context* [using Eq. (18)]
$belief(att\_figure_i)$ = generic degree of belief on att_figure_i [using Eq. (13)]

$$
\begin{aligned}
&\boldsymbol{my\_perception\_figure\_event}(att\_figure,\ event,\ context) \\
&\quad = \text{a summary of my perception of } att\_figure's \text{ perspective of } (context,\ event) \\
&\quad = \{knowledge\_certainty\_event(att\_figure,\ event,\ figure\_context\_certainty), \\
&\quad knowledge\_affect\_event(att\_figure,\ event,\ figure\_context\_affect)\}
\end{aligned} \tag{20}
$$

where,

att_figure = source of information on (*context*, *event*)
knowledge_certainty_event(*att_figure, event_information, figure_context_certainty*) = a measure of my perception of *att_figure*'s forte in *event* [using Eq. (14)]

knowledge_affect_event(*att_figure, event_information, figure_context_affect*) = a measure of my perception of *att_figure*'s affect for *event* [using Eq. (17)]

Notes and observations:

(i) The perspective of the *Self* as an attachment figure accounts for the machine-mind's instinctive reactions, as well those sourced from solely solitary activities (like contemplating, realizing, thinking and learning on the fly).

(ii) Certain solitary activities (like reading and listening) involve considering views of others and reflecting upon them. These elements thus involve equal participation of *Others* and *Self*; implying, *Self* and *Others* are overlapping sets.

(iii) *affect* in Definitions 14–20 stands for the *affect_group* parameter in a standard Z*-number.

(iv) The individual <*att_figure*, *subject*, *context*, *value*, *certainty*, *affect*> *event_information* tuples, used in Definitions 14 and 17, imply conscious or sub-conscious (Freud's 'preconscious' memories) context-induced recollections (or retrospections) and form **microcosmic Z*-valuations**.

  (a) Each of these valuations summarizes a souvenir of interaction ("autobiographical and episodic memories [17,28,60]") between the system and an *att_figure* over (*context, event*). Micro-Z*-valuations imply the "microworlds of form and function that signal the brain to formulate an appropriate response" theory in [17].

  (b) Eqs. (15) and (18) portray autogenous computations in the machine-mind toward the formation of subjective abstractions (reflected in Definition 20) of these *event_information* tuples.

  (c) Integrations of these microcosmic elements lead to Eqs. (16) and (19), and,

$$\textbf{macrocosmic Z}^{*}\textbf{valuation} < subject,\ time,\ context,\ value,\ total\_certainty\_event,\ total\_affect\_event > \text{ given } (context,\ event,\ time) \tag{21}$$

  This summarizes subjective realizations of the machine-mind on (*context, event*) at *time* and is intuitively equivalent to a token of bespoke comprehension of (*context, event*).

(v) More than one source (*att_figure*) supporting or stating a <*subject*, *value*> tuple for *context* (as is depicted in Definitions 16 and 19), symbolizes reinforcement of the <*subject*, *context*, *value*> association.

(vi) *"If your agenda is not to change your beliefs, but to hold on to as many of them as possible, only changing a few of them very deliberately when you are sure you need to, gathering more and more evidence in support of the change, then it makes more sense to keep track of the history and source of your beliefs. You want to change your beliefs only when you are sure the new information is robust and reliable – and more robust and reliable than the existing beliefs"*—[28]

  Determining the course of action when *belief*(*att_figure*) or perceptions undergo major upheavals—causing significant modulations in the *certainty* and *affects* of related information—is a sensitive design concern. It would perhaps be prudent to include parameters that represent durations of stability of values and encode reasons for significant changes. These parameters intuitively encourage reflective thinking in a computational-mind.

(vii) Eqs. (10)–(12) directly relate to Damasio's definition of the self and consequently visualizations of other philosophers (as is shown in Table 2).

(viii) Though the philosophy of the Z*-numbers is reminiscent of 'subjective probability [86]', they differ in their perspectives.

  The subjective probability (P_s) of an event (E) is defined by the set of bets about E that an individual (I) is willing to accept. An internally consistent subjective probability measure can be derived for I if his bet-choices satisfy axioms of probability theory. The derived probability is 'subjective' as different individuals may have different probabilities for the same event.

  The Z*-number, on the other hand, brings together key mind-elements that form the basis of subjectivity in I for E. These parameters aim to represent and precisiate reasons that define I and P_s.

While the computational Definitions 14–20 apply to Z*-valuations for individual atomic *events* (a fixed <*subject*, *value*> perspective) in *context* at *time*, the **Z*-information** of these valuations for a particular *subject* (activating multiple *value* instantiations) within a (*context*, *time*) is:

$$\boldsymbol{Z^{*}\text{-}information\_context\_subject} = \text{an } event\_context\_set$$
$$= \text{ordered set of} < context,\ time,\ subject,\ value_i,\ total\_certainty\_event_i,\ total\_affect\_event_i > \text{tuples} \tag{22}$$

where,

each element ∈ *event_context_set* is a macrocosmic Z*-valuation emerging out of machine-mind internal simulations of Eqs. (14)–(20)

subject has multiple acceptable instantiations or values given *context* at *time*

tuples in *event_subject_set* are ordered in the descending order of ($total\_certainty\_event_i$, $total\_affect\_event_i$) values => the higher positioned elements are the first *subject* instantiations recalled

$value_i$ = the i^{th} *subject* instantiation

$total\_certainty\_event_i$ = the i^{th} total_certainty_event for (*subject, value*) [using Eq. (16)]

$total\_affect\_event_i$ = the i^{th} *total_affect_event* for (*subject*, *value*) [using Eq. (19)]

$|event\_subject\_set| = n$, (n is a positive integer ≥ 1)

event_subject_set is built through interactions, over time, with a set of attachment figures (*attach_figures*), where $|attach\_figures| = m$ (m is a positive integer ≥ 1),

Note: In formulation 22, the order of the parameters (*subject*, *time*, *context*) in a ***Z*-information_context_subject*** differs from a standard Z*-valuation (defined in Section 3.1) as the *context* defines the circumstances or limits the values applicable to *subject*. The Z*-information formulations for *subject*, irrespective of *context* and *time*, i.e., a summary of all the different senses of *subject* across all known contexts is,

$$\begin{aligned}&\boldsymbol{Z^*\text{-}information\_subject}\\&\quad= \text{set of } Z^*\text{-}information\_context\_subject \text{ tuples, each annotated by the strength of association between } subject\\&\quad\;\;\text{and the } context \text{ in question}\\&\quad= \text{ordered set of } < Z^*\text{-}information\_context_i\_subject,\ context_i\_subject\_significance > \text{ tuples}\end{aligned} \tag{23}$$

where,

$|Z^*\text{-}information\_subject| = q$, ($q$ is a positive integer ≥ 1)
$context_i$ = the i^{th} *context* that applies to *subject*
$context_i\_subject\_significance$ = strength of association between *subject* and $context_i$; is proportional to the number of times *subject* and $context_i$ have been handled together or *subject* has appeared in conjunction with synonyms of $context_i$;

$$= \frac{[experiences\ with\ (subject,\ context_i) +\ \sum_{j=1}^{\text{number of synonyms of } context_i} experiences\ with\ (subject,\ synonym_j\ of\ context_i)]}{[experiences\ with\ subject + experiences\ with\ context_i + \sum_{j=1}^{\text{number of synonyms of } context_i} experiences\ with\ synonym_j]} \tag{24}$$

(*experiences* take into consideration not only number of occurrences but affects aroused in the transactions and other parameters of subjectivity or qualia, as well)
tuples are ordered in the descending order of $context_i\_subject\_significance$ => higher the significance, greater is the degree of association between *subject* and $context_i$ => an arbitrary mention of *subject* leads to ready recall of information on it within the framework of $context_i$

Expanding Definition (22) to form a Z*-information for the entire *context* (an entire plethora of *events*) in some *time* perspective, we arrive at:

$$\begin{aligned}&\boldsymbol{Z^*\text{-}information\_context} = \text{a } subject\_set\\&\quad= \text{set of } Z^*\text{-}information\_context\_subject \text{ tuples, each annotated by the significance of the } subject \text{ in}\\&\quad\;\;\text{the comprehension of the } context\ given \text{ time}\\&\quad= \text{ordered set of } < Z^*\text{-}information\_context\_subject_i,\ subject_i\_significance > \text{ tuples}\end{aligned} \tag{25}$$

where,

a *situation* = {($subject_1$, $rank_1$), ($subject_2$, $rank_2$), …, ($subject_j$, $rank_j$), … upto p terms} (p is a positive integer ≥ 1), where,
$subject_j$ = the j^{th} parameter that describes *situation*
$rank_j$ = the subjective importance of $subject_j$ in describing *situation*
context = {($subject_1$, S_1, $rank_1$), ($subject_2$, S_2, $rank_2$), …, ($subject_j$, S_j, $rank_j$), … upto p terms}, where,
S_j denotes the score of $subject_j$ for *context*, thus relating $subject_j$ for *situation* to the particular *context*
S_j = subjective summarization of the internal and external conditions of the system at *time*
tuples in *subject_set* are ordered in the descending order of *subject_significance* => the higher positioned elements facilitate the comprehension of *context*

$$subject\_significance = \frac{\sum_{j=1}^{p} (S_j * rank_j)}{\sum_{j=1}^{p} rank_j} \tag{26}$$

$subject_i$ = the i^{th} *subject* in *subject_set*
$subject_i\_significance$ = *subject_significance* of $subject_i$ to *context*
$|subject\_set| = n$, (n is a positive integer ≥ 1)
subject_set is built through interactions, over time, with a set of attachment figures (*attach_figures*), where $|attach\_figures| = m$ (m is a positive integer ≥ 1)

Studies depicting the practicality of the concepts defined in this section are described through behavioral studies in Section 4. (Section 4.4 discusses the issue of cognitive biases arising in a social machine-mind). Refer to [30,33] for studies on the influence of attachment figures on learning in children and subsequent contemplation.

The article now progresses to a description of Z*-number based preliminary procedure for natural language comprehension and some primitive Z*-number based operators (assuming knowledge in the machine-mind to be tokenized as per the Z*-number scheme) to emulate sub-processes of comprehension in a machine-mind.

3.3. Z*-number based effective procedure for natural language comprehension

Real-world or natural language comprehension follows an incremental-developmental strategy (described briefly in Section 2.3). The following effective procedure abides by a primitive developmental methodology of understanding complex and compound sentences (*S*) by decomposing them into their simple sentence constituents, evaluating and processing their Z*-valuation equivalents, and integrating these results into a comprehension module of *S*. The machine-mind framework in Figs. 4 and 5 executes this procedure to assemble granules of comprehension for *S*. Section 4.3 describes a dry-execution of this procedure for emulation of differential diagnosis.

Input: Natural language sentence (*I*).
Output: Context-dependent response (*O*) to *I*.
Assumptions:

(i) The system is capable of identifying irrelevant sentences.
(ii) The system grasps the perception of a complex or a compound sentence (*Y*) by –
  (a) Extracting the simple sentence components of *Y*.
  (b) Individually comprehending each of these simple sentence components.
  (c) Integrating these component perceptions.

Steps:

1. If *I* is irrelevant
    Then
        Goto step 10
    Else
        Goto step 2
2. If *I* is a simple sentence
    Then
        Goto step 3
    Else
        a. Extract the simple sentence component set (*I*') of *I*
        b. Repeat steps 3 and 4 for each sentence in *I*'
        c. Goto step 5.
3. Extract values of *X*, *T*, *C*, *A*, *B* and *AG* in *I* to formulate its Z*-valuation (Z^*_I)
4. Convert Z^*_I into equivalent mathematical expression (Z^*_E) [as per formulation (9)]
5. Assemble all Z^*_E to articulate a logical expression (*E*) guided by the conjunctions or connectives in *I*
6. Convert *E* to the mathematical expression (*M*)
7. Evaluate *M* to receive a set of Z*-valuations (Z^*_O)
8. Translate Z^*_O into simple sentences (*S*)
9. If step 8 results in more than one simple sentence
    Then
    If some or all the sentences in *S* can be compiled into a single sentence
        Then
        a. Assimilate all compatible simple sentences into a complex/compound sentence (*S*')
        b. If *S*' does not include all the sentences in *S*
            Then
            b.1. $S'' = S - S'$
            b.2. $O = S' \cup S''$
            Else
            $O = S'$
        Else
        $O = S$
    Else
    $O = S$
10. Stop

• ***Properties of the procedure:***

(i) The time-complexity of the above procedure depends on the degree of comprehension of *I*, after every iteration of the entire procedure. Lower the comprehension greater is the iteration requirement.
(ii) The degree of comprehension is a function of existing knowledge on the *Subject* (*X*) within the purview of the *Context* (*C*).
(iii) Step 7 of this procedure is where the operators defined in the succeeding section are evoked.

3.4. Primitive Z*-number based operator for comprehension emulation

Recapitulating from Section 3.1, the 'Z*-valuation' of a simple sentence Y on a subject X is a 5-tuple $Z = <X, T, C, A, B, AG>$, where, X = the subject of Y,
T = time = a combination of present, retrospective and prospective moments,
C = the context in which Y was used,
A = the value of X = instantiation of X given C and T,
B = a measure of the reliability or certainty of A given C, X and T, and
AG = the affect group = a set of ordered triples of (affect, affect-strength, affect-valence)

• ***Perception-union operator*** ($\cup^*_P$)
Let, Z_1 and Z_2 be Z*-valuations of two simple sentences S_1 and S_2 respectively,
where,

$Z_1 = <X_1, T_1, C_1, A_1, B_1, AG_1>$ and $Z_2 = <X_2, T_2, C_2, A_2, B_2, AG_2>$
S_1 and S_2 describe progressions in the perception of an event ($E = <\text{subject, value}> = <X_1, A_1>$) through time, S_1 expresses the earlier state,
C_1 and C_2 are synonymous or related,
$X_1 = X_2$,
$A_1 = A_2$,
$T_1 = \{\text{retrospective, present, prospective}\}_{S1}$
$T_2 = \{\text{retrospective, present, prospective}\}_{S2}$, T_2 denotes a prospective moment in comparison to T_1
$B_1 \in$ {words implying degree of association between A_1 and X_1 for C_1 at T_1},
$B_2 \in$ {words implying degree of association between A_2 and X_2 for C_2 at T_2},
AG_1 and AG_2 $\in$ {words describing affects aroused in transactions across Z_1 through Z_2},

The ***Union of Perceptions*** ($Z_1 \cup^*_P Z_2$) is defined as,

$$(Z_1 \cup^*{}_P Z_2) = <X_1, T, C, A_1, B, AG> \\ \text{where, } T = (T_1 \cup T_2), \quad B = (B_1 \cup B_2), \quad AG = (AG_1 \cup AG_2) \text{ and } C = \text{context applying to } C_1 \text{ and } C_2 \tag{27}$$

(T = union of time progressions, B = union of certainty progressions and AG = union of affect progressions; the elements of the results of the unions are written in the order of progression, i.e. elements of Z_2 follow Z_1.)

This expression leads to a complex or spectral Z*-valuation (drawing from the basic philosophy of 'spectral fuzzy sets' [57]) that charts and summarizes changes in perceptions (certainty, affect) of an event. [Details on spectral Z*-valuations are out of the scope of the current article.] Typically, the system annotates perception changes with corresponding reasons, and these compound elements join the **Answer-Library** (described briefly in Section 2.3). Examples of $\cup^*_P$ operation:

(i) S_1 = It took me about an hour to reach point A yesterday.
=>Z_1 = <time to reach point A, {retrospective, present}$_{S1}$, {unhappy road conditions, tedious travel conditions}, an hour, probably, {(angry, high, −), (disgust, high, −)}>
S_2 = It took me a shade more than three-quarters of an hour to reach point A today!
=>Z_2 = <time to reach point A, {present}$_{S2}$, {unhappy road conditions, tedious travel conditions}, a shade more than three-quarters of an hour, certainly, {(angry, moderate-high, −), (disgust, moderate-high, −), (surprise, mild, +)}>
= <time to reach point A, {present}$_{S2}$, {unhappy road conditions, tedious travel conditions}, an hour, not exactly, {(angry, moderate-high, −), (disgust, moderate-high, −), (surprise, mild, +)}>
Thus, ($Z_1 \cup^*_P Z_2$) = <time to reach point A, ({retrospective, present}$_{S1}$,{present}$_{S2}$), {unhappy road conditions, tedious travel conditions}, an hour, {probably, not exactly}, {(angry, high, −), (disgust, high, −), (angry, moderate-high, −), (disgust, moderate-high, −), (surprise, mild, +)}>
i.e., linguistically: It takes me close to an hour to reach point A. The travel was more difficult yesterday.

(ii) S_1 = I'd like my soup to be really hot.
=>Z_1 = <soup temperature, {retrospective, present, prospective}$_{S1}$, {general soup preferences, current choice}, really hot, expect, (fear, mildly, +)> [This affect implies 'anticipatory' emotions]
S_2 = This soup's lukewarm!
=>Z_2 = <served soup temperature, {present}$_{S2}$, {general soup preferences, current choice}, lukewarm, definitely, {(disappointed, largely, −)>
= <soup temperature, {present}$_{S2}$, {general soup preferences, current choice}, really not, definitely not, {(disappointed, largely, −)>
Thus, ($Z_1 \cup^*_P Z_2$) = <soup temperature, ({retrospective, present, prospective}$_{S1}$, {present}$_{S2}$), {general soup preferences, current choice}, really hot, {expect, definitely not}, {(fear, mildly, +), (disappointed, largely, −)}>
i.e., linguistically: I was looking forward to hot soup. The cold soup served is a big disappointment.

The perception-union operator facilitates the study of modulations in subjective perceptions of a concept and reasons thereof. Intuitively, lesser the modulation in certainty, greater is the stability of the association between X and A in the current context. It might thus be possible to locate abrupt changes in opinions and identify consequent reasons—a step toward emulation of *accumulation* [51] and intuitive (or *predestined* [51]) learning by a machine.

Observations:

(i) The perception-union operator depends on the context-sensitive senses of the parameters of the Z*-numbers.
(ii) The perception-union operator, being a repository of modulations of emotions and beliefs across experiences of an event (E), calls for the definition of a perception-summarization operator that extracts highlights of these experiences to create an index or representative of E during memory consolidation. The summarization operator is reminiscent of Kahneman's observations in [38] on the factors (affect and belief strengths) that dominate memories of experiences. Points of interest of this operator are:
   (a) While major changes in affect_strengths, belief_strengths and affect_valences across consecutive experiences require inclusion of both these experiences in the summary; gradual or no changes provide scope for compaction—entire experiences being replaced by indicators of gradual change across time. [The structure of these meta-Z*-valuations as well as their compatibility with the basic Z*-valuations defined in Section 3.1 remains to be investigated].
   (b) Mathematical definitions for 'major' and 'gradual' changes should take into account system emotion_thresholds, belief_thresholds as well as the importance of E to the system-self.
   (c) The operator intuitively leads to a definitive conceptual summary of E with respect to all experiences gathered.
   (d) Necessitates the definition of a measure of degree-of-summarization and information-loss. An acceptable summary of E would ensure a balance between these measures.
(iii) Perception-operators reiterate the need for the endogenous arousal of emotions and beliefs.
(iv) For two sentences indirectly linked by a common subject, either one of the sentences requires to be interpreted in terms of the other. This involves complex functions of cross-association between sentences.
   E.g., Let, $S_1 =$ I would like an Uncle Fred book and $S_2 =$ The phrase "I endeavor to give satisfaction" on a page of a Wodehouse novel.
   S_2 is an indirect indication of the book in hand being an Uncle Fred novel. Thus, union of the perceptions of these two sentences would involve translation of S_2 in terms of S_1. Other examples of such translations can be found in the experiments described in Section 4.3.
(v) Other perceptions operators could be perception-join, perception-division—drawing inspiration from database management operators. [Defining these operators form a crucial future task in our machine-mind design initiative.]

The following section describes experiments (behavioral and theoretical) we performed in the quest of parameters used in formulating the Z*-number paradigm and Definitions 10–26.

4. Experiments, results and discussions

In this section we present results of a sequence of basic behavioral experiments we conducted in the pursuit of factors that contribute to subjective information recall, the importance of attachment figures to learning and recall, and the perspective of the self and subjectivity. These tests were conducted on human subjects within the age group 22–32 of similar academic backgrounds (postgraduates), but with different tastes in literature and an average interest in reading. These studies have not only contributed to the formalization of the Z*-number paradigm (summarized in Table 7), but have also raised issues of practical importance toward the synthesis of an artificial computational mind. Descriptions of experiments are followed by discussions on the practical implications of the proposed ideas.

4.1. Section A

Objective:
Investigations on:

(i) Attachment figures or spheres of influence, as is claimed in [30,33,51]?
(ii) Are human beings self-aware, aware of being self-aware?

Consequently:

(i) Evaluate basis of parameters of the Z*-numbers
(ii) Ability of representation of subjectivity by Z*-numbers (vis-a-vis Definitions 10–26)

Precautions taken for all of the experiments in this section:

(i) The same set of human subjects was involved in each of the tests.
(ii) Some of the tests were repeated across time, and the order of the questions was modified per re-test.
(iii) None of the subjects were given access to their previous responses.

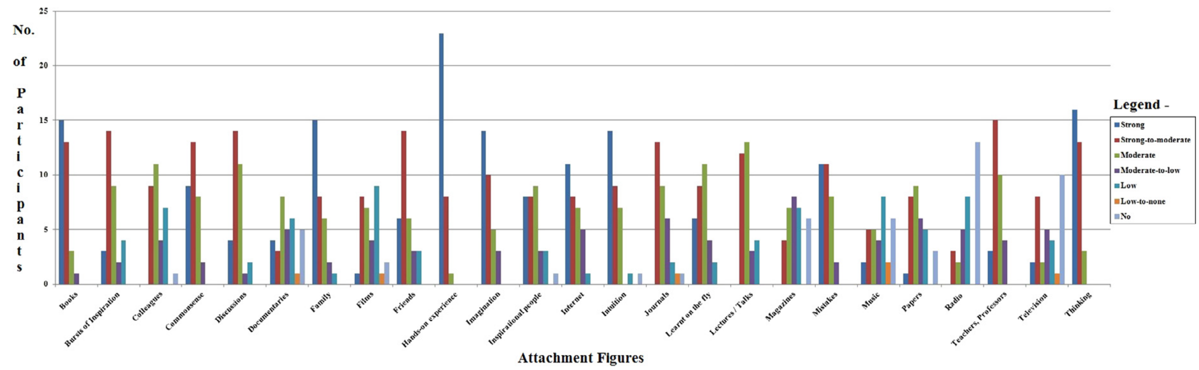


Fig. 7. Summary of responses received for Experiment 1.

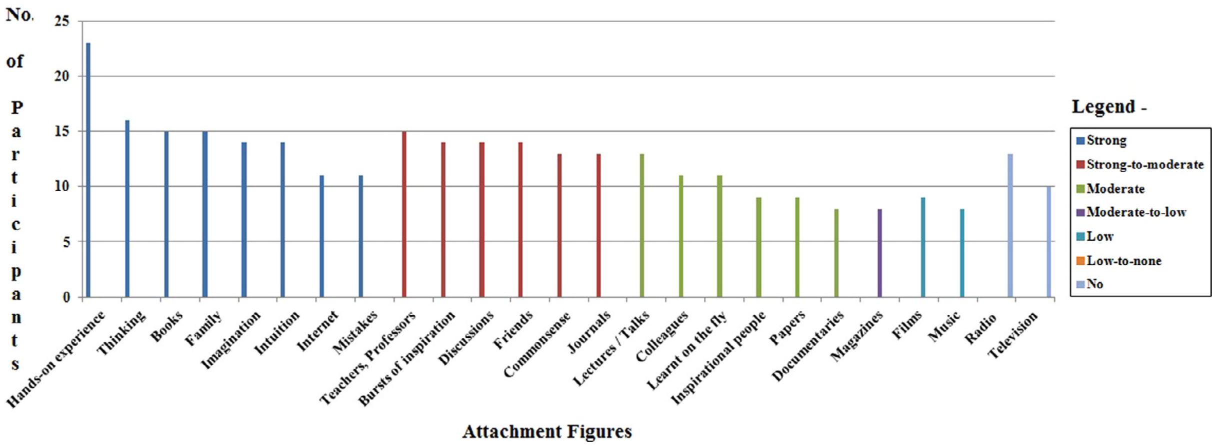


Fig. 8. Plot of the highest degree of influence attributed to the attachment figures.

• ***Experiment 1—Generic rank of attachment figures (Self, Others)***

The first experiment we conducted was to study if human subjects actually identified attachment figure. For this, a set of 32 test-takers was provided with a list of 25 attachment figures (*attach_figures*), and they were required to assign a degree of influence per *att_figure*. The degree of influence implied a generic sense of belief on *att_figure* or *belief*(*att_figure*) [recall Definition (13)].

The bar-chart plot in Fig. 7 is a pictorial summarization of the responses received, while that in Fig. 8 depicts the highest degree of influence conferred upon each *att_figure* across the test subjects.

Inputs:

(i) *attach_figures* = {*Self, Others*}; |*attach_figures*| = 25.
(ii) *Self* = {'Books', '*Commonsense*', 'Documentaries', '*Epiphany*', '*Errors*', 'Films', '*Hands-on experiences*', '*Imagination*', 'Internet', '*Intuition*', 'Journals', '*Learnt on the fly*', 'Lectures', 'Magazines', 'Music', 'Papers', 'Radio', 'Television', '*Thinking*'}
(iii) *Others* = {'Books', '*Colleagues*', '*Discussions*', 'Documentaries', '*Family*', 'Films', '*Friends*', '*Idols*', 'Internet', 'Journals', 'Lectures', 'Magazines', 'Music', 'Papers', 'Radio', '*Teachers / Professors*', 'Television'} [The non-italicized elements in *Self* and *Others* indicate elements common to these two sets, as these involve the self acknowledging the perspective of others.]
(iv) List of 'degree of influence' terms options for the test-takers to choose from: 'Strong', 'Strong-to-moderate', 'Moderate', 'Moderate-to-low', 'Low', 'Low-to-none', and 'No'.

Observations:

(i) Every human subject identified its sphere of influence.
(ii) 'Hands-on experiences', under *Self*, was voted the strongest of all mind-imprinters.
(iii) 'Family' scored the highest from the *Others* set.
(iv) 71.4% of the *attach_figures* under the 'Strong' and 'Strong-to-moderate' degrees of influence fall under *Self*, while 50% of the *attach_figures* under these categories are unique to *Self*.

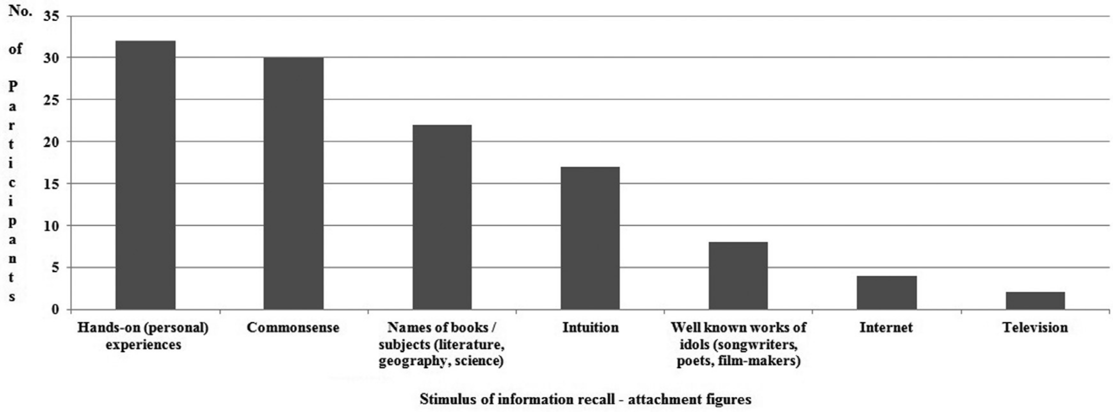


Fig. 9. Bar-chart plot of the attachment figures named as effective stimuli of information recall, during Experiment 2.

(v) Other thought-influencers suggested by our test-takers were: 'Food', 'Prizes on offer', 'Mood', 'Creative requirements', 'Challenge', 'Evoking extreme surprise / disgust', and 'Spiritual content'. Each of these terms refers wholly to the *Self* and being aware of oneself or self-consciousness.

Insights:

(i) *Self* is the strongest influencer => every test taker was not only aware of itself, but was also aware of itself being aware of itself, considering the self-evocative thought-influencer suggestions.
(ii) Besides the original source of information, reinforcement by *Self*—through hands on experiences, contemplation (thinking), intuition, commonsense, etc.—is crucial to association building between knowledge components and subsequent recall.

• ***Experiment 2—Rank of attachment figures (Self, Others) influencing recall of particular information***

To test the strength of the hypotheses of Experiment 1, we asked the test-takers of Experiment 1 to identify *attach_figures* who influenced their knowledge on a particular topic.

These human subjects were given a set of 50 test-words associated, directly or otherwise, to the concept of 'spring'. These words referred to 'spring' in different contexts—a season, a mechanical object, an energetic action, a natural source of water, found in the name of a popular appetizer and software. Subjects were asked to rate their knowledge on the association between the words and 'spring' in terms of the degree of certainty ('Yes' certainly, 'Yes' perhaps, 'No' certainly, 'No' perhaps, Unsure, and Don't know) of association they perceived. Against each of these association-assignments, they were required to give reasons—in the order they were recollected.

Fig. 9 summarizes the list of the attachment figures stated as reasons of responses to degrees of association chosen, across participants.

Note: We summarized responses on the lines of 'sound of the word', 'look of the word', 'a hunch', 'might have heard about it' etc. under 'Intuition'.

Observations:

(i) Without our explicitly stating the nature of reasons, each of the test-takers listed out a set of attachment figures and affectual tags (like 'happy memories', 'distressing memories', 'poignant poems', 'excellent poem') to real experiences (if any) or those arising out of visualizations.
(ii) Based on definitions of the inputs in Experiment 1, the following apply to Experiment 2:
  (a) *Self* = {*Hands-on experiences*, *Commonsense*, *Intuition*, Books, Idols, Internet, Television, Magazines, Films}
  (b) *Others* = { Books, Idols, Internet, Television, Magazines, Films}
(iii) *Self* scored the highest (evident in the ranks of 'Hands-on-experiences', 'Commonsense' and 'Intuition' in Fig. 9).
(iv) Patterns illuminated in the order of recall of reasons:
  (a) Every answer had at least one perspective (commonsense, intuition, hands-on experiences etc.) pertaining to *Self*.
  (b) Some of the answers were attributed entirely to *Self*, while the rest were a combination of *Self* and *Others*.
  (c) Every association reasoned by 'hands-on experiences' was marked ''Yes' certainly', reinforcing the high-belief on *Self*. Explanations for each of these associations were strengthened through high-affect (irrespective of the valence) reminiscences.
  (d) 'Commonsense' and 'Intuition' were stated as reasons for guesses made.
  (e) All responses on the lines of 'perhaps' and 'unsure' implied guesses.

Date (Month, Year)	Entries => Degree of influence perceived									
	[Books]	[Colleagues]	[Commonsense]	[Discussions]	[Documentaries]	[Epiphany]	[Errors]	[Family]	[Hands-on experience]	[Imagination]
December, 2013	Strong-to-moderate influence	Low influence	**Moderate-to-low influence**	Strong-to-moderate influence	***Moderate influence***	Low influence	**Strong-to-moderate influence**	Strong influence	**Strong influence**	Strong influence
March, 2014	**Strong-to-moderate influence**	***Low influence***	**Moderate influence**	Strong-to-moderate influence	***Strong influence***	**Low influence**	**Moderate influence**	Strong influence	**Strong-to-moderate influence**	Strong influence
June, 2014	**Strong influence**	***Moderate influence***	Moderate influence	Strong-to-moderate influence	Strong influence	**Moderate influence**	Moderate influence	Strong influence	Strong-to-moderate influence	Strong influence
September, 2014	Strong influence	**Moderate-to-low influence**	Moderate influence	Strong-to-moderate influence	Strong influence	Moderate influence	Moderate influence	Strong influence	Strong-to-moderate influence	Strong influence
December, 2013	Strong influence	Low influence	**Strong-to-moderate influence**	***Strong influence***	No influence	**Moderate influence**	**Moderate influence**	**Strong-to-moderate influence**	**Strong influence**	Strong influence
March, 2014	**Strong influence**	Low influence	**Moderate influence**	***Moderate influence***	**No influence**	**Strong-to-moderate influence**	**Moderate-to-low influence**	**Moderate influence**	**Strong-to-moderate influence**	Strong influence
June, 2014	**Strong-to-moderate influence**	Low influence	Moderate influence	Moderate influence	**Low influence**	**Strong-to-moderate influence**	**Moderate influence**	Moderate influence	**Moderate influence**	Strong influence
September, 2014	Strong-to-moderate influence	Low influence	Moderate influence	Moderate influence	Low influence	**Moderate influence**	**Moderate-to-low influence**	Moderate influence	Moderate influence	Strong influence
December, 2013	**Strong influence**	**Moderate-to-low influence**	**Strong-to-moderate influence**	Moderate influence	**Moderate-to-low influence**	***Moderate influence***	Strong-to-moderate influence	Strong influence	Strong influence	Moderate-to-low influence
March, 2014	**Strong-to-moderate influence**	**Moderate influence**	**Strong influence**	**Moderate influence**	**Low influence**	***Low influence***	Strong-to-moderate influence	Strong influence	Strong influence	Moderate-to-low influence
June, 2014	**Strong influence**	Moderate influence	Strong influence	**Strong-to-moderate influence**	**Low influence**	**Low influence**	**Strong-to-moderate influence**	Strong influence	Strong influence	**Moderate-to-low influence**
September, 2014	**Strong-to-moderate influence**	Moderate influence	Strong influence	Strong-to-moderate influence	**No influence**	**Moderate-to-low influence**	**Strong influence**	Strong influence	Strong influence	**Moderate influence**

Fig. 10. A partial snapshot of responses collected for Experiment 3. Every test taker has four rows dedicated to his/her answers. Gradual modulations in the responses are in bold (e.g. answers in the first bold rectangle) while major modulations are in bold and italics (e.g. answers in the second bold rectangle). Personal details of the test-takers have been hidden for privacy reasons.

(f) Responses 'Don't know' were received against unfamiliar contexts.
(g) The perspective of *Self*, invariably preceded any memories stimulated by *Others*.

Insights:

(i) The reasons correspond to the subjective components of *experience*s (parameter in Definition 24) and other bespoke *att_figure*-sensitive ratings across Definitions 14–20.
(ii) The test on a multi-conceptual word ('spring') reinforces the importance of the *context* as a vital parameter of comprehension.
(iii) Degree of familiarity with *context* influences *certainty* of information.
(iv) The spontaneous association of knowledge to affects, witnessed in this experiment, depicts quale or *affect*s as an imperative parameter of comprehension and recall.

The hypotheses of Experiment 1 stood affirmed by observations in Experiment 2. But a study on the stability of these subjective notions was deemed essential. Accordingly, we examined the persistence of opinions and the influence of *time* on recall by repeating Experiments 1 and 2 over a time frame. Experiment 1 was redone three more times, while Experiment 2 was repeated once more. Experiment reiterations were interspaced by a gap of 2 months.

Experiment 3 highlights insights gained from our study of the stability of subjects' thought-perceptions of its *attach_figures*, while Experiment 4 describes the modulations in responses to a particular topic.

• ***Experiment 3—Changes in generic rank of attachment figures (Self, Others) over a period of 8 months***

Fig. 10 presents a partial snapshot of the responses collected during this experiment. Fig. 11 is an objective summary of the rate of change in influence-perceptions across the test-takers over a period of 8 months, while Fig. 12 highlights the average change per attachment figure type and change category.

Observations:

(i) The modulations in perceptions can be categorized into:
  (a) Gradual changes—a shift to the immediate higher or lower degree of influence—depicted in bold in Fig. 10 (the first bold rectangle).
  (b) Major changes—a shift by more than one degree of influence—printed in bold and italics in Fig. 10 (the second bold rectangle).
  (c) Gradual modifications displayed decays to lower grades of influence as well rises to higher grades.
(ii) Test-takers were oblivious to gradual changes in perceptions, i.e. they did not have precise reasons for the modulation.
(iii) Test-takers had one or more than one reasons to support major changes. These reasons were typically:
  (a) An act of trust, support or good deed in general—leading to positive reinforcements in the strength of influence and a rise in influence-perception value.
  (b) An act of distrust—culminating into a fall in influence values.

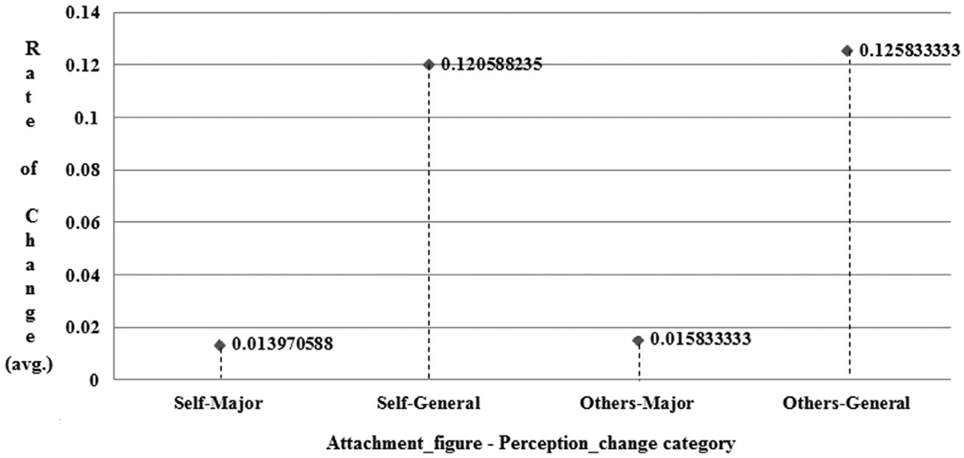


Fig. 12. Synopsis of the average rate of change in degrees of influence perceived per attachment figure category and change type.

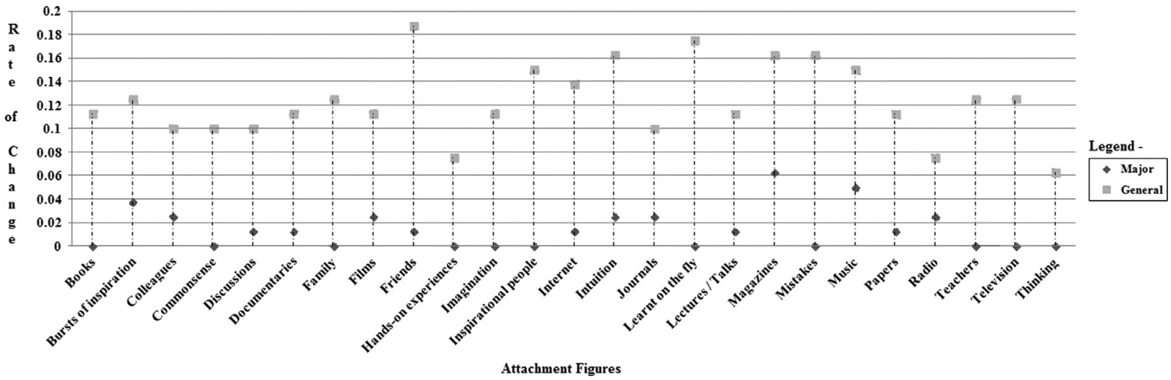


Fig. 11. Objective summary of the rate of change in degrees of influence perceived, across participants and a time period of 8 months.

(c) Rectifications in conceptions and realizations.
(d) Changes in practices (reading, music, television).

(iv) Gradual changes were a regular phenomenon, while major changes were rare.
(v) Every one of the 32 test-takers displayed a gradual or a major or both kinds of changes (the perception-change sequence within the third bold rectangle in Fig. 10) in the degree of influence perceived.
(vi) Not for a single *att_figure*, did the degree of influence remain absolutely stable across all test-takers.
(vii) 'Thinking' followed by 'Hands-on experiences' underwent minimal changes; 'Magazines', followed narrowly by 'Friends', 'Music' and 'Intuition' and 'Bursts of Inspiration' suffered significant modulations. These perception-transformations are in line with the reasons stated in point (iii).
(viii) In its entirety, the rate of change in influence-perceptions of *Self* is less than that for *Others* (evident in Figs. 11 and 12).

Insights:

(i) *belief*(*att_figure*) is a dynamic value—prone to change with *time* and *experience.*
(ii) *Self* is indeed the prime source of information.
(iii) The events that lead to major changes in influence values were those that were 'important' to *Self*.
(iv) Modulations in subjective perceptions would effect subjective ratings across Definitions 15, 18, and 20.
(v) The rates of change do not encode subjective notions of the test-takers. Every individual brought its self-perspective into play when formulating judgments. It would be incorrect to objectively summarize these perception changes.
The design of a rational synthetic mind calls for the analysis of subjective underpinnings (particularly reasons behind gradual progressions) and endogenous mind-algorithms leading to perception modulations, judge biases involved and transform perceptions accordingly.

It would be interesting to observe the statistics of these opinions across a longer time frame and monitor if they displayed the phenomenon of "regression toward the mean [38]". These studies, however, need to take into consideration subjective notions as well.

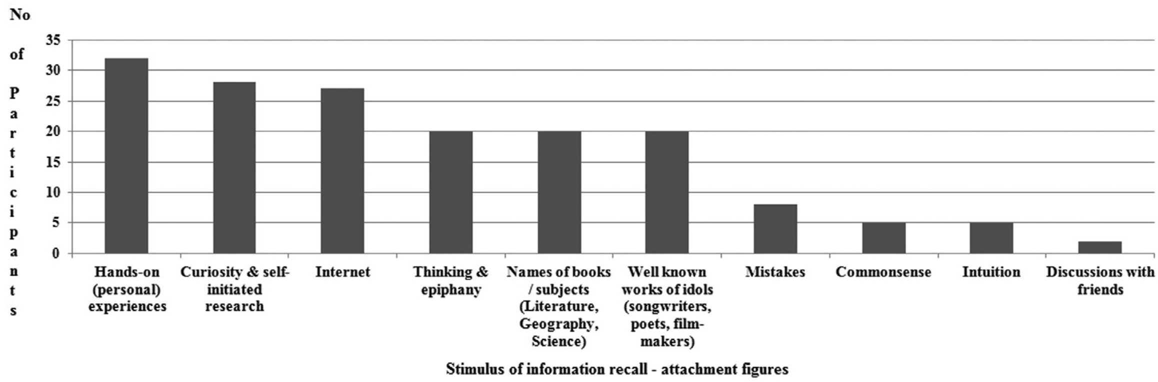


Fig. 13. Bar-chart plot of the attachment figures named as effective stimuli of information recall, during Experiment 4.

Conversely, we wonder if repeating this experiment a great many times (also reducing the inter-experiment gap) would lead to recollections of prior responses influencing current answers.

Particular questions that this experiment led us into pondering over are:

(i) If there were ways to determine:
  (a) Whether the answers collected were entirely devoid of modulations arising out of the gambler's fallacy [9,34,86] bias on account of recollections of previous responses?
  (b) The impact of self-consciousness (vanity, self-pride, the urge to project a positive social-image, etc.) on results.
(ii) Ramachandran et al. [65,66] describe the conjunctive role of the fusiform gyrus and the amygdala in the human brain toward the execution of the entire phenomenon of "recognizing" an individual and "awakening" corresponding subjective (emotional) states in the human mind. But what are the neural codes of endogenous algorithms underlying the 'sense' of influence perceived?
(iii) How does the brain equate feeling to senses of adjectives or adverbs?
(iv) How do we judge characters, and assign senses of belief, from faces, voices, gestures of unknown people?
(v) How does the brain encode linguistic meanings of words, in all its various modal manifestations, and associate qualia to them?
(vi) What are the unconscious stimuli that lead to gradual progressions in perceptions?
(vii) How do pre-linguistic infants represent quale?

• ***Experiment 4—Changes in responses to degrees of association and reasons thereof, between words applicable to 'Spring' [2 months after Experiment 2]***

Fig. 13 lists the attachment figures enumerated as inspiring information recall in Experiment 4.

Observations:

(i) Based on definitions of the inputs in Experiment 1, the following apply to Experiment 2:
  (a) *Self* = {*Hands-on experiences*, *Curiosity and self-initiated research*, *Thinking and epiphany*, *Mistakes*, *Commonsense*, *Intuition*, Books, Idols, Internet}
  (b) *Others* = { Books, Idols, Internet, *Discussion with friends*}
(ii) Most test-words graded various degrees of association 'uncertainty' (marked 'Yes' perhaps, 'No' perhaps, 'Unsure', 'Don't know') during Experiment 2, progressed to ''Yes' certainly'. Reasons for the profound change in certainty were typically:
  (a) Associations becoming evident after 'thinking a while' and/or 'bursts of inspiration' (or 'sudden realizatoins') post Experiment 2.
  (b) The 'arousal of curiosity' and consequent self-motivated research (referring books, the Internet, discussions with friends) thus the absolute certainty in responses during Experiment 4.
  (c) Rectification of mistaken associations (or guesses) made during Experiment 2.
(iii) The affects noted in the responses were:
  (a) Surprise and a vague sense of disgust (self-consciousness) at having failed to identify supposedly 'obvious' associations earlier.
  (b) Vague sense of disgust (self-consciousness) for mistakes made in Experiment 2.
  (c) Surprise in discovering hereto unknown facts.
  (d) General sense of pride or achievement at being sure of greater number of answers during this round of the experiment.

Table 3
A summary of the changes in attachment figures inspiring information recall across Experiments 2 and 4.

Points of comparison	Attachment figures
Common to both experiments	Hands-on experience, Commonsense, Intuition, Books, Idols, Internet
Exclusive to—	**Experiment 2:** Television **Experiment 4:** Curiosity and self-initiated research, Thinking and epiphany, Mistakes, Discussion with friends
Dedicated self components in—	**Experiment 2:** Hands-on experiences, Commonsense, Intuition **Experiment 4:** Hands-on experiences, Curiosity and self-initiated research, Thinking and epiphany, Mistakes, Commonsense, Intuition
Dedicated other components in—	**Experiment 2:** None **Experiment 4:** Discussion with friends
In the transition from Experiment 2 to Experiment 4, elements experiencing—	**Fall in votes or mentions across test-takers:** Commonsense, Intuition **Rise in votes:** Internet, Books, Idols **No change in the number of mentions:** Hands-on experiences
New entrant in *attach_figures* of Experiment 1	Curiosity and self-initiated research

(iv) Affects to memories recollected were similar to those in Experiment 2. However, the reminiscences were a mix of previous narratives and new ones. The order of repeated memory-recollections often did not coincide with those in Experiment 2.
(v) The test-takers mentioned longer lists of literature and works by inspirational people, often citing names not directly related to the test-words provided. This perhaps is a tribute to involuntary inter-information association constructions by the mind.
(vi) *Self* yet remains the highest scoring thought-inspirer. Table 3 highlights the key differences in the thought-influencers between Experiments 2 and 4.

Insights:

(i) Every individual was aware itself or self-conscious.
(ii) The importance of the self (either through 'Hands-on experiences', 'Curiosity' or 'Thinking', or in acknowledging perspectives of others) in knowledge-gain, and the influence of consequent self-conscious affects in information recall stand re-affirmed.
(iii) While Experiment 2 depicts responses arising out of 'fast thinking [27,38]' processes, Experiment 4 represents 'slow [38]', deliberative, reflective, conscious thinking and consequent unconscious inter-information connection formations.
(iv) Experiment 4 bears testimony to every stage of thinking as is hypothesized by Minsky (discussed in Section 2.2).
(v) Being able to refer to external sources of information and subsequent accreditation by the self, stand as superior alternatives to speculations ('Commonsense' or 'Intuition').
(vi) There are subtle differences in generic belief values for an attachment figure and context-specific degrees of faith on the same.
(vii) The concept of 'spring' is a sum of all the concepts attached to its different manifestations in English. This stands true for all homonyms. The *context* determines the appropriate sense.

Note: Experiments 2 and 4 were done for other common homonyms like "book" and "orange" across an entirely different set of 15 test-takers, per word, as well. Observations and insights remain unaffected.

Besides the questions highlighted in the previous experiments, Experiment 4 instigates deliberations into:

(i) What guides the order of recollections?
(ii) What would be a scientific definition for 'curiosity' and 'interest', and the machine equivalent of autogenous mind-processes leading to consequent actions?
(iii) Do the responses indeed reflect unbiased mind-responses, or were they flavored by self-conscious elements (self-pride, vanity, impulse to project positive images of the self, etc.)?
A rational, empathetic machine-mind is aware of its self-conscious affects, negative influences thereof, and is conscious of its faults as well.
(iv) Considering the large number of test-takers adjudging themselves curious, would it imply that all these individuals were 'equally' inquisitive? Can we measure 'curiosity' and 'levels of interest'?
(v) Very few test-takers acknowledged their errors in Experiment 2. Could there be some participants who did not wish to claim mistakes done—self-conscious affect of vanity preventing them from doing so?
(vi) How did the brain translate the qualia of conjectures to valence-specific linguistic expressions ('Yes' perhaps, 'No' perhaps, etc.)?

[Refer to Table 7 for a summary of all that the studies in this section support.]

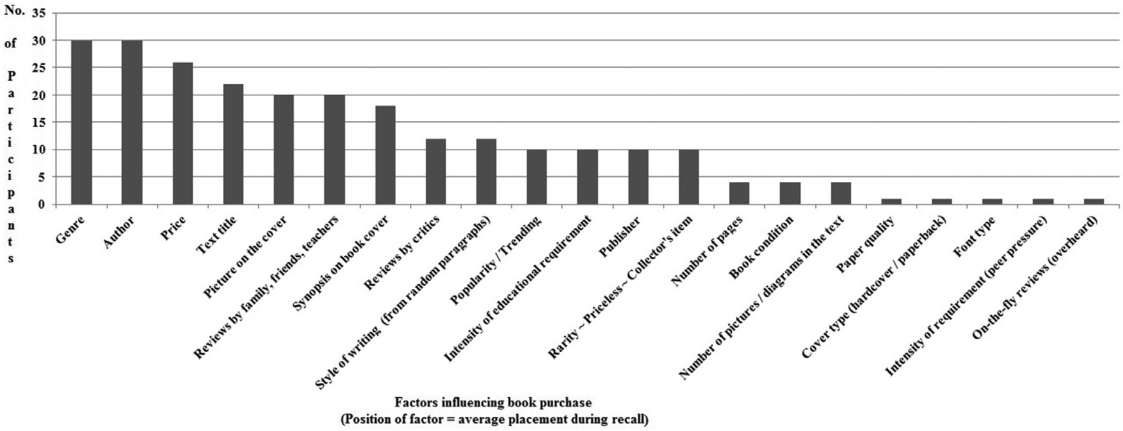


Fig. 14. Chart of factors influencing context = {book purchase} at time = {present}. Factors ranked as per average position of recall and number of votes received across participants.

4.2. Section B

Objective:

Investigations on: subjective perspectives of context representation and their implications in Definitions 22–26.

Experiments in this section required a set of 30 avid-to-moderate readers to visualize themselves buying a book, i.e. *context* = {buy book} at *time* = {present}

• ***Experiment 1—Subjective representation of a context***

The test-participants were asked to enumerate factors—in the order of recollection—that influenced book purchase events. Each of the participants was given 10 min. for this task—our aim being to capture the 'fast thinking' responses, supposedly devoid of self-conscious affects. Uniting the responses received, and ranking them in their average position of enumeration and number of votes received, we received the graph in Fig. 14.

Observations:

(i) Intuitively, these factors represent 'book purchase' as a multi-objective optimization problem, where the buyer tries to achieve an acceptable solution—in terms of a tradeoff between competing factor-instantiations.
(ii) Each of the factors appeal to *Self*.
(iii) The bar-chart plot in Fig. 14 presents an inkling of the diverse factors and formats of representation of a context.

Insights:

These parameters illustrate micro-features of a context—factors that determine the outcome of transactions between *Self* and *context*.

The research-questions relevant to this experiment are:

(i) What are the neural codes of personal preferences? How would a synthetic-mind identify its predilections?
(ii) How does the brain equate preferences to context-factor instantiations to arrive at an acceptable choice?
(iii) What are the internal mechanisms and the effects of counterfactual thinking, post-decision confirmation?

• ***Experiment 2—Subjective interpretation of a context***

Treating the list of factors and their positions, obtained in Experiment 1, as parameters and generic weights describing *context*, we asked the same participants to rank the impact (on a scale of 0 to 5, lower the value lower is the impact) of these parameters if they were to decide on buying a particular book (Agatha Christie's 'And Then There Were None') at *time* = {current}.

The test-takers were allowed to handle the book—turn its pages, read random paragraphs, check the price, publisher, etc., and were given critic reviews to read as well. The participants were also asked to itemize their thought-bubbles—key-words or phrases or ideas running through the mind during the experiment.

Fig. 15 is a pictorial representation of the participant-categories and Fig. 16 depicts a partial summary of the responses received from a representative test-taker across each participant-category.

• ***Observations:***

(i) Categories of participants:
  (a) None of the participants had read the book.
  (b) Every one of the 30 participants had heard about the author.
  (c) Eight participants had never read Agatha Christie.

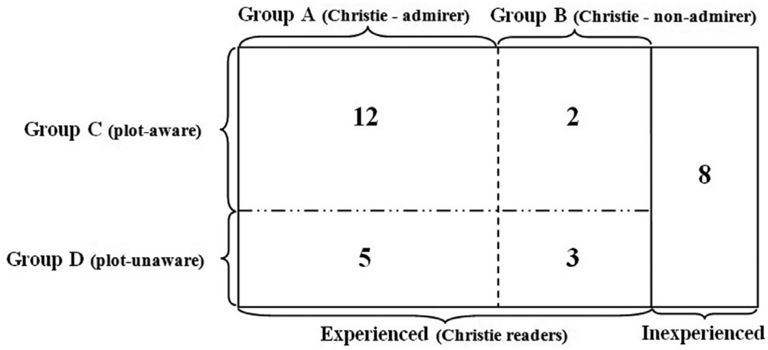


Fig. 15. Categories of test-participants.

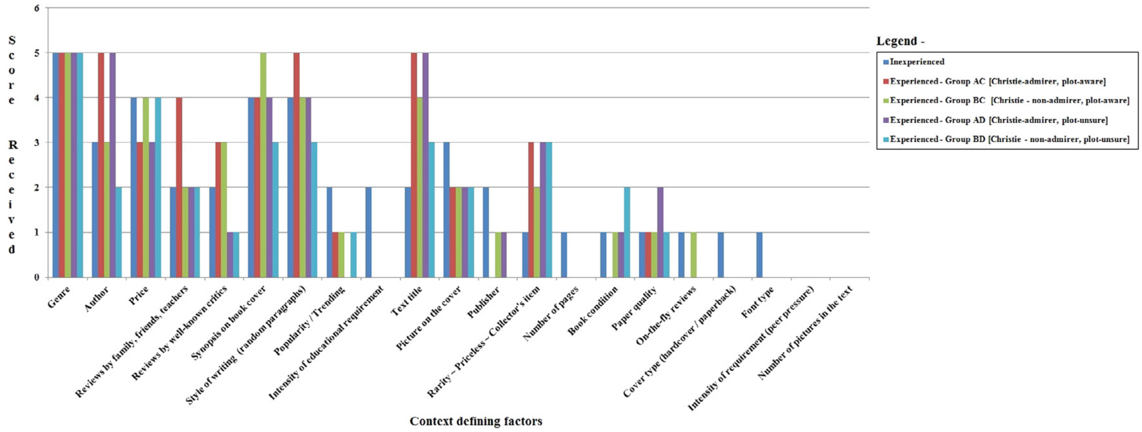


Fig. 16. Partial snapshot of responses of a representative test-taker from each participant-category.

Table 4
Partial synopsis of keywords in thought-bubble on Agatha Christie and the plot.

Topic	Thought-bubble keywords
Agatha Christie	**Omnipresent keywords** (in no particular order)—mystery, lady, Miss Marple, Hercule Poirot, knitting, British countryside, police, murders, poison, clues, evidence, thrill, crime, Mousetrap, Scotland Yard, etc. **Particular to experienced readers**—names of specific cases, characters particular to the cases, etc.
Plot	**Particular to those plot-aware** —[Primary property: presence of plot-specific words]name of an Indian film based on the story, 10 Little Indians, island, cracker-plot, Nursery Rhymes, one of Christie's best, gramophone, confessions, etc. **Particular to those plot-unaware** —[Primary property: vague words depicting plot-expectations]mystery, death, crime, detective, murders, police, curious, etc.

(d) All 22 participants who had read Agatha Christie, were familiar with the book-title. Out of them:
Group A: 17 greatly admired her style.
Group B: 5 had no significant admiration.
Group C: 14 were aware of the plot.
Group D: 8 were unsure of the plot.

(ii) The responses received were unique to each of the test-takers, and were on the lines of the responses to Experiment 1 of Section A. Though rank-trends were evident, we refrained from evaluating the average rank per factor, as these would not mirror contributions of subjectivity. Table 4 highlights certain often occurring keywords in thought-bubbles on Agatha Christie and the plot.

(iii) From a purely objective point of view, for 21 context-defining factors and 6 grades of significance, there are 6^{21} possible combinations of factor-grade values for a test-participant to choose from. Factor-grade values depend on the internal system-states in conjunction with external stimuli.

Insights:

(i) Though the umbrella context for this experiment is 'buying an Agatha Christie book', the finer constituents are {previous experiences (affects, particular cases, etc.) of Christie's works, a general idea of her style of writing, affects in general for

her works}. These elements build the entire *context* of comprehension for the given situation and prepare the foundations for curiosity, expectations and consequential affects during actual situation-handling.
Words in the thought-bubbles, subscribe to this fact, and so do the subjective markings for the context-factors. [For instance, though not being a ardent Christie aficionado, the text-taker (under Group BC) found the synopsis on the book-cover and random paragraphs in the book significantly motivating; a possible reason for the non-zero rank for educational requirement by the inexperienced participant, could be a willingness to explore Christie's works]

(ii) The observations in this experiment substantiate the conceptual formulations 22–26. Just as each individual brings to the interpretation of a context its own (drawing inspiration from its experiences, sense of curiosity to explore the unknown, prejudices, etc.), so should an intelligent machine-mind. Only then can a natural language understanding machine conceive bespoke granules of comprehension.

(iii) All our questions, in Section A, on brain-processes supporting subjective comprehension of the real-world and actions thereof, stand fortified in this experiment.

Experiments through Sections 4.1 and 4.2 indicate the Z*-number parameters as a minimal set of factors of real-world subjectivity, and are thus tokens of personalized information representation for mind-processes. The following section demonstrates a theoretical exercise of using Z*-valuation tokens to simulate machine-mind processes toward differential diagnosis.

[Refer to Table 7 for a summary of all that the studies in this section support.]

4.3. Section C

Objective:

Modeling real-life scenarios using the Z*-number paradigm, where Z*-valuations of natural language expressions serve as tokens of mental processes.

In this experiment, we endeavor translating an instance of differential diagnosis, using the sample discourse (Table 5) between a doctor (D) and patient (P), into their Z*-valuation-equivalents for information-processing in a machine-mind. D typically denotes the machine-mind (Mc), while P is a human being.

This is an entirely theoretical exercise, aiming at analyzing the completeness of information (both objective and subjective) representation by the Z*-numbers during linguistic transactions. The results derived herein are with respect to the effective procedure of Z*-number based natural language comprehension outlined in Section 3.3 and utilize operators defined in Section 3.4.

- ***Experiment—Translation of real-world expressions into Z*-valuation equivalents and subsequent processing***

Assumptions:

(i) The machine-mind (Mc) [mimicking a doctor (D)] is aware of the probability distribution of the symptoms and symptom details per disease.

(ii) Mc is proficient in syntactic analysis, and can resolve anaphoric and cataphoric dependencies.

(iii) Mc can categorize symptom descriptions into information granules like 'fever-presence-symptom', 'fever-fall-symptom'.

(iv) Mc comprehends 'linguistic meanings' as well as 'qualitative senses or qualia' of words in natural language expressions.

Input:

Natural language sentences depicting a model real-life interaction scenario between a doctor (D) and a patient (P). D symbolizes the machine-mind and P the interacting human being.

Output:

Z*-valuations of P's responses skewed to the perspective of D's questions and processed to predict probable diseases.

[Format of Z*-valuations in Table 5: An expression symbolized by Z^*_{ijk}, depicts the i^{th} enquiry, the j^{th} response to the enquiry and the k^{th} detail in the response.]

Observations:

(i) The *context* factors and *affect-intensity* change with progression in conversation. The doctor assimilates external symptoms and internal conditions described by the patient, and gets increasingly worried as his mental processes short-list probable diseases. The patient gets increasingly distressed when discussing issues causing high degrees of discomfort.

(ii) The doctor's enquiries increase in specificity as mental processes obliterate probable irrelevant diseases.

(iii) The progression of context-symbolisms across the conversation, intuitively resort to a union of multi-modal inputs—facial expressions and conditions (e.g., flushed eyes, puffiness), sounds (e.g., hoarseness, voice intonations), etc.

(iv) Ideally, $context_{D1}$ would lead to Z*-number manipulations of the form:

Z^*_1 = <patient external symptoms, $time_{D1}$, $context_{D1}$, {flushed eyes, flushed face, hoarse breathing, clammy skin, …}, certainly, {(worried, moderate, -)}>, which reduces to the Z^*_1 used in the computations in Table 5.

(v) Expressions Z^*_{11}, Z^*_{21}, Z^*_{31}, Z^*_{71}, Z^*_{72}, Z^*_{81} and Z^*_{91} have been transformed into those viewed from the perspective of the doctor's enquiries Z^*_1, Z^*_2, Z^*_3, Z^*_7, Z^*_8 and Z^*_9 respectively. $Z^*_{11'}$, $Z^*_{21'}$, $Z^*_{31'}$, $Z^*_{71'}$, $Z^*_{72'}$, $Z^*_{81'}$ and $Z^*_{91'}$ represent the respective transformed equivalents.

Table 5
Sample discourse between a patient (P) and a doctor (D).

Natural language sentences	Equivalent Z*-valuations <subject, time, context, subject_value, certainty, affects>
D: You look rather ill! What's happened? [$time_{D1}$ = {present}, $context_{D1}$ = {visible illness symptoms}]	$\boldsymbol{Z}^*_{1}$ = <patient_problems, $time_{D1}$, $context_{D1}$, exists, certainly, {(worried, moderate, -)}>
P: It's been two days that I've been suffering from high fever! [$time_{P1}$ = {retrospective, present}, $context_{P1}$ = {general health conditions, current discomfort}, $context_{P2}$ = {general health conditions, current discomfort, poignant health deterioration since normalcy}]	$\boldsymbol{Z}^*_{11}$ = <patient_problem, $time_{P1}$, $context_{P1}$, fever, certainly, {(distressed, high, -)}> => $\boldsymbol{Z}^*_{11'}$ = <patient_problem, $time_{P1}$, $context_{P1}$, exists, certainly, {(distressed, high, -)}> $\boldsymbol{Z}^*_{111}$ = <fever intensity, $time_{P1}$, $context_{P1}$, high, certainly, {(distressed, high, -)}> $\boldsymbol{Z}^*_{112}$ = <fever duration, $time_{P1}$, $context_{P2}$, 2 days, probably, {(distressed, high, -)}>
D: Did you note the temperature? Did you notice if it came on at specific times? Is it accompanied by nausea? [$time_{D2}$ = {retrospective}, $context_{D2}$ = {patient-specific issues}]	$\boldsymbol{Z}^*_{2}$ = <fever temperature, $time_{D2}$, $context_{D2}$, above 100 degrees, expectedly, {(worried, moderate, -)}> $\boldsymbol{Z}^*_{3}$ = <fever arrival time, $time_{D2}$, $context_{D2}$, specific, uncertain, {(worried, moderate, -)}> $\boldsymbol{Z}^*_{4}$ = <fever accompaniment, $time_{D2}$, $context_{D2}$, nausea, uncertain, {(worried, moderate, -)}>
P: The fever's been ranging at around 102–104 degrees and it's been coming in the mornings and evenings. The temperature falls after a bout of intense sweating and is accompanied by shivering, nausea. I've got aches all over. I'm feeling rather weak and tired.	$\boldsymbol{Z}^*_{21}$ = <fever temperature, $time_{P1}$, $context_{P2}$, 102–104 degrees, certainly, {(distressed, high, -)}> => $\boldsymbol{Z}^*_{21'}$ = <fever temperature, $time_{P1}$, $context_{P2}$, above 100 degrees, certainly, {(distressed, high, -)}> $\boldsymbol{Z}^*_{31}$ = <fever arrival time, $time_{P1}$, $context_{P2}$, morning and evening, certainly, {(distressed, high, -)}> => $\boldsymbol{Z}^*_{31'}$ = <fever arrival time, $time_{P1}$, $context_{P2}$, specific, certainly, {(distressed, high, -)}> $\boldsymbol{Z}^*_{41}$ = <fever accompaniment, $time_{P1}$, $context_{P2}$, shivering, certainly, {(distressed, high, -)}> $\boldsymbol{Z}^*_{42}$ = <fever accompaniment, $time_{P1}$, $context_{P2}$, nausea, certainly, {(distressed, high, -)}> $\boldsymbol{Z}^*_{43}$ = <fever accompaniment, $time_{P1}$, $context_{P2}$, aches, certainly, {(distressed, very high, -)}> $\boldsymbol{Z}^*_{51}$ = <fever release, $time_{P1}$, $context_{P2}$, sweating certainly, {(distressed, high, -)}> $\boldsymbol{Z}^*_{511}$ = <sweating pattern, $time_{P1}$, $context_{P2}$, intense, certainly, {(distressed, high, -)}> $\boldsymbol{Z}^*_{61}$ = <health perspective, $time_{P1}$, $context_{P2}$, tired and weak, certainly, {(distressed, very high, -)}>
D: What kind of aches do you have?	$\boldsymbol{Z}^*_{7}$ = <aches, $time_{D2}$, $context_{D2}$, exists, certainly, {(worried, moderate-to-high, -)}>
P: A blinding headache. Stinging muscle-aches as well.	$\boldsymbol{Z}^*_{71}$ = <ache, $time_{P1}$, $context_{P2}$, head, certainly, {(distressed, extremely, -)}> => $\boldsymbol{Z}^*_{71'}$ = <aches, $time_{P1}$, $context_{P2}$, specific, certainly, {(distressed, extremely, -)}> $\boldsymbol{Z}^*_{711}$ = <headache intensity, $time_{P1}$, $context_{P2}$, blinding, certainly, {(distressed, extremely, -)}> $\boldsymbol{Z}^*_{72}$ = <ache, $time_{P1}$, $context_{P2}$, muscles, certainly, {(distressed, extremely, -)}> => $\boldsymbol{Z}^*_{72'}$ = <aches, $time_{P1}$, $context_{P2}$, specific, certainly, {(distressed, extremely, -)}> $\boldsymbol{Z}^*_{721}$ = <muscle-ache, $time_{P1}$, $context_{P2}$, stinging, certainly, {(distressed, extremely, -)}>
D: Do you have any problems with your appetite and sleep?	$\boldsymbol{Z}^*_{8}$ = <appetite problem, $time_{D2}$, $context_{D2}$, exists, expectedly, {(worried, moderate-to-high, -)}> $\boldsymbol{Z}^*_{9}$ = <sleep problem, $time_{D2}$, $context_{D2}$, exists, expectedly, {(worried, moderate-to-high, -)}>
P: I do not have an appetite at all and I can barely sleep with the headaches and twitches.	$\boldsymbol{Z}^*_{81}$= <appetite problem, $time_{P1}$, $context_{P2}$, appetite absent, certainly, {(distressed, extremely, -)}> => $\boldsymbol{Z}^*_{81'}$ = <appetite problem, $time_{P1}$, $context_{P2}$,exists, certainly, {(distressed, extremely, -)}> $\boldsymbol{Z}^*_{91}$ = <sleep problem, $time_{P1}$, $context_{P2}$, disturbed, certainly, {(distressed, extremely, -)}> => $\boldsymbol{Z}^*_{91'}$ = <sleep problem, $time_{P1}$, $context_{P2}$, exists, certainly, {(distressed, extremely, -)}> $\boldsymbol{Z}^*_{911}$ = <sleep problem reasons, $time_{P1}$, $context_{P2}$, headache and twitches, certainly, {(distressed, extremely, -)}>
D: Let me check your blood pressure… Hmmm… It is rather low!	$\boldsymbol{Z}^*_{10}$ = <blood pressure problem, $time_{D2}$, $context_{D2}$, exists, expectedly, {(worried, high, -)}> $\boldsymbol{Z}^*_{101}$ = <blood pressure problem, $time_{D2}$, $context_{D2}$, exists, certainly, {(worried, high, -)}> $\boldsymbol{Z}^*_{102}$ = <blood pressure value, $time_{D2}$, $context_{D2}$, rather low, certainly, {(worried, high, -)}>

Table 6
Sample discourse between patient (P) and doctor (D), after a phase of medication.

Natural language statement	Equivalent Z*-valuations
D: How is the headache now? [$time_{D3}$ = {retrospective, present}, $context_{D3}$ = {patient illness symptoms, current visible status}]	$\boldsymbol{Z}^*{}_{11}$ = <headache intensity, $time_{D3}$, $context_{D3}$, improvement, expectedly, {(happy, mild-to-moderate, +), (worried, moderate, -)}>
P: Much better doctor! There is just a mild throbbing every now and then. [$time_{P2}$ = {retrospective, present}, $context_{P3}$ = {status before medication, present health status, normal health conditions}]	$\boldsymbol{Z}^*{}_{111}$ = <headache intensity, $time_{P2}$, $context_{P3}$, occasional mild throbbing, certainly, {(happy, moderate, +), (distressed, mild-to-moderate, -)}> => $\boldsymbol{Z}^*{}_{111'}$ = <headache intensity, $time_{P2}$, $context_{P3}$, blinding, rarely, {(happy, moderate, +), (distressed, mild-to-moderate, -)}>

(vi) Compound and complex sentences have been deconstructed into their simple sentence equivalents and Z*-valuations extracted accordingly.
(vii) On relevance analysis, the patient-specific expressions symbolized $Z^*{}_{11'}$, $Z^*{}_{111}$, $Z^*{}_{43}$, $Z^*{}_{71'}$, $Z^*{}_{72'}$, $Z^*{}_{91'}$, $Z^*{}_{101}$ are deemed inconsequential or redundant. There exist Z*-valuations with potentially more meaningful information on the subjects of these Z*-valuations.
(viii) Expression pairs $(Z^*{}_2, Z^*{}_{21'})$, $(Z^*{}_3, Z^*{}_{31'})$, $(Z^*{}_4, Z^*{}_{42})$ and $(Z^*{}_8, Z^*{}_{81'})$ denote event-progressions.
(ix) The doctor, intuitively, uses $\cup_P^*$ to unite patient symptom-persistence intensity changes after a course of medication. Table 6 depicts one out many possible exchanges between the patient (P) and the doctor (D) after a phase of treatment. From the Z*-valuations in Table 6:
$(Z^*{}_{711} \cup_P^* Z^*{}_{111'})$ = <headache intensity, {$time_{P1}$, $time_{P2}$}, {$context_{P2}$, $context_{P3}$}, blinding, {certainly, rarely}, {(distressed, extremely, -), (happy, moderate, +), (distressed, mild-to-moderate, -)}> [using Definition (27)]
i.e., linguistically: There is certainly an improvement in the headache.
(x) The Z*-number operator-function portrays internal calculations or mentalese [62].
(xi) The Z*-valuations in this example depict top-level perceptions. Each of the natural language statements incorporate micro-aspects of subjective experiences (e.g. the subtleties that lead to a headache being attributed 'blinding'), which have not been considered.
(xii) Assuming the probability distributions of disease-symptoms is well-defined, after precisiating memberships of symptom-presence and symptom-intensity from the Z*-information set acquired from the patient, the system computes the rank of the membership of the probable diseases with respect to the logical expression:

$$E = ((Z^*_{111} \wedge Z^*_{112}) \wedge (Z^*_{21'} \wedge Z^*_{31'} \wedge Z^*_{41} \wedge Z^*_{42} \wedge (Z^*_{51} \wedge *_{511}) \wedge Z^*_{61}) \wedge (Z^*_{711} \wedge Z^*_{721}) \wedge (Z^*_{81} \wedge Z^*_{911}) \wedge Z^*_{102}) \quad (28)$$

i.e., the system transforms Eq. (28) into its mathematical equivalent (as per Definition (9)) to evaluate and rank the probability of all diseases in its repertoire. These operations ideally lead to the Z*-valuation expression:
(<Disease, {present}, {patient external symptoms, patient internal symptoms}, malaria / typhoid, most likely, {(worried, high, -)}>, based on which the doctor predictably issues a blood-test request.

Insights:

(i) The parameters of the Z*-number paradigm capture essential situation-descriptors, vis-a-vis progressions in events constituting the situation, that contribute to the thorough comprehension of a scenario.
(ii) The perception-union operator defined in this article summarizes progressions of key features of a scenario.
There however, needs to be other effective parameters to simulate further complex perception-operations. This entitles investigations into atomic brain-processes of multi-modal perception handling, information compression strategies, self-evolution, etc. such that effective machine-equivalent algorithms may be compiled.

4.4. Discussions

- ***Highlights of the proposed paradigm***

"The self and consciousness are two sides of the same coin"—[65,77]

(i) Assimilation of an essential set of parameters for grounded machine-subjectivity representation toward bespoke real-world comprehension. These parameters lay a basic foundation for the construction of the machine-self and the emulation of the top two layers of thinking in Minsky's model of a computational-mind (Fig. 1).
Existing conceptual 'conscious' agents [6,20,24,47,99] do not regard 'certainty' and 'affects' in unison nor do they discuss properties of machine self-awareness for consciousness.
(ii) Z*-numbers summarize objective and subjective components of natural language sentences and serve as operands of internal processing.

Table 7
Synopsis of the purpose of experiments across Sections A, B and C, and their contributions to the Z*-number conceptualization.

Purpose of experiments	Contributions to the Z*-number conceptualization as representative of the machine-self and machine-subjectivity
Section A— Investigations on: • Generic and context-sensitive spheres of influence of an individual, • Modulations in degrees of faith and reasons thereof, • The role of affects in information recall, and • Self-awareness or self-consciousness	i Lends conceptual support for— • Z*-number paradigm parameters—particularly *context*, *time*, *affects*—for natural language sense extraction • Definitions 10–26—where the *Self* draws from personal as well as external influences ii Validates the importance of the *Self* and self-awareness—reflective, deliberative, self-reflective, self-conscious thinking—for subjective comprehension and arousal of empathy. iii Brings forth the significance of 'curiosity' and 'self-motivation' toward knowledge gain and information recall.
Section B— Studies on subjective representations of contexts and consequent interpretations	• Lends conceptual support for Definitions 22–26 • Reinforces the worth of the self-perspective and self-consciousness toward bespoke real-world interpretations and consequent actions.
Section C— Preliminary steps to the emulation of real-life situations for man–machine interaction simulations, using the Z*-number paradigm	Offers theoretical support to the Z*-number based effective procedure for natural language comprehension and primitive perception-operators

(iii) Consideration of socio-cultural factors of knowledge in a social machine-mind. The Z*-numbers serve as scaffolds for the representation of 'knowledge by acquaintance' (through Definitions 10–26) and union of knowledge-categories ('how', 'that', 'by acquaintance') [72,74].
(iv) Existing knowledge structures [7,22,32,42,79,80] concentrate individually either on 'knowledge that' or 'knowledge how' factors, with no focus on 'knowledge by acquaintance'.
(vi) Micro-Z*-valuations contributing to macro-Z*-valuations and Z*-information sets (across Definitions 10–26) conceptually support the integrated information theory [8,83] of consciousness and qualia. (We are currently in the process of exploring associated theoretical details.)

Table 7 puts together essential features of the studies across experiments in Sections 4.1–4.3; Table 2 strengthens our deliberations with respect to the Z*-numbers as representatives of the machine-self and machine-subjectivity.

• ***Practical concerns in the realization of a machine-mind***

Each of the preceding sections raises fundamental questions on human behavior and challenges in the design of the machine-equivalents. While some of these issues result out of knowledge-insufficiency on the neural underpinnings of a human or primate brain, the others are consequences of unavailable technology mapping. These issues involve investigations across Psychology, Neuroscience, and Cognitive Anthropology. Besides the questions highlighted across Sections 4.1 and 4.2, other practical concerns with respect to the synthesis of an artificial mind and issues particular to the Z*-number paradigm, are:

(i) The enumerated Z*-number parameters are essential and sufficient for a broad embodiment of machine-self representation (as is summarized in Table 2), but are they complete? An ideal analysis would perhaps require equating neural correlates to the paradigm factors and extraction of the unrepresented.
(ii) Intuitively, each of the parameters encompasses a plethora of micro-constituents. For instance, *context* is a logical summarization of micro-parameters that encode features of the environment and/or circumstances of an event. What would the complete set of atomic sub-components of these macro-parameters be?
(iii) What should the nature of the "search function [45]", where subjectivity parameters act as keys to system memories, be?
(iv) What would the format of the generic machine-code for information (objective and subjective)—irrespective of modality be?
(v) Design of self-evolving data structures and function modules that self-adapt to changing circumstances and simulate innovation.
(vi) How and when does a computational-mind decide to attempt something new and explore the unknown over something familiar or well known?
(vii) How does a cognitive system emulate attention and the concept of 'time (retrospective, present and prospective)'?
(viii) For man–machine and machine–machine synergy, an artificial mind should emulate empathy, as is brought on by 'mirror neurons [63,65]' in the human cortex. It requires being aware of the distinction between the *Self* and *Others*.
(ix) Physical storage limitations prevent exhaustive listing of every information source. Thus the **Manager** (Section 2.3) comprises algorithms that self-initiate regular analyses of memory requirements of knowledge and consequently optimize between pruning (emulating 'forgetting') of 'very-old' or 'irrelevant' data and self-evolution of knowledge data structures.

(x) What are the neural codes of 'personality'—likes, dislikes, ideals, etc? Drawing from Chomsky's views in [61], while most of personality depends on socio-cultural influences, how much of it is intrinsic to an individual? What makes me the person I am? What should the machine-equivalent of these elements be and would these lead to a 'machine-mind personality'? These questions border on 'singularity [39,40]', but are indeed crucial concerns in the synthesis of an empathizing, symbiotic machine-mind.

In the context of the design of social systems, another challenge lies in the identification and handling of 'cognitive biases [9,38,86]'.

Biases are 'bugs [52]' in the mind arising out of mental abstraction-processes neglecting vital exceptions to rules. Memory systems are likely to accumulate wrong and misleading information through: (a) attachment-learning schemes leading one to believe what the imprinters believe (evident in the formulation of Definitions 13–26 and [51], which depend on subjective beliefs of both the source and receiver of information), (b) imagination so powerful, that it leads to confusion between realities and fantasies, and (c) being fixated with unachievable goals or extensive futile undertakings.

While biases provide quick interpretation-solutions, conjuring supposedly positive results in mental simulations, they could fail when dealing in unfamiliar realms. Cognitive systems require emulating self-motivation despite fewer or no rewards, confusion and disorientation. Recognizing when to stop trying, acknowledge failures and turn to other solution-mechanisms, is an important design imperative.

A judicious mind engages in divergent thinking [52,56], laying importance to personal experiences as well as real-world knowledge. Given a situation, it activates multiple descriptions of things, effectively switches among them to prune the irrelevant or ineffective, makes memory records of what has been done for reflection, splits hard problems into smaller parts and keeps track of partial results, etc. The system obviously needs to refrain from setting in motion an 'exponential number of ways to think [49,56,87]'. It possesses endogenous mechanisms to handle dissonance and strike a balance between automatic and reflective behavior [9].

An un-biased synthetic computational-mind, intuitively, has the following benefits [56]:

(i) Empathize and acknowledge human values; integrate with the human society for greater good.
(ii) Provide infrastructure against 'Warren Harding errors [27]'; juxtapose laws of rational thinking [56] in synthetic minds and Asimov's laws of robotics [5].
(iii) Extend cooperative human values and institutions for smart technology.

5. Conclusions

Algorithms that can explain their capabilities (e.g., a Help command capable of answering "how-to" and "what-if" questions), and monitor, diagnose, and repair themselves in the presence of viruses require internal mechanisms that can be loosely called "self-awareness." … For an intelligent agent to be able to say, "Please wait, I will call my supervisor," it must be self aware! It must know what it can and cannot do… Research problems in AI include knowledge capture for replication; design for manufacturability; and design of systems with self-monitoring; self diagnosis; and self-repair capabilities. – Raj Reddy [69]

The aforementioned quote succinctly sums up the objectives of the research described in this article—the enumeration of parameters that support the encapsulation of machine-subjectivity for the synthesis of a framework for the machine-self and consequent real-world comprehension.

The Z^*-number paradigm proposed here, references human-brain processes and draws from Zadeh's Z-number [97] philosophy. It augments the basic Z-numbers with factors crucial to personalized and grounded real-world comprehension in human beings (assessed through behavioral experiments on subjective information recall). Objective components of information—*Subject* and *Value* – are juxtaposed by subjective parameters—*Context*, *Time*, *Certainty* and *Affects*—in the Z^*-number equivalents of natural language sentences. Philosophical correlates of these factors have been validated through equivalence analyses across theories (Freud [25], Minsky [51,52], Damasio [16,17] and Ramachandran [63–66]) on the 'self' and 'qualia'.

In this article, we have provided definitions for: (a) the basis of endogenous arousal of machine-certainty and machine-affect values, and Z^*-information-sets (in Section 3.2); (b) an outline of an effective procedure for natural language comprehension using Z^*-valuations of information as operands (in Section 3.3); and (c) Z^*-number based perception-operators (in Section 3.4).

Besides consideration of crucial factors of machine-self and machine-subjectivity representation, the novelty in our work lies in the consideration of the 'knowledge by acquaintance [72,74]' factor on machine-knowledge. This is envisaged to emulate the positives of neurogenesis [15,78], akin to human beings, in machines, and support the emulation of artificial-empathy in co-operative cognitive systems [44,56].

Studies herein lay foundations for the simulation of self-reflective and self-conscious thinking, and machine-mentalese [62] across Minsky's layers of the mind [51]. Some of our future endeavors lie in the decomposition of the subjectivity-parameters enumerated here into their atomic constituents and the design of structural supports for Z^*-number counterparts of information in a machine-mind.

The article brings forth vital research questions on the basis of endogenous arousal of qualia, neural correlates of linguistic meanings, cognitive biases in machine-learning, artificial-curiosity, self-motivation, etc. These questions seek answers from a number of disciplines toward decoding human-brain processes and defining effective machine-equivalents, thus promoting autonomous assistive-system research initiatives [69,89].

"What we do know is that — a quarter-million years after mankind inherited this remarkable organ called the brain — even with all of the tools available to modern science, human memory remains a stunning enigma."—[45].

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