A MATHEMATICAL PERSPECTIVE OVER THE MIND-BODY REDUCTION PROBLEM

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ABSTRACT: Is mental phenomena reducible to body phenomena? Reductive Analytical Method (RAM) have algebraic roots. "To reduce" translates, in a Cartesian sense, to the action of isolating independent variables. If RAM were dismissed, multiple variable problems would either: require more time and resources; be prohibitively difficult or unsolvable. Arguably, this bears truth to the majority of hard science's problems. Recent cognitive and neuro imagery studies included mental phenomena to RAM's scope, defying the tradition. Information Theory (IT) provides quantitative methods for the information contained: in the whole; in the sum of its parts; and in their relation. Justifying why it seems useful in evaluating RAM. According to IT: no set's information can be greater than the information in the sum of its parts; RAM only provides a partial account of neuronal dynamics. The negative and affirmative answers to the mind-body reduction question are, respectively: quantifying the whole as "greater than the sum of its parts"; extrapolating RAM's scope. Both answers seem to imply some mathematical claims, but, if our IT interpretations are correct, lack the mathematical ground. Novel and Traditional research methods have tried untangling the mind. Methods accounting for mind's tangled nature may contribute to debate as well.

KEYWORDS: Mind-body problem, Philosophy of mind, Information theory.

RESUMO: Fenômenos mentais são redutíveis a fenômenos corporais? Método Redutivo Analítico (MRA) tem raízes algébricas. "Reduzir" traduz-se, no sentido Cartesiano, pela ação de isolar variáveis independentes. Se MRA fosse descartado, problemas de múltiplas variáveis: requereriam mais tempo e recursos; seriam proibitivamente difíceis ou insolúveis. Discutivelmente, isso vale à maioria dos problemas nas ciências duras. Recentemente, estudos cognitivos e de neuro imagem incluíram fenômenos mentais ao escopo do MRA, desafiando a tradição. Teoria da Informação (TI) fornece métodos quantitativos para a informação contida: no todo; na soma das partes; e na sua relação. Justificando porquê ela parece útil ao avaliar o MRA. De acordo com TI: para nenhum conjunto a informação pode exceder a informação na soma de suas partes; MRA fornece apenas uma consideração parcial da dinâmica neuronal. As respostas negativa e positiva à redução mente-corpo, respectivamente: quantificam o todo como "maior do que a soma das partes"; extrapolam o escopo do MRA. Ambas respostas parecem implicar certas afirmações matemáticas, mas, se as nossas interpretações de TI estão corretas, carecem de base matemática. Métodos de pesquisa novos e tradicionais tentaram desemaranhar a mente. Métodos que levem a natureza emaranhada da mente em consideração possam também contribuir para o debate.

PALAVRAS-CHAVE: Problema mente-corpo, Filosofia da mente, Teoria da informação.

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1 Introduction

The motto "The whole is greater than the sum of its parts" synthesizes a contrasting alternative to reductionism [Poynton 1987, Healey 2016]. On grounds of information theory [Shannon 1948], it is possible to mathematically demonstrate that integration constrains the information held by the whole below the limit of the sum of its parts [Edelman and Tononi 2003].

On the other hand, following the reductionist stance, explaining all the components and mechanisms of the Central Nervous System would yield an exhaustive description of the phenomena, taking for granted that Cartesian Analysis is applicable. Considering coupled L-C electric circuit oscillators [Hanias, Karras and Mobarak 2009, Erro: Origem da referência não encontrada], a very simple system indeed, and yet it is easy to demonstrate that it impinges the Cartesian Analysis' scope, as it gives rise to chaotic behavior [Capra 1996, Prigogine and Lefever 1974, Gleick 2011]. Resembling neurons, the coupled oscillator pair analogy produces wave patterns that approximate, to some extent, empirically measured signals produced in the human scalp due to brain activity [Luck 2014].

Consistently, a two-neuron "brain" model forming a feedback loop should also display sensitivity to initial conditions. If we were to increase the complexity of the model by including: a greater than two number of neurons; neurotransmitter and hormonal chemistry; gene/environment interactions [Sapolsky 2017], this would only strain the reductionist approach even further. Not to mention (at risk of overshooting the target) early development stimuli, parental support, cultural group influence [Dunbar, Dunbar and Barrett 2007]. Reductive analysis is tailored for systems composed by independent parts, but it suffers from relevant limitations when it comes to analyzing dependent variables. Up to now, information theory has been reliable for understanding and researching complex systems by providing first-base principles that can quantify the integration between the parts. Arranging for a sound framework in guiding conceptual analysis on the mind-body problem, information Theory (IT) may yield a reading key for the conceptual interpretation of empirical cognitive studies.

A long-lasting philosophical debate has been recently reignited by the birth of cognitive studies, whether the mind may or may not be reducible to CNS' activity, or, putting it in broader terms, whether mental life can be taken as independent of matter [Junior 2020, Hatcher and Tofts 2004]. This brief text cannot exhaustively explain IT and its relation to mental life. Yet, two analogies can be drawn: the *first* by considering the whole modeled as a set of bits, the interrelation between the bits subtracts/constrains information instead of adding/freeing it; the *second* is that the model equations for a single neuron cell "brain" spiking give us no reason to expect any deterministic behavior, quite the opposite, even for a two-neuron loop, its precise dynamics after a long period becomes highly unpredictable.

A few words of caution. Mathematicians, physicists and computer scientists may find the mathematical prose not up to standard. Yet, philosophers and psychologists should indulge some license for the shallow literature review on the mind-body problem. This paper is not supposed to be read as a treatise, but as the schematics for a plausible transdisciplinary interpretation regarding the interface between the subjective mental experience and the objective measurable observable neuronal activity. The rhetorical maze between humanities and hard sciences is not to be underestimated. Our limited knowledge in both areas may hinder our ambitious goals.

In order to consider the mind as a whole in its relation to the sum of its parts, a solid understanding is required on basic principles. How the assembling of parts relates to the information they can contain? [Edelman and Tononi 2003, Bauer 2011].

According to information theory [Shannon 1948]: *the information in the whole is less or equal to the information in the sum of its parts***.** Increasing the amount of parts tends to increase the information, provided the parts have some independence. Otherwise, if there's only one rigid pattern highly integrated, no matter how many components are added, it will have the same total amount of possible combinations, namely two – exactly the same number of possible combinations in a system composed by a single bit.

2 Ongoing disagreement over reducibility

The mind-brain mechanisms show inherent complexity [Bassett and Gazzaniga 2011, Sporns 2002]. Rigorous conceptualization in philosophy of mind should be compatible with observed phenomena. Complexity is found in many intricate levels: physical, chemical, biological, evolutionary, neurological, developmental social etc.

> The term emergence is a multi-faceted concept whose exact meaning depends on context and invariably the field of study. In the field of (low-energy) nuclear physics, emergent phenomena are always associated with highly complex and highly non-linear behavior. [Luu and Meißner 2019]

In humanities, the historical basic notion of emergence stretches back to Aristotle [O'Connor 1983]. Echoed by modern scientists [Capra 1996, Varela, Thompson and Rosch 2016], Aristotle defines emergence as: "In the case of all things which have several parts and in which the totality is not, as it were, a mere heap, but the whole is something beside the parts" [Ross et al. 2014]. Even though Aristotelian physics has been majorly outdated centuries ago, his intuitions on emergence are still considered relevant to philosophy.

As an example, we can imagine a gear watch[2] and mentally take it apart. The scattered parts will no longer record the passage of time, are now free to be assembled back into a gear watch or in any other configuration. Without the context to constrain the possibilities, the information contained in each part comes strictly from its material properties. Stripping out the context suppresses the emergent "tracking time" property from the parts. The context didn't add information. The information was already in the parts, all the context did was to constrain the watch parts to one possibility, subtracting all the other possibilities. In the right context, a gear watch is nothing but a gear watch.

Examples of predictable set include logic gates in a well assembled computer; water molecules in a cloud are an example of a rather unpredictable set. In the cloud, the integration is much lower, molecules enjoy much more freedom. The slightest mistake in calculation for predicting the cloud behavior, due to the practical necessity of approximating the numbers, will feed back, stacking up in a loop, making future dynamics uncertain.

Total integration is dull, a brain with all neurons perfectly in sync would be as interesting as a light switch, either it is on or off. Table 3 shows that it does not matter how big is the number of parts, maxing out integration will always reduce the entropy of the whole system to 1. Total independence, on the other hand, is noisy, one never knows exactly what's next, similar to watching an old TV screen turned on with no channel selected. The interesting spot lies somewhere in the middle. As an example we can think of an ant bridge between branches. Enough rigidness to enable the bridge formation, but not excessively, not to compromise the flexibility in adapting to the environment.

According to the reductionist approach, exhaustively providing the algebraic description of each part would suffice in providing enough data for restoring the whole system back by adding up all the parts. This approach works flawlessly in the scope of linearly independent equations. Unnecessary obscure intermediary entities are thus avoided [Quine 2011]. In this regard, IT promises to take off the blindfold on the dependence between variables in systems that can only be properly described with the use of nonlinear equations, while keeping the reductionist's virtue of not multiplying any entity.

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[2] In the predictability spectrum a gear watch is located closer to more predictable clocks and away from unpredictable clouds [Popper 1965], nonetheless, the chaos theory is deemed as a very promising theory for statistically evaluating the degrees of freedom in order to map different phenomena, including brain phenomena [Başar 2012], along the predictability axis.

Chalmers famously argued reductionism to be unfit for describing the facets of human consciousness because the materialistic description can't account for an essential property, namely, the phenomenological experience of consciousness. Cognitive studies only face the soft problem of consciousness, i.e. the problems that objective science can explain, but not the hard problem of consciousness, the problem involving first-person qualitative experience, or in his words, the non-physical [Chalmers 1995, Chalmers 1996]. In his version of property dualism, Chalmers claims that in order to face up the hard problem of consciousness one is required to posit the existence of a non-physical entity. He claims experience is the most likely candidate for the non-physical entity thus posited.

Famous thought experiments also challenged mind-body reduction arguing through counterexamples [Jackson 1986, Nagel 1974]. They point out the ineffable nature of consciousness, which lies beyond our reach. The reasoning bears resemblance to mysticism [Gellman 2019] in the sense that words and science will never express the quality of the experience felt; only the creature experiencing the feeling directly in the first person can understand it. A leap of faith is required as there is no other way to know what the experience feels like other than feeling it. This criticism poses a real threat for this paper, as we cannot afford to describe the features of consciousness that, by the very "ineffable" definition, cannot be described nor studied by science. We should not underestimate such limitations.

Dennett openly opposes Chalmers' soft/hard problem categories [Dennett 2000]. To talk about the metaphysical, essential inner experience as a non-physical entity in itself is depicted as a dangerous extrapolation. A living human body composed of orchestrated biological cells in a "gear watch like" "nanobot" operation having its own intentionality [Dennett 2008] should leave little room for imaginary entities (not to mention, risking heresy, free will [Dennett 2015]). Dennett's skepticism seems justified in the context of disbelief, from some groups in society, towards academic secular institutions. We may be aware of confirmation bias effect – people's general tendency favoring their own hypothesis rather than the alternatives [Klayman 1995], but awareness grants us no immunity whatsoever. We share the secular ideology, but this only puts us in greater risk of being too charitable to Dennet's position.

There is little we can offer beyond the prolific debate. Our brief contextualization did not even scratch the surface of it. The reason we are mentioning the controversy is to warn about the deep problems that may be ahead of us. Unsurprisingly, there seems to be little agreement on the possibility of describing the nature of the phenomenon of human consciousness. Neuroscientists are struggling to get a glimpse of the complex mechanisms on our bodies that reflect directly on our behavior, without having the onus of explaining what lies beyond physics.

As we are no experts in neuroscience, we must rely on the lengthy and ongoing literature produced by specialized journals. Different facets of human consciousness are being meticulously put into scientific evaluation [Changeux 2006, Eisenberger and Lieberman 2004, Cohen et al. 2002, Greene 2013, Nicolelis 2011, Parvizi and Damasio 2001, Sapolsky 2017, Zak 2008, Tononi et al. 2016, Hohwy 2013]. If we ever hope to give any contribution to the above discussion, future work may present a modest compilation of a few connections that seem reasonable to draw between conceptual ideas regarding the human mind to the empirical data collected, suggesting general notions from which philosophers may eventually take profit.

When considering the best candidates to predict significant loss in performance in different tasks relevant to human consciousness due to specific damaged areas in the brain, IT may provide some insight. The neuroscientific data gathered by reductive approach is required to be insulated. The crucial lesson IT is suggesting is that, even though methodology is reductive, the whole should not be seen as the simple addition of all the parts, but as components that depend upon and provide support for other parts. The encapsulated modularity [Fodor 1983] is more efficient in terms of energy consumption, but a null value of integration between modules, i.e. completely insulated modules, could only produce a fragmentary outcome from the sum of its parts. There is a subtle balance between freedom and teamwork. Similar to the instruments played in an orchestra, sometimes the instruments are mostly in sync with the melody, in other times some instruments may play a counterpoint. There is no need for all the modules to be in agreement all the time.

Integration adds no new information to what was already there. On the contrary, according to equation 3, the entropy of the whole is equal to the entropy of the sum of the parts minus the integration between the parts, entailing no extra entities. Even though no single neuron is irreplaceable per se, it may require a great deal of neuroplasticity – or even clinical intervention [Cramer et al. 2011]– to cover for the loss of a whole cluster of neurons arranged in a module. To understand the patterns formed by the neurons fitting into the whole picture requires not only the reductive understanding (beyond the authors' grasp) of the physical, chemical, biological, evolutionary, neurological, developmental, social, etc., phenomena, it's all that **plus** taking a step back from each category studied through reductive approach in order to realize that no isolated field holds all the answers for all the questions at once. Each field offers tools for finding specific answers to specific questions, more or less relevant depending on the question at hand. When taken together, the frameworks from different fields may provide a richer point of view to the problem. Beyond the solipsistic mind-body conceptual problem, we might also address the development-enviroment problem. This paper focuses on the contribution from IT, suggesting a possible methodological approach to evaluate systems composed of dependent parts.

Optimistically, this may ground, from basic premises, tools for evaluating both the holistic and reductionist approaches. Ideally, the definition of integration and the discussion on the mathematical caveats for solving nonlinear equations program may prevent misunderstanding whether it is possible, or not, to reduce complex systems into more basic mechanistic ones.

3 While it is complicated, Information and Integration set the upper limit – metaphysics lies beyond.

Tononi's definition of integration [Edelman and Tononi 2003] can provide us a starting point:

$$\phi(x) = \sum_{i=1}^{n} h(x_i) - h(x) \quad (1)$$

Table 1: Definition of Integration and Entropy

Symbol	**Meaning**
φ(x)	Integration
$\sum_{i=1}^{n} h(x_i)$	Sum of the entropy values for all individual components considered independently
h(*x*)	Entropy of the system considered as a whole

Source: author.

In equation 1 integration is on the left side of the equality sign, but it is simple to manipulate it so that the *h(x)* gets isolated on the left side, better matching the order of the variables written in the holistic motto "The whole is greater than the sum of its parts".

Adding $+h(x)-i(x)$ on both sides of the equation keeps the equality sign unchanged. The simple rearrangements steps are meant for better visualizing the issue at hand, though they are not strictly necessary.

$$\phi(x) + h(x) - \phi(x) = \sum_{i=1}^{n} h(x_i) - h(x) + h(x) - i(x) \tag{2}$$

$$h(x) = \sum_{i=1}^{n} h(x_i) - \phi(x) \tag{3}$$

Equation 4 analyzes three possible interval values for $\varphi(x)$.[3] Even though there is no real case scenario represented by negative parameter values of integration – it can be either greater than or equal to zero – we considered this possibility because this would be required in order for the whole to store more information than the sum of its parts. Two parts can be either related to each other ($\varphi(x)>0$) or not ($\varphi(x)=0$); ($\varphi(x)<0$) has no counterpart in the world, it doesn't make sense to say the parts are less than unrelated. Two neurons, for instance, can either be in a stimulatory or inhibitory relation to each other, or no relation at all.

$$\text{if}: \phi(x) \begin{cases} > 0 & \text{then}: h(x) < \sum_{i=1}^{n} h(x_i) \\ = 0 & \text{then}: h(x) = \sum_{i=1}^{n} h(x_i) \\ < 0 & \text{then}: h(x) > \sum_{i=1}^{n} h(x_i) \end{cases} \tag{4}$$

Simply put, integrating the parts (positive integration) decreases the degrees of freedom, entropy, and information. Isolating the parts (zero integration) does the opposite, increasing

[3] **Positive integration (first line of the equation)**: the possible patterns are constrained, restricting the degrees of freedom (physics' jargon meaning the system is more likely to be in a particular set of configurations). Positive values of integration translates into the entropy for the whole being less than the entropy for the sum of its parts.
Zero integration (second line of equation): to the particular case where integration is zero, the whole can assume the same number of possible patterns of activity as all the possible patterns of the isolated parts. Referring to the previously mentioned gear watch analogy, each component can be arranged in any possible way regardless of the structure.
Negative integration (third line of equation): negative values for integration means that all the parts are not only completely independent of each other, they are even more independent than that. Of course, this is incurs in a self-contradictory statement. According to equation 3, for the holistic motto "the whole is greater than the sum of its parts" to be true, the entropy of the whole has to be greater than the entropy of the sum of its parts. Negative values for integration don't exist in the real world. The whole system can only store as much information as the sum of its parts.

them. There is a limit for the information of any given set of parts because there is a limit to the possible combinations they can assume.

4 Biting the bullet: can one bit hold more information than one bit?

Long story short, no. The amount of information a bit can hold is limited to the bit itself (flabbergasting). The conclusion is obvious. At risk of being repetitive, this section explains basic ideas of information theory and how they are related to the present discussion.

According to information theory, in order to increase the amount of information held by the whole above the sum of its parts, integration has to assume negative values. Demonstrating that integration is either zero or positive, never negative, should settle that the holism motto cannot be true in terms of information theory. Relations between the system's parts do not add information, they only constrain information, i.e. the system is constrained to only assume particular patterns. Simply put, the whole has either the same amount of information than the sum of its parts, or less.

Let us consider throwing a coin in a sequence. Each throw can only assume two possible binary outcomes: head (0) or tail (1). We'll analyze a finite sequence of, say, three throws (n=3). The total of possible combinations is equal to 2^n, i.e $2^3 = 8$.

Table 2: What would be the outcomes from tossing a fair coin 3 times?

Possibility	1st	2nd	3rd	4th	5th	6th	7th	8th
Outcomes	000	001	011	010	100	101	110	111

Source: author.

Considering probability of event happening (p) and base [4] (b), the information (i) is determined from the following equation [Carter 2007]:

$$i(p) = -log_b(p) \tag{5}$$

For each throw of a fair coin there is 0.5 chance of head and 0.5 chance of tail. Therefore: $i(head)=i(tail)=-log(0.5)=1\ bit$.

Considering the number of outcomes (n). Entropy is the average amount of information from the event.

[4] in information theory the logarithmic base most commonly used is binary.

$$h(x) = -\sum_{i=1}^{n} p(x_i) log_b(p(x_i)) \qquad (6)$$

The total entropy for 1 throw equals 1 and so on. $h(1)=1$;[5] $h(2)=2$;[6] $h(3)=3$; $h(n)=n$.

As a thumb rule, entropy is equal to the number of bits required to express the possible combinations. As shown in table 2, it takes three binary digits to express the combinations from three throws because that is the necessary and sufficient number of bits to exhaustively express all the possibilities.

Let us see what happens to entropy when integration comes into the picture. Now, we can discuss unfair coins, i.e. throws can now be dependent on previous throws. From equation 3, we can build a table for the possible values to the parameters of our coin tossing example. We considered the minimum and maximum values of integration, respectively.

Table 3: Minimum vs. Maximum integration

Throws	Integration	Entropy for isolated throws	Entropy for the throws as whole
1	-	1	1
2	0	2	2
2	1	2	1
3	0	3	3
3	2	3	1
n	0	n	N
n	n-1	n	1

Source: author

Three throws (n=3) can be: **a)** totally independent – producing 8 different possible outcomes (3 bits of entropy); **b)** totally dependent, producing 2 possible outcomes (1 bit of entropy) – all heads (000) or all tails (111); or **c)** something in between – some possibilities get excluded due to a mild association between throws; for instance, assuming as a rule that the

[5] $h(onetoss) = - (0.5log_2 (0.5) + 0.5\ log_2 (0.5)) = -(log_2 (0.5)) = 1$

[6] As we're considering a fair coin each throw is independent. $h(twotosses)=h(onetoss)+h(onetoss)=1+1=2$.

first and second throw have to be equal, but the third is independent, may or may not be different, this rule allows for 4 different outcomes (2 bits of entropy).

According to equation 3, it would be required negative integration values for the whole system's entropy in 3 throws to be greater than the sum of its parts above 3 bits of entropy. First, three coin throws cannot produce more than the 8 possible combinations shown in the table 2. Second, if we were to allow two bits to hold together more information than they hold in separate, information would quickly explode to infinity as this increment would accumulate each time one bit is added. Third, integration is not to assume negative values because negative integration values imply the parts to have even more independence from each other than complete independence, producing an absurd statement.

Claiming that the whole system can store more information than the sum of its parts is in conflict with information theory[7]. The mathematical conclusion is relevant to the mind-body problem because it stresses that relations between neurons can never add information; instead, relations restrict/subtract possibilities.

If neuronal patterns arranged during evolution and early development were not restricting information, the sheer number of neurons in our brain would yield a combinatorial mayhem run by factorial growth of possibilities. The predictive brain theory suggests we somehow mark scenarios as more or less likely [Hohwy 2013]. The neuronal arrangements are more likely to be triggered by a limited set of specific stimuli, under an acceptable margin of predictive error. This is compatible with the hypothesis we forward, suggesting that, were neurons free to rearrange at will[8], our world perception would change constantly – any sensorial input possibly triggering an array of different action potentials –, no matter how bizarre. All scenarios would then be deemed as equally probable, because in this scenario neuronal pathways are completely independent.

5 Two neurons are irreducible. What about billions?

The reductionist position takes for granted that complex systems can be reduced to more basic phenomena, neurons correspond to the basic "building blocks" of the CNS. Therefore, studying the isolated building blocks of the CNS, i.e. the behavior of individual neurons, would

[7] The motto "the whole is greater than the sum of its parts" in itself doesn't specify if it's referring to information or something less precise, such as in the property/relational holism [Healey 2016]. Further evaluation on alternative interpretations of holism are beyond the current paper's scope.

[8] Data suggest this not to be the actual case, as adult neuronal plasticity is quite limited. We bring the hypothetical scenario for the sake of the argument.

hold the keys for solving the mind-body problem. In order to test this version of the reductionist hypothesis, a pretty forward approach is to go ahead and model the phenomena.

Through the following L-C analogy, we suggest the reductive method is unfit for explaining the CNS, let alone the human mind. A coupled L-C electrical circuit oscillator may be regarded as the closest physics metaphor to two neuron cells. Also known as resonant circuit, the L-C circuit consists of an inductor (L) and a capacitor (C) connected in series to a power source. One L-C circuit can be coupled with another by placing each inductor close to the other. L-C circuits oscillate. The capacitor stores energy in the form of electric field (E) between its plates; while the inductor, in its magnetic field (B). The circuit oscillates energy back and forth, from the capacitor to the inductor and vice-versa.

The coupled L-C circuit is a simplified model for two neuron cells. The mechanism for transmitting action potentials is thus replaced by a simple electromagnetic inductor-capacitor exchange. A two-neuron cells model consists of two neurons, the axon from the first neuron reaching the dendrites of the second, the axon of the second neuron feeding back to the dendrites of the first. When there is enough stimulation coming to the dendrites – above the potential threshold – the neuron is stimulated and will send a signal through its axons forward to the next neuron. After sending the signal, it returns to the resting potential baseline.

The behavior of an ideal (zero resistance) L-C circuit can mathematically be described as a harmonic oscillator, similar to a pendulum subject to the gravitational field, swinging back and forth. Moreover, coupling two L-C circuits together results in chaotic behavior. The same goes for coupling two pendulums (the double pendulum) [Hanias, Karras and Mobarak 2009, Erro: Origem da referência não encontrada]. Intuitively [9], the same goes to coupling two neurons together. It seems absurd to hold that the "two-neuron model", a more complicated version of the coupled L-C oscillators, would yield a less chaotic behavior.

There is little doubt that the neurons' symphony plays a significant contribution to mental states. Nonetheless, we argue that studying them in isolation is only sufficient for partial explanations. Human behavior is also influenced by a myriad of other factor out our heads [Noë 2009]; the gene/environment relation where one gene only expresses itself under certain environment conditions, if and only if said environment condition is present – and environment conditions activate the gene if and only if the gene is present [Sapolsky 2004, Sapolsky 2017]. It is an ambitious project to update the philosophical conceptualization of the mind-body problem in accordance to plausible interpretations of the current scientific knowledge.

[9] The formal mathematical demonstration for this is beyond this paper's scope.

Nonetheless, taking into account other disciplines suggests that instead of the solipsistic mind-body problem, one may instead favor a less restricted alternative: the mind-development-environment-body problem.

The majority of research progress relies heavily on reductionist methods. Intrinsic error sources are unavoidable due to the multiple dependent variables in the complex nature of the mind when conducting cognitive and psychological studies. This brings suspicion on multi-variable studies. It has been a while since Laplace's demon has been thoroughly exorcised from physics [Shermer 1995, Jedlicka 2014]. Maybe it is about time to untangle 19th-century determinism from philosophy of mind.

Our paper suggests that reductive science does not entail that mental phenomena can be reduced to body phenomena (μ). Nor does it entail that mental phenomena cannot be reduced to body phenomena (≠μ). A third alternative is presented: mental phenomena may result from body phenomena, embedded in the environment-culture, in an integrated fashion.

Neglecting many aspects of neuronal dynamics, the mathematical models for describing single neuron spiking are simplified [Gerstner 1998]. Techniques for examining the receptive fields allows for understanding the "[…]behaviour of individual cells, but fails to deal with the problem of the relationship of one cell to its neighbours" [Hubel and Wiesel 1962]. An account of the obstacles suggests the reductionist theory purport of a comprehensive description of a complex system, such as the brain, from its basic components to be naïve. The reductive approach lacks the proper explanation for how to overcome the intrinsic difficulties of isolating the intricate network of densely packed and highly organized neurons the current mammalian brains have [Gerstner and Kistler 2002].

Communication between us may be possible, as we share similar cognitive apparatus and backgrounds. Even so, uttered sentences "resonate" (slightly or critically) differently for each one of us. Each person has an unique understanding, according to one's own history. This may be a source for angst, risen from the fact we can never know exactly the thoughts behind the other person's gaze [Sartre 1943].

It is usual to define Theory of Mind as the capacity for attributing beliefs, intentions or desires for others [Perera and Stein 2018, Premack and Woodruff 1978, Griffin and Baron-Cohen 2002, Saxe and Kanwisher 2003]. Trying to read another person may easily put us under cognitive stress. There is simply too much information, from multimodal inputs, to compute in a short time-lapse. We can briefly present, as illustration, how an IT methodology may be applied to provide a reading key in the context of Theory of Mind. Suppose one is to perform a lie detection task: whether another person's statement is in accordance to said person's beliefs or not. Microexpressions, body language, tone of voice, timing, and baseline deviance are some of the variables which may or may not bear relevance to our task of estimating the person's sincerity. In accordance to IT, we should take the information from each variable in relation to all the others. Do all the parts fit together coherently, or not? Is the tone of voice (or any other variable) in harmony with the message? Variables have meaning in themselves, but by contrasting them, one may realize one variable is contradicting others.

We cannot directly access the inner causes behind other people's behavior. The best we can do is to provide educated guesses. In order to predict other people's behavior, one has to infer mental states. Primate species are highly social. It has been found that, for primates, the best predictor for greater Encephalization Quotient is a greater maximum group size [Dunbar, Dunbar and Barrett 2007]. The default mode network, which plays a major role in Theory of Mind [Spunt, Meyer and Lieberman 2015], is the network that takes up most of the human brain's volume, available time, energy and resources, in order to figure social interactions and group hierarchy. This evidence suggests an explanation why we humans show a natural tendency to be remarkably proficient at gossiping. Is human's unique ability to write and create theories about minds related to the fact that we have the biggest brain to body mass ratio in the animal kingdom?

6 Taking it all together

From the discussion so far, we have highlighted some limitations in two classical approaches to the mind-body problem. Be when it comes to extrapolating the whole to be greater than the sum of its parts, or taking a whole complex system of dependent variables to be reducible to the sum of its isolated parts, our confidence on the scientific tools for measuring and probing into the material substance should not blind us to data on human subjective behavior. Our efforts can easily backfire, as humans get harder to predict as more clever they get.

It seems prudent to restrict ourselves to outlining what a theory of consciousness should not to be, instead of arguing for what a theory of consciousness should be. Theories may be able to provide the best answers only within a limited range of questions. However, at the present time, no single theory has been capable of providing the best answers for a range covering all the different disciplines relevant to the human mind. For approaching this complex system we deemed reliable to use the integration definition derived from integrated information theory, yet the apparent simplicity of mathematical models is only illusory, as it should incorporate complexity. It is merely a framework to be employed in order to review and incorporate the findings from different scientific branches into a broader perspective. Restricting the scope to the mind-body problem appears to be a dangerous oversimplification. Instead, the complexity of human mind should require more sophisticated tools, due to the growing amount of scientific evidence suggesting contextual influences from development and environment are relevant to interactions between mind and body.

Future research may take profit from looking: **first**, how pons and midbrain connects the peripheral nervous system to the neocortex; **second**, how different cortical areas filter, divide, organize and integrate the incoming information in order to share access to other areas, eventually giving rise to awareness, and **third**, taking each different basic modules studied from a reductive approach into a global perspective. Of course, the task of building a bridge between mind and body is colossal, but still, the effort seems justified.

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