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Essay

Robots with Quantum Minds: From the Psychology of Fiction to the Physical Roots of Biology

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Abstract: In this discussion paper, I give an account for non-experts of, arguably, quantum dynamics in the brain, underlying the modeling of affective behavior of humanoid robots in the making. Outreach to the larger audience inevitably leads to abbreviations and simplifications; nonetheless, I try to offer the backgrounds of why it is important to study the virtual aspects of 'people' we meet online, what dimensions play a role in assessing such creatures, what humanities, psychology, communication, and computer science provide to help us understand how we become attached to non-existent others. As its capstone for the time being, an approach derived from physics is discussed for a robot to handle emotional ambiguity and vagueness of its user. Two computational models, Silicon and Quantum Coppélia, are discussed for their potential and limitations in explaining human affective behavior while dealing with mediated characters.

Keywords: fictional characters; quantum computing; human affective behavior

1. Silicon and Quantum Coppélia: claims to fame

Like Silicon and Quantum Coppélia (Hoorn, Baier, Van Maanen, & Wester, 2021; Ho & Hoorn, 2022), there are theories about virtual others but they have no mathematical counterpart and are therefore less precise. Like Silicon and Quantum Coppélia, there are computational models of affect but they have undergone but sporadic empirical validation. Unlike Silicon and Quantum Coppélia, none of those models is rooted in the humanities and therefore does not handle the fictitiousness of media. No other model than Silicon and Quantum Coppélia is capable of seeing something good in the bad or something beautiful in the ugly. No other model gives a full formal account of human emotional ambiguity and having vague feelings. Silicon and Quantum Coppélia are the most complete, consider the most factors, and pay ample attention to the fictional side of interacting with mediated others or even with non-mediated others. Coppélia is the only model that handles parallel processes and does not consider psychological dimensions as exclusively bipolar. It is best validated in terms of diversity of virtual creatures, from movie character to robot, using frequentist and Bayesian test theory. It unites the most diverse disciplinary backgrounds, from literary studies to psychology and then on to quantum physics. The model is fully implemented as a software, using fuzzy logics. The model is fully formalized in terms of quantum probability, providing a non-classical basis for biological brain processes and forming a starting point for a new kind of decision theory. Silicon and Quantum Coppélia stand unrivaled. For a verbal explanation, check out Hoorn (April 29, 2021).

2. Nowadays

Fake news, false identities, phishing, word-of-mouth, game addiction; many of us live in a world of virtuality and are confused about what to believe or not (Gaozhao, 2021). Chat bots, avatars, game characters, impersonations; scam artists conjure up false personalities that feature in made-up stories. Whether we believe in a world of gods and saints, of black holes, white dwarfs, and dark matter, or in a world of social-media gossip, humans live in an epistemics of the virtual. All the world's a stage and as you like it or not, it's digital and every hoax goes worldwide these days.

3. Humanities

The first syllable in Artificial Intelligence is art. Yet, many researchers of media fare and digital environments ignore the ages of theorizing in the humanities about the amount of fiction in non-fiction novels, the surreal in Medieval painting, the exaggeration of emotions in theater performances, and about the suspension of disbelief. The humanities know what we are dealing with these days and it is called fictional characters.

In literature and theater, characters are analyzed for their moral fiber (*ethics*: good or bad guys), their attractiveness (*aesthetics*: beautiful, ugly), and the realism of the depiction (*epistemics*: realistic, unrealistic). These three dimensions modulate how much a reader or viewer 'identifies' with that character and likely believes 'what it says.'

4. Psychology and communication

The second word in Artificial Intelligence is intelligence. Although psychology still struggles with its definition (see Falck, 2020), many artificers of digital devices do not shun to call their systems smart, they call them electronic brains, cellular automata, a network of neurons, and indeed, intelligent. The advantage of psychology and communication over the humanities is that they put their theories to the test and so 'identification' with a character, like the 'intelligence' of that fictional creature, is seen as an attribution by the observer rather than a quality of the virtual being or the artificial device itself. Moreover, identification seems to be an extreme state on a scale of being *involved* (e.g., feeling sympathy). Not everybody identifies all of the time with so many characters. Additionally, one may be aloof or indifferent, bored really, so involvement is compensated by a feeling of emotional *distance* (cf. antipathy). The other aspect of 'identification' would be *similarity*, in how far the character and the observer are alike – in personality or with respect to life's vicissitudes, being in the same situation.

Central in emotion psychology is the degree to which something impacts a person's personal goals and concerns (e.g., McRae & Gross, 2020). Psychologists call that *relevance*, indicating how important something is to an individual. The direction of affect is called *valence*, whether you have positive and/or negative expectations for the far or near future about that (un)important person you encountered or event that just happened.

The psychologists and communication experts who dedicate themselves to the use of technology indicate that people discern certain *affordances* in a device, action possibilities, which facilitate or inhibit achieving certain goals (cf. Wang, Wang, & Tang, 2018). The wheels on a robot tell that it cannot walk and that it needs an even plane to ride on. Movable lips would indicate that a robot can talk. Its perceived intelligence tells whether an artificial system can advise the user on a mortgage or could beat the world champion on a game of Go. Being evaluated for their relevance and valence, affordances trigger *intentions to use* the technology in a certain way or to put it aside.

Being involved with a character while keeping a certain distance to it and – if interactive like a game character or a social robot – being willing to use the character to achieve personal goals (e.g., do a financial transaction, have a conversation) would lead to an overall level of *satisfaction*: I like the virtual therapist, I dislike the health coach.

Whereas the humanities excel in setting up grand theories that capture the depth and variety of meaning, the social sciences are strong on examining hypotheses by running experiments and other empirical tests, probing the external validity of our thinking. In doing so, bits and pieces of theory are accepted or rejected with higher or lower likelihood while relationships between dimensions (e.g., a morally better character is regarded as more relevant) are quantified: A function may be written that tells how much the one increases with the increase of the other.

While following this reasoning, in about 20 years' time, we validated the theory *(Interactively) Perceiving and Experiencing Fictional Characters* for movie characters, media figures, office assistants, game characters, virtual tour guides (Hoorn & Konijn, 2003; Konijn & Hoorn, 2005; Van Vugt, Hoorn, Konijn, & De Bie Dimitriadou, 2006; Van Vugt, Hoorn, & Konijn, 2009), speed-dating avatars (Hoorn, Konijn, & Pontier, 2018), and social robots in various settings (e.g., a robot doctor, a robot grandchild) (Hoorn, Konijn, Germans, Burger, & Munneke, 2015). We found the functions that tell how much the said psychological dimensions suppress or enhance one another, running from ethics and affordances through relevance and valence up to involvement, distance, and use intentions.

Problem is that the going-up-and-down may be more-or-less the same and that who is addressing who among the psychological dimensions by-and-large is comparable but all of it is not very exact. There is quite some room for variation. The equations shift with every sample taken.

Psychology and communication often present research results in the form of regression equations. For example, if something is threatening, the fear increases by that much on average. Then they draw a circle with an arrow to another circle and add the correlation or a beta weight. That's about it. And although they are psychologists, the premise is mathematical, not psychological. Why regression? Why not something else? Many researchers don't ask that question. To what extent is 'regression' what the brain does? In all those psychological models, regressions are written with every arrow in the path model, but the values differ per study. A regression equation estimates the relationship between two or more variables, where one variable (threat) is thought to predict the other (fear), but the percentages of explanation may differ from study to study and are sometimes as little as 30%. Which means that 70% remains unexplained. So yes, there is a lot of room for guesstimation and that measure of 'chance' can be approached in different ways. We'll get back to that later when we discuss 'fuzziness' and 'quantum probability.'

Mind you that academically, it may make perfect sense to make distinctions in a theoretical model that empirically cannot be traced back in the answers that participants provide. Social scientist tend to revise their theories to simplified versions because 'the data have spoken' but it may just be that lay people do not think about such things as profoundly as academics do. Or they are unaware of those things. What we need is general theory that is socially stratified or psychologically specified. "Eppur si muove," mind you.

5. Computer science

The third concept in Artificial Intelligence is formal modeling. Computer scientists do not care much about what average users think of their models. Oftentimes, that is too bad when a self-driving car runs over a jaywalker because it cannot handle exceptions to the rule but there is an upside to this mentality as well. Before anything, computer scientists are logicians and mathematicians. Whereas humanities sketch the grand conception and social scientists fight over the empirical validity of opposing findings, mathematics is so abstract that it prompts us to unify our diversified theorizing. Formal modeling helps the internal verification of a theory and detects flaws in the logics or pinpoints unspecified variables, the meaning of which to social scientists seem so obvious but that computers do not do anything with unless you spell it out to them in unmistakable terms.

5.1. Why formalization?

For example, Media Equation theory (ME) (e.g., Złotowski, Sumioka, Eyssel, Nishio, Bartneck, & Ishiguro, 2018; Lee-Won, Joo, & Park, 2020) and Computers Are Social Actors (CASA) (e.g., Gambino, Fox, & Ratan, 2020) say that humans apply social scripts to media (TV, computers, robots) as if they were real people (cf. blaming your computer for doing it wrong). Note the *as if*, because that takes those media straight into the realm of fiction (see Hoorn, 2020a; 2020b). The *as if* also indicates a level of similarity, not equality, and because ME and CASA do not provide any equations for their predictions (how similar should a medium be before applying social scripts to it?), the very name of Media Equation is misleading. Because ME and CASA say little about equations, we may assume the simplest, which is a linear regression. The more social cues a system supplies, the more it is treated like a human being (social robots more so than TV sets): $y = ax + b$. Level of perceived human-likeness y = number of social cues x, growing at a rate of a, starting from some baseline b (that's the minimum cue the machine should provide to get a human-likeness response at all).

As a counterpoint, Uncanny Valley theory (UV) states there is a dip in the appreciation of human-likeness (e.g., Zhang, Zhang, Du, Qi, & Liu, 2020). If robots become lifelike but not yet good enough, people get scared. UV does not offer equations either but shows a graph that goes up, then down when just not good enough, and higher-up again when the robot approaches near-humanness. That's an equation with a cubed x in it, otherwise you don't get that wave form.

Yet another theory is singularity (e.g., Kurzweil, 2016), posing that one day, AI and robots outsmart human beings and supersede them, a process that would happen at an 'exponential rate.' Here, human-likeness is not about applying social scripts, eerie appearance or behavior, but about intelligence, the commodity humans attribute to other humans, to animals, or to artificial systems. The term exponential gives us a good grip on the growth curve as it means that human-likeness (i.e. intelligence) is attributed to machines with a^x.

Through formalization, three completely different theories have become fully comparable. They all do predictions on human-likeness but in different ways: linear ($\sim x$), dual-extremum (e.g., representable in a power series with at least cubic behavior ($\sim x^3$), and exponential (a^x). ME and CASA predict a linear, and maybe quadratic relation ($\sim x^2$) (a parabola or inverted U) if there is an optimum (which they do not mention), UV expects a dual-extremum (a curve that goes up–down–higher-up), and singularity assumes an exponential growth curve. Mathematics show that three theories diverse at surface level are manifestations of the same underlying assumption: more humanlike cues lead to higher perceived human-likeness (ME, CASA) but there may be an optimum (UV) or there is no end to it (singularity).

5.2. Different logics

In classic logic, things are black or white, true or false, on or off, 1 or 0. That hardly represents the way humans naturally think, feel, and behave, which oftentimes is more ambiguous and vague than either like or dislike. There is another kind of logic that to a degree can deal with the intermediate values between true and false. Fuzzy logic works with percentages or 'membership functions' by which the value to 'how you feel' may lie between 0 and 1, the grey zone. Instead of saying that a person is good or no good, with fuzzy logics we can assign a degree of goodness to a character. Thus, the verdict does not have to be 'totally good' or 'entirely not good.' A character that is deemed 'somewhat good' now becomes within range of computational assessment (cf. Raghuvanshi & Perkowski, 2010).

We took the validated theory *Interactively Perceiving and Experiencing Fictional Characters* and translated it into a mathematical model, using fuzzy logics (Hoorn, Pontier, & Siddiqui, 2012; Hoorn, Baier, Van Maanen, & Wester, 2021). Like this, the computer could mimic how humans assess mediated others (humans online, chat bots, etc.). After implementation as a software, now dubbed Silicon Coppélia, we tested our system with girls speed-dating an avatar that was driven by our AI or by real boys. Our AI passed the Turing Test (both frequentist and Bayesian statistics): Silicon Coppélia's performance was indiscernible from that of a human being (Hoorn, Konijn, & Pontier, 2018).

6. Physics

The hardware of a computer system is totally different from the wetware of a human brain. The physical circumstances under which information is processed has an effect on how that information is processed and so influences its results: The way you see or assess things. If an AI is to simulate brain processes ('neural' networks, 'genetic' algorithms), it perhaps does so functionally but certainly not biologically.

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A computer builds up voltage in series of capacitors and above a certain threshold value such a capacitor releases the current (1) and then returns to 0. A computer is therefore an enormous switch box, which fires on-off in different pulse patterns one after the other; like some kind of Morse code. This is certainly not how the human brain functions. An organic brain is not digital (on-off) and not exclusively serial (one pulse after another). An organic brain considers the same information in more places at once: a feeling about a thought, a thought about a feeling. Conventional computers cannot do so.

The main information carrier in the brain is the electron. There are biochemical processes involved to carry over information from one brain cell to another but bottom line is that the transportation of information is done by such particles at the sub-atomic level that, arguably, makes them susceptible to quantum fluctuations because all tiny particles in nature are susceptible to quantum phenomena – so why would the brain be an exception (Hamerof & Penrose, 2014)? If so, then quantum superposition would suddenly be a thoroughgoing explanation why the brain can process information so quickly, while considering so many dimensions and in doing so, connecting so many brain regions at once (Hoorn & Ho, 2019).

Tiny packages of energy like electrons have different properties such as the way they spin or the place where they stay. Particles exhibit wave characteristics in the quantum realm, being delocalized in general. It means that "an electron's position" is undetermined unless measured – as if it could be present in one location and concurrently in another location as well. So don't think of an electron as a small compact marble but like a piece of chewing gum. The wave function (the shape of the chewing gum) of the particle reflects its energy state. Each state is represented by a waveform and thus can be superposed. Therefore, it can take so many forms and a multitude of quantum states (e.g., diverse energies with different wave functions) can be put together (be in superposition) such that the outcome is yet another viable quantum state: The same information is distributed at various locations in the brain, and multiple pieces of information can be coupled at all these locations to become a new form of information (cf. Fan, Peng, Zhang, Liu, Mu, & Fan, 2019). We can reflect in the neocortex over an emotion established in the limbic system while having another emotion over that very same thought. Multiple psychological states (e.g., happy and sad) can be taken together in superposition and the output is another quantum state (i.e. happy to be sad). Additional information may disturb the original information and thus, change the psychological states of happy–sad ('entanglement'). The estimation how much happy feelings and sad thoughts are fluctuating and balancing, dancing with one another, is called quantum probability. By writing quantum equations, we get closer to what the brain does than with fuzzy logics on conventional computers. With quantum probability, we would describe an aspect of what the brain actually does to process information.

With quantum probability you can describe vagueness and ambiguity, so that someone is a bit fearful but also courageous and by that we can assess parallelism in information processing. With quantum probability, you can be anxious and at the same time (!) not. So an emotional state stays in superposition, balancing, weighing, entangled, until a decision is made ('measurement') and only then are we back to a simple overt 'Yes, I want' or 'No, not for me' but in the back of your mind the uncertainty remains. Moreover, quantum probability is not only mathematical but would describe the actual physics underlying the biopsychology. Neither regressions nor fuzzy logics do that.

6.1. Vagueness and ambiguity

As said, fuzzy logics can represent that a person, event, or fictional character is *somewhat* good, relevant, or interesting. Keep in mind, however, that in fuzzy terms the vagueness that the word *somewhat* expresses does not mean a fusion of yes and no but rather indicates uncertainty about whether to assume a yes or a no. The value of the membership function, the percentage that a behavior may count as 'good' or 'friendly,' tells the 'psychological' state the system is in.

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Quantum Coppélia interprets vagueness in a different way. That already shows that picking one or the other mathematical approach (regression, fuzziness, quantum) makes you implement another perspective on the world. In Quantum Coppélia, good, not good, bad, not bad, beautiful, not beautiful, realistic, not realistic, etc. are envisioned as a series of two-state systems of states $|1\rangle$ and $|0\rangle$. Never mind the conventions in quantum notation; it suffices to know that $|1\rangle$ means that a dimension like goodness is fully present and that $|0\rangle$ means fully absent. States $|1\rangle$ and $|0\rangle$ may be superposed to form a new viable quantum state. Probabilities of the states that are thus linearly combined are indicated by their respective amplitudes (since the states are waves). Up until a measurement or observation is performed (through EEG, fMRI, or a questionnaire), the indeterminate status of the combined state produces vagueness. In a coordinate system with $|1\rangle$ and $|0\rangle$ on the 90° axes, two arrows or vectors would indicate the outcome: This person is partially good and to another extent, no good.

Most importantly, the quantum representation is profoundly different from fuzzification both physically (what it says about the world) and logically (the way it reasons about the world) (Raghuvanshi & Perkowski, 2010). The 'percentage' in fuzzy logic deterministically tells the extent to which a psychological state is somewhere along a continuous linear scale between the extremes of, for instance, good versus no good. Yet, quantum logic describes the psychological state itself before and after measurement, estimating probabilistically the possible outcome. Still, the outcome is rather definitive. By that, measurement or observation is an act of decision making.

To indicate vagueness, fuzzy logic tells the extent to which a psychological state is part of a dimension (e.g., goodness). Quantum addresses vagueness through the probability of a covert psychological state being either $|1\rangle$ or $|0\rangle$. At the overt observational level, after measurement has taken place, the expected value of quantum probability equals that of a fuzzy membership function. Quantum logics can represent fuzzy states but fuzzy logics cannot represent quantum states that precede observation.

Vagueness is not being sure, being uncertain about a (combined) psychological state – you feel something but in how far you feel it is blurred. Ambiguity is that you feel the same aspect with a mix of many perspectives at once with different strengths: You feel multi-valued quantities of information. In Silicon Coppélia, a personality can have multiple values as in being 'very intelligent' ($|1\rangle$), doing simple additions and subtractions but relatively 'absent-minded' ($|0\rangle$) with increased complexity. Such an ambiguous intelligence is achieved in Quantum Coppélia through a mixed (quantum) state of two states (or more in general), carrying respective weights in the statistical sense, where one of the two states consists of a dominant amplitude of $|1\rangle$ and the other of a dominant amplitude of $|0\rangle$. Such would be a 'mixed state' for, in this case, the factor *affordances* to which intelligence pertains. As a particular personality may consist of a mix of perspectives with different states of intelligence, ambiguity transpires.

Additionally, a personality can have multiple values as in being 'emotionally intelligent' but 'silly' at playing chess. This is achieved through a 'unipolar' scale going from 0 → 1 *intelligent* alongside a unipolar scale going from 0 → 1 *silly*. Such a combo we call 'bi-dimensional unipolar scales' but Quantum Coppélia also does something extra, as another dimension of ambiguity, naturally, as the quantum properties of mixed states (Ho & Hoorn, 2022). Let's say that in a portrait of Quasimodo or Cyrano de Bergerac, the man is so ugly that he becomes beautiful again. Now we have a peculiar perspective on *aesthetics*, an extended dimension of states of different beautifuls and uglinesses. The ambiguity is in the uncertainty about which dimension the observer (a human, a robot) actually takes. In quantum, holding multiple perspectives on an issue is fully possible and can be accounted for – even if it is about only one of the bi-dimensional unipolar scales: Too beautiful is not so beautiful anymore. No conventional model can represent what at laboratory level seems contradictory. Modeling not just for internal veracity but also for external validity requires an alternative logics.

7. The future: robots with quantum minds

Now we should put things to the test but quantum computers are hardly existing, because they take an enormous amount of deep-freezing to stabilize a qubit, the quantum switch board that handles the $|0\rangle$ and $|1\rangle$. At present, we can do no more than simulations. The few qubits that exist are with IBM and Google and their number by far is not enough to try a complex model like Quantum Coppélia.

Thus, robots that connect to quantum computers and understand the vagueness and ambiguity of human assessment and decision making are futuristic still. Nonetheless, the very thinking into this direction guides our neurological research: Where in the brain do quantum phenomena take place – if at all? It may direct our technological efforts: Perhaps quantum computers should be shot into deep space – because that's very very cold!

On an ethical note, do we want robots with quantum minds? If used in the wrong way, we have another deceitful creature on our hands but this time with unimaginable capabilities. If used in the right way, we have an advisor that helps make multidimensional decisions in a chaotic world that offers but little reliable information.

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