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Cognitive dimensions of public space

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Abstract: The paper presents a new approach to cognitive aspects of public space based on the Bayesian framework for cognition. According to it, cognition is powered by hypothesis-testing brain, constantly minimizing its prediction error. Expectations the brain generates can be analyzed at three different levels of organization: (1) neural implementation, comprising of three distinctive cortical networks, (2) mental computation, consisting of three parts of the Bayes' rule, and (3) social behavior inside three different social networks. Properly designed the public space can be part of the extended mind of its inhabitants, enhancing or substituting their brains' activity.

Keywords: Bayesian brain, predictive mind, salience network, central executive network, default mode network, extended mind

We tend to assume that other people perceive the world as we do. This false-consensus effect (Ross, Greene & House, 1977) is responsible – among others – for interpreting the human mind as hardwired into the human brain. According to this view, cognition can be safely understood without considering the context in which it occurs. Mental states are postulated to be distinct, recognizable phenomena, shared with most our fellow humans due to our common evolutionary heritage. We express them rather quickly on our

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faces and through our body posture, when dedicated clusters of neurons leap into action and cause the body to act in a specific way.

At the heart of this traditional view of the human mind lies the theory of reactive perception, progressively accumulating elementary two-dimensional sensory features and bounding them together into complex three-dimensional perceptual shapes. The way people saw in the past can be compared to how we see today, because physically and psychologically they were very much like us, cumulatively processing bottom-up sensory features, yielding perceptual categories which activate stored conceptual knowledge. This classical sandwich model of the mind (Hurley, 2001) assumes linear one-directional flow of information from sensory input to behavioral output, with cognition sandwiched between them, passively waiting for environmental stimuli. In this view the world isn't encountered as a locus of meaning, expected to be in the most probable shape by the predictive brain (Clark, 2016).

However, perception isn't reactive but proactive, powered by hypothesis-testing brain, constantly minimizing its prediction error (Hohwy, 2013). This marvelous organ diagnoses the world on the basis of stimulations of the senses. In case of vision, it tries to find out what in our surroundings is responsible for this particular retinal image. Making an intelligent guess isn't easy, because there is too little sensory information available to the perceiver. The brain is forced to deliver the extra knowledge replacing the missing retinal information and recovering the 3D world from a 2D image. The extra knowledge becomes apparent as visual data is degraded (e.g. *Charles Bonnet syndrome* affecting people who are going blind), or ambiguous scenes are presented (e.g. face-vase illusion) (Stone, 2012).

The knowledge necessary to perform reliable inference from 2D image to 3D world takes the form of inborn biases or acquired beliefs. Both cannot be obtained from the retinal image. They are priors making it possible for the human brain to see (Frisby & Stone, 2010), even when there is too little available information to be seen. In terms of neural connections, 10 percent of visual information comes from the eyes, and the rest are the priors coming from brain networks

(Lotto, 2017) and making sense of all retinal images. This lack of balance between bottom-up input and top-down priors lets neuroscientists call perception “controlled hallucination” (Clark, 2016, p. 14).

Retinal images and different priors are ingredients of the Bayesian framework for vision. It allows to explain how incoming sensory information can be combined with existing neural information to produce knowledge about the world. Of course inference about the world draws on many different priors which point to many possible causes of this particular retinal image. The problem of vision is how the right prior – in the form of hypothesis – is selected. Selection is inferential and demands three basic parameters: (1) sensory input (p(i)), (2) possible hypotheses (p(h)), and (3) likelihood of the hypotheses, i.e. how likely it is that a given hypothesis fits the sensory input (p(i | h)). Bayes’ rule lets the brain update the probability of the hypothesis, given the sensory input, the prior probability of this hypothesis, and its likelihood:

Fig. 1 Bayes’ rule

$$p(h \mid i) = p(i \mid h)p(h)/p(i)$$

Interpreting sensory input in the context of previous knowledge can be illustrated with an example of a musician doing a part time job in a music store. Suppose the retina of his eye registers 2D image of a piano. His brain knows that this image is consistent with many possible objects in the world: the piano itself, the maquette of the piano, the photo of the piano, the mirror image of the piano, etc. The brain’s task is to figure out the most probable causes of the sensory data using a vast repertoire of its prior beliefs.

Suppose that the probability of this given sensory input – i.e. the retinal image of a piano – in the space of a music store is 0,081 (p(i) = 0,081). Then likelihoods of two hypotheses: 80% of pianos give these sensory symptoms (p(i | piano) = 0,8), and – let’s assume – 90% of mirror images of the piano give the same symptoms (p(i | mirror image of the piano) = 0,9). And last but not the least, everyone knows that pianos are common in the music store, whereas their mirror images are rare: p(piano) = 0,1 vs. p(mirror image of the piano) = 0,001. The musician can use his prior knowledge to decide which situation in the world – the piano or its mirror image – caused the sensory image in his eye. Arriving at a conclusion requires considering the product of the likelihood and the prior probability of the hypothesis divided by the probability of sensory input.

Fig. 2 Bayes' rule for both hypotheses discussed above

p(piano | i) = p(i | piano)p(piano)/p(i) = 0,8 x 0,1 / 0,081 = 0,988

p(mirror image of the piano | i) =
= p(i | mirror image of the piano)p(mirror image of the piano)/p(i) =
= 0,9 x 0,001 / 0,081 = 0,011

The results prove why we shouldn't take the input alone to decide which situation in the world is responsible for the retinal image. The equations must take account of the previous knowledge of the relative prevalence of pianos (p = 0,1) and mirror images of the pianos (p = 0,001) in music stores. The Bayes' rule combines prior knowledge with sensory data to interpret these data, showing that the predictive brain is a well-adapted inference engine.

Creating a visual percept in the form of hypothesis "what's out there" (Gregory, 2009), required extra information in the form of biases or prior beliefs. Bayesian updating of beliefs is the result of cumulative neuronal selection creating epistemic complexities that make up our conscious minds. The humanistic concepts and philosophical purposes – we often think with and about – emerge from repeated selection of best hypotheses tested against sensory data. Our mental objects we care about most – concepts, scripts, schemas, hypotheses, theories – must have complicated histories during which information is discarded and complexity is created. Meaning of the conscious percepts (Norretranders, 1998) doesn't arise from the information in the mental states, but from the information discarded (Bennett, 1990) during the process of computational selection. In result, the conscious content makes sense in some context, creating behavior we perceive as purposeful.

It's clear that to understand the human mind and its creations that build our public space we must explain the origin of complex mental states at the level of neuronal implementation. Their purpose-like character is measured by complexity of the algorithms that executed them, using the network-like structure of the brain's cortex. All complex forms of cognition depend on interconnected networks, integrating both cross-modal information and sensory stimulation with prior knowledge.

Three basic neural networks (Koutstaal & Binks, 2015) are evolutionarily devoted to formation of ideas connected with homeostatic security, analytic problem solving and creative reflection. They are organized in "a cascade of layers in which the higher layers make Bayesian predictions about what the next layer down in the system will "see" next" (Dennett, 2017). Many-layered expectations the brain generates are at three distinct levels of computations: (1) sensations are guesses about what the brain is going to receive from the physical world, (2) perceptions are guesses about the cognitive niche, and (3) conceptions are guesses about the axiological mind. If prediction error is small (i.e. the place is perfectly matched with brain's expectations), the surrounding can be treated as a part of the extended human mind.

The first network – called "the salience network" (Uddin, 2017) – is integrating external and internal information that is significant (i.e. salient) for us. Its action is connected with principle of optimal energy utilization, specifically by the human brain, which is – relative to its weight – the most expensive organ of the body. Maintaining the health requires sensory representations of the body condition in the form of distinct feelings based on interoceptive integration in insular cortex of the brain (Craig, 2015). At the level of the sentient self, responsible for attaining optimal energy efficiency, our behavior is guided by emotional motivations, allowing Arthur (Bud) Craig to phrase "I feel, therefore I am" (Craig, 2015, p. XVII).

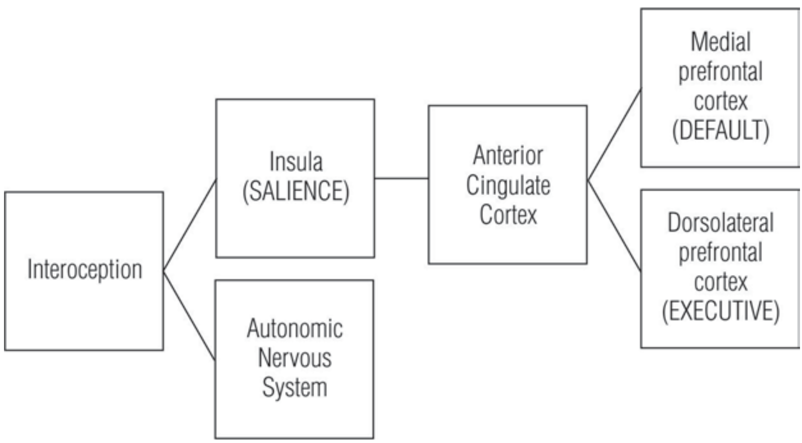
Thanks to interoception, any sensation coming from the body is transformed to a feeling in the area of insular cortex. Bodily awareness is generated in its posterior part ("I'm cold", "it hurts"), and social awareness in its anterior part ("I'm happy", "I'm safe"). When anterior insula signals high level of safety, the information moves to anterior cingulate cortex, responsible – among the others – for human motivation. A motivated man is a safe man, especially in a social domain, connected with his or her family.

What's important, feelings from the body are accompanied by autonomic reflexes, either in sympathetic division (stress on) or parasympathetic division (stress off). Emotional feelings are generated by bodily actions caused by autonomic reaction: we are scary because we started fleeing, not the other way round. The anatomical and functional organization of the salience network gives credit to the James-Lange theory of emotion, underlining the fact that autonomic activation precedes awareness of feelings.

The salience network – assuming it's safe all around – can switch between two other networks, the central executive network and the default mode network (Bressler & Menon, 2010). The first is responsible for externally driven effortful mental activity, and its key brain regions are the dorsolateral prefrontal cortex (holding goals and executing working memory), anterior cingulated cortex, already met as a part of the salience network (error monitoring and evaluating progress) and posterior parietal cortex (attentional control and attentional switching) (Koutstaal & Binks, 2015, p. 126). The working memory of the executive brain (Goldberg, 2010) holds up to 120 bits of information per second, being the bottleneck of the brain. In consequence, this part of the cortex can easily be information overloaded (Levitin, 2015), leading to Attention Deficit Trait (ADT) (Hallowell, 2005). Our susceptibility to distracting high-tech world (Gazzaley & Rosen, 2016) – acting as a collection of supernormal stimuli – results mainly from the mismatch between our ancient bodies and our fast changing world (Gluckman & Hanson, 2006). The crisis of attention makes our lives more fragmented and ourselves less coherent (Crawford, 2015).

The salience network collects sensory stimuli (p(i)) and builds the sentient self ("I feel therefore I am"). The central executive network tests hypotheses, evaluating their likelihoods (p(i | h)) and builds the epistemic self ("I think therefore I am"). The third cortical network, the default mode network (Raichle & Snyder, 2007) generates hypotheses during leisure time (p(h)) and builds the reflective self ("I imagine therefore I am"). The last cortical network gets automatically activated when the mind starts wandering and we stop paying attention to the tasks at hand (Corballis, 2015). It comprises ventromedial and medial prefrontal cortex (self-related and emotional information), the posterior cingulate cortex (mental imagery and autobiographical memory) and posterior parietal cortex (attentional control and attentional switching). The default mode network carries out mindreading, creative thinking, mental time travel and axiological evaluation of one's and other people's deeds. Its activity – always "on" when we are wandering, and "off" during task execution – is necessary for building the conceptual self. The Oracle at Delphi urging all to "know thyself" and Socrates exhorting people that "the unexamined life is not worth living" (Plato's *Apology*, 38a5-6) both unintentionally refer to the default mode network activity (Lieberman, 2013, p. 184).

Fig. 3 Cortical networks in the human brain – simplified schema



The predictive mind and its neuronal implementation – the Bayesian brain – occupy two of three levels of understanding of the human information processing system. David Marr, the maverick British mathematician, computer scientist and one of the founders of cognitive science, called these two levels, respectively, the algorithm level (the mind) and the hardware level (the brain) (Marr, 1982). The third level, "computational", describes the behavior of the system which processes information at the level of the mind and physically implements it at the level of the brain. This third computational level incorporates cognitive dimensions of the public space, being part of the extended human mind.

The public space is definitely an example of a complex system, composed of myriad agents whose collective characteristics aren't easily predicted from the properties of individual components themselves (West, 2017). They are continuously interacting with the rest of the system, which lacks any central control. The system as a whole exhibits emergent, self-organized behavior, easily adaptable to changing external conditions. That's why it's often called "complex adaptive system" (Miller & Page, 2007) evolving and increasing its – whatsoever measured – fitness. Although the public space can be thought of in terms of its physicality – urban places or natural scenes – it is first of all a social community behaving remarkably similar all over the world. The integration and interplay of both physical and social networks give rise to cognitive phenomena of extended minds, whose boundaries encompass individual brains, bodies and designed artifacts. Extending boundaries of the mind beyond boundaries of the brain increases individual creativity and intelligence, social innovation and economic output.

Of course the size of public space is changeable, depending on social networks density, connectivity and transitivity (Massey, 2005). From the outset of our life, when attachment rules our emotional development, we live in intimate networks ranged in size from three to seven people (Milardo, 1992). What counts then is an intense exchange of emotional resources during face-to-face interactions. They create the first cognitive dimension of public space that can be called "experiential dimension" after the classical Steen Rasmussen's book on architecture (Rasmussen, 1962). Experiencing is analyzed at the level of mental sensations, implemented by the salience network, whose key part – anterior cingulate cortex – registers both physical and social pain. Social stigmatization hurts more than a broken leg, and ostracism is among the highest forms of punishment (Lieberman, 2013, p. 56).

Then goes the effective network maintained to deal with the logistics of everyday life, when people pursue instrumental goals associated with work, leisure time, career and accumulation of material and symbolic resources. Emotional exchanges give way to epistemic strategic exchanges, mainly in the form of mindreading, carried out both by the default mode network and the central executive network.

Mindreading ability develops between 2 and 4 years of life, and engages mental percepts which refer not to physical world (like sensations), but cognitive niche composed of packets of valuable information. They are called “affordances” and defined as what the environment “offers the animal, what it provides or furnishes, either for good or ill” (Gibson, 1979).

The effective networks range from 6 to 34 people (Milardo, 1992) and constitute functional dimension of the public space. “Functional” because strategic games played by social actors let them treat the others as clever tools, forming a cognitive scaffolding for their own brains. There are two ways of forming packets of valuable information: neuronal and behavioral. The first road uses our own neuronal machinery which discards and selects sensory information (over 11 million bits per second) and creates conscious states containing little (120 bits per second) but very valuable information. This process is costly and takes time, at least 350 milliseconds (Libet, 2005). Our consciousness is always little bit off-line, but we don’t recognize this cognitive time-lag. The second road is paved for us by others – parents, teachers, bosses – designing affordances which, in the form of developing cognitive niche, make each generation more intelligent than the previous ones (Flynn, 2016).

Our children are getting smarter not because their brains have phylogenetically changed, but because former generations made a hard epistemic work, helping them to understand the world better and to interpret its phenomena in a consistent way. The behavioral road is cheaper and explains why the basic form of learning is an imitation. As Caliban says in the second scene of Shakespeare’s *The Tempest*: “Remember, first to possess his books; for without them he’s but a sot, as I am”. Cognitive artifacts can make a difference, other people minds can change our worldview, not necessarily our own brain’s activity. The evolutionary process of niche construction is well known and responsible for our exceptional epistemic progress across the ages (Laland, 2017).

The last but not the least network is called “extended” and consists of distant kin, professional acquaintances, and “friends of friends” (Massey, 2005), in the number between 100 and 400 persons. Relations between them are “weak ties”, crucial – as Mark Granovetter (1974) showed – not only for our professional success, but – thanks to Matthew Lieberman's neurocognitive work – indispensible for building conceptual selves among teenagers (13-18 years of age). Their brains, in the area of the default mode network, create the sense of self mostly on the basis of other people's opinions about their owners. In consequence, Lieberman offers a Trojan horse self hypothesis, according to which "the self may be evolution's sneakiest ploy to ensure the success of group living. (…) the self is, at least in part, a cleverly disguised deception that allows the social world in and allows us to be 'overtaken' by the social world without our even noticing" (Lieberman, 2013, pp. 189-190).

The mental states created by the default mode network are conscious concepts referring to axiological content of the moral neural sense (our conscience) located probably in the lateral frontal pole (Neubert et al., 2014). It means the objects of consciousness aren't the states of the physical world, nor affordances of the cognitive niche, but mostly values of our moral minds. Jonathan Haidt (2012) claims there are six of them, responsible for our decisions questioning the economical analysis of costs and benefits (Ariely, 2013), and crucial in the process of self formation (Błaszak, 2013). The third cognitive dimension of the public space can be called "rational", supplementing our perception of other people as biological organisms (sensations), cognitive tools (perceptions) with concepts letting us see them as axiological subjects.

The study of public spaces considered as complex adaptive systems cautions scientists against naively breaking the system into independently acting individual agents. The postulate of a "cognitive dimensions of public space" points to the idea that the content of mental states isn't fully defined by activity of the human brain. The valuable information implemented in cultural artifacts and in minds of other people is equally important. It seems then that the brain isn't the only level of causation in psychology, and the science of human beings shouldn't be neuro-centered the way Francis Crick saw it in his "The Astonishing Hypothesis": "'You', your joys and your sorrows, your memories and your ambitions, your sense of personal identity and free will, are in fact no more than the behavior of a vast assembly of nerve cells and their associated molecules" (Crick, 1995, p. 3).

Fig. 4 Three cognitive dimensions of public space

	Public space		
Size	Intimate networks	Effective networks	Extended networks
Behavior	Experiential	Functional	Rational
Mind	Sensations (p(i)) The sentient self ("I feel therefore I am")	Perceptions (p(i|h)) The epistemic self ("I think therefore I am")	Concepts (p(h)) The reflective self ("I imagine therefore I am")
Brain	The salience network	The central executive network	The default mode network

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