Perceptual time and the evolution of informational investment

Wednesday, 18 June 2014

by Bradley Alicea

Photo credit

Humans tend to think of the flow of time in the context of evolution and biology as a fairly consistent thing [1]. We are used to the conceptual mechanisms of molecular clocks, thermodynamic entropy, and circadian rhythms. All of these mechanisms maintain regularity with respect to the flow of time. However, this order may not be as universal as we would like to believe. In fact, there may be a form of perceptual relativism enabled by evolution, physiology, and (increasingly) technology that unseats this order in many unexpected ways. This post will utilize two recent papers as a means to explore this issue.

A recent paper entitled "**Metabolic rate and body size are linked with perception of temporal information**" by **Kevin Healy** and colleagues [2] demonstrates that differences in visual sampling across species living in different ecosystems are constrained by the metabolic rate of the organism. Visual sampling can be measured in terms of an organism's **critical flicker fusion (CFF) frequency**. CFF frequency is the sampling rate (or rather, the minimum sampling rate) at which images captured by the retina are integrated by the brain into coherent visual scenes (see Figure 1 for a demonstration). A very-high or very-low CFF frequency may lead to differences in how the flow of environmental events is perceived by the organism [3], and can lead to other differences in performance. One example of this is a human trying to swat a fly – this is often a futile exercise for the human due to a mismatch between the fly's visual acuity and the human's reaction time.

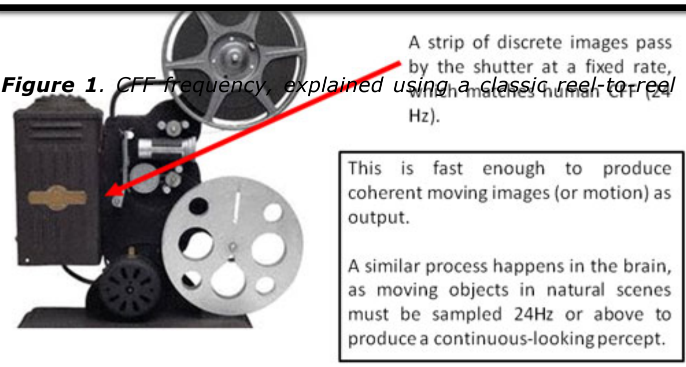

***Figure 1**. CFF frequency, explained using a classic reel-to-reel movie projector.*

This academic paper has elicited an interesting set of reactions in the news media. In some cases, this is being sold as a suggestion that flies experience a lifespan equivalent to that of humans, even though the human lifespan (in terms of biological processes) is much longer [4]. Regardless of the speculation, the potential for relativistic time-keeping [5] across species may also be interesting from an evolutionary standpoint. Is the CFF frequency determined solely by the requirements of ecological niche [6], or is the CFF frequency constrained by metabolic rate, and why? It is well-known that metabolic rate scales allometrically with body size [7], for reasons that are clearly due to energetic efficiency. But might this also extent to CFF frequency?

The authors suggest that CFF frequency is merely constrained but not determined by the metabolic rate. This pattern is predicted by the expensive tissue hypothesis [8]. This hypothesis (see Figure 2 for a demonstration) suggests that amount and structure of neural tissue in an organism must be highly-optimized due to the high energetic cost of electrical activity/excitability. In general, the more neural tissue used by the organism (e.g., bigger brains, more elaborate eyes), the higher the energetic cost. If the cost is high enough, this clearly serves as an absolute constraint on the size of an organism's neuronal architecture. But what are the consequences of this with respect to cognitive complexity [9]?

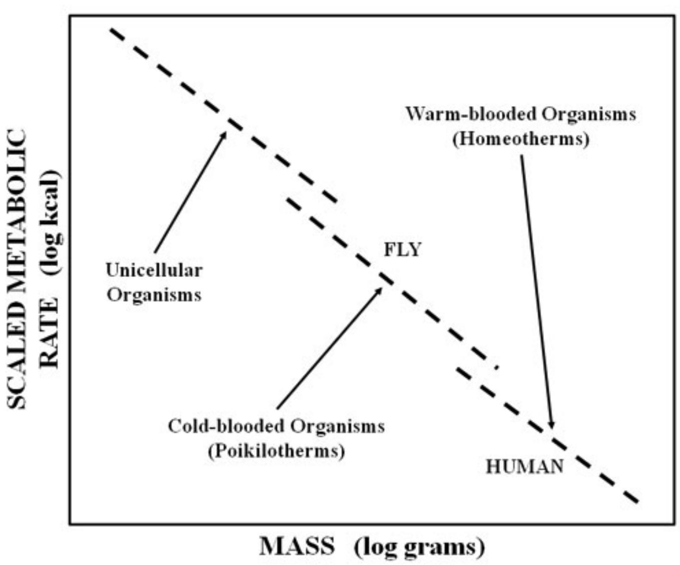

***Figure 2**. The principle behind the expensive tissue hypothesis*

At this point, I would like to propose something called the "animation bottleneck" hypothesis, and is similar to one role ascribed to **early attentional selection** mechanisms in human consciousness [11]. The animation hypothesis suggests that while higher frequency visual sampling of the environmental provides an advantage for identifying and executing very-high frequency events (being able to catch insect prey or the beginnings of an explosion), lower frequency visual sampling may have other advantages that result in an evolutionary tradeoff. In the case of CFF frequency, a lower sampling rate might result in a greater need to make proper inferences as to what will happen in between the samples. This could result in bigger brains. However, it might also have other consequences, such as the evolution of **attentional capacity** [12]. If so, variation in the sampling rate within a species might have unique fitness consequences.

So what happens when you have variation in the environment that far exceeds the baseline ability of perception? In natural populations, the findings of [2] demonstrate that environmental stimuli are less of a selective pressure than often assumed [6]. But in the technological environment, there might be signals that exceed what are typically found in the natural world (e.g. ultrafast extreme events). Such is the case with **HFT (high-frequency trading** [13]. HFT is defined by [14] as computer-driven algorithm-based trading at speeds measured in millionths of a second. An article the *New York Times* by Charles Duhigg [15] demonstrates the two type of advantage (30 millisecond and 500 millisecond) enabled by HFT technology at very short timescales. This certainly has consequences for human-assisted trading decisions, sometimes quite unintentional as we shall soon see. What if human perception and decision-making could be imbued with the attributes of a high-frequency trading algorithm?

A recent paper on HFT and decision-making called "**Abrupt rise of new machine ecology beyond human response time**" considers just this possibility [16]. In this case one can use artificial agents to explore whether or not the information sampling capacity discussed in [2] is merely a constraint of animal visual systems or if it is a consequence of fitness and selection. The authors of [16] do this by exploring the relationship between the collective action of agents, share price, and strategies employed by agents. This is an intriguing paper, but does not fits cleanly into the context of biological evolution and/or human performance. Nevertheless, it raises a few key points about the evolution of neurobiological information processing.

The authors model this as a competitive process of trading agents using their own ecological perspective. A simulation is used to better understand the relationship between strategies employed by a population of agents and ultrafast extreme events (e.g., the high-frequency trading of shares or, in some cases, a so-called **flash-crash**). In [17], HFT-reliant trading behavior enables three key advantages, which stem from both having access to very-high-frequency environmental samples and the ability to act upon them [16]. These include: better access to the market, a major speed advantage, and a greater understanding of the market's temporal microstructure. Another ecological explanation suggests that computers trading at very-high frequencies safeguard the market against irrational or inexperienced traders [18].

that most of these ultra-high-frequency events are not the information they are made out to be. Rather, the real information in markets may reside in longer interval periods. Individuals that sample the markets at HFT-like frequencies may actually be **aliasing (or oversampling)** their environment [19]. In fact, it may be that the purported advantages of HFT are largely driven by noise (e.g. benefits derived from chance) and not information. Returning to the fly visual system, it could also be the case that flies deal with large amounts of visual noise, which may act to suppress any perceptual (or fitness) advantage they may gain from being able to detect things at very high frequencies.

In short, are visual systems and cognitive complexity selected for the right amount of information in the environment, or are they constrained by other factors? And what consequences does this have for the evolution of signaling and perception? Perhaps very-high and very-low frequency events can be inferred by the visual system and brain in a way that is "good enough" not to be detrimental to fitness. Or the other hand, perhaps very-high and very-low frequency events provide an opportunity to create new niches and hide communication from predators/prey and/or conspecifics. In both cases, these types of events have a subtle effect on cognition and behavior that is largely mysterious in nature. The deployment of evolutionary simulations might provide us with some answers.

Originally Published on **Synthetic Daisies blog**, September 24, 2013.

Notes:

[1] For a alternate philosophical and theoretical view, this book might be interesting: Vrobel, S., Rossler, O.E., Marks-Tarlow, T. Simultaneity: Temporal Structures and Observer Perspectives. *World Scientific* (2008).

[2] Healy, K., McNally, L., Ruxton, G.D., Cooper, N., and Jackson, A.L. **Metabolic rate and body size are linked with perception of temporal information**. *Animal Behavior*, 86, 685-696 (2013).

[3] Assuming that CFF frequency is the only component of visual perception, and that the functions of these components are not linked. For more on this, please see: Skorupski, P. and Chittka, L. **Differences in photoreceptor processing speed for chromatic and achromatic vision in the bumblebee *Bombus terrestris***. *The Journal of Neuroscience*, 30: 3896–3903 (2010).

[4] The popular media have spun this paper a number of different ways (e.g., Google: **"Healy" + "Animal Behavior" + "Fly" + "Hz"**), and seems to be a lesson in what the public takes away from a research paper. A few examples:

a) Silverman, R. **Flies see the world in slow motion, say scientists**. *The Telegraph*, September 16 (2013).

b) **Slo-mo Mojo**. *The Economist*, September 21 (2013).

c) **Time is in the eye of the beholder: time perception in animals depends on their pace of life**. *ScienceDaily*, September 16 (2013).

please see: Alicea, B. **Relativistic Virtual Worlds: a emerging framework**. arXiv, 1104.4586 (2011).

[6] A competing hypothesis (strong ecological) predicts that the response dynamics of retina are ecosystem-specific. For more information, please see: Autrum, H. **Electrophysiological analysis of the visual system in insects**. *Experimental Cell Research*, 14(S5), 426-439 (1958).

[7] Brown, J.H., Gillooly, J.F., Allen, A.P., Savage, V.M., and West, G.B. **Towards a Metabolic Theory of Ecology**. *Ecology*, 85(7), 1771-1789 (2004).

[8] Aiello, L.C. and Wheeler, P. **The Expensive-tissue hypothesis: the brain and the digestive system in human and primate evolution**. *Current Anthropology*, 36(2), 199-221 (1995).

[9] Assuming these comparisons can be made for CFF frequency in the first place. For more on this, please see: Chittka, L., Rossiter, S.J., Skorupski, P., and Fernando, C. (2012). **What is comparable in comparative cognition?** *Philosophical Transactions Of The Royal Society*, 3671, 2677-2685.

[10] Savage, V.M., Allen, A.P., Brown, J.H., Gillooly, J.F., Herman, A.B., Woodruff, W.H., and West, G.B. **Scaling of number, size, and metabolic rate of cells with body size in mammals**. *PNAS*, 104(11), 4718–4723 (2007).

[11] For more background on early attentional selection and the connections between vision and the construction of conscious percepts, please see:

a) Zhaoping, L. and Dayan, P. **Pre-attentive visual selection**. *Neural Networks*, 19, 1437-1439 (2006).

b) Van Rullen, R. and Koch, C. **Is perception discrete or continuous?** *Trends in Cognitive Sciences*, 7(5), 207 (2003).

c) Ogman, H. and Breitmeyer, B.G. **The First Half-Second: the microgenesis and temporal dynamics of unconscious and conscious visual processes**. MIT Press (2006).

[12] For more on the evolution and life-history variability in attentional capacity, please see:

a) Kruschke, J.K. and Hullinger, R.A. Evolution of attention in learning. In N.A. Schmajuk (ed.) Computational Models of Conditioning. pgs. 10-52, Cambirdge Press, Cambridge, UK (2010).

b) McAvinue, L.P., Habekost, T., Johnson, K.A., Kyllingsbek, S., Vangkilde, S., Bundesen, C., and Robertson, I.H. **Sustained attention, attentional selectivity, and attentional capacity across the lifespan**. Attention, Perception, and Psychophysics, 74(8), 1570-1580 (2012).

c) Humphreys, G.W., Kumar, S., Yoon, E.Y., Wulff, M., Roberts, K.L., and Riddoch, M.J. **Attending to the possibilities of action**. *Philosophical Transactions of the Royal Society B*, 368, 20130059 (2013).

[14] Patterson, S. and Rogow, J. **What's behind high-frequency trading?** *Wall Street Journal*, August 1 (2009).

[15] Duhigg, C. **Stock traders find speed pays, in Milliseconds**. *New York Times*, July 23 (2009).

[16] Johnson, N., Zhao, G., Hunsader, E., Qi, H., Johnson, N., Meng, J., and Tivnan, B. **Abrupt rise of new machine ecology beyond human response time**. *Scientific Reports*, 3, 2627 (2013).

[17] Lopez, L. **A high-frequency trader explains his three basic advantages**. *Business Insider*, September 20 (2012).

[18] Smith, N. **A healthy side-effect of high-frequency trading?** *Not Quite Noahpinion blog*, August 11 (2013).

[19] Alicea, B. **Economic trace, pondered**. *Synthetic Daisies blog*, November 12 (2011).

____

Bradly Alicea is a multi-disciplinary scientist who works at the intersection of systems biology, computation, and interactions between the brain and technology. Bradly Alicea received his PhD from Michigan State, and serves as the administrator of Synthetic Daisies blog. Contact Bradly at **bradly.alicea@outlook.com**.