Static Images as Agencies: Performative, Algorithmic and Normative Functions

(Working paper: critical feedback is welcome)

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The focus of this paper is the static image, that is, a stable configuration of shapes and colors which is perceived by a human subject in a particular context. Whether such visual patterns are natural or artificial will be considered irrelevant for the purpose of this inquiry into the capacity of images to control behavior because both are equally parts of the human environment and it can be assumed that the decision of characterizing the source of the visual information from which images are constructed is posterior to their perception and pertains to cultural knowledge. The choice of static rather than kinetic images is purely heuristic and can be justified by the methodic necessity of reducing the problem to the simplest terms possible as a first step toward an understanding of its inclusive complexity.

1. Epistemological strategy: time and explanation.

Explanations, scientific or otherwise, consist of relating observed phenomena to abstract models of lesser or greater generality. These models are time-sensitive in the sense that they differ depending of the temporal frame they select. Usually, this latter component of models remains implicit and is taken for granted within particular epistemological subcultures. Modern semiotics has traditionally accepted a psychological perspective with respect to the time scale of its descriptions. Whether the historical sources of these descriptions are in empirical, phenomenological or philosophical models of explanation, the various streams of semiotic inquiry elaborated models of signification which pertain to the extended present of individual or historical consciousness. Structuralist semiotics operates within the constraints of a state-of-play which is inferred from the simultaneous evidence provided by linguistic and cultural data. Psychoanalytical semiotics takes the human life span as its frame of reference but reduces it to a recursive narrative. Social semiotics, often explicitly derived from Marxism, foregrounds processes and systemic changes under the pressure of social forces within the boundaries of humanity as it is represented in historical consciousness, but this dynamic is assessed in term of current tensions and transformations. Biosemiotics, as it stands now, is nothing but a form of structuralism since, under the resilient influence of Jakob von Uexküll, its most obvious aim seemingly is to describe sign-based optimal states of equilibrium in various life forms. Its processual aspects are framed within a teleological, anti-Darwinian perspective that is compatible with stable ontologies and comprises time as a mere variable.

Semiotics, as it developed during the XXth century, is more concerned with the question of *how* a variety of biological, psychological and sociological phenomena can be described in terms of a single model and its combinatorial variants than with asking *why* these phenomena came to be what they appear to be and *why* they require some form of general description or explanation. If we accept the premisses of evolutionism by natural selection, which is presently the only theory able to explain the emergence of complex adaptive behavior, explanatory semiotic models must be commensurate with evolutionary rather than psychological or historical time. One may decide, of course, to limit one's inquiry to the morphological structure and interactive behavior of organisms as they appear now. But this brings little understanding of the complex nexus of causes that created these states of affair over several hundred million years and necessarily continues to decisively impact the story of life on earth. Failing to understand how and why humans process, store, manage and share which information, and with which consequences, can only be disastrous for a species that has succeeded in drastically modifying its environment for short-term advantages. A semiotic theory that would conceive of the problems to be solved within the time frame of evolution could probably lead to more interesting and relevant explanations than descriptions and classifications of virtual entities without concern for the origin and development of the intrinsic mechanisms of the vital processes they claim to model.

2. The construction of images.

Visual information accesses the human brain in processed forms., as representations, and appears to consciousness as bounded sets of parts of various shapes and colors. Although there are some circumstances in which we puzzle over the meaning of what we see, most of the time we seem to assign automatically appropriate categories to the visual configurations that focus our attention with greater or lesser intensity and we make appropriate, that is, adaptive decisions. Understanding this phenomenon requires that we put it in perspective and trace the sensitivity to sunlight back to early organisms which gained an advantage from getting information that originates beyond their immediate surroundings.

Karl Popper (1990), in a late lecture devoted to the notion of evolutionary epistemology, speculated about the consequences of the emergence of photosensitivity and photosynthesis, and showed how the deep history of this “enlightenment” accounted for the form and function of human knowledge, its potentialities and limitations. From the light-sensitive patches of very simple organisms to the complexity of the primate visuo-motor apparatus, eyes have evolved in many forms. Early functional optical structures that eliminate fuzziness have been found, for instance, in a Devonian phacopoid trilobite, *Erbenochile* (Fortey and Chatterton 2003) with strongly curved eyes endowed with towers of lenses made of mineral calcite that commanded a 360-degree horizontal visual sweep, or in a later marine invertebrate, an echinoderm, the brittlestar (*Ophiocoma wendtii*) that possesses a microlens array on the upper-arm joints of each of its five arms, with bundles of nerve fibres at each focal spot (Aizenberg et al. 2001). Palaeontologists associate the exponential evolution of vision systems with the Cambrian, some 540 million years ago, when life started to diversify at a much faster pace. The problematic cause of this evolutionary explosion has been assigned to the natural selection of improved visual accuracy and the arm race it triggered between predators and preys involving both detection at distance and adaptive motor responses either for capture or escape (Parker 2003). The new environment created by populations of seeing organisms also caused the proliferation of deceptive morphologies through camouflage and mimicry. Eyes evolved in many forms in five different phyla, each system solving the problem of using light sensitivity to process information from its distal environment and, at times, showing convergence of the solutions. The cuttlefish eye, for instance, is very similar to the human eye. Both were built independently in two different phyla from similar basic materials and under similar evolutionary pressure to achieve the same function with respect to the specific ecological niche within which each reproduces. A current debate among evo-devo researchers bears upon the alternative view that eyes evolved only once in a microbe which became a symbiont and took diverging paths under a variety of adaptations. This theory is based on the discovery of a gene (Pax-6) which is involved in eye formation in fruitflies, mice and humans, and whose precursor versions have been found in primitive forms of life (Pennisi 2002).

But whatever the phylogeny of photoreception may turn out to be, each adaptation to the processing of light information and its representation in the brain had to solve a particular set of problems and, as David Marr (1982) pointed out in his seminal work on vision, each organism has evolved special-purpose mechanisms which can be fully understood only when the problems they solve are made explicit. Human vision may appear to be much more general than some of the other systems which have been elucidated so far, but it is not less bounded by the nature of the problems it happens to solve most of the times, in spite of many shortcomings that human inventiveness strives to compensate with various prostheses.

In vision, the surrounding information coming from light reflexion is first organized as an image, that is, a representation, which is then processed by the brain which determines an appropriate behavior. But such a formulation, which is generally taken for granted, enunciates a series of problems rather than provides an explanation.

First, the image must be relatively stable in spite of the constant motions of the eyes (saccades and ballistic eye movements), the body (gravity adjustments, gestures and various tasks) and the environment (with both object and background motions). If an organism needs only to orient itself, or move toward a source of light in order to proceed with photosynthesis, the definition of the image can afford to be fuzzy, but, if it requires a level of definition that enables the distinction between mate, predator and prey, a blurred image cannot be adaptive. It has been recently discovered (Masland 2001, Ölveczky et al. 2003) that the vertebrate eye is not a passive receptor that simply collect raw information. The retina is indeed the locus of a rich microcircuitry whose highly differentiated neurons (rods and cones, numerous highly diversified amacrine cells, bipolar cells and retinal ganglions) compute the photic information, compensate locally for the fuzziness caused by various sources of motion, structure and compress the information detected by the photoreceptors and feed this information for further processing to the retinal ganglions whose collectively bundled axons make up the optic nerve. Between the input of the photoreceptors and the output of the retinal ganglion an image is elaborated in the form of a stable representation and is conveyed through the optic nerve to the brain's visual centers (the *lateral geniculate nucleus* and the *primary visual cortex*) and to areas where cognitive, emotional and dynamic responses occur.

Secondly, it must be understood where and how the image is further processed, whether or not it reaches consciousness and how it relates to decisional behavior. Since the pronouncements of J.J. Gibson (e.g., 1966), much research has been done in the field of the visual and cognitive neurosciences. There is now little doubt that, through algorithmic processes, collectively dubbed by some "visual intelligence", the brain constructs adaptive representations from the sporadic information which impacts the retina and reaches the visual brain in pre-processed forms. The neuronal computations that lead to semantic categorizations and motor responses may or may not interface with phenomenological awareness. Donald Hoffman (1998) has compiled the available evidence coming from neuro-pathologies and neuro-psychological experiments to argue that what we see is what the brain constructs. However, this does not amount to radical idealism since the algorithmic shortcuts he formulates as "rules"(e.g., Rule 23: "Construct as few light sources as possible" or Rule 24: "Put light source overhead") have evolved as statistically adaptive behaviors. When discontinuous patches are constructed as a continuous edge, it pays off most of times to behave as if there were indeed an edge in the relational world. The phenomenological world needs only to fit approximately the latter. Such probabilistic views broadly converge with the current approaches found for instance in Gigerenzer and Selten ( ) or Glimcher (2003), which take into account the neuro-cognitive data yielded by contemporary advances in neuro-imaging (Gazzaniga 2002).

Thirdly, it must be understood how visual information in the form of images interfaces with cognitive, emotional and motor systems in the brain. Images package information in biological relevant patterns which must be attended by the whole set of resources afforded by the brain. From this point of view, artificial images have a peculiar status since, in their making, visual information is pre-processed entirely within the phenomenological world. The retinal computations must indeed deal in this case with standardized clearcut boundaries within which the ordering of information is relatively predictable in a given cultural environment.

Images as agencies: shaping the brain

The active, even pro-active part played by the retina and the brain in constructing representations of aspects of the environment that are relevant to the growth, maintenance and reproduction of organisms in which vision has evolved, should not lead however to consider images as inert or passive results of these processes. The external constraints on pattern productions, literally in the eyes of the beholders, contribute decisively to the capacity of the maturing brains to adaptively process images.

Given the degree of plasticity of the human brain which allows it to learn and to automatize responses to a huge variety of visual and other patterns, both natural and artificial, it is obvious that images have an impact of their own. Sensory experience does indeed modify the neural connections in the developing visual system, and, later creates idiosyncratic associations and habituations. The necessity of patterned visual inputs for establishing functional synaptic connections in the developing visual pathway was demonstrated some three decades ago by Hubel and Wiesel (e.g.) in their deprivation experiments on cats. Since then, more evidence have consolidated and expanded their conclusion that selective synaptic connectivity depends on visual experience during the critical period of ocular dominance plasticity (Chiu and Weliky 2003). New experiments by Zhou et al. (2003) tested in vivo the relation between spontaneous neural activity within the developing visual pathway of a tadpole (*Xenopus*), which contains a high degree of local and long range spatiotemporal correlations, and the long-term neural changes induced in the receptive field by specific visual stimulations. Their evidence suggests that the neural activity evoked by visual experience profoundly influence the development of circuits within the visual pathway, although it still remains unclear how this activity is translated into long-term structural changes in the neural connections (Chiu and Weliky 2003: 1891)

Admittedly, the above evidence comes from experiments conducted on the brain of cats and tadpoles but they should not be dismissed as irrelevant to human vision because evolution involves as much conservation as change. The ability of cats and humans, for instance, to share living spaces such as a furnished apartment, and activities such as play, implies a high degree of overlap in their respective visual systems. It is not surprising therefore that there is equally compelling evidence of the shaping of brain connectivity by images in the development of human functional vision. For instance, it is well established that the primate brain, particularly the human brain, is an expert face processor, a crucially adaptive competence in a highly social species. Experiments have shown that the neonate brain is hardwired for distinguishing gross facial patterns (basically, two darker dots on a horizontal line separated by a distance congruent with the average spacing of eyes in the human face) from other patterns that do not elicit the same positive responses (Brown). But more recent research indicates that early visual experience (during the first few months of life) is necessary for the normal development of expert face processing. Le Grand et al. (2001) have shown that pathological deprivation of patterned visual input (e.g., bilateral congenital cataracts) from birth until 2-6 months causes permanent deficits in configural face processing. It appears that early visual information decisively contributes to setting up the neural architecture which will eventually specialize in expert configural processing of faces over the next 10-12 years. Further tests suggest that this deficit in configural processing is restricted to the processing of faces. These results are congruent with those of Pascalis et al. (2002), which "demonstrate that 6-month old infants are equally good at recognizing facial identity in both human and nonhuman primates, whereas 9-month old infants and adults show a marked advantage for recognizing only human faces".

But the impact of images on the brain circuitry that processes visual information is not restricted to early development stages. The intensive electronic production of images has altered the human environment during the last few decades and many questions have been raised concerning the effects of this technocultural change on human vision and cognition. Green and Bavelier (2003) have tested the effects of video-game playing on visual selective attention. Five series of standard experiments in attentional studies, designed to provide a comparative measure of attentional resources and their spatial distribution, have shown that video-game playing increases the capacity of the visual attentional system and that the training of non-video-game players results in the same performance improvement. These results are relevant to the argument of this section in as much as, although the experiments presupposed exposure to the dynamic images of action video games rather than the processing of static images, they show that visual attentional processes which are crucial in processing visual information can be radically altered by an image producing industry. The tests comprising the experiments involved indeed static images with target tasks and distractors, an artificial modeling of natural conditions when images must be constructed from widely distributed visual information swamped with noise.

Images as agencies: controling behavior

The process known as "imprinting"is probably the most dramatic example of the capacity of images to control behavior because it determines the sexual development of an organism as it matures. Very early exposure to the "wrong" image can deprive an organism of the possibility of reproducing by natural means since courtship and copulatory behaviors are set on visual targets alien to the species of the imprinted organism. Parasitism provides another dramatic example of the power of images to prompt counter-adaptive behavior in species whose resources are channeled towards the reproductive advantage of another species. But these are only cases that owe their saliency to their apparent transgression of our Rousseauist ideology of fairness and goodness of nature. In fact, as the foremost specialist of vision Richard Gregory (2001:21) points out: "The knowledge we use when we see has come from millions of years of interacting with objects. [...] As knowledge is so important, tricks of camouflage and deceit became potent biological weapons". This remarks follows the observation that whereas the proximal senses of touch, taste and smell directly monitor the state of the environment, the 'distance'senses of vision and hearing provide only indirect knowledge on what matters and require interpretations and assumptions. "One cannot eat or be eaten by the optical images in eyes. Images are useless shadows until their significance is read [...] Perceptions are guesses -- predictive hypotheses -- of what may be out there". The evolutionary consequences of vision since the Cambrian biological explosion has been compellingly spelled out by Andrew Parker (2003).

It is indeed the images, not the actual incomplete and sporadic light information, which interface with the brain decision and motivational centers. The discovery of mirror neurons is relevant to our better understanding of the impact of images on behavior. These neurons fire both when a particular movement is perceived and when it is enacted (Gallese and Stamenov 2002) but they obviously interface not with the raw information that hits the retina but with the processed images. There is no doubt that these images are constrained to a degree by relational information but they remain at best educated guess. To which extent mirror neurons react to percepetual illusions does not seem to have been investigated yet. But even two-dimensional static images that have been artificially produce have the capacity of arousing emotions and triggering action in humans (Bouissac 1992) and animals. For instance, Cannicci et al. (reviewed by Lincoln 2002) have tested the snap judgements made by climbing crabs (*Sesarma leptosoma)* which must avoid encounters with another species of crabs (*Epixanthus dentatus*) that prey on them when they climb down the mangrove trunks to reach the swamp below. By varying the design of dummies, they have tested the pattern threshold of the visual cues that determine avoidance behavior and shown the effectiveness of a highly simplified design. Similar decision-making processes have been studied in hermit crabs (*Pagurus bernhardus*) in the context of motivational analysis (Elwood and Neil 1991). There is anecdotal evidence of a young cat reacting with a defence posture to the exposure to a large photograph of the face of a male tiger.

The effectiveness of images on human behavior can be easily observed and tested. The systematic use of images to control cognition and emotion, both intra- and interspecifically, seems to have emerged with *Homo sapiens*, although some image-based vital behaviors are deeply rooted in evolutionary time for all species that evolved pattern-sensitive vision. Many phenotypes have been image-driven by natural selection and hard-wired responses have co-evolved with these image arm races. The fear and flee responses in particular have been shown to be grounded in very ancient neuronal circuitry centered on the amygdala ( ). The same generic image may also interface with several functionally distinct brain areas. Images can trap the motivational and decisional centers into ambiguous patterns with catastrophic consequences. The classical examples provided by the psychology of visual perception, such as the purposefully designed rabbit / duck silhouette, does not convey the true risk involved in ambiguous perceptions because the two patterns in this classic example refer to two equally attractive prey. It is a matter of what we eat rather of whether we eat or are eaten. Camouflage in warfare gives a better measure of the vital urgency of solving ambiguous images.

Visual sexual signals are vital processes in many animals. The red swelling of female chimpanzees is an effective way of broadcasting reproductive availability in a species which relies on promiscuity for maximizing its fitness. Images play a no less prominent part in human reproduction. Seductive postures and appearances, either natural or contrived, erotic performances in private or public settings, pornographic images in print or electronic forms, offer a robust example of the power of images on human behavior (Bouissac forthcoming). Research is unfortunately lacking in this area because ethical restrictions and prejudices often interfere with the ability of securing research grants for projects investigating human sexuality unless they are construed as means towards improving fertility, curing pathologies or controling social behavior. Those who made empirical contributions to this domain remain somewhat stigmatized (e.g., Money and Baker) but the knowledge which has accrued so far is nevertheless important in showing the role of images and imaging in human reproduction.

Sociality is also largely regulated by images. Faces, postures, gestures, garments, implements and the like have been thoroughly investigated by cultural semiotics over the last five decades or so. But some more fundamental visual interactive patterns, such as the "leuco-signals", are still to be investigated, notably with the benefit of neuro-imaging. In these signals, the facial muscular contractions display a range of white patterns by varying the shape and degree of opening of the mouth and eyes, thus revealing or hiding the teeth and the sclera. The maximal light reflection produced by these white components of the human face makes them optically efficient at a distance and their various combinations determine the mode and degree of sociality they convey, with the behavioral consequences they imply (Bouissac 2001). The efficacy of these patterns is exploited in the making of artificial images, for instance in the Japanese hentai, for the purpose of controling emotional and sexual arousal. Such artistic and commercial uses of natural images, whose production totally escapes awareness during normal social interactions, can be conceived as a domestication process rather than the mere manipulation of an inert tool.

Images as agencies: exploiting the brain

It is usually taken for granted that images can be copied. However the handicraft of copying is not a simple, unproblematic process. This skill involves complex neuronal algorithms to transform a visual input into a motor output. The computation must be done on the level of representations and sort out the relevant information from a noisy background. Feedback and feedforward loops guide the motor output. Multimodal perceptual constraints necessary play a part in the artifactual production of images as it is indicated by the drawings made by the blinds (Kennedy). To explain successful copying behavior, it must be assumed that the constraints comes from the model itself which can therefore be described as a set of instructions concerning features and their mutual relationships. From a general point of view it could be said, of course, that all perceived images are a set of instructions in as much as they are categorized not in a purely cognitive framework but in a pragmatic one, with reference to basic survival value. Indeed, in natural conditions, only images of interest are perceived on a scale congruent with the evolved biological apparatus that must process visually relevant information. This is necessarily true of all organisms that have evolved eyes. However, it does not seem that any organism, except Homo sapiens, ever produces copies of the images it processes and perceives. It is as if, in the case of the human brain's visual interfaces, images would carry a supplementary instruction of the form: copy me, in addition to other normative functions.

Let us assume, heuristically, that this is the case, and raise the issue of how it could be so. Pursuing arguments of this sort may lead to blind alleys but might also identify pertinent questions and help formulate falsifiable hypotheses. It is generally considered that the crucial indicator of the emergence of symbolic behavior in anatomically modern humans is the artifactual production of images. It is at the same time taken for granted that this is a landmark progress toward art and consequently considered as a positive step in human evolution. The rock art literature is permeated with this self-serving argument which implies that humans are the apex of evolution. The ladder metaphor often vitiates evolutionary reasoning and obfuscates otherwise interesting evidence. Recent comparative research on imitation (e.g., Prinz and Meltzoff) suggests that the capacity for imitating coincides with the latest considerable relative enlargement of the brain of *Homo sapiens sapiens* that some palaeontologists now situate around three hundred years ago. However, there is some evidence that such an imitating capacity is double-edged and must be selectively inhibited if it is to be truly adaptive (Kinsbourne). Imitating is a behavior to which image copying must be intimately related. Obviously, it involves complex mediating processes which require the temporary activation of the neuronal substrates of images whose algoritms are virtually preserved in the visual memory circuitry of the brain, a requirement for the fast sorting out of visual information toward vital recognition and identification. But dysfunctions occur and optimality cannot be assumed. Intrusive or deceitful images can take over the brain mechanisms in cases of hallucinations, illusions, obsessions, miscategorisations, and other situations in which the visuo-motor system is driven toward ill-adaptive behaviors. In this sense, images appear to implement programs of their own that do not necessarily coincide with the organism's vital and reproductive programs but exploit them in a parasitic manner.

Memetics (e.g. Aunger 2000) provides a conceptual framework that may be appropriate to attempt to understand the power of images on human behavior. A biological system which largely depends on vision must have built-in resistance to such exploitation, but, at the same time, must be able to make fast decisions in the face of incomplete or ambiguous information, and thus opens the way to a degree of uncertainty. Indeed, a visual system makes generic assumptions in order to interpret visual data and must quickly weight probabilities (e.g., Freeman 1994) and take chances. The behavioral, cognitive and emotional odds are high but this is the best provisional solution evolution by natural selection could tinker.Unfortunately, there is as yet only scant neurobiological knowledge of how visual algorithms interface with motivational and emotional circuitries in the brain (e.g., Dolan 2002). However, it seems that it can be plausibly hypothesized that the complexity of these algorithms are windows of opportunity for noise, variations, interferences or intrusions by alien endogenic or exogenic algorithms.

Conclusion: a research agenda

It is important to make a distinction between declarative theory -- that is, the explicit propositions articulated by a researcher to describe the epistemological principles he or she claims to follow -- and tacit theory -- that is, the actual cognitive constraints and presuppositions which sustain research strategies. If reasoning is a skill, it is, like all skills, largely automatised. It requires only the awareness involving working memory. Gigerenzer and Selten (200 **)** explore the evolutionary constraints that bind cognitive strategies to the conditions of their emergence and development. But this does not amount to claim that human cogniton is powerless. Research keeps evolving. Models must be discarded at times when epistemological landscapes change and new syntheses are being attempted. A revision of visual semiotics as it stands now is in order. Its declarative and tacit theories must be examined. This branch of semiotics is indeed still based upon the philosophical speculations of C.S. Peirce, whose "empirical" examples can be traced back to Augustine and the Stoics. When semioticians do not use mere thought experiments, they rely in their arguments upon notions of visual perception that go back to the research of Gestalt psychologists and the work of J.J. Gibson. These achievements are now history.

References

Barinaga, Marcia (2002) Neurons turn a blind eye to eye movements. *Science*, vol. 295 (2347)

Chiu, Chiayu and Michael Weliky (2003) Synaptic modification by vision. *Science*, vol 300 (1890-1891)

Dolan, R.J. (2002) Emotion, cognition and behavior. *Science*, vol. 298 (1191-1194)

Elwood, R.W. And S.J. Neil (1991) *Assessments and Decisions: A Study of Information Gathering by Hermit Crabs*. London: Chapmen and Hall

Fortey, Richard and Brian Chatterton (2003) A devonian trilobite with an eyeshade. *Science,* vol. 301 (1689)

Freeman, William (1994) The generic viewpoint assumption in a framework for visual perception. *Nature*, vol. 368 (542-545)

Gazzaniga, Michael ( ) Cognitive Neurosciences. 2nd Edition. Boston: MIT Press

Gigerenzer, and Selten ( ). *Bounded Rationality*

Green, C. Shawn and Daphne Bavelier (2003) Action video game modifies visual selective attention. *Nature*, vol. 423 (534-537)

Gregory, Richard (2001) Perceptions of knowledge. *Nature*, vol. 410 (21).

Hoffman, Donald (1998) *Visual Intelligence: How We Create What We See*. New York: Norton

Land, Michael (2002) What is a naked retina good for? *Nature,* vol. 420 (30-31)

Le Grand, Richard, Catherine Mondloch, Dahne Maurer and Henry Brent (2001) Early visual experience and face processing. *Nature,* vol. 410 (890)

Lincoln, Tim (2002) Snap judgements. *Nature*, vol. 415 (748)

Marr, David (1982) *Vision: A Computational Investigation into the Human Representation and Processing of Visual Information*. New York: Freeman

Masland, Richard (2003) The retina's fancy tricks. *Nature,* vol. 423 (387-388)

Ötvecsky, Bence, Stepphen Baccus and Markus Meister (2003) Segregation of object and background motion in the retina. *Nature*, vol. 423 (401-407)

Parker, Andrew (2003) *In the Blink of an Eye: How Vision Sparked the Big Bang of Evolution*. New York: Basic Books

Pascalis, Olivier, Michelle de Haan and Charles Nelson (2002) Is face processing species-specific during the first year of life? *Science*, vol. 296 (1321-1323)

Pennisi, Elizabeth (2002) Evo-devo devotees eye ocular origins and more. *Science*, vol.296 (1010-1011)

Popper, Karl (1990) *A World of Propensities*. Bristol: Thoemmes Press

Purves, Dale and Beau Lotto (2002) *Why We See What We Do: An Empirical Theory of Vision*. New York: Sinauer

Sambles, Roy (2001) Armed for light sensing. *Nature*, vol. 412 (783)