Grey Matters: The Origami Brain: From Neural Folds to Neuroethics

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Starting from an uncut paper square and proceeding through a series of careful folds, origami master Brian Chan has fashioned a detailed replica of the human brain, which he displays on his website. Art imitates nature as tissue paper patterns the shape of living tissue. The fine wrinkles and fragile creases of Chan’s extraordinary model depict the brain’s intricate ordering and delicate construction.

Nature also imitates art. The development of the nervous system begins with a tiny layer of cells, and as they grow, they undergo an elaborate sequence of foldings that culminate in the structure of the brain. The resemblance to origami is evident as early as the beginning of the third week of human life. Like a crease in a piece of paper, a narrow groove known as the primitive streak appears on the surface of the embryonic ectoderm. Expanding toward the primitive streak, the lateral edges of the slipper-shaped neural plate gradually elevate to form the neural folds. By the fourth week the neural folds approach each other at the midline and fuse, rendering the neural tube. The narrow portion of the neural tube organizes into distinct layers of cells that form the spinal cord. The cephalic portion of the neural tube broadens, and its cusp—the cranial neuropore—undergoes closure, sealing off the dilatations that form the brain vesicles. A series of flexures in the brain vesicles demark the prosencephalon, mesencephalon, and rhombencephalon. With further growth, the prosencephalon bends sharply, dividing the telencephalon from the diencephalon. By the fifth week the telencephalon divides into two outpocketings that will form the cerebral hemispheres, whereas the diencephalon will form the
thalamus, hypothalamus, optic tracts, and posterior portion of the pituitary gland. A deep furrow divides the diencephalon from the mesencephalon, which will form the midbrain, and a fissure separates the mesencephalon from the rhombencephalon, which will form the pons, cerebellum, and medulla.\textsuperscript{2}

By seven months, the cerebral hemispheres are organized into the frontal, parietal, occipital, and temporal lobes, which are named according to the bones of the skull that overlie them. Several deep grooves outline the lobes of the brain. The medial longitudinal fissure divides the left and right cerebral hemispheres from one another. The lateral sulcus divides the frontal and parietal lobes from the temporal lobe, and the central sulcus divides the primary somatosensory cortex from the primary motor cortex.

In addition to prominent frontal lobes, a distinctive anatomical feature of the human brain in comparison to that of other animals is its highly convoluted cerebral cortex. The cerebral cortex consists of a sheet of neural tissue folded in such a way that its large surface area fits within the confined space of the cranium. Ripples of gyri and sulci shape a surface of undulating cortical folds. By adulthood, the cerebral hemispheres enfold 2500 cm\textsuperscript{2},\textsuperscript{3} which is 1.4 times the surface area of the front page of the \textit{Wall Street Journal}.\textsuperscript{4}

Myriads of paper folds would be needed to model the microscopic interior of the brain. Replicating the manifold twists and turns of 100 billion neurons sharing 160 trillion synapses would challenge the most nimble-fingered origamist. This level of structural intricacy, though impressive, is less remarkable than the brain’s functional capacity. From a folded sheet of neurons emerge such high-level cognitive faculties as perception, language, abstract reasoning, and creative expression. From this grey matter also comes the skill to guide hands to fold paper into precise geometric shapes that transform ideas into visual metaphors and delight the imagination.

Origami, the Japanese art of paper-folding, is about creating graceful paper sculptures in three dimensions. To fold a sheet of paper is to specify its shape by making a linear crease across its surface. Ethics is about drawing lines that distinguish the boundaries of acceptable and unacceptable conduct in the moral dimension. In Japanese culture, origami also symbolizes peace.\textsuperscript{5} Likewise, ethics is concerned with living in harmony with others. As Chesterton observed, ?Art, like morality, consists in drawing the line somewhere.? Insofar as origami and ethics both concern relationships that can be represented geometrically, the spatial language of origami may provide some insights for neuroethics.

Whence does neuroethics derive its moral folds? Are they prearranged by natural conditions that are part of an objective moral order, or are folds intentional and subject to the choice of the individual or group? Is the topography of morality more distinct than a crinkled sheet, the defining features of which are left to the imagination? For ethical contours to be meaningful, they must have consistency, coherence, and be subject to investigation and understanding. Creases must be consequential, and folds must express real character.
An origami theory of neuroethics would recognize in moral topography both given and chosen folds. Fixed ethical boundaries would be like the gridlike creases in a paper roadmap, which must be refolded along prespecified lines. As yet undecided ethical boundaries might be as open as a flat piece of blank tissue paper. In life, most ethical decisions will lie somewhere in between.

The possibilities for folding may be infinite, but they are not unbounded. Some folds are logically prohibited. For example, it is impossible with a single fold to divide a sheet of paper into three equal parts. Other folds are futile. Once a fold is made, the options for further folds are constrained to those that respect the geometry of existing folds. The organizing principles and existing folds in the realm of moral reality are critical to recognize. Just as efforts to fold contrary to the shape of things will degrade their form, decisions heedless of the contour of moral topography are ultimately harmful or ineffective.

Neuroscience provides a bottom-up approach toward discerning the topography of neuroethics. Progress in neuroscience consists of an unfolding of increasingly precise and detailed descriptions of the nervous system and its interactions. The reductionistic methodology of neuroscience, which examines the nature of complex systems by studying its parts, has proven extremely useful in elucidating how the brain works.

Within the last century, science brought biology within the fold of chemistry just as chemistry had been brought within the fold of physics. Neuroscience now enters the fold of the exact sciences, and, with it, psychology, philosophy, and spirituality, all of which are subject to increasingly detailed descriptions in terms of brain function. The neurobehavioral processes corresponding to perception, awareness, belief, emotion, empathy, the formation of moral sentiments, ethical reasoning, motivation, and decision-making all draw upon specific cortical circuits that can be localized through functional brain imaging techniques. These cortical circuits, which relate to uniquely human experiences and behaviors, consist of highly interconnected clusters of neurons exchanging information that is chemically encoded at the molecular level.

Technological convergence refers to the paradigm in which the distinctions that separate scientific disciplines break down, allowing for advances in one field to inform new ideas in others. The National Science Foundation report Converging Technologies outlined a vision for the unification of cognitive science with the other sciences. Its opening sentence reads: "We stand at the threshold of a new renaissance in science and technology, based on a comprehensive understanding of the structure and behavior of matter from the nanoscale up to the most complex system yet discovered, the human brain." One of the proposed NSF research programs would be a "Human Cognome Project to understand the nature of the human mind by means of natural mechanisms. In a similar vein, Francis Crick writes of "the scientific belief that our minds-the behavior of our brains-can be explained by the interactions of nerve cells (and other cells) and the molecules associated with them."

If Crick and others are correct that the human mind is fully reducible to the molecular behavior of the brain, then neuroethics also reduces to neurochemistry and morality to molecules. Michael Gazzaniga, for example, argues for a brain-based neuroethics, writing that he would like to support "the idea that there could be a universal set of biological responses to moral dilemmas, a sort of ethics, built into our brains." A complete theory of neuroethics could, in principle, be attained by mapping out the moral folds of the brain through technology that counts and
measures the blips that denote the behavior of grey matter.

The neurobiological case for moral realism may be reasonably criticized for violating the naturalistic fallacy in that it attempts to derive an ?ought? from an ?is? by defining values in terms of facts. William Casebeer, in pressing the case for a brain-based neuroethics, identifies the goal of showing ?that norms are natural and that they can arise from and are justified by purely natural processes.? If this can be done, he adds, then the naturalistic fallacy is not actually a fallacy (it merely amounts to saying that you don?t have a good naturalized ethical theory yet). This is not, of course, a scientific claim based on evidence but a wishful assertion based on the assumption that more facts will finally close the gap between categories that are indubitably irreconcilable.

Much can be affirmed about a brain-based theory of neuroethics. Because neuroscientific findings can be empirically tested, measured, and stated objectively, its conclusions in regard to ethics can be universally acknowledged. A brain-based neuroethics also recognizes all of humanity as belonging to a common moral community.

The aspiration to identify a brain-based neuroethics, however, fails to furnish a complete account of human nature. Though accurate, it cannot be the whole truth about the mind and its place in the moral universe. There are truths that are not empirically subjective. Such a theory lacks any external standard by which to judge a given behavioral phenomenon as good or evil. It would also seem to permit the option of using biotechnology to reengineer the brain into a posthuman entity by reshaping its moral folds in some artificial image.

As in any art form, paper folding has practical limits. Some simplification would be needed for an origami model of even a single cerebellar Purkinje neuron with its 200,000 finely arborizing dendritic fibers. Folding may also have philosophical limits. For example, does the architecture of the brain mathematically delimit boundaries to human knowledge? Within those boundaries, are there things that cannot not be known? Are there aspects to human dignity that, because they cannot be measured, cannot be manipulated? Outside those boundaries, what grand indecipherable thoughts might lie beyond human comprehension?

Folded paper always points beyond itself. Each fold is a finite line along a path whose direction extends infinitely. Where folds converge, they make a corner that also points beyond itself. An exquisitely folded work of origami implies the existence of one who conceived the figure and did the folding. Neuroethics relates richly to art and is firmly grounded in neuroscience. Neuroethics also points beyond itself to purpose and meaning in human life beyond description.

Recognizing in morality a transcendent source, Feinberg and Feinberg argue that certain acts are inherently right and others inherently wrong. They are so because they either reflect or do not reflect the character of the God who made the world and all in it. Whereas the origamist divides paper and the neuroscientist divides neurons, the Scriptures declare that God?s creative power is such that he divides light from darkness, waters from waters, and soul from spirit.

A brain-based neuroethics ultimately is a paper ethics, a morally thin construction that tears under stress and collapses under pressure. A genuinely human neuroethics, by contrast, rises beyond its stature and reflects a wisdom not entirely its own.

*Editor?s Note: The views expressed herein are Dr. Cheshire?s own and do not necessarily reflect the position of Mayo Clinic.* This article originally appeared in
ENDNOTES


3 Ibid.


7 M. Jeeves, From Cells to Souls and Beyond: Changing Portraits of Human Nature (Grand Rapids: Eerdmans, 2004).


10 Ibid.


17 *Isaiah* 55:8.


19 *Genesis* 1:4.


21 *Hebrews* 4:12.

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