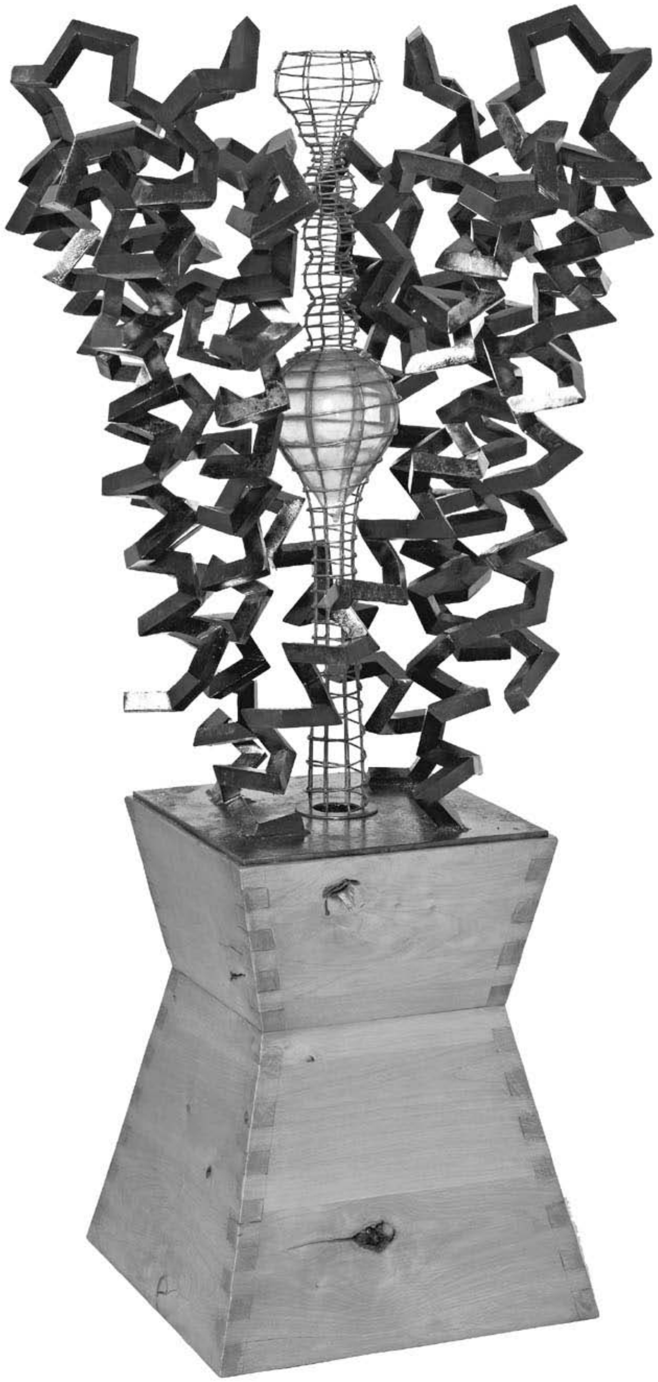

Article Frontispiece: *Birth of an Idea*, steel, glass, and wood, 60 x 32 x 32 in (150 x 80 x 80 cm), 2007. (<c> Julian Voss-Andreae. Photo: Dan Kvitka. Collection of Roderick MacKinnon, Rockefeller University, New York City, N.Y.) This sculpture, based on the structure of the *potassium channel protein*, was commissioned by Roderick MacKinnon, who won the 2003 Nobel Prize in Chemistry for his work on this structure. Ion channels function as our nervous system's smallest logical units, controlling the nerve cells' ability to fire. For a color image see the artist's website [1].

Unraveling Life's Building Blocks:

Novel Sculpture Inspired by Proteins

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Abstract

The foundation of life is explored through art. Inspired by life's molecular building blocks, the presented work recreates the emergence of three-dimensional bodies from one-dimensional DNA. Utilizing an algorithmic approach as his point of departure, the artist follows his vision freely, creating sculptures which bring life's isolated components emotionally back to life. In this sequel to an earlier *Leonardo* article, which covers the inception of his protein-inspired sculptures [2], the author presents the unfolding of his vision: Large-scale works of increasing formal and conceptual complexity display the emergence of an organic aesthetics from geometric elements and inspire a more holistic view of life than that provided by reductionist science alone.

Introduction

There are a number of common themes weaving through the fabric of my sculptural work. One such theme is the idea of the fundamental building block, the smallest unit that, upon assembly, displays an extraordinary transformation from geometric simplicity to organic complexity. Some of my recent work was inspired by quantum physics, the study of the building blocks of the physical world [3,4]. A large body of work, begun in 2001 after having switched careers from quantum physics to art, is concerned with the structure and conceptual potential of proteins, the molecular building blocks of all life forms. This article presents the evolution of this body of work. I will begin by giving a brief outline of my use of compound mitered cuts as a starting point for creating sculptures of proteins, and then present a chronologic selection of works. The article's final section places the work in the context of contemporary efforts that aim at expanding the current paradigm beyond the confines of scientific reductionism.

Proteins as Miter-Cut Objects

It is through proteins that life transitions from one-dimensional DNA, the molecular carrier of genetic information, to three-dimensional organisms. Proteins are chains of amino acids arranged in a specific sequence that is encoded in the DNA's sequence of base-pairs, the 'rungs' on the DNA 'ladder'. The structure of a protein is determined by its sequence of amino acids. Inherently still one-dimensional, the linear molecular chain folds up into a well-defined, compact shape with comparable height, width, and depth: a three-dimensional object. Functionally, the only twenty different amino acids are comparable to the letters of our alphabet, capable of making up thousands of different words. And just as well-arranged words can impart meaning and beauty, many proteins and other biomolecules together can form a living, sentient and even conscious being.

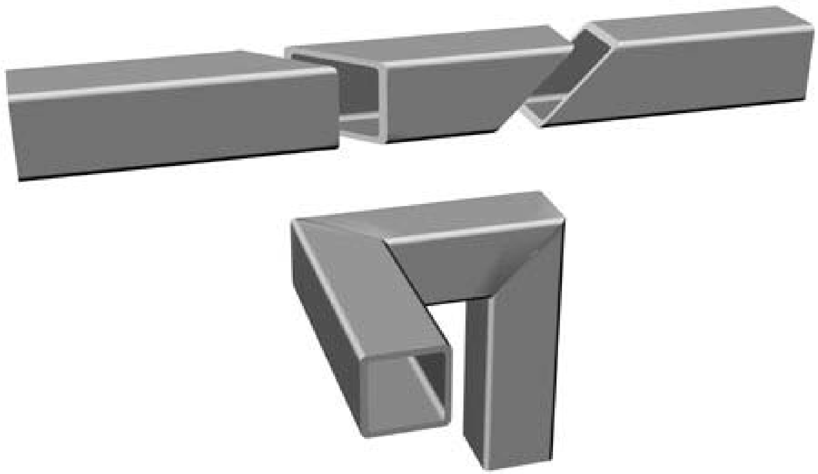

Fig. 1. The technique of mitered cuts. (<c> Julian Voss-Andreae) A one-dimensional piece of material is cut (top) and rearranged into a three-dimensional configuration (bottom).

The application of compound mitered cuts, rotation of every other part, and subsequent reconnection, is a natural way to create three-dimensional objects from the ubiquitous one-dimensional building materials, such as lumber or steel tubing (Fig. 1). Fascinated by the potential of this technique to recreate the emergence of our bodies' three-dimensionality, I set out to develop a method for creating protein sculptures using mitered cuts. I wrote a computer program that takes structural protein data, reduced to a sequence of points in space, and turns them into building instructions for a miter-cut sculpture (See Fig. 2). My process is to search for proteins that are aesthetically as well as conceptually intriguing and that have been resolved to atomic resolution. After downloading their structural data I run my algorithm to generate the cutting instructions that provide the starting point for my sculptures. The basic ideas and processes outlined here are described in detail elsewhere [5,6].

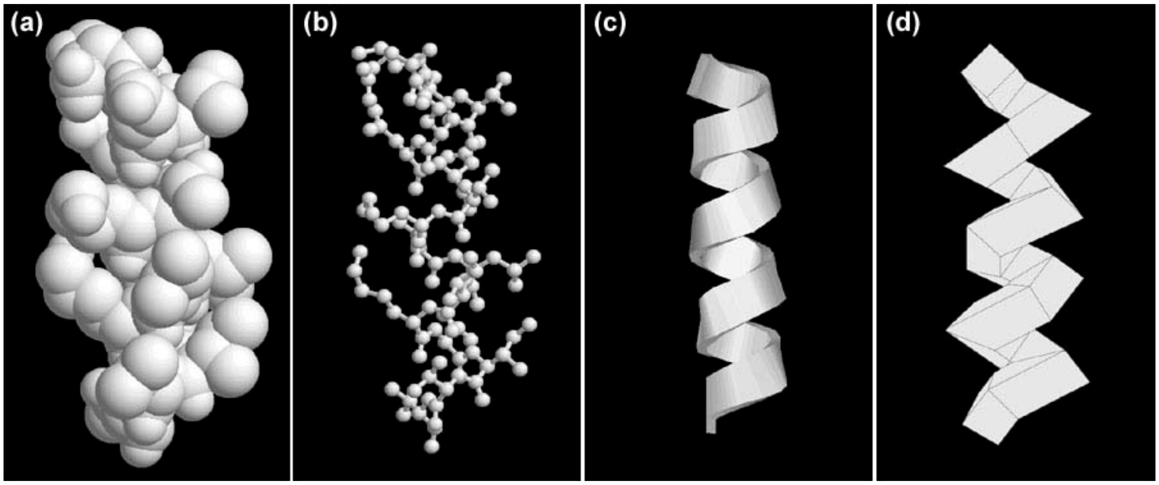

Fig. 2. The same protein depicted in four different ways. (<c> Julian Voss-Andreae) The panel shows a coiled amino acid sequence known as *alpha helix*, commonly found in many proteins. Panel (a) depicts the alpha helix as a 'space fill' model: All (non-hydrogen) atoms of the molecule are drawn as intersecting spheres. Panel (b), a 'ball and stick' model, has smaller atoms that are connected by rods indicating the chemical bonds. Panel (c), the 'ribbon' model, reduces the protein to its backbone which is depicted as a smoothened ribbon in space. Panel (d) shows the alpha helix as a miter-cut object, the technique used for the sculptures presented here. Instead of smoothing the backbone into a curve, each amino acid corresponds to a straight miter-cut piece. Compare this image to Color Plate 0 (d) for a photo of an actual sculpture created after the same computer model. Panels (a—c) were generated using the molecular graphics visualization software 'RasMol' [7] and panel (d) was generated using my own software.

Due to the inherent properties of the miter-cut representation, sculptures based on smaller proteins are reminiscent of the impersonal aesthetic language of modernist sculpture [8]. But as the number of amino acids increases to several hundreds or even thousands, an exciting transition takes place: The cold and crystalline feel of a small number of polyhedral faces gives way to something much ‘warmer’ and the more complex aesthetics of the organic world starts to emerge.

Sculptures

Light-Harvesting Complex

Plants and photobacteria (bacteria capable of photosynthesis) absorb the sunlight, thereby providing us and virtually all other creatures with the energy and low entropy we need to maintain life. Photobacteria possess a beautiful and well-understood photosynthetic apparatus embedded in their cell membranes. Instrumental to the initial absorption of the light is a structure known as the *light-harvesting complex*, an array of two concentric rings of protein spirals. The alpha helices, as the coiled protein segments are called (see Fig. 2), transverse the cell membrane and hold light-absorbing pigments in between the rings. Intrigued by both its structure and function, I created a sculpture based on the light-harvesting complex. Each of the two protein rings is made up of nine identical subunits, which I portrayed using ½-in-diameter (13 mm) wooden dowels. The whole complex consists of 850 amino acids, corresponding to the same number of one-inch (25 mm) long pieces of wood. Each protein subunit is anchored in position in a thick layer of transparent casting resin on a wooden disc. With a candle in its center, the sculpture is placed on the floor of a dimly lit room so that the structure casts moving shadows on the wall (See Fig. 3). The sculpture’s shadow evokes the image of plants moving in the wind. It seems as if the macroscopic plants of our world have become ephemeral shadows, while the microscopic, and ordinarily not perceivable basis for their existence, has become the tangible object [9,10,11].

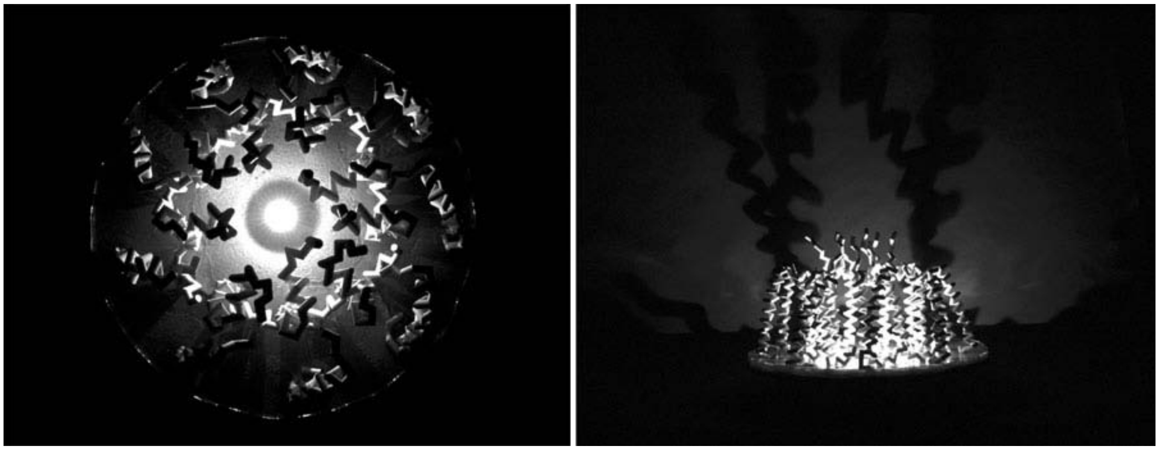

Fig. 3: *Light-Harvesting Complex*, wood, casting resin, and candle, 22 x 25 x 25 in (56 x 64 x 64 cm), 2003. (<c> Julian Voss-Andreae) The left panel is a top view showing the two concentric rings of alpha helical proteins. A candle placed in the center of the structure serves as the only light source. The right panel shows a side view with the helical structures casting moving shadows on the wall of the small chamber where the piece is displayed.

Alpha Helix for Linus Pauling

One of the first deeper insights into protein structure came through Linus Pauling's discovery of the alpha helix, an amino acid spiral that is a fundamental component of most proteins (see Fig. 2). Pauling (1901--1994) received the 1954 Nobel Prize in Chemistry in part for his discovery of the alpha helix and the 1962 Nobel Peace Prize for his fight against nuclear armament, making him the only person ever to win two unshared Nobel Prizes. I was commissioned to create a sculpture in celebration of Pauling's memory for his childhood home in Portland (Ore.), now the *Linus Pauling Center for Science, Peace, and Health*. Basing my design on the alpha helix structure, I rearranged a 20-ft (6.10 m) steel beam into a spiral of half the length and visually balanced it on one corner. I powder-coated the sculpture in primary red, complementary in color to the foliage of a large tree towering above the sculpture (See Color Plate 0 [d]). Reminiscent of an oversized LEGO block, the choice of color and surface finish emphasizes the tension between Nature, as represented by the tree, and man's concept of Nature, as represented by the alpha helix [12]. Other alpha helix-based sculptures I created include sculptures made from natural materials, including tree trunks [13] and timber bamboo (Fig. 4) [14].

Fig. 4: *Bamboo Alpha Helix* (detail), bamboo, hardwood and copper wire, length 4 ft (1.20 m), 2003. (<c> Julian Voss-Andreae. Collection of David P. Wessel, San Francisco, Calif.) The parts of the alpha helix sculpture were cut by using the natural segmentation of the bamboo to determine the length of each piece. The parts were then connected by winding copper wire around wooden pegs inserted into the bamboo.

Unraveling Collagen

Another helical structure of vital importance is found in collagen, our bodies' most abundant protein. Reminiscent of a rope, three amino acid spirals wind around each other to create a meta-spiral. Collagen provides our bodies mainly with structural support [15]. In a sculpture inspired by collagen I emphasized its structural function by reducing each of the sculpture's faces to a cross-braced outline to reveal the dominant force lines in a way that resembles utilitarian structures such as cranes or pylons, as well as many modern buildings and bridges. Custom-developed computer code allowed me to have each face individually laser-cut from stainless steel sheet. For aesthetic and conceptual reasons, I departed from the actual molecular structure by opening up the intertwining helices towards the top (See Fig. 5). This becomes a metaphor for aging [16,17]: It is the degradation of collagen that famously leads to the wrinkles that accompany aging. At the same time, the playful upwards movement of the sculpture imparts a sense of aging as growth, a journey toward completion, where 'unraveling' becomes 'unfolding'; the fulfillment from innate potential into reality.

Fig. 5. *Unraveling Collagen*, stainless steel, height 11 ft 3 in (3.40 m), 2005. (<c> Julian Voss-Andreae). Inspired by the most abundant protein in our bodies, *Unraveling Collagen* is based on the collagen structure. In contrast to the tightly coiled molecule, the sculpture's three strands unravel towards the top.

Heart of Steel

Hemoglobin, the oxygen carrying molecule that gives our blood its red color, is another protein essential to our existence. The color stems from hemoglobin's iron atoms that are key to capturing oxygen from the air and distributing it to our whole body. I created a sculpture based on the hemoglobin structure and alluded to the basis of our body's ability to breathe by letting a similar reaction occur on the artwork's surface: Initially sanded to a bright, silvery sheen, the steel sculpture started forming a reddish oxide layer soon after its unveiling at an outdoor gallery. As the sculpture's entire body became successively saturated with oxygen it acquired an increasingly deeper color [18,19] (Color Plate 0 [a—c]). The intricately shaped steel piece is complemented by a large, red glass sphere in its center, evoking the image of a drop of blood. The sculpture reacts sensitively to wind and touch, answering each push with an unexpected shiver, echoing the complex vibrational dynamics of large biomolecules [20].

Nanos

The small protein *microcin*, synthesized by a certain strand of the common gut bacterium *E. coli*, features a most unusual structure resembling a lasso whose tail folds over and enters the noose. It is this knotted structure that kills off other bacteria by interfering with its victim's protein synthesis machinery [21]. "Nanos", named after the Greek word for "dwarf", is a 6' (1.80 m) tall sculpture based on microcin's structure. In addition to referring to the nanoscale these molecules inhabit, the name hints at the anthropomorphic character of the sculpture with the noose on top evoking an oversized head (Fig. 6).

Fig. 6. *Nanos,* stainless steel, height 6 ft (1.80 m), 2006. (<c> Julian Voss-Andreae. Collection of Shari and Alan Newman, Lake Oswego, Ore.) While resembling an abstract modernist sculpture, *Nanos* is actually representational since its shape is based on the unusual structure of a small antibacterial protein.

Steel Jellyfish

My passion for proteins began with the *Green Fluorescent Protein* (GFP) [22,23], a beautiful molecule that enables a Pacific jellyfish to glow green in the dark of the ocean. GFP is one of the most widely used proteins in biological research because it is expressed readily in many organisms after being inserted into their genome, which makes it an ideal marker for other proteins of interest. I created the GFP-based sculpture pictured in Fig. 7 for the Friday Harbor Laboratories on San Juan Island (Wash.) where the molecule was discovered in 1962 by Osamu Shimomura, earning him the 2008 Nobel Prize in Chemistry [24].

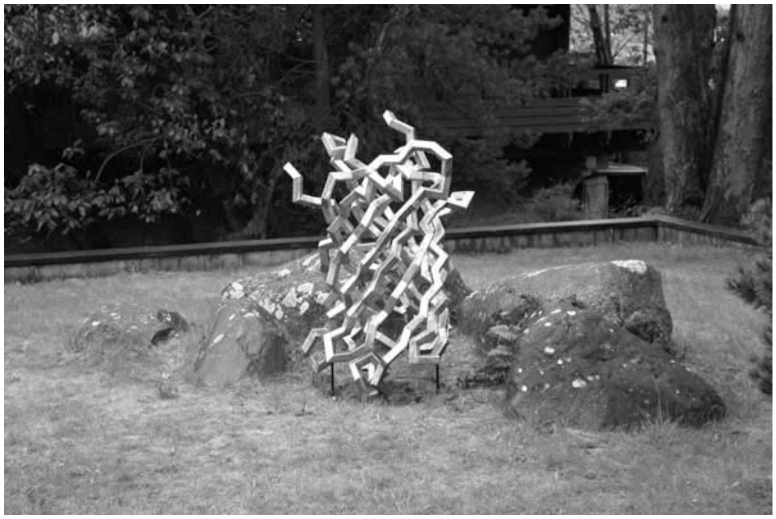

Fig. 7. *Steel Jellyfish*, stainless steel, height 55 in (1.40 m), 2006. (<c> Julian Voss-Andreae. Collection of the Friday Harbor Laboratories, San Juan Island, Wash.) A Pacific jellyfish's green glow originates within the *Green Fluorescent Protein's* beautiful, bird-cage-like structure. Isolated from hundreds of thousands of jellyfish collected at the Friday Harbor Laboratories, *Steel Jellyfish* celebrates the 1962 discovery of one of the most widely used proteins in biological research.

Birth of an Idea

In 2007 I completed a sculpture based on the structure of an *ion channel protein* for Roderick MacKinnon who received the 2003 Nobel Prize in Chemistry for his seminal work on such a molecule (see Article Frontispiece). Found in the nerve cells that make up our brain and its nervous connections to the rest of our body, ion channels control the passage of specific atoms through the nerve cells' membranes. Intimately connected to our intellectual and emotional responses to the world, this mechanism is at the very foundation of the living nerve cells' characteristic activity, the filtering and relaying of information through selective firing. When I was commissioned to create this sculpture, I was inspired by the ion channel's potential to symbolize the 'spark,' the small but all-important idea at the beginning of everything we do. Although we will probably never be able to point at one structure in our brain where that proverbial spark emerges, the ion channel provides a beautiful metaphor for it because it functions as the smallest logical unit in the vast network of our brain. Inspired by depictions of the potassium channel's interior [25], I created an object welded from steel wire to represent the pore's cavity. This pore object, lacquered in a translucent blue, resembles an 'isodensity plot' of the electron density [26], featuring bulges at the ions' fixed locations during their single-file passage through the protein. The largest bulge corresponds to the channel's main cavity where the ion's surrounding water molecules are stripped off to be replaced by specific protein atoms. The pore object contains a yellow blown glass bubble evocative of a rising balloon. The sculptural pedestal is fabricated from hand-planed, one-inch (2.5 cm) thick wooden boards connected by the ancient technique of finger joints, mirroring the fourfold rotational symmetry of the protein.

Angel of the West

When I was commissioned to create a sculpture based on the structure of our immune system's key molecule, the antibody, I noticed an interesting similarity between this molecule and the human body both in proportion and function: Shaped like a "Y", the antibody features a pair of identical protrusions resembling arms that are able to move due to a flexible region in the molecule's center. These 'arms' end in highly specific regions comparable to hands. The 'hands' hold on to an intruder, for example a virus particle, thereby tagging it for destruction through the immune system. In order to allude to the similarity between man's body and antibody, I designed the sculpture so that it subtly evokes a Renaissance icon deeply anchored in popular culture, Leonardo da Vinci's 1490 study of the human proportions, *Vitruvian Man*. When I superimposed the frontal view of the antibody's 1,336 amino acid structure as provided by Eduardo Padlan [27] onto the *Vitruvian Man*, I was struck by the fact that both images coincide perfectly (See Fig. 8). For my design I decided to utilize this powerful similarity and let the antibody molecule stand in place of Leonardo's man while turning the surrounding circle into a tapered ring. I then added thin rods under the arms radiating out from the position where the center of the head was located in the drawing (Fig. 9). This design element makes the image reminiscent of spiritual imagery with a set of rays emanating from a central source [28]. Together with the wing-shaped ‘arms’ the image is meant to be associated with an angel [29]: Our antibodies act like legions of tiny guardian angels, constantly protecting us from ill and disease. Their ability to bind very specifically to certain molecules is also the reason the antibody molecule has become an indispensable tool in biomedical research, crucial for understanding the machinery of life and therefore an appropriate symbol for the *Scripps Research Institute* that commissioned the sculpture as the signature piece for their new Florida campus (See Color Plate 0 [e]). I chose the name “Angel of the West” as a play off of Antony Gormley’s monumental sculpture “Angel of the North” (1998) in Gateshead, UK. The ‘West’ refers to the Western approach to healing through the tools of Western science. The fabrication of the sculpture resembles a gigantic three-dimensional puzzle with about 1,400 pieces, laser-cut from steel sheet of different thicknesses to fit the structural requirements [30].

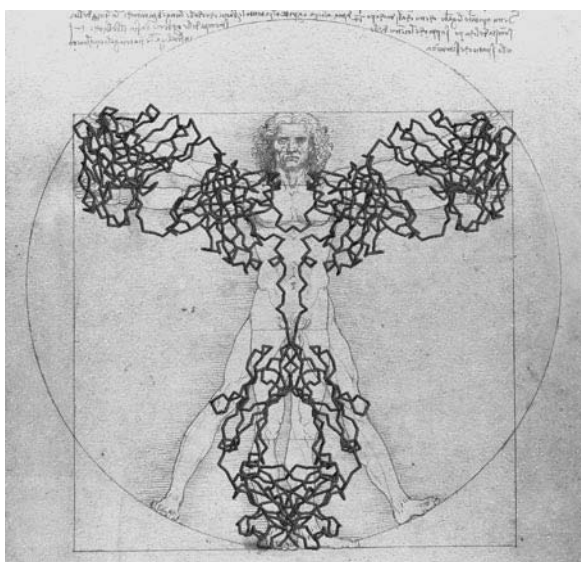

Fig. 8. *Antibody Structure Superimposed on Leonardo’s Vitruvian Man*, computer sketch of the idea for *Angel of the West*, 2006. (<c> 2006 Julian Voss-Andreae) Eduardo Padlan’s 1994 composite model of the antibody molecule was superimposed on Leonardo’s 1490 *Vitruvian Man*, revealing a striking resemblance between man’s body and his antibody in proportions as well as function.

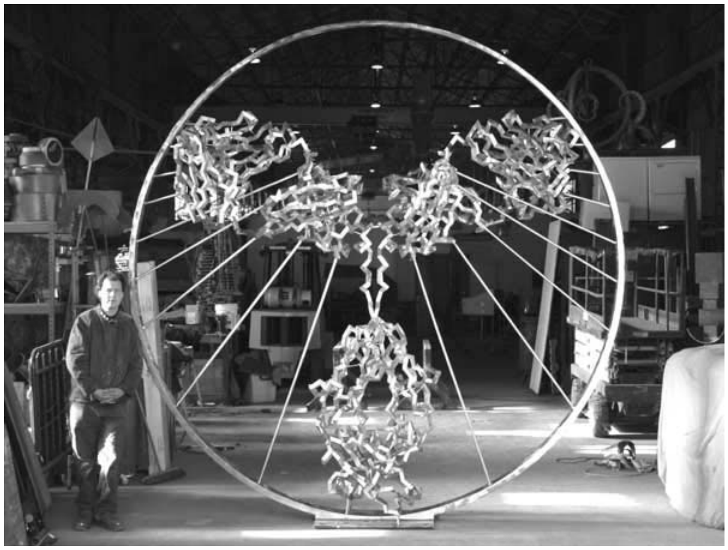

Fig. 9. *Angel of the West*, stainless steel, 12 x 12 x 4 ft (3.70 x 3.70 x 1.20 m), 2008. (<c> Julian Voss-Andreae. Photo: LeeAnn Gauthier.) Studio shot of the sculpture featuring a 10’ (3 m) tall antibody molecule surrounded by a 12’-diamter (3.70 m) ring. The sculpture is shown with the artist to give an illustration of the scale.

Color Plates 0 (a—c): ***Heart of Steel (Hemoglobin)*****, weathering steel and glass, height 5 ft (1.60 m), 2005. (<c> Julian Voss-Andreae) The images show a time-sequence of the sculpture's metamorphosis: Photo (a) was taken right after unveiling, (b) after 10 days, and (c) after several months of exposure to the elements. Plate (d).** ***Alpha Helix for Linus Pauling*****, powder-coated steel, height 10 ft (3 m), 2004. (<c> Julian Voss-Andreae. Collection of the** ***Linus Pauling Center for Science, Peace, and Health*****.) This memorial for Linus Pauling is located in front of Pauling's childhood home in**

Portland (Ore.). Plate (e). ***Angel of the West*****, stainless steel, 12 x 12 x 4 ft (3.70 x 3.70 x 1.20 m), 2008. (<c> Julian Voss-Andreae. Photo: Christopher Fay) Commissioned as the signature sculpture of** ***The Scripps Research Institute*****'s new campus in Jupiter (Fla.) this sculpture plays off the striking similarity between the human body and our immune system's key molecule, the antibody.**

Art and Scientific Reductionism

Despite our increasingly heavy reliance on science-derived technology, today only a minority of people recognizes science as a vital part of human culture or has experienced a feeling of wonder from a scientific observation in the same way as they would from, say, a beautiful sunset. After an era of relative faith in science, culminating post-World War II, the public's attitude toward the natural sciences shifted around 1970 [31]. My generation, born during that time, grew up with a new sense of mistrust that was triggered by the growing suspicion that the reductionist approach inherent in science and technology, and its profound effects on our lifestyle, could not be separated from the global environmental and spiritual crisis that became increasingly apparent then. Scientific reductionism, the assumption that complex systems can be completely understood through an understanding of their components, is deeply ingrained in the very structure of the natural sciences and has been an extraordinarily successful guiding principle since the Age of Enlightenment [32]. Art, by contrast, is non-reductionist in its very nature: The profound effect a great work of art can have on the viewer cannot be understood by adding the effects the separated parts of the work would have. Nor can art's impact be reduced to intellectual knowledge of specific interpretations of it. True appreciation of art seems impossible in a frame of mind that clings to the object-subject dichotomy that has become so deeply entrenched in Western thinking for the last centuries. According to Einstein, in art "we show [what we behold and experience] in forms whose interrelationships are not accessible to our conscious thought but are intuitively recognized as meaningful" [33]. The presented works take the notion of artistic counterreductionism to another level: Departing from a mere structural representation of proteins, the exemplary specimens of reductionist biology, these works take living beings' components, typically considered inanimate [34], and bring them metaphorically back to life. This way these sculptures, born from scientific data, are capable of imparting an artistic experience of life that is complementary to the conceptual understanding provided by reductionist science alone.

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30 The creation and installation of the "Angel of the West" was covered by Oregon Public Broadcasting Television's art series "Oregon Art Beat": V. Patton (producer), "Quantum Sculptures with Julian Voss-Andreae," Oregon Art Beat Oregon Public Broadcasting Television (December 18, 2008) <http://www.youtube.com/watch?v=LqsQYVFAgPo>.
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34 When we cut an organism into parts small enough to be handled intellectually, we lose its essential property of being alive, both literally and emotionally. Perceiving the parts of a living being as inanimate often lets us wrongly assume that the 'aliveness' of the whole being is just an illusion. Maybe the opposite is true: Because the whole is alive, all its parts are in the same sense alive and should therefore be worthy of the same emotional attachment.