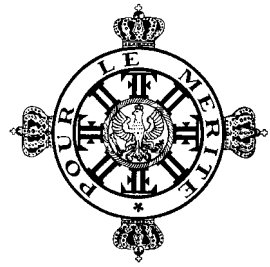
POUR LE MERITE

VORTRÄGE

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THE AGE OF INSIGHT

The central challenge of science in the twenty-first century is to understand the human mind in biological terms. The possibility of meeting that challenge opened up in the late twentieth century, when cognitive psychology, the science of mind, merged with neuroscience, the science of the brain. The result was a new biological science of mind that has allowed us to address a range of questions about ourselves: How do we perceive, learn, and remember? What is the nature of emotion, empathy, thought, and consciousness? What are the limits of free will?

This new biological science of mind is important not only because it provides a deeper understanding of what makes us who we are, but also because it makes possible a meaningful series of dialogues between brain science and other areas of knowledge. Such dialogues could help us explore the mechanisms in the brain that make perception and creativity possible. In a larger sense, this dialogue could open up a new dimension in intellectual history and help make science part of our common cultural experience.

I would like to take up this scientific challenge today by focusing on how the new biological science of mind has begun to engage with

figurative art. In my life as a scientist, I have taken a reductionist approach. I explore a large problem that interests me – in my case this is memory – by initially focusing on its simplest example, and trying to explore it deeply. I have also done this, *here*. I purposely will limit my discussion to one particular form of figurative art – portraiture – and to one particular cultural period – modernism in Vienna at the beginning of the twentieth century. I do this not only to focus the discussion on a central set of issues but also because both this art form and this period are characterized by a series of pioneering attempts to gain new insights into the human mind, and – in so doing – to link art and science.

I focus on Portraiture because it is a highly suitable art form for scientific exploration. In part because of work at Rockefeller, we now have the beginnings of an intellectually satisfying understanding – in both cognitive psychological and biological terms – of how we respond perceptually, emotionally, and empathically to the facial expressions and bodily postures of others. Modernist portraiture in »Vienna 1900« is particularly suitable because the artists' concern with the truth lying beneath surface appearances was paralleled and influenced by similar, contemporaneous concerns with unconscious mental processes in scientific medicine, psychoanalysis, and literature. Thus, the portraits of the Viennese modernists, with their conscious and dramatic attempts to depict their subjects' inner feelings, represent an ideal example of how psychological and biological insights can enrich our relationship to art.

I focus on the Viennese modernists because they are appropriate for this analysis in other ways as well. To begin with, they can be explored in depth because there are so few of them – only three major artists, Klimt, Kokoschka and Schiele – yet they are important in the history of art both collectively and individually. As a group, they sought to depict the unconscious, instinctual strivings of the people in their portraits and drawings, yet each artist developed a distinctive way of using facial expressions and hand and body gestures to communicate his insights. In doing so, each artist made independent conceptual and technical contributions to modern art.

Let me begin by putting Viennese Modernism into a bit of perspective for you:

Modernism in Vienna, in fact Modernism in general, has its roots in the middle of the nineteenth century as a response not only to the restrictions and hypocrisies of everyday life, especially in relation to women, but also as a reaction to the Enlightenment's emphasis on the rationality of human behavior. The Enlightenment, or Age of Reason, was characterized by the idea that all is well with the world because human action is governed by reason. It is through reason that we achieve enlightenment, because our mind can exert control over our emotions and feelings.

The immediate catalyst for the emergence of the Enlightenment in the eighteenth century was the scientific revolution of the sixteenth and seventeenth centuries, which included three momentous discoveries in astronomy: Johannes Kepler delineated the rules that govern the movement of the planets, Galileo Galilei placed the sun at the center of the universe, and Isaac Newton discovered the force of gravity, invented calculus (Gottfried Wilhelm Leibniz independently discovered it at the same time), and used it to describe the three laws of motion. In so doing, Newton joined physics and astronomy and illustrated that even the deepest truths in the universe could be revealed by the methods of science.

These contributions were celebrated in 1660 with the formation of the first scientific society in the world: The Royal Society of London for Improving Natural Knowledge, which elected Isaac Newton as its president in 1703. The founders of The Royal Society thought of God as a mathematician who had designed the universe to function according to logical and mathematical principles. The role of the scientist – the natural philosopher – was to employ the scientific method to discover the physical principles underlying the universe and thereby decipher the codebook that God had used in creating the cosmos.

Success in the realm of science led eighteenth-century thinkers to assume that other aspects of human action, including political behavior, creativity, and art could be improved by the application of

reason, leading ultimately to an improved society and better conditions for all humankind. This confidence in reason and science affected all aspects of political and social life in Europe and soon spread to the North American colonies. There, the Enlightenment ideas that society can be improved through reason and that rational people have a natural right to the pursuit of happiness are thought to have contributed to the Jeffersonian democracy that we enjoy today in the United States.

The Modernist reaction to the Enlightenment came as an aftermath of the Industrial Revolution and took the form of a search for a new world view that was more consistent with the modern world.

As astronomy and physics inspired the Enlightenment, biology inspired Modernism. Darwin's 1859 book *On the Origin of Species* introduced the modern idea that all of animal life is related. Humans were not created uniquely by an all-powerful God but were biological beings that evolved from simpler animal ancestors.

In his later books, *The Descent of Man* and *Selection in Relation to Sex*, and again in *On the Origins of Species by Means of Natural Selection,* Darwin discusses the role of sexual selection in evolution. He argues that sex is central to human behavior because the primary biological function of any organism – be it plant or animal – is to reproduce itself. As a result, sexual attraction and mate selection are critical in evolution. In natural selection, males compete with each other for females, and females choose some males rather than others. These ideas find expression in Freud's emphasis on the sexual instincts as the driving force of the unconscious and on the central role of sexuality in human behavior.

Darwin held that since people evolved from simpler animals, people must have the same instinctual behaviors evident in other animals, not only sex but also eating and drinking. Freud saw in Darwin's concept of instinctual behavior a way of explaining much of innate human behavior. Finally, Freud's pleasure principle – the hedonistic seeking of pleasure and avoidance of pain – was outlined by Darwin in his last great book, *The Expression of the Emotions in Man and Animals*, published in 1872. In that book Darwin points out that

emotions are part of a primitive, virtually universal approach-avoidance system designed to seek out pleasure and decrease exposure to pain. This system exists across cultures and is conserved through evolution. Thus Freud – often referred to as the Darwin of the Mind – extended Darwin's revolutionary ideas about natural selection, instincts, and emotions to his own ideas about the unconscious mind.

Modernism had roots in Germany, Italy, France, as well as in the Austria-Hungary Empire. But during the period 1890 to 1918, Vienna emerged as the leading center of Modernist thought and culture. The Viennese Modernists confronted conventional attitudes and values with new ways of thought and feeling, *and they questioned what constitutes reality, what lies below the surface appearances of people, objects, and events.*

By going below the surface of appearances, Modernism in Vienna assumed three main characteristics:

1. A new view of the human as not truly rational, but driven by unconscious sexual and aggressive drives;
2. Self-examination as the first step in setting the rules that govern the human;
3. The attempt to integrate and unify knowledge – an attempt that is driven by science.

I will interweave in my talk three intellectually and chronologically distinct themes originating in Vienna 1900. The first theme, which centers on Vienna 1900, is the independent discovery of different aspects of unconscious emotion by a physician and psychologist (Freud), a physician and novelist (Schnitzler), and three Viennese Modernist painters (Klimt, Kokoschka, and Schiele). I trace those independent discoveries to a common source: the Vienna School of Medicine, particularly the teachings of Karl von Rokitansky, its intellectual and scientific leader. I will try to make the argument that the Vienna School of Medicine was one of the driving forces influencing the emergence of Austrian Expressionism.

The dramatic efforts of Freud, Schnitzler, and the Austrian Expressionists to explore the unconscious emotional life leads to my second

theme: the efforts first of Alois Riegl, and subsequently Ernst Kris and Ernst Gombrich of the Vienna School of Art History, in their attempts in the 1930s to construct a bridge between art and science. Riegl focused on psychology and argued that art, in particular modern art, invites the viewer's participation. The Beholder's share is essential to the completion of the picture.

The cognitive psychological insights into the viewer's response to Expressionist art leads to the third theme of my talk: The Biology of the Beholder's Share. The emergence in the last decades of the 20th century and the first decade of the 21st century of a beginning biology of perception, emotion, and empathy opened up this approach. This advance began in the 1950s and continues to this day in the new discipline of neuroaesthetics. Pioneering work in the science of vision was carried out by Stephen Kuffler, a contemporary of Gombrich and Kris in Vienna, who also trained at the Vienna School of Medicine in the 1930s.

Let me begin with Viennese Medicine and its contribution to Viennese Modernism. The Medical Faculty of the University of Vienna was founded in 1745 by Queen Maria Theresa who recruited to Vienna the great Dutch physician Gerhardt van Swieten. Van Swieten began the transformation of Viennese medicine from therapeutic quackery to scientific medicine. Over the next century, Viennese medicine gradually achieved this goal so that by 1840 it had acquired such international prominence that Rudolf Virchow called it the »Mecca of Medicine.« The Vienna School of Medicine achieved this renown by creating a scientific basis for medicine.

Vienna introduced into clinical medicine the idea of clinical-pathological correlations. As a result, the Vienna School of Medicine was the first to use the insights of pathology to develop a rational and objective method of diagnosis. Key to this development was the collaboration at the Vienna General Hospital (Das Allgemeine Wiener Krankenhaus) between the great pathologist, Carl von Rokitansky (1804-1878) and his clinician colleague Joseph Skoda (1805-1881). Das Allgemeine Krankenhaus offered a unique opportunity for this collaboration. Contrary to other hospitals in Europe, such as those in

Paris, where each clinician did his own pathology, in Vienna all the patients who died went to the head pathologist, Rokitansky.
Rokitansky, who became professor at the University of Vienna in 1844, argued that before one can treat, one must have an accurate diagnosis of the disease. This cannot be achieved by merely examining the patient at the bedside and evaluating the signs and symptoms, since the same symptoms and signs could be produced by very different illnesses. One needed, Rokitansky argued, to go deeper, below the skin, and examine the diseased organs directly. One needed to understand the biological substratum of the disease. Rokitansky therefore insisted that every patient who died in the Wiener Allgemeine Krankenhaus be studied at autopsy and that the result of these studies be correlated with the pre-existing clinical picture obtained on the same patient, often by Joseph Skoda.
Rokitansky performed about 30,000 autopsies! With this wealth of material, Rokitansky focused his research program on two issues:

> »First, sorting the facts scientifically on a purely anatomical basis and thereby creating the subject of general pathological anatomy which would justify its separate existence as such …«

> »Second, demonstrating the applicability of the facts and their utilization for diagnosis in live patients …«

By emphasizing that biological understanding must precede treatment, Rokitansky and the Faculty of Medicine of the University of Vienna stimulated the flowering of biological research in the service of clinical care which has characterized modern academic medicine. Vienna advocated the seminal ideas that serve as the catechism of modern scientific medicine: that research and clinical practice are inseparable and inspire one another, that the patient is an experiment of nature; the bedside, the doctor's laboratory; and that the teaching hospital of the University is nature's school.
Sigmund Freud attended The University of Vienna School during the last years of Rokitansky's tenure. Freud became a thoroughly

trained neuroanatomist who worked with the neuroanatomist Meynert and with the physiologist Brüke. Freud, influenced by Breuer, carried the analysis of mental processes one step further by pointing out that in mental illness as in other diseases, one must follow Rokitansky's principle: To understand the symptoms of a mental illness, one must go below the symptoms, below the skin, so to speak, to reach the underlying unconscious conflicts that cause the disease. In addition to introducing the modern concept of the unconscious, Freud also introduced two other themes that are relevant to this discussion:

1. That human psychological functioning is driven by the interactions of two dominant instincts: Eros, the life instinct, and Thanatos, the death instinct – love and aggression; hope and despair.
2. Freud traced adult character and adult neurosis to earlier stages of mental development. In so doing, he drew attention to the mind of the child, in which he discovered both infantile sexuality and infantile aggression. He found that the child's fantasy life is not empty but rich, neither is it completely virtuous, but rather it is filled with the sexual tensions and aggressions evident around him or her.

I would argue that Austrian Expressionist art represents an extension of the intellectual concerns about the search for deeper meaning, a truth that lies below the surface, an idea first introduced into medicine by Rokitansky and elaborated by Freud. However, Austrian Expressionism emerged from the idea that to develop modern art in Vienna, one needed to penetrate the Victorian veneer of middle-class Viennese life, particularly their restrictive and hypocritical attitude toward their mental life, their attitudes toward sex and aggression, and toward women and their sensuality.

To give but a few examples of their attitude toward women, a law passed in 1867 explicitly prohibited women from engaging in any political activity. As a result, middle-class women were largely unprepared to take up their own cause. In polite Viennese society of 1900, women were severely restricted. Their reading was censored, their outings were supervised, and an environment was created

through lessons in piano, drawing, and foreign languages to divert them from erotic thoughts. They were supposed to be well-bred, unsuspecting, to be shaped and led in marriage by their husbands without a will of their own.
Gustav Klimt (1862-1918), who founded the modern school of Viennese painting in 1900, referred to as the »painter of the unconscious,« exposed women's lives and their stirrings. His students Kokoschka and Schiele carried this experiment even further. It should therefore come as no surprise that the work of the Viennese school is preoccupied with issues that were denied by Viennese middle class society, issues concerned with sex, aggression, and death.
Klimt is extremely important for three reasons: 1) He is one of the founders of Viennese modernism; 2) He is a key transitional figure between the decorative lines of art nouveau (Jugendstil) and the explosive lines of Expressionism; and 3) He was the first Austrian artist to have an international impact. Until the beginning of the 20th century, Austria had never produced painters of the stature of its composers.
Klimt made five key innovations in painting:

First, he helped become a great liberator of women's sensuality. In an endless stream of drawings, Klimt tried to capture the feeling of femaleness. One way was the flowing hair to mediate the sinuous body. In his exploration of the erotic, Klimt banishes the moral sense of sin that had plagued his father's generation, and in its place substitutes a fear of sex that has haunted many people – many of the men of his generation.

Gustav Klimt: Semi-Nude (1913); Reclining Semi-Nude (1914)

Second, he recognized that the liberation of sensuality carries with it an anxiety about death. In Klimt's painting, *Judith*, is one of the major works of Viennese Jugendstil and a fine example of his erotic art. Here Klimt introduces the themes of aggression and castration, in

this case disguised as decapitation. Judith, fresh from killing Holofernes in a love slaying, glows in her voluptuousness.
Here is a young, extravagantly made-up woman, her semi-nudity handled with great sophistication, placed frontally to the viewer whom she seems to regard sensually through her half-opened eyes. She is absentmindedly stroking the head of a man who appears in the lower part of the picture. Although the title identifies the figures as the Jewish heroine Judith and her people's nemesis Holofernes, this dangerous beauty – this giant-killer – is portrayed in the same way as are the elegant ladies of the contemporary Viennese upper class that Klimt painted and bedded. In fact, though the picture's subject is biblical, its execution in dress and depiction is clearly contemporary. Her jewelry is archaic in style but obviously of modern production, while the dress recalls the fine materials that were the hallmark of the Vienna Wiener Werkstätte.
Judith is a true femme fatale. She evokes both lust and fear. Nevertheless, the murder of Holofernes could hardly be presented in a more sublime form. We understand why Holofernes fell for her. Moreover, even after the beheading, there is no trace in the picture of blood or violence. Although she is a murderess, Judith's is a symbolic murder only.
Klimt here discloses the psychological problem, which accompanies the attempt to liberate sexuality and the constraints of a moralistic culture. *The new freedom was turning into a nightmare of anxiety.*
Klimt grappled with this philosophical theme for 20 years as evident in *Life and Death.* A mass of humanity – life's force – is grouped on the right opposed to the dominating solitary figure of death on the left. The awareness of death is integrated into life, with separate color zones. Death wraps himself in the colors of night, while the human bodies expressing life and love display a rich diversity of colorful gay ornaments. *(In Life and Death: The Life Force (Eros) and the Force of Death (Thanatos))*

Third, Klimt introduced a new level of ornamentation into painting, an ornamentation derived from Jugendstil in the Wiener Werkstätte

also evident in the work of Otto Wagner. *His paintings therefore conveyed the aesthetic atmosphere of a daydream undisturbed by any recourse to reality.*

Fourth, the son of a goldsmith, Klimt applied his father's trades to creating gold laden canvasses whose decorative motifs evoked the entire history of art. His lavish application of gold leaf anticipated the collage. To facilitate his work he visited Ravenna in Italy and viewed the mosaics of San Vitale and began to paint in a Byzantine manner. This introduced the golden period where Klimt turned to gold and metallic colors and forms.

The apex of Klimt's golden style is evident in *The Kiss*. This is probably the most popular of Klimt's paintings and it escalates the intensity of the sensuous effect by expanding the symbolic at the expense of the realistic aspects of the painting.

In *The Kiss*, the flesh is covered yet the sensuous effect is heightened by the line of the caressing gesture. In the clothing as in the flowery base near the lovers, the ornamental elements also serve as symbols. The drapery of both male and female stands distinguished by its ornamental design. The single rectangle that Klimt had used in his painting of *Danae* as a phallic symbol is proliferated in The Kiss on the male's cloak while the woman's dress is alive with symbols that run ovular and floral. The two defined fields of sexual symbols are brought into a union of opposites by the vibrant cloth of gold that is their common ground. Having passed through an art of movement and literary illusions to one of static abstraction, Klimt has in *The Kiss* adopted an indirect statement to portray once again a strong if not more harmonious erotic feeling.

With time, Klimt replaced the angelic sweet feminine types of his earlier pictures with women as sensual creatures developing their full potential for pleasure and pain, life and death. He now focused on becoming a psychological painter of women.

To summarize, Klimt was the first of the Austrian expressionists to raise the idea that there exists a female sexuality and a female sexual appetite to parallel that of men. Using a variety of stylistic devices,

he exposed an erotic depth existing beneath the veneer of the Viennese middle class. However, his exposure is incomplete. Klimt's figures inhabit a sensual daydream. They bear little relation to reality. He depicts, as Kokoschka would later say, society ladies trifling with sexuality. His women seem detached, as in the painting of *Judith*. They are Jugendstil, not Expressionist. They do not go below the skin. Klimt beautifies the world, rather than exposing it. The critic Karl Kraus would emphasize that art can only come out of protest, out of a cry, not out of lulling. Kraus and the architect Loos imposed upon art the responsibility to be absolutely truthful and both denounced work like Klimt's as reflecting a corrupt society trying to cover up its evil behind ornamentation and culture.

Finally, Klimt became involved with the Vienna School of Medicine and introduced their biological thinking into his art.
Similarly, Klimt incorporated biological symbols into his painting of Zeus coming to *Danaë*. Here, the artist transforms the shower of golden raindrops, symbolizing Zeus's sperm, on the left side of the canvas into early embryonic forms, symbolizing conception, on the right side.
Berta Zuckerkandl recognized the influence of contemporary science on Klimt's work. She wrote that the artist profiled »the endless ceasing and becoming,« to which Braun adds the phrase, »deep beneath the surface of things.« »Klimt's evolutionary narrative,« Braun continues, »places him in the fluid post-Darwinian, pre-Freudian cultural matrix.« Berta describes in her *Autobiography* how Klimt's interest in biology emerged from her husband's exciting lectures.

Oskar Kokoschka (1886-1980) was the first to move Austrian art from Art Nouveau towards Expressionism. In addition to being a great painter, Kokoschka was also a dramatist. Indeed, he is the actual founder of Expressionist drama.
Like many other German and Austrian painters who were to develop in the direction of Expressionism, Kokoschka's background was in applied arts. Kokoschka was born in 1886 in Pöchlarn, a small

town on the Danube about 100 kilometers west of Vienna. Young Kokoschka threw Vienna into turmoil in 1909-10 when he created a series of portraits of Viennese intellectuals that were flagrant violations of contemporary tastes for the flattering Klimtian lines of art nouveau and the elegance of Klimt's portraits of women. These early Kokoschka portraits are central not only to Austrian Expressionism but to Expressionism generally.

Kokoschka concentrated less on giving a literal record of his sitters as Velázquez, for example, had done, and instead portrayed their psychological traits, their mood and the feel of his subject. Kokoschka would write that his objective in portrait painting was »to intuit from the face, from its play of expressions and through gestures, the truth about a particular person and to recreate in my own pictorial language the distillation of a living being.« Kokoschka sometimes remarked that what he most wanted to paint were nervously disordered portraits, »a portrait of nerves out of control.« This style allowed Kokoschka to capture the inner character rather than the outward appearance. Indeed, his work is marked by broken colors and forms, which sometimes show actual nerves on the exterior of the sitter's face.

In this way Kokoschka attempted to depict the inner world – the neurotic aspects – of his subjects. Much as Rokitansky wanted to go below the skin and Freud thought of consciousness as only the surface of the mental apparatus, the aim of Kokoschka, like that of psychoanalysis, was to strip away the deceptive external façade layer by layer to reveal a piece of the mind's unconscious conflicts beneath. He brings out the reflection of a man's character dynamically in his face, especially in his eyes, face, and hands, which between them, sometimes as in the case of Rudolf Blümner, convey sheer terror.

Kokoschka claimed in his *Autobiography* that he had discovered the importance of unconscious motivation at the same time and independently of Freud.

Kokoschka was described as having x-ray eyes because of his ability to penetrate the intellect and feelings of his models. Kokoschka described himself as a psychological tin can opener. He would use a

variety of methods to encourage the sitter to move, talk, read or become absorbed in his or her thoughts, unconscious of the artist's presence, before he would start work. Most of the early portraits are half-length, usually stopping just below the hands, upon which Kokoschka placed a great deal of emphasis.

To achieve these insights into personality, Kokoschka developed three main ideas:

1. that self-portraits are the best way to learn about the psyche;
2. that body gesture, especially hand positions, can be used to communicate inner feelings; and
3. that the inner feelings are often informed by sexuality or aggression, and that these strivings are not restricted to the mature psyche but are even evident in the inner life of the child.

Let me take each of these points in turn:

First, Kokoschka developed the idea that came independently to Freud (and earlier to Rembrandt), that self-analysis must precede the analysis of others.

This is the way Kokoschka looked in 1909. As a reaction to Vienna's shocked response to his portraits in 1909, Kokoschka shaved off his hair to acknowledge that he recognized himself as a troublemaker at the margin of society.

In his famous *Self-Portrait* of 1910 created for the magazine *Der Sturm*, Kokoschka analyzed his own personality as penetratingly and as mercilessly as Freud had analyzed himself. Kokoschka turns himself into a cross between a criminal (shaved head, powerful jaws) and a saint from Christian iconography. He is anxious, almost terrified and this anxiety is heightened by streaks of dark green in the background converging upon him. The tumultuous affair with Alma Mahler, a much more mature and experienced woman, began in 1912 and ended in 1915, dominating his early life. Kokoschka met Mahler on April 12, 1912, 11 months after the death of Gustav Mahler. Three days later the much younger Kokoschka (he was 26, she was 33) proposed to her in a passionate letter and they started their stormy relationship. When it ended with Alma Mahler leaving him for the architect Walter Gropius, Kokoschka expressed his sor-

row in a series of portraits and allegorical reenactments of the relationship.

We see this prescience in two remarkable portraits from this period: that of Ludwig Ritter von Janikowski and that of Auguste Forel.

Ludwig Ritter von Janikowski, a literary scholar and friend of Kraus, is depicted as descending into psychosis, which he did shortly after the portrait was completed. Kokoschka portrays this mental state by focusing on Janikowski's head and painting it as if it were in motion, slipping out of the bottom of the picture. The bright, almost surrealistic patches of color on his face and in the background create a sense of terror, which people characteristically feel as they begin to have a psychotic breakdown. Janikowski looks directly at the viewer. We comprehend his enormous anxiety and feel sympathetic toward him because he looks so terrified – his eyes are asymmetrical and frightened, his ears are asymmetrical, he lacks a neck, and his coat jacket merges with the background. To further suggest that Janikowski is at the edge of madness, Kokoschka uses the wooden end of the paintbrush to carve lines and create deep furrows and wrinkles on his face, eyes, mouth, and bright red ears, as well as on the background.

Another example of Kokoschka's prescience is his 1909 painting of Auguste Forel. Forel was, like Freud, an internationally known psychiatrist. He was widely recognized for reorganizing, modernizing, and earning an international reputation for excellent patient care at Burghölzli, the Psychiatric Hospital of the University of Zurich. He was also interested in comparative anatomy and behavior and had devised his own neuron doctrine independent of Freud and Santiago Ramón y Cajal. In the spring of 1910, Kokoschka painted a portrait of Forel that was commissioned by Loos, who at the time managed all of Kokoschka's portrait work. As in the other portraits of this period, Kokoschka rubbed and scraped the paint with his brush and his hand, conveying a sense of the direct presence of the sitter. But in this painting, Forel's right hand and right eye are atypical and look very different from his left hand and eye. He holds his right hand in a flexed position and supports it by placing the right thumb into the left sleeve of his jacket. The right eye has a staring quality quite dif-

ferent from the left, suggesting, as it did to Forel and his family, that the man had had a stroke on the left side of his brain.
Forel had the option of accepting or rejecting the finished picture. Once he saw the portrait, he rejected it. Kokoschka privately agreed that the painting depicted Forel as if he had suffered a stroke. Two years later, while bending over his microscope, Forel had a stroke that affected his right face and arm exactly as Kokoschka had painted them. Whether the painting reflects a purely accidental depiction by Kokoschka of Forel's impending stroke, or whether the artist's eye for detail and his sense of the physical and psychic attributes of his subject enabled him to spot a transient ischemic episode, the precursor signs of stroke, is not clear.
Hilton Kramer, the art critic for *The New York Times* and *The New York Observer*, wrote of these early Kokoschka portraits:

> The style that Kokoschka perfected in the early portraits has sometimes been called »nerve painting« or »soul painting,« terms which provide a salutary warning that the conventions of realistic depiction – never mind pictorial flattery – are not to be expected in these pictures. … There is, instead, a depth of empathy and a determination to remain undeceived by the masks of public demeanor that together have the effect of seeming to penetrate the inner core of the psyche itself. To achieve this effect, Kokoschka places each of his subjects in a pictorial space that is neither the space of nature nor that of some recognizable domestic interior. It is an infernal space, at once eerie and unearthly, haunted by demons and threatened by dementia. … And when the artist came to paint his own *Self Portrait* (*Hand on Chest*) in 1913, he did not exempt himself from this radical candor. [*The New York Observer*]

This depiction of gesture was influenced, in part, by Viennese medicine and by psychoanalysis. Following Breuer and Freud, many doctors had become fascinated by the hysterical manifestations of some of their patients and in the process of describing these in their publications, they created an aesthetic typology of body images associ-

ated with hysteria that coincided with the developing expressive art of modernism.

The Stein Children was also painted in 1909 and depicts five-year-old Lotte and eight-year-old Walter, the two children of the bookstore owner Dr. Richard Stein. Kokoschka does not depict two children in poses typical of childhood innocence. These are not the idealized children portrayed by Rubens and Velázquez, Gainsborough or Reynolds. Rather, he suggests through their body language, irregular coloring, and the vaguely defined background on which they are lying that the relationship is not neutral nor innocent. Rather, the children are portrayed as struggling with their fascination with one another and the attraction and conflict between them. The boy appears in profile while the girl is facing the viewer. And, like the painting of the art historians Tietze, the models' arms serve to communicate a length between the two. His left hand is reaching for the girl's right hand, which is clenched in a fist. One can see why the public was shocked by this early Kokoschka (1909). The Nazis used *The Stein Children* painting as one of the clearest examples of degenerate art and removed it in 1937 from the State Gallery in Dresden.

Gombrich describes this painting in the following terms:

> »In the past, a child in a painting had to look pretty and contented. Grown-ups did not want to know about the sorrows and agonies of childhood, and they resented it if this aspect of it was brought home to them. But Kokoschka would not fall in with these demands of convention. We feel that he has looked at these children with a deep sympathy and compassion. He has caught their wistfulness and dreaminess, the awkwardness of their movements and the disharmonies of their growing bodies … His work is all the more true to life for what it lacks in conventional accuracy.« (*The Story of Art*, p. 427)

It is interesting that Kokoschka is dealing here with a theme that was emerging in general discussion following the publication in 1905 of three essays Freud wrote on sexuality in which he said:

»One feature of the popular view of the sexual instinct is that it is absent in childhood and only awakens in the period of puberty. This, however, is not merely a simple error but one that has had grave consequences, for it is mainly to this idea that we owe our present ignorance of the fundamental conditions of sexual life. A thorough study of the sexual manifestations of childhood would probably reveal the essential characters of the sexual instinct and would show us the course of its development and the way in which it is put together from various sources.« (*Zeitschrift Für Kunstgeschichte* 64. Band / 2001, 512.)

The interest in infantile sexuality led Kokoschka to explore the prepubescent female and male nude where he emphasized both the naturalness and the awkwardness of these pre-adolescent girls. He started this as early as 1906 while still a student, perhaps influenced by Klimt and by Gaugin's Tahiti pictures. Some of these use as their model his fellow student Lilith Lang. These nude studies are focused on personality and lives.

Oskar Kokoschka: Standing Nude Girl with Hand on Side (1907)

These several ideas of Kokoschka were taken up by Egon Schiele, four years younger than Kokoschka.
Egon Schiele (1890-1918) was the son of a stationmaster in the small Austrian town of Tulin, near Vienna. His greatest strength, evident from his early youth, was an exceptional ability in drawing. In 1906 he entered the art school of The Vienna Academy of Fine Arts.
Although influenced by Klimt, Schiele never used the marvelously sinuous lines of Klimt or the profusion of decorative detail that dissolves the figure in Klimt's portraits. Schiele's line is sharp, nervous, emphatic and precise. It both animates and controls the people depicted, sometimes reducing them to caricatures and sometimes endowing them with brazen self-confidence, especially in self-portraits. The nudes seem to enact rather than embody sensuality. By 1910 he

had moved away from Klimt and had established his own expressionistic idiom. Schiele's drawing style was influenced by an assimilation of Rodin's special way of drawing which was newly invented around 1895, and which has been defined as continuous drawing. This is based on direct observation of the subject by the artist without taking the eye off the model. Drawing in this manner created a completely new line different from the sensuous line of Klimt and Jugendstil. The contours were now drawn with quick strokes of a pencil or pen and the flesh tones were subsequently filled in with watercolor. This method gave to the drawing a lively freshness and to placement of the figure in the center of the page an almost abstract monumental aspect. He could make dozens of sketches from a model without ever using an eraser. He would add color only later. Schiele's lines, although at times frenetic, convey explosive energy. Schiele, like Kokoschka, treated the human figure as his preferred vehicle for personal discovery and conquest. He, like Kokoschka, shared with the hypocritical Viennese a fascination with sex and sexual practices – but sexuality is fused with anxiety.

Egon Schiele: Act of Love (1915)

Here, sexuality, eroticism, and world-weariness have become fused with one another.

Schiele's anxiety is evident not only substantively, in the narrative themes he selects to draw and paint, but also stylistically. In contrast to the ornamentation and graceful lines that characterize Klimt's art and Kokoschka's early work, Schiele's mature work is somber and often lacking in vivid color.

In 1910 Schiele entered a new phase, moving radically away from Klimt and establishing an Expressionist style, one that was initially influenced by Kokoschka but that quickly became distinctly his own. In addition to eliminating ornamentation, Schiele distanced himself from Klimt by using himself as the prime subject of his psychic explorations. Thus, whereas Klimt never did a self-portrait, Schiele did

a very long series of them – nearly one hundred – in 1910 and 1911. In that respect, he exceeded even Rembrandt and Max Beckmann, both of whom specialized in studying human nature over the life cycle by studying themselves throughout their lives.

In his search for what lies below the surface of everyday life, Schiele, like Kokoschka, was a true contemporary of Freud and Schnitzler: he studied the psyche and believed implicitly that to understand another person's unconscious processes, he had first to understand his own. Schiele exhibited himself compulsively in his drawings and paintings – again and again, alone or in combination with a partner – sometimes with truncated limbs, sometimes with missing genitalia, with contorted muscles, bones racked, flesh mortified with leprosy. He reveals his whole body, often naked and usually looking starved, awkward, distorted, and troubled. He uses his poses, postures, and tremendous bodily distortions to convey the full range of human emotion – anxiety, apprehension, guilt, curiosity, and surprise, combined with passion, ecstasy, and tragedy.

All of Schiele's self-portraits depict him in front of a mirror, sometimes in the act of masturbating. The paintings of himself masturbating are bold on several levels, not the least of which is that many people in Vienna at that time thought that masturbation by men led to insanity.

But the self-portraits are not simply an exhibition of nudity, they are an attempt at full disclosure of the self, a self-analysis, a pictorial version of Freud's *The Interpretation of Dreams*. In an essay entitled »Live Flesh,« the philosopher and art critic Arthur Danto has written:

> Eroticism and pictorial representation have co-existed since the beginning of art. … But Schiele was unique in making eroticism the defining motif of his impressive … œuvre. [Schiele's paintings] are like illustrations of a thesis of Sigmund Freud … that human reality is essentially sexual. What I mean is there is no art-historical explanation of Schiele's vision.

The bodies he paints – especially his own – are disjointed, his arms and legs contorted and twisted painfully, as if they were Jean-Martin Charcot's hysterical patients. But whereas Charcot's patients assumed their postures unconsciously, Schiele's posturing was a conscious and practiced attempt to use the position of hands, arms, and body to convey inner emotion. He often rehearsed and analyzed various postures in front of a mirror. He expressed his character and conflicts through histrionic, almost hysterical – but in reality well-planned – whole-body posturing.

Thus, Schiele's art is not simply Mannerist, it is mannered. Freud and his followers used the term »acting out« to refer to the expression of forbidden impulses in action. Schiele was the first artist to use acting out to convey his inner turmoil, anxiety, and sexual desperation. Much as Max Dvořák championed the art of Kokoschka, so Otto Benesch, Dvořák's contemporary at the Vienna School of Art History and the director of the Albertina Museum in Vienna, the world's most important collection of drawings and prints, wrote the Foreword to the catalogue of the 1918 Schiele exhibition at the Galerie Arnot and championed Schiele throughout his career. In addition, the Benesch family supported Schiele as patrons. Otto Benesch's father, Heinrich, was a patron of Schiele's, and in 1913 the artist painted a double portrait of the two: *Chief Inspector Heinrich Benesch and His Son Otto*.

Like Kokoschka, Schiele did a large number of self-portraits. The force of expression of some of these is heightened by an application of the thick white halo and gouache around the outlines of the figure which gives to the figure a more pronounced spatial definition and a greater contrast and it isolates the figure and makes it stand out against the background but at the same time emphasizes its volumetric form.

In 1910 when Egon Schiele was 20 years old, he painted three major self-portraits in rapid succession. One of these, *Self-Portrait Kneeling with Raised Hand and the Other Kneeling in the Nude*, is remarkable for several reasons. First, they are very large. They constitute the largest canvas that he had yet attempted. Second, any trace of Klimt's

influence evident up until 1909 seems to have been discarded. He has replaced the soft line of Klimt with a surgical knife and he replaced the dream state of art nouveau with an oppressive reality. It gives one an inescapable sense of an overbearing physical presence. Also what constitutes a self-portrait for Schiele has radically changed. It is no longer the face or half-torso, but the entire body. To reveal the psyche now for Schiele literally means revelation of the body. This is not nudity exhibited, this is exposure.

Shiele's gestures in general are exaggerated in almost theatrical or frequently spasmodic ways. Schiele favored contorted bodies, strange poses, nervous and often jagged contours, and unusual combinations of colors to define parts of the body, and convey moods of the character of a figure. Thus we see again that Schiele is first and foremost an exceptional draftsman. Even in his paintings his primary emphasis remains the structural elements of the composition. His use of color is not for the purpose of modeling but for expressiveness. Like Kokoschka, he tries to communicate internal psychic mood to vivid surprising color such as blue, red, or green as well as deep browns and blacks.

Schiele's self-portraits, many of them depicting him in the act of masturbating and executed in front of a mirror convey through facial expressions as much as through bodily contortion, the anxiety, apprehension, guilt, curiosity, and surprise at the depth of his own emotion.

Egon Schiele: Self-Portrait With Striped Armlets (1915)

In this self-portrait Schiele presents himself as a social misfit. A kind of clown or fool. He has colored his hair bright orange and his wide-open eyes have the look of madness about them. His head tilts precariously on top of an unusually slender neck. The armlets with their vertical strips recall the typical costume of a court jester.

In portraiture, the genuine self could only be revealed if the realistic façade was shattered and broken. In 1912 Schiele was sentenced to

24 days in jail for having made pornographic drawings of a schoolgirl. His studio had been raided and one of his sketches burned by the examining judge. Schiele's nudes caricatured the society ladies whom Klimt had painted in flattering fashion.
Schiele died on October 31, 1918 from influenza just three days after his wife died from the same disease.
Alois Riegl was the first art historian to systematically apply scientific thinking to art criticism. He and his colleagues at the Vienna School of Art History attained international renown at the end of the nineteenth century for their efforts to establish art history as a scientific discipline by grounding it in psychology and sociology.
In studying the group paintings of seventeenth-century Holland, such as Frans Hals's *The Banquet of the Officers of the St. George Militia* or *Haarlem* and Dirck Jacobsz's *Civic Guards*, Riegl discovered a new psychological aspect of art: namely, *that art is incomplete without the perceptual and emotional involvement of the viewer*. Not only does the viewer collaborate with the artist in transforming a two-dimensional likeness on a canvas into a three-dimensional depiction of the visual world, the viewer interprets what he or she sees on the canvas in personal terms, thereby adding meaning to the picture. Riegl called this phenomenon the »beholder's involvement« (Gombrich later elaborated on it and referred to it as »the beholder's share«).
This conception – that art is not art without the direct involvement of the viewer – was elaborated upon by the next generation of Viennese art historians: Ernst Kris and Ernst Gombrich. Based on ideas derived from Riegl and from contemporaneous schools of psychology, they devised a new approach to the mysteries of visual perception and incorporated that approach into art criticism.
In developing this line of thought further, Kris and Gombrich began to try to develop the beginning science of how the viewer responds to a work of art based on cognitive psychology, an emerging field that used insights into unconscious emotion derived from art history, psychoanalysis, and Gestalt psychology to study complex mental processes such as perception and the aesthetic response to art: the emo-

tional response of the viewer to the exaggerated forms and substance of Expressionist art.

Kris shifted the emphasis of psychoanalytic art criticism from Freud's psychobiography of artists to an empirical investigation of the perceptual processes of the artist and the beholder.

Ernst Kris's study of ambiguity in visual perception led him to elaborate on Riegl's insight that the viewer completes a work of art. The extent of the beholder's contribution depends on the degree of ambiguity in the work of art. Kris argued that when an artist produces a powerful image out of his or her life experiences and conflicts, that image is inherently ambiguous. The ambiguity in the image elicits both a conscious and an unconscious process of recognition in the viewer, who responds emotionally and empathically to the image in terms of his or her own life experiences and struggles. Thus, just as the artist creates a work of art, so the viewer re-creates it by responding to its inherent ambiguity.

In speaking of ambiguity, Kris was referring to an idea that the literary critic William Empson introduced in 1930, namely, that ambiguity exists when »alternative views [of a work of art] might be taken without sheer misreading.« Empson implies that ambiguity allows the viewer to read the aesthetic choice, or conflict, that exists within the artist's mind. Kris, on the other hand, argues that ambiguity enables the artist to transmit his own sense of conflict and complexity to the viewer's brain.

Kris was also familiar with the Swiss-German art historian Wilhelm Worringer's 1908 essay, »Abstraction and Empathy: A Contribution to the Psychology of Style.« Strongly influenced by Riegl, Worringer argues that two sensitivities are required of the viewer: empathy, which allows the viewer to lose himself or herself in a painting and be at one with the subject, and abstraction, which allows the viewer to retreat from the complexities of the everyday world and follow the symbolic language of the forms and colors in a painting.

While studying with Dvořák, who regarded the elongated features and distorted perspective of the mannerist painters as precursors of austrian expressionism, Kris became interested in how artists use

distortion to convey their insights into a subject's psyche and how viewers respond to that distortion. Through Karl Bühler, a Gestalt psychologist who chaired the department of psychology at the University of Vienna, Kris became interested in the scientific analysis of facial expressions. These interests formed the basis of his first attempt to combine his training in art history with his psychoanalytic insights. In two studies, published in 1932 and 1933, Kris focused on the exaggerated facial expressions of a remarkable series of heads sculpted in the 1780s by Franz Xaver Messerschmidt, the extraordinarily gifted portrait sculptor whose work was exhibited in the Lower Belvedere Museum in Vienna 1900 and who very likely influenced Kokoschka and Schiele in their breakthrough to Expressionism.

In emphasizing the creative aspect of the beholder's share, Kris not only acknowledged common aspects of creativity between artists and viewers, but also implicitly recognized common aspects of creativity between artists and scientists. Like Kokoschka, Kris realized that figurative painting presents a model of reality (or in the case of a portrait, a model of a person) that relies on a process of investigation and discovery in much the same way that science does, whether the science is cognitive psychology or biology. Gombrich later referred to this process of investigation as »visual discovery through art« [*The Image and the Eye*, pg 11].

By combining art history with the intuitive ideas derived from psychoanalysis, the more rigorous thinking of Gestalt psychology, and the hypothesis testing of unconscious and conscious inference, Kris and Gombrich laid the foundation for a cognitive psychology of art. Moreover, they understood that since art is in part a creation of mind, and mind is a series of functions carried out by the brain, the scientific study of art must include neuroscience as well as cognitive psychology.

Gombrich, Kris, and Riegl took key steps in delineating that principle. Riegl took the first step by bringing psychological science to bear on the study of art and thus recognizing the beholder's share. Kris moved forward in one direction by realizing that art is a form of unconscious communication between the artist and the beholder and

that the beholder responds to the ambiguity inherent in a work of art by unconsciously re-creating the image in his or her brain. Gombrich moved forward in another direction by focusing on the creativity inherent in visual perception and analyzing how the beholder uses a combination of Gestalt principles and hypothesis testing in viewing a work of art. Together, Kris and Gombrich used their insights to show us that art sets out, self-consciously, to encourage both perceptual and emotional processes of re-creation in the viewer's brain.

Kris and Gombrich now realized *that cognitive psychology occupies an essential explanatory position between the behavior of individuals* – such as the beholder's share – *and the biological processes in the brain that mediate that behavior*. They anticipated that this psychology, with its empirical footings, might eventually serve as the basis of a dialogue between art and the biology of perception, emotion, and empathy. In a sense, Kris and Gombrich were following Freud's attempt to establish a cognitive psychology that could link the psychology of mental processes to the biology of mind.

In the course of their work together, Kris and Gombrich began to see Expressionist painting as a reaction against conventional means of depicting faces and bodies. The new style derived from a fusion of two traditions: high art, derived from the Mannerists, and caricature, introduced at the end of the sixteenth century by Annibale Carracci. Carracci, a Mannerist artist, used distortion and exaggeration to emphasize individual identifying features. Later, Gian Lorenzo Bernini, a Roman architect and sculptor, took caricature to a new level. As Gombrich and Kris describe it in an unpublished manuscript that they later elaborated upon in their book *Caricature*:

> »Bernini's drawings focused not on variations in bodily features but on the face alone and on the unity of facial expression. … Rather than single out and exaggerate distinctive physical traits … Bernini starts out with the whole, not with the parts; he conveys the image which we fix in our mind when we try to recall someone in memory, that is with the unified expression of the

face – and it is this expression which he distorts and heightens.« [as cited in Rose, 2010, pg 220-221]

This holistic view, as we shall see, is a Gestalt principle that Bernini had grasped intuitively.

With Kris's encouragement, Gombrich began to develop a multi-pronged approach to art, combining insights from psychoanalysis, Gestalt psychology, and scientific hypothesis testing. Gombrich's insights into psychoanalysis came from Kris. The Gestaltist influence came initially from Bühler. The idea of perception as hypothesis testing came, as we shall see, from Hermann von Helmholtz and Karl Popper.

Gombrich realized that the powerful, largely innate principles of gestalt psychology apply primarily to the lower levels of visual perception, to bottom-up visual processing. Higher-order perception also incorporates knowledge based on learning, hypothesis testing, and goals, which are not necessarily built into the developmental program of the brain. Because much of the sensory information that we receive through our eyes can be interpreted in a variety of ways, we must use inference to resolve this ambiguity. Based on experience, we must guess, given the current situation, what is the most likely image in front of us. The importance of top-down processing in visual perception had already been established by Sigmund Freud, who described agnosias – deficiencies in object recognition – in people who could accurately detect features such as edges and shapes, but could not put them together to recognize an object.

Helmholtz, one of the most important physicists of the nineteenth century, also made major contributions to many areas of sensory physiology and was the first modern, empirical scientist to study visual perception. In his earlier studies of tactile perception, he succeeded in measuring the speed with which electrical signals move along the axon of a nerve cell and found that it is surprisingly slow (about 90 feet per second) and that our reaction time is slower still. This discovery caused him to propose that much of the brain's processing of sensory information is carried out unconsciously. Further-

more, he argued that information is routed to and processed at different sites in the brain during perception and during voluntary movement.

When Helmholtz turned his attention to the study of vision, he realized that any static, two-dimensional image contains poor-quality, incomplete information. To reconstruct the dynamic, three-dimensional world from which the image was formed, the brain needs additional information. In fact, if the brain relied solely on the information it receives from the eyes, vision would be impossible. He therefore concluded that perception must also be based on a process of guessing and hypothesis testing in the brain, based on past experiences. Such educated guessing allows us to infer on the basis of past experience what an image represents. Since we are not normally aware of constructing visual hypotheses and drawing conclusions from them, Helmholtz called this top-down process of hypothesis testing unconscious inference. Thus, before we perceive an object, our brain has to infer what that object might be, based on information from the senses.

Helmholtz's remarkable insight is not restricted to perception: it provides a general principle that, as we shall see, applies to emotion and empathy as well. The noted cognitive psychologist Chris Frith of the Wellcome Center for Neuroimaging at University College London has summarized Helmholtz's insight in the following terms: »We do not have direct access to the physical world. It may feel as if we have direct access, but this is an illusion created by our brain« [pg 40].

The insight that the perception of the beholder involves a Helmholtz-Popper top-down influence convinced Gombrich that there is no »innocent eye«: that is, all visual perception is based on classifying concepts and interpreting visual information. One cannot perceive that which one cannot classify, Gombrich argued. As we shall see later, Gombrich's psychological insights into perception were to serve as a solid footing for a bridge between the visual perception of art and biology.

The view of the brain as a creativity machine that constantly uses inferences and guesses to reconstruct the external world – the view advocated by Ernst Kris and Ernst Gombrich – was a dramatic shift from the naïve philosophical realism of the seventeenth-century British philosopher John Locke that dominated thinking about mind at that time. Locke conceived of mind as receiving all the information capable of being gathered by the senses, a view in which mind simply mirrors the reality of the external world. Kris's and Gombrich's view of the brain was a modern version of Kant's theory that sensory information allows reality to be invented by mind.

The images in art, like all images, represent not so much reality as the viewer's perceptions, imagination, expectations, and knowledge of other images – images recalled from memory. In a sense, to see what is actually painted on a canvas, the viewer has to know beforehand what he or she might see in a painting. In this way the creative process engaged in by the artist's brain – the modeling of physical and psychic reality – parallels the intrinsically creative operations of every human brain in everyday life.

As Gombrich's fascination with visual perception deepened, he became intrigued by Ernst Kris's ideas about ambiguity in art and began to study the ambiguous figures and illusions made famous by Gestalt psychologists. In the simplest cases, illusions allow for two distinctly different readings of an image. Such illusions are the simplest example of the nature of ambiguity, which Kris held was the key to all great works of art and to the beholder's response to great art. Other illusions contain ambiguous images that can lure the brain into making perceptual errors. Gestalt psychologists used these errors to explore the cognitive aspects of visual perception. In the process, they deduced several principles of the brain's perceptual organization before neuroscientists discovered them.

Such ambiguous figures and illusions intrigued Gombrich because in viewing a portrait or a scene, multiple choices are possible to the viewer. Often, several ambiguities are embedded in a great work of

art, and each of them may present the beholder with a number of different decisions.
Gombrich was particularly interested in ambiguous figures and illusions that cause perception to flip between two rival interpretations. One such figure is the drawing of a duck-rabbit created in 1892 by the American psychologist Joseph Jastrow and illustrated by Gombrich near the opening of Art and Illusion. The viewer cannot see both animals at the same time. If we focus on the two horizontal bands at the left that look like long ears, we see the image of the rabbit; if we focus on the right, we see the duck, and the two bands at the left become a beak. We can initiate the switch between rabbit and duck with a movement of our eyes, but that eye movement is not essential for the switch.

KEY: What impressed Gombrich so greatly about this drawing was that the visual data on the page do not change. What changes is our interpretation of the data. »We can see the picture as either a rabbit or a duck,« he wrote. »It is easy to discover both readings. It is less easy to describe what happens when we switch from one interpretation to the other.« What happens is that we see the ambiguous image and then, based on our expectations and past experiences, unconsciously infer that the image is a rabbit or a duck. This is the top-down process of hypothesis testing that Helmholtz described. Once we have formulated a successful hypothesis about the image, it not only explains the visual data but also excludes alternatives. Thus, once we have assigned the image to the duck, we have committed to the hypothesis of duck, and the hypothesis of rabbit is, so to speak, off the table. The reason these percepts are mutually exclusive is that when each image is dominant, it leaves nothing to be explained, no ambiguity. The image is either a duck or a rabbit, but never both.

This principle, Gombrich realized, underlies all of our perceptions of the world. The act of seeing, he argued, is fundamentally interpretative. Rather than seeing the image and then consciously interpreting it as a duck or a rabbit, we unconsciously interpret the image as we

view it; thus, interpretation is inherent in visual perception itself. Simply by seeing the image, we recognize it as either a duck or a rabbit. We can consciously »flip« from one interpretation to the next, but we cannot see both animals in the image at the same time.

The Rubin vase, devised by the Danish psychologist Edgar Rubin in 1920, is also an example of perception flipping between two rival interpretations and also relies on unconscious inferences made by the brain. But unlike the rabbit-duck illusion, the Rubin vase requires the brain to construct an image by differentiating an object (figure) from its background (ground). The Rubin vase also requires that the brain assign »ownership« of the outline, or contour, that separates the figure from the ground. Thus, when the brain assigns ownership of the contour to the vase, we see the vase, and when it assigns ownership to the faces, we see the faces. The reason the illusion works, according to Rubin, is that the contours of the vase match the contours of the faces, thus forcing the beholder to select one image or the other.

The Kanizsa triangle is another example of the visual system constructing a reality that is not there. In this illusion, created in 1950 by the Italian artist and psychologist Gaetano Kanizsa, our minds construct an image of two overlapping triangles. The contours that seem to define these triangles, however, are entirely illusory. There are no triangles in this image, just three open angles and three semicircles. As the brain processes this sensory information into a perception, the presence of a solid black triangle obscuring the white outline of another triangle beneath it emerges. The brain creates this image using Helmholtz's unconscious inferences. The brain is hardwired to interpret patterns like these as indicative of triangles, and thus constructs a triangular perception so strong that it seems darker than the page on which it appears, even when we know this to be false. Zeki argues that the Kanizsa triangle described is an example of »finishing it off« – of the brain trying to complete and thereby make sense of an incomplete or ambiguous image. His later imaging experiments with people indicated that when a person looks at implied lines, neurons in the primary visual cortex and in the V2 and V3 re-

gions become active, as do neurons in an area of the cortex that is critical for object recognition.

Presumably, the brain completes lines because nature often presents occluded contours that must be completed in order to perceive an image correctly, as might happen when a person sees someone coming around a corner or a lion stepping out from behind a bush. As Richard Gregory reminds us, »Our brains create much of what we see by adding what ›ought‹ to be there. We only realize that the brain is guessing when it guesses wrongly, to create a clear fiction« [*Seeing Through Illusion*, pg 212].

Ernst Kris emphasized that a great work of art is inherently ambiguous and can therefore be read in a number of ways, eliciting different re-creations from different beholders. Ernst Gombrich implicitly elaborated on this idea when studying illusions, which are simple examples of visual ambiguity. Gombrich realized that there is no rigid distinction between perception and illusion and that an understanding of the biology of perception would also yield insights into the beholder's response to ambiguity.

Kris's and Gombrich's studies of ambiguity and of the beholder's share led them to conclude that the brain is creative – it generates internal representations of what we see in the world around us, whether as an artist or a beholder. Moreover, they held that we are all wired to be »psychologists« because our brain also generates internal representations of other people's minds – their perceptions, motives, drives, and emotions. These ideas contributed greatly to the emergence of a modern cognitive psychology of art.

But Kris and Gombrich also realized that their ideas were the result of sophisticated insights and inferences that could not be examined directly and were therefore not amenable to objective analysis. To examine the internal representations directly, to peer into the black box of the brain and see how the deconstruction of form gives rise to figural primitives – the building blocks of perception – cognitive psychology had to join forces with brain biology.

How does the brain of the beholder respond to a work of art? As we shall see, both the beholder's perception of art and his or her emo-

tional response to art depend entirely on the activity of nerve cells in specific regions of the brain. But before we begin to examine the neural mechanisms underlying our visual and emotional processes, we need a basic understanding of the overall organization of the central nervous system.

To begin to appreciate what is required to accomplish the marvel of visual perception, it is useful to compare the brain's information-processing capabilities to those of artificial computational devices. By the 1940s, emerging knowledge about the biology of the brain and about information processing gave rise to the first computers, the first »electronic brains.« By 1997, computers had become so powerful that Deep Blue, a chess supercomputer built by IBM, defeated Gary Kasparov, thought to be the world's best chess player. But to the surprise of computer scientists, Deep Blue, which was so skilled at learning the rules, logic, and calculation of chess, had great difficulty learning the rules of face perception and did not come close to distinguishing between faces. This is still true of the most powerful computers today. Computers are better than the human brain at processing and manipulating large amounts of data, but they lack the hypothesis-testing, creative, and inferential capabilities of our visual system.

How are the analytical triumphs of visual perception achieved? Richard Gregory raised the question: »Is the visual brain a picture book? When we see a tree is there a tree-like picture in the brain?« He replies that the answer is clear: No! Rather than having a picture, the brain has a hypothesis about a tree and other objects in the outside world that it reflects as the conscious experience of seeing.

The key idea that emerged from these psychological and neurobiological studies of visual perception and aesthetic response is that the brain is not a camera but a creativity machine. The brain does not simply photograph external reality; rather it recreates the outside world as would a Homeric storyteller. Each time the brain perceives an external reality, including an emotional reality, it recreates that reality anew according to its own rules, exaggerating some features and diminishing others.

Vision thus begins in the eye, which detects information about the outside world in terms of light. The data emerging from specialized cells in the retina resemble the visual world in the same way that the pixels in the image on your laptop computer resemble the actual image that you see on the screen. Both the biological and the electronic system process information. The visual system, however, creates representations in the brain (in the form of neural codes) that require far, far more information than the modest amount the brain receives from the eyes. That additional information is created within the brain.

Thus, what we see in »the mind's eye« goes dramatically beyond what is present in the image cast on the retina of our real eye. The image on the retina is first deconstructed into electrical signals that describe lines and contours and thus create a boundary around a face or an object. As these signals move through the brain, they are recoded and, based on Gestalt rules and prior experience, reconstructed and elaborated into the image we perceive. Luckily for us, although the raw data taken in by the eyes are not sufficient to form the content-rich hypothesis called vision, the brain generates a hypothesis that is remarkably accurate. Each of us is able to create a rich, meaningful image of the external world that is remarkably similar to the image seen by others.

It is in the construction of these internal representations of the visual world that we see the brain's creative processes at work. The eye does not work like a camera. A digital camera will capture an image, be it a landscape or a face, pixel by pixel, as it appears before us. The eye cannot do that. Rather, as the cognitive psychologist Chris Frith writes: »What I perceive are not the crude and ambiguous cues that impinge from the outside world onto my eyes and my ears and my fingers. I perceive something much richer – a picture that combines all these crude signals with a wealth of past experience … Our perception of the world is a fantasy that coincides with reality.«

How does the visual system create this world, this »fantasy that coincides with reality«? A guiding principle in the organization of the

brain is that each mental process – perceptual, emotional, or motor – relies on distinct groups of specialized neural circuits located in an orderly, hierarchical arrangement in specific regions of the brain. This is also true of the visual system.

The nerve cells that process visual information are grouped into hierarchical relays that send information along one of two parallel pathways in the visual system. These relays begin in the retina of the eye, go on to the lateral geniculate nucleus of the thalamus, continue to the primary visual cortex in the occipital lobe, and then to some thirty additional areas in the occipital, temporal, and frontal lobes of the cerebral cortex. Each relay performs a particular transformation process on the incoming information. The relays that make up the visual system are distinct from those that process information about touch, hearing, taste, and smell, and they occupy their own distinctive real estate in the brain. Only at the very highest level of the brain does information from the several sensory systems come together.

Each of the two parallel pathways in the visual system analyzes different aspects of the visual world. The what pathway is concerned with color and with what is to be seen in the world; relays in this pathway send information to areas in the temporal lobe concerned with color, object, body, and face recognition. The where pathway is concerned with where those objects are to be found; its relays send information to the parietal lobe. Thus, each pathway consists of a series of hierarchically organized relays that receive, process, and convey visual information on to the next relay. The cells in each relay connect to cells in the next relay, and so on, giving rise to the visual system.

Once information reaches the higher regions of the what pathways, it is reappraised. This top-down reappraisal operates on four principles: disregarding details that are not behaviorally relevant in a given context; searching for constancy; attempting to abstract the essential, constant features of objects, people, and landscapes; and, particularly important, comparing the present image to images encountered in the past. These biological findings confirm Kris's and Gombrich's

inference that vision is not simply a window onto the world, but truly a creation of the brain.

The biological study of visual perception was launched by another towering figure with roots in Vienna – Stephen Kuffler, a contemporary of Ernst Kris and Ernst Gombrich. In the 1950s, first Kuffler and then his younger colleagues David Hubel and Torsten Wiesel began to examine the question that fascinated Kris and Gombrich: how the brain deconstructs images as it processes visual events. They examined the response of neurons in the visual system to specific stimuli and made possible the advance from a cognitive psychology of perception to a biological analysis of perception.

Their work began to provide answers to several fundamental questions: Do certain cells in the brain encode figural primitives, the building blocks of forms? Do the combined activity of these cells coalesce into representations of complete forms? The image on the retina is deconstructed, but where in the brain is it reconstructed?

The processing of visual information begins, as we have seen, in the retina, proceeds through the lateral geniculate nucleus of the thalamus, and continues through thirty-some visual areas of the cerebral cortex.

In a series of seminal studies, Kuffler, Hubel, and Wiesel discovered that the signals sent by neurons in the brain ultimately produce what becomes our conscious awareness of distinct aspects of a visual image. They found that neurons in the early stages of the visual system (the retina and the lateral geniculate nucleus) respond most effectively to small spots of light. Neurons in the next relay, the primary visual cortex (V1, the first relay in the brain), organize visual information into lines, edges, and corners; these elements are combined to yield contours and figural primitives. Subsequent relays in the visual cortex, which receive information from the primary visual cortex, also carry out specialized functions: V2 and V3 respond to virtual lines and to borders, V4 responds to color, and V5 responds to motion. Finally, work by other neuroscientists showed that in the highest regions of the visual brain, neurons respond to complex forms, to hands, to bodies, and particularly to faces. Neurons in these regions

representing specific places, faces, bodies, hands, and complex visual scenes identify the color, location in space, and movement of these forms.

Kuffler's work revealed that vision is, in essence, information processing. The nervous system first deconstructs an image into neural information and then transforms that information into a code that the brain uses to form the building blocks of perception. Kuffler's studies and subsequent studies by his younger colleagues in America, David Hubel and Torsten Wiesel, and by the British brain scientist Semir Zeki, uncovered how the visual system of the brain deconstructs the form, color, and movement of images and then recombines them into three-dimensional representations in the higher reaches of the brain. Parallel cognitive psychological and biological studies on emotion, on social interactions, and on empathy, which began with Darwin's realization that emotion is a means of social communication, extended the ability of cognitive psychology and brain science to enrich our understanding of the beholder's response to art.

These biological findings began to clarify what the Austrian Modernists and Kris and Gombrich could only infer – that the emotional and cognitive power of art stems from the artist's ability to create images that target and manipulate specialized regions and information processing systems in the viewer's brain. Moreover, the regions that are specialized for processing faces, hands, bodies, emotion, and social behavior respond most strongly to exaggerated expressions and depictions of movements – exaggerations that the Austrian Expressionists employed to great effect. Thus, the portraits of Klimt, Kokoschka, and Schiele enable us to explore in depth a new dimension of neuroaesthetics – the perceptual and emotional neuroaesthetics of the face and body.

These new insights into the biological basis of perception, memory, emotion, empathy, and creativity have established a discourse between brain science and art that promises to enrich both areas of study. In a broader sense, this new dialogue re-establishes the conversation between art and science that began in Vienna 1900 and rein-

troduces scientific ideas into contemporary intellectual discourse and culture.

Kuffler began by recording the action potentials generated by individual retinal ganglion cells, both those in the center of the retina and those in the periphery. He found that these specialized neurons receive information about a visual image from both cones and rods, that they encode that information into a pattern of action potentials, and that they then transmit the information to the brain. In the process, he made his first surprising discovery: retinal ganglion cells never sleep. They fire action potentials spontaneously, even in the absence of light or any other stimulation. Like a self-starting device, this slow, spontaneous firing searches the environment for signals and provides an ongoing pattern of activity on which subsequent visual stimuli can act. Excitatory stimuli increase this firing and inhibitory stimuli decrease it.

Kuffler then made a second discovery. He found that the most effective way to change the spontaneous firing pattern of retinal ganglion cells is not by shining a powerful, diffuse light over the whole retina, but by shining a tiny spot of light on only a portion of it. In this way, he found that each of these neurons has its own territory on the retina, its own receptive field that corresponds to a particular piece of the outside world. Each neuron reads and responds only to stimulation within its own receptive field, and each conveys information to the brain only from its own receptive field. Kuffler next found that the frequency of a neuron's firing is a function of the intensity of the light striking its receptive field, and the duration of its firing depends on the duration of the light stimulus. Since the entire retina is blanketed with the receptive fields of different nerve cells, no matter where on the retina a light is shone, some neurons will respond. This finding was one of the earliest indications of how meticulously specialized the visual system is for picking out tiny details in the environment.

The retinal ganglion cells with the smallest receptive fields are in the center of the retina. They receive information from the most densely packed cones, those concerned with the sharpest visual dis-

crimination – looking at the details of a painting, for example – and that read the smallest pieces of the outside world. Some ganglion cells a little bit off the center of the retina have somewhat larger receptive fields that combine information from many cones. These cells begin the process of analyzing the coarse-scale, holistic components of images. Kuffler found that the receptive fields of retinal ganglion cells are progressively larger the farther the cells are from the center of the retina; this accounts for the peripheral cells' inability to process fine detail and results in the blurry images discussed earlier.

As Kuffler systematically explored the retina by shining a tiny light on the receptive field of various retinal ganglion cells, he made a third discovery. He found that there are actually two types of retinal ganglion cells, that they are distributed equally throughout the retina, and that they differ in the nature of their central and surrounding regions. On-center neurons are excited when a small spot of light strikes the very center of their receptive field and are inhibited when light strikes the surrounding area. Off-center neurons have the opposite response: they are inhibited when a small spot of light strikes the center of their receptive field and excited when light strikes the surrounding area.

The discovery of this *center-surround organization* of retinal ganglion cells revealed that the visual system responds only to those parts of an image where the intensity of light changes. In fact, Kuffler's work showed that the appearance of an object depends principally on the contrast between that object and its background, not on the intensity of the light source.

This led Kuffler to another insight about vision: retinal ganglion cells do not respond to absolute levels of light; rather, they respond to the contrast between light and dark. The reason a large spot of light or diffuse light is not effective at stimulating retinal ganglion cells is because diffuse light covers both the excitatory and the inhibitory regions of each neuron's receptive field. His finding also provided a biological basis for the related principle that the brain is designed to ignore unchanging patterns and to respond selectively and dramati-

cally to contrasts. We can see this illustrated in Figure 15-12. The two gray rings are identical in hue, but one appears brighter than the other because the different backgrounds produce different contrasts. Finally, the center-surround organization of retinal ganglion cells explains why the visual system is so sensitive to discontinuities in the light falling on the retina and why neurons respond more strongly to sharp changes than to gradual changes in the luminance, or brightness, of an image. In this way Kuffler found, much as Gombrich had predicted, that only very specific visual stimuli will »pick the locks« on the neural gateways to vision.

In the course of a collaboration that lasted more than 20 years, David Hubel and Torsten Wiesel carried Stephen Kuffler's analysis of the early stages of vision into those regions of the brain and dramatically enhanced our understanding of how the various relays there process visual information. Their work and that of Semir Zeki of University College London provided our initial understanding of how the brain constructs the lines and contours necessary for object recognition. Zeki writes of Hubel and Wiesel's discovery:

> The discovery that … cells respond selectively to lines of specific orientation was a milestone in the study of the visual brain. Physiologists consider that orientation selective cells are the physiological building blocks for the neural elaboration of forms, though none of us knows how complex forms are neurologically constructed from cells that respond to what we regard to be the components of all forms. In a sense, our quest and our conclusion is not unlike those of Mondrian, Malevich and others. Mondrian thought that the universal form, the constituent of all other more complex forms, is the straight line; physiologists think that cells that respond specifically to what some artists at least consider to be the universal form are the very ones that constitute the building blocks which allow the nervous system to represent more complex forms. I find it difficult to believe that the relationship between the physiology of the visual cortex and the creations of artists is entirely fortuitous. [*Inner Vision*, pg 113]

Hubel and Wiesel also demonstrated in their animal studies that the computations of the visual system are hierarchical: an image enters the eye in an unprocessed form and is elaborated in the higher regions of the visual system into the image that we perceive. Moreover, they and Zeki discovered that neurons in the primary visual cortex, but especially those in the next two regions of the visual cortex, V2 and V3, respond to a virtual line as effectively as to a real line. As a result, these neurons are capable of completing contours, an ability that accounts for the phenomenon Gestaltists call closure.

An essential feature of object recognition, as we have seen, is the separation of a figure from its backgroun. Figure-ground separation is continuous and dynamic because the same elements that serve as part of the figure in one context can serve as part of the background in another. Some cells in the V2 region of the visual cortex that respond to virtual lines, like those in the Rubin vase, also respond to the sides of figures – their borders. But simply locating borders is not enough to distinguish a figure from its background. It is also necessary to infer from the context of the image which of the two regions abutting a border owns it. The question of border ownership is particularly salient in figure-ground switching, such as that in the Rubin vase and the rabbit-duck figure.

Zeki and his colleagues have imaged the brains of people during such figure-ground switching. Their experiments reveal that while looking at the Rubin vase, activity in the brain shifts from the face-recognition areas of the inferior temporal cortex to the area involved in object recognition in the parietal cortex. Moreover, each reversal is accompanied by a transient lull in the activity of the primary visual cortex. The activity of the primary visual cortex is essential for the perception of an image, be it a vase or two faces, but that activity must be stopped in order for a shift to occur. Finally, when the percept changes from one image to the other, the fronto-parietal cortex also becomes active. Zeki and his colleagues suggest that this activity represents top-down processing and that it determines which percept is consciously attended to. Thus, the fronto-parietal cortex is required to make the beholder aware that an image has just switched.

The reason line drawings succeed so brilliantly is that our brain cells are excellent, as Hubel and Wiesel found, at reading lines and contours as edges. The brain integrates simple lines to form the edges that differentiate a figure from its background. Each moment that our eyes are open, orientation cells in the primary visual cortex are constructing the elements of line drawings of the scene before us. Moreover, the primary visual cortex uses the inhibitory regions of those neurons' receptive fields to sharpen the contour lines of an image.

The neuroscientist Charles Stevens illustrates this point even more dramatically, using as an example a *Self-Portrait* of Rembrandt painted in 1699. Stevens compares a line drawing of the artist with the painting and shows that even though the line drawing does not bear a literal resemblance to the painting, the viewer can easily recognize a similar, three-dimensional image of Rembrandt in the drawing. Stevens argues that our ability to recognize a line drawing of Rembrandt instantly and effortlessly reveals a fundamental aspect of the way images are represented in the brain. For us to recognize a face, it is enough that the face be abstracted to just a few special contour lines, those defining the eyes, the mouth, and the nose. This allows artists room to make extreme distortions to a face without affecting our ability to recognize it. As Kris and Gombrich emphasized, this is why caricaturists and Expressionists are capable of moving us so powerfully.

Artists' great success in using contours to represent edges in drawings raises a profound question about our perception of art: is it learned or is it genetic? Do we learn the convention that artists can substitute contour lines for naturally occurring edges? Or does our visual system have a built-in capability for perceiving an artistic depiction of a face or a landscape as a real face or landscape?

In a larger sense, the ability of our visual system to interpret contours as edges in a drawing is but one example of our ability to see a three-dimensional figure on a two-dimensional background. This creative reconstruction, based on processing information from the retina, is particularly evident in the case of art. The retina, as we

have seen, extracts only limited information from the external visual world, so the brain must continuously make creative guesses and assumptions about what is out there to see. No matter how realistic a painting or drawing is, it always exists on a two-dimensional surface that must be elaborated upon.
Patrick Cavanagh, a student of perception, refers to the technical devices used by artists to create these illusions as *simplified physics*. He argues that our brain uses such simplified physics to interpret a two-dimensional image of art as a three-dimensional image, as illustrated above in the line drawing of Rembrandt:

> The rules of physics that apply in a real scene are optional in a painting; they can be obeyed or ignored at the discretion of the artist to further the painting's intended effect. Some deviations, such as Picasso's skewed faces or the wildly colored shadows in the works of Matisse and other Impressionists of the Fauvist school, are meant to be noticed as part of the style and message of the painting. There is, however, an »alternative physics« operating in many paintings that few of us ever notice but which is just as improbable. These transgressions of standard physics – impossible shadows, colors, reflections or contours – often pass unnoticed by the viewer and do not interfere with the viewer's understanding of the scene. This is what makes them discoveries of neuroscience. Because we do not notice them, they reveal that our visual brain uses a simpler, reduced physics to understand the world. Artists use this alternative physics because these particular deviations from true physics do not matter to the viewer: the artist can take shortcuts, presenting cues more economically, and arrange surfaces and lights to suit the message of the piece rather than the requirements of the physical world. [*The Artist as Neuroscientist*, pg 301]

The brain's ability to tolerate illusions or simplified physics in works of art demonstrates its remarkable visual flexibility. This flexibility has allowed artists across the ages to take dramatic liberties in their

presentation of a visual scene without necessarily sacrificing the believability of the image – liberties ranging from the subtle manipulations and alterations of light and shadow by artists in the Renaissance to the overt and drastic spatial and chromatic distortions of the Austrian Expressionists. The types of distortions we tend to tolerate and the assumptions about physics made in these pictorial cues give us great insight into how the brain makes sense of images.

Donald Hoffman, another student of visual perception, has created an example of our ability to use simplified physics to re-create what we see in a work of art. He calls this paradigm the »ripple.« The ripple is a drawing on a flat, two-dimensional surface, but it appears to be undulating in space like waves on a pond. As is true of other convincing three-dimensional drawings, you will not succeed in seeing the ripple as flat.

The ripple has three parts: a bump in the center, a circular wave around the bump, and another circular wave on the outside. As an aid to discussing the figure, Hoffman has drawn dashed curves along the boundaries of these parts, delineating the troughs between the waves. If you turn the figure (or your head) upside down, you will see an inverted ripple with new parts. The dashed curves now lie on the crests of the waves and not, as before, in the troughs. Turning the figure upright restores the original parts. If you turn the figure slowly, you can catch it in the act of flipping from one set of parts to the other.

The ripple is an impressive feat of your own construction. The curves you see on the page, and the ripply three-dimensional surface, are completely constructed by your brain. Hoffman writes: »You also organize the ripple into three concentric parts, which look like water waves; the dashed contours in the troughs mark roughly where one part stops and the next begins. You aren't a passive perceiver of parts, but their active creator« [*Visual Intelligence*, pg 2-3].

We can now begin to appreciate how important unconscious mental processes are to the perception of art. We are also beginning to see the value of Gombrich's ideas about figural primitives from the historical perspective of the evolution of painting. We see that even the

earliest artists we know, the cave painters of Southern France and Northern Spain, had already discovered what Gombrich called the master keys for opening the neural locks of our unconscious senses. The work of Kuffler, Hubel, and Wiesel on low- and intermediate-level visual processing and, as we shall see in the next two chapters, subsequent studies of high-level visual processing have given us valuable insights into how the unconscious brain creates what we see.

How is facial representation reflected in cellular terms? Do some cells in the brain constitute the building blocks of a face, and do their combined activities constitute representations of a face? Or do specific cells encode the image of specific faces? Two possible answers to this question arose in the 1970s in response to the work of Hubel and Wiesel. One was the hierarchical, or holistic view, which held that there must be specific »pontifical« cells at the top of the hierarchy that encode images of persons – your grandmother, for example – or any other complex object, for that matter. According to this view, you might have more than one pontifical »grandmother« cell, and these cells might respond to different aspects of your grandmother, but each cell would carry a meaningful representation of her image. The alternative parts-based, or distributed representation, view was that you have no grandmother cells that encode her particular image. Instead, the representation of your grandmother resides in coded patterns of activity in a large ensemble of neurons, a neuronal college of cardinals.

The first person to attempt to distinguish between these two alternatives was Charles Gross. Picking up on the work of Hubel, Wiesel, and Bodamer, Gross began in 1969 to record from single cells in the inferior temporal cortex of monkeys, the region that, if damaged in people, can cause prosopagnosia. Gross found, amazingly, that some cells responded specifically to people's hands, while other cells responded to their faces. What is more, the cells that responded to hands did so only when the individual fingers were visible: they did not respond when there was no separation between the fingers. These cells also responded regardless of the orientation of the hand –

whether, for example, the thumbs and fingers pointed up or down. The cells that responded to faces were not selective for any unique face but for the general category of faces. This suggested to Gross that a particular face, a particular grandmother, is represented by a small, specialized collection of nerve cells – an ensemble of grandmother cells, or proto-grandmother cells.

The late twentieth century saw the advent of imaging methods such as positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) that revolutionized the study of the brain. They allowed scientists to measure blood flow and oxygen consumption by nerve cells, activities that are thought to correlate with nerve cell activity. These methods do not show the activity of individual cells, but rather the activity of regions of the brain containing many thousands of cells. Nevertheless, for the first time, neuroscientists had a way to correlate mental functions with various brain regions and to study those functions in the living, behaving, and perceiving human brain.