Chapter 2
A Primer on Neurobiology and the Brain for Information Systems Scholars

Abstract This chapter provides an introduction to neurobiology and the brain. Specifically, it summarizes basic knowledge on human physiology for IS researchers who want to become familiar with basic concepts and mechanisms from neurobiology and neuroscience. We start with a description of fundamental concepts in genetics. A description of the human nervous system follows, including an account of the major components and basic functioning of the nervous system. Next, we discuss the human brain. Specifically, we outline important brain structures along with their major functions. We also summarize basic terminology used in neuroscience to describe locations in the brain. Due to its usefulness for IS research, this contribution also describes fundamentals of the structure and functioning of the autonomic nervous system. We close the chapter with a brief reflection on brain plasticity.

2.1 Genes: The Foundations of Life

Over the past several decades, genetics research has revealed fascinating insights regarding human health and appearance, as well as thoughts, feelings, and behavior. Scientific understanding of the genetic and physiological foundations of psychological phenomena has increased to a level where it is possible to directly influence neurobiological structures, including the development of drugs that affect brain activity via neurotransmitters, thereby restoring normal psychological functioning of humans with otherwise abnormal characteristics. Here, we describe selected foundational concepts from the study of genetics, with the goal of introducing basic concepts that instigate further examination of specialized literature.

The question of how nature *and* nurture contribute to the manifestation of human behavior has been one of the most fundamental research issues in psychology. It also holds strong relevance in IS research that focuses on user behavior. Importantly for behavior research, a specific behavioral trait is *not* associated with a single gene, but is, rather, produced by many genes acting in concert with an individual's

environment. The basic mechanism of genetic influence on a behavioral trait follows a process (Gazzaniga et al. 2010): Genes predispose individuals to specific behaviors (e.g., risk-taking, trust) that are also influenced by physical and social environment (e.g., nutrition, support by other individuals) $\rightarrow$ those behaviors elicit specific responses from the social environment $\rightarrow$ the resulting mutual interactions shape phenotypes such as an enduring personality trait (e.g., trust propensity), via experience and corresponding biological changes (e.g., structural alterations in the brain). It is important to note, however, that the relevance of an enduring behavioral trait for individual behavior in a specific situation may vary significantly. An understanding of basic genetic concepts helps to clarify the relationship to behavior.

The genome is the entirety of an organism's hereditary information, and it is embodied within almost every cell. The genome can be viewed as a blueprint that provides instructions for the development and functioning of an organism. In human development, the instructions for the growth of organs (e.g., heart, lungs, brain) are transmitted by the genome, as is information that determines appearance (e.g., shape of the head and face, eye color). Whether a specific cell becomes part of an organ, or of any other part of the body, is determined by which genes are turned on or off within that cell. This "turning on/off" is determined by an organism's environment.

It is estimated that the human body consists of 10^{14} cells, and within each cell are chromosomes. A chromosome is a threadlike linear strand of DNA and associated proteins in the cell nucleus that carries the genes and functions in the transmission of hereditary information. A normal human being has 23 pairs of chromosomes—one half of each pair comes from the father, and the other half from the mother. One pair determines an individual's sex (male = XY, female = XX). A chromosome, in turn, consists of deoxyribonucleic acid (DNA), which is a substance built up of two intertwined strands of molecules. The sequence of these molecules along each DNA strand determines the production of specific proteins, which for humans number in the thousands. These proteins affect cell activity in order to carry out specific tasks in the body. A gene, finally, is a segment of the DNA that affects the production of proteins.

Figure 2.1 summarizes important concepts relevant to biology and genetics (human body, cells, chromosomes, DNA, genes), and illustrates that appearance, health, thoughts, feelings, and behavior are affected by both biological factors (top) and an organism's physical and social environment (bottom). Moreover, the double-sided arrows show that an interrelationship exists between biological factors and the physical and social environment.

Every human has two copies of each gene (inherited from father and mother). A large number of genes are identical for all humans, but a small number differ among individuals (<1 %). Such different forms of the same gene (i.e., genes with slight differences in their sequence of DNA bases) are referred to as alleles; the alleles contribute to individual differences in humans. Genes may vary significantly in size, typically ranging from several hundreds of DNA bases to more than two million bases.
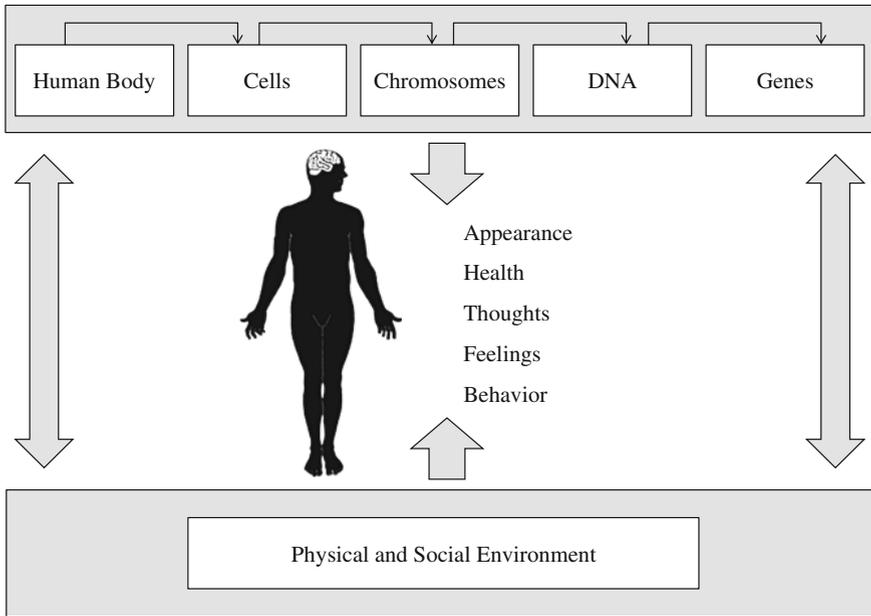
Fig. 2.1 Biology, environment, and behavior

A major breakthrough in genetics research occurred with the *Human Genome Project*, an international research initiative carried out between 1990 and 2003. This project pursued two primary goals, namely identification of all 20,000–25,000 genes in human DNA, and determination of the sequences of the chemical base pairs that make up human DNA (see http://genomics.energy.gov/). Mapping of the entire structure of human genetic material is important for the development of effective treatments for many diseases; moreover, it enables better understanding of genetic influences on psychologically and socially relevant variables (e.g., intelligence, trust), and the development of psychiatric interventions (e.g., psychotropic drugs).

Figure 2.2 conceptually depicts a cell (and its nucleus), chromosomes, DNA, genes, and the nucleobases A, G, T, and C (Adenine, Guanine, Thymine, and Cytosine, which are the four primary nucleobases in DNA). The nucleobases form specific base pairs. Specifically, A pairs only with T (and vice versa), while G pairs only with C (and vice versa). Moreover, the illustration shows the double helix structure of DNA (Watson 1968).

To develop a preliminary understanding on this theme for people who are not trained in genetics, the Centre for Genetics Education in Australia (see http://www.genetics.edu.au/) has published a useful "book metaphor." Imagine a publication entitled "Book of Life" that is made up of two volumes. One volume is given to you by your father and one by your mother, just as one half of your genetic material comes from your father and the other half comes from your mother. Next, both
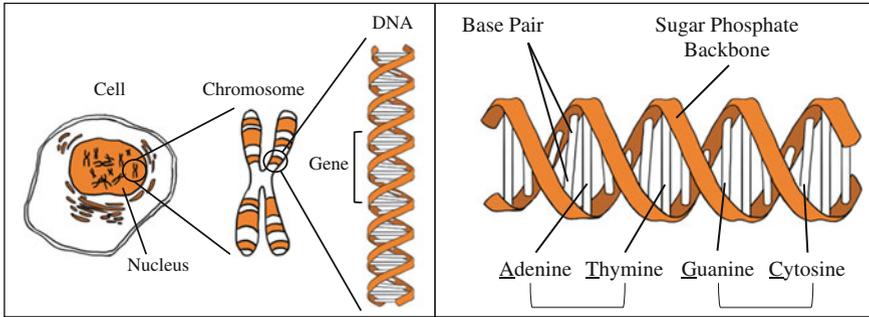
Fig. 2.2 From a cell to a gene (*left*); DNA double helix structure (*right*)

volumes contain 23 chapters each, representing the chromosomes (which are part of your body cells). Each of the 23 chapters has a different number of pages, representing the genes. In the case of books, chapters may contain 10, 20, or 30 pages. With respect to the number of genes, a chromosome may consist of fewer than 100 to several thousands. (Remember that the total number of genes across all $23 \times 2 = 46$ chromosomes is 20,000–25,000.) Finally, examination of the words on the pages reveals that all the words consist of three letters only (referred to as triplets), and the alphabet itself consists of only four letters, namely A, G, T, and C. The body reads the triplets in the DNA to know how to grow, develop, and guide cell functioning (more precisely, triplets tell the cell to produce a particular amino acid, the building blocks of proteins).

From an IS perspective, it is of particular importance to understand that biological factors as well as environmental factors affect human behavior, and that the complex interplay between these factors makes it difficult to disentangle the specific influence of each on behavior. Despite this difficulty, the discipline of *behavioral genetics* pursues this goal of disentanglement. This discipline studies the inheritance of behavioral traits, with a focus on the two important concepts of genotype and phenotype. *Genotype* is the genetic makeup of an organism that is determined at the moment of conception. *Phenotype*, in contrast, is an organism's observable physical characteristics (e.g., appearance, behavior), which are typically the result of the interplay between genetic and environmental influences.

For example, monozygotic twins share the same genes, and therefore their genetic makeup is identical. Because genetic makeup affects physical features such as skin color, monozygotic twins should exhibit the same skin color. However, because skin color is not only affected by genes, but also by one's environment (in some regions there is much more sunlight than in others), an organism's phenotype might differ significantly even though genetic makeup is similar (shared by family members) or even identical (shared by monozygotic twins). Thus, if monozygotic twins live in regions with significant differences in sunlight, their skin colors might differ to a notable degree.

In addition to basic human characteristics such as skin color, behaviorally relevant traits (e.g., intelligence, personality, fears, risk-taking, or trust) also have a genetic basis. Despite this genetic influence, however, evidence indicates that behaviorally relevant traits, particularly, are the outcome of the interplay between genetic and environmental influences (e.g., Cacioppo et al. 2000).

A final important concept is *heritability*, which is a statistical measure of the variation in a trait caused by differences in heredity (e.g., Gazzaniga et al. 2010). For example, if, within a specific population, a trait such as trust behavior has heritability of 20 %, a 20 % trust behavior variation among individuals within the population is genetic (Cesarini et al. 2008; Riedl and Javor 2012).

2.2 The Human Nervous System

2.2.1 Parts of the Nervous System

The human nervous system is necessary for perceptions, thoughts, feelings, and behavior. It consists of two parts—the central nervous system (CNS; brain and spinal cord) and the peripheral nervous system (PNS; neural tissue except for the CNS). Even though these two systems are anatomically separate units, their functions are interrelated (Gazzaniga et al. 2010). Figure 2.3 illustrates the components and the main functions of the human nervous system.

The functioning of the nervous system can be described in five stages (shown in Fig. 2.3). First, receptors detect changes in the internal and external environments. Such receptors are somatic-sensory (e.g., located in the skin to provide information on touch, pressure, pain, and temperature sensations), visceral-sensory (to monitor the state of internal organs), or specialized to provide olfactory, taste, visual, acoustic, and balance information. Second, the information collected by the receptors in peripheral tissues and organs is brought to the brain via the spinal cord. The sensory division of the PNS is important in this stage. Third, once the information has entered the brain, it is integrated and processed in different parts of the brain; the number of brain regions involved in information processing, as well as the exact interplay of these regions, depends on the type of information and the situation, among other factors. Fourth, the brain sends commands to peripheral tissues and systems via the motor division of the PNS. Here, the somatic nervous system (SNS) and/or the autonomic nervous system (ANS) come into play; the SNS controls skeletal muscle contractions, while the ANS provides regulation of smooth muscles (e.g., iris of the eye), cardiac muscles, and glands, among other body structures. Fifth, the effectors of signals from the brain may alter the activities of the different target organs, which may lead to behavior changes.

From an IS standpoint, both the brain (Dimoka et al. 2012; Riedl et al. 2010) and the ANS (Riedl et al. 2014) deserve special attention. Because the brain is the central information processing organ, a basic knowledge of the anatomy of the brain is
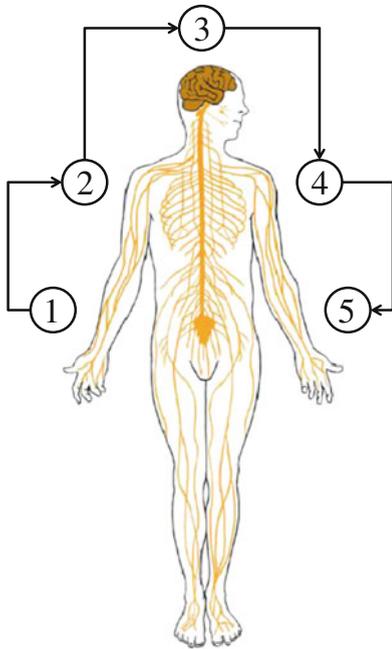
(1) Receptors (e.g., somatic-sensory, visceral-sensory, or specialized receptors such as visual) detect changes in the internal and external environments.

(2) The information collected by the receptors in peripheral tissues and organs is brought to the brain via the spinal cord. The sensory division of the peripheral nervous system (PNS) is important in this stage.

(3) Once the information has entered the brain, it is integrated and processed in different parts of the brain.

(4) The brain sends commands to peripheral tissues and systems via the motor division of the PNS. The somatic nervous system (SNS) controls skeletal muscle contractions, while the autonomic nervous system (ANS) provides regulation of smooth muscles, cardiac muscles, and glands.

(5) The effectors of signals from the brain may alter the activities of the different target organs, which may lead to behavior changes.

Fig. 2.3 Functioning of the human nervous system

indispensable. The ANS, in contrast, is highly relevant in IS research due to its importance in stress situations (Riedl 2013), and is crucial in many other IS research situations, including emotions and mental workload. Stress is a phenomenon that pervades virtually all domains of human life, including human interaction with information and communication technologies, and interaction among humans in IS contexts (e.g., computer users and software engineers). After an outline of the basic mechanisms of human nervous system functions, we discuss both the brain and the ANS, creating a conceptual basis for the sections on brain and ANS functioning that follow.

2.2.2 Functioning of the Nervous System

The core element of the nervous system is the *neuron*, which is an electrically excitable nerve cell that receives, processes, and sends information. Operation of a neuron is based on electrical impulses, and communication with other neurons occurs through chemical signals. A typical neuron consists of a cell body (referred to as the soma), dendrites, and an axon. Information processing takes place in the soma, receipt of information occurs via dendrites, and an axon sends information (see Fig. 2.4). Typically, a cell body has multiple dendrites, but only one axon (note
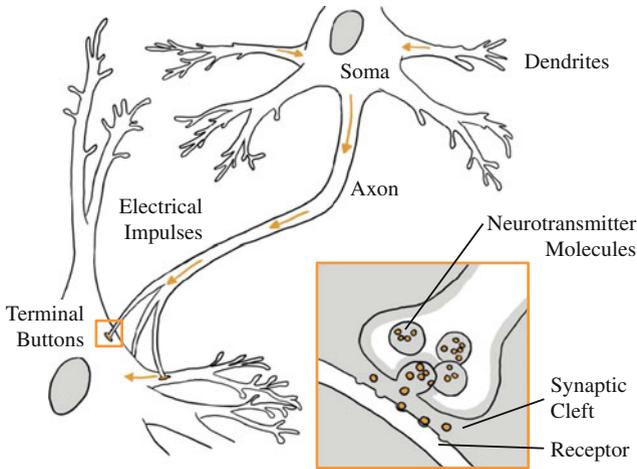
Fig. 2.4 Neuron and information transmission via a synapse

that an axon can nevertheless have many branches before its termination). Networks of neurons form the physiological basis for the development of psychological activity. Such networks are referred to as *neural networks*, and the human brain is estimated to consist of 100 billion neurons, with each neuron estimated to have connections to 10,000 other neurons.

Generally, neurons do not undergo cell division. Thus, the total number of neurons does not increase during life, and a newborn already has the 100 billion neurons in the brain. Despite this fact, however, it is important to note that generation of new neurons has *sometimes* been observed in specific brain structures (e.g., hippocampus). In general, what is changing in an individual's brain is the number of connections between the neurons, as a consequence of experience (learning). Another important fact is that the number of neurons decreases naturally with aging, as it does as a result of a number of other factors, such as alcohol consumption and neurological disease.

Three basic types of neurons exist (Gazzaniga et al. 2010). First, *sensory neurons* detect information from the external environment and send that information to the brain (via the spinal cord). Because information is sent to the brain, these neurons are also called afferent neurons. Second, *motor neurons* direct muscles to contract or relax, generating movement. Because information is sent from the brain, these neurons also called efferent neurons. Third, *interneurons* are nerve cells that communicate within local circuits. Thus, these neurons integrate information within a narrow region, rather than transmitting information to distant brain areas or other parts of the body (e.g., muscles).

Information is conveyed to dendrites via an axon. At the end of an axon are *terminal buttons*, small nodules that receive electrical signals and then release chemical substances (neurotransmitters) to the *synapse* (see Fig. 2.4). This area is

located between the axon of a sending neuron and the dendrites of receiving neurons. The neurotransmitter molecules are necessary to transmit information from one neuron to another one, where receptors exist for specific neurotransmitter molecules. To secure rapid transmission of information along an axon, it is insulated by a myelin sheath (consisting of glial cells).

A neuron can be active or inactive. When a neuron is resting, the ratio of negative to positive ions is greater inside the neuron than outside, which is referred to as *resting membrane potential*. When neural communication occurs, a neuron responds to incoming stimulation by changing electrically. The electrical signal passes along the axon, causing the release of neurotransmitters from terminal buttons into a synapse. This phenomenon is referred to as *action potential* or *neural firing*. Signals that arrive at dendrites can be either excitatory or inhibitory; while excitatory signals depolarize the cell membrane, inhibitory signals hyperpolarize the cell membrane (Gazzaniga et al. 2010). Depolarization increases a neuron's firing probability, while hyperpolarization decreases firing probability.

The signals received by a neuron's dendrites are summed, and if the total amount of excitatory input reaches a specific level, an action potential develops. Note that a neuron works on an *all-or-none-principle*, which means that a neuron cannot partially fire. Thus, a neuron either fires or does not fire, and the firing of a neuron cannot be strong or weak (or of any other magnitude). How often a neuron fires is a function of stimulation strength—is dependent upon the number and frequency of excitatory and inhibitory signals.

Information transmission from one neuron to another one is based on neurotransmitters, which are sent by a presynaptic to a postsynaptic neuron. Once neurotransmitters are released at the synaptic cleft, they bind to receptors of the postsynaptic neuron. This binding process causes an excitatory or inhibitory signal, thereby initiating or suppressing an action potential. Note that one specific neurotransmitter can send excitatory or inhibitory signals, depending on specific characteristics of the receptor. During the past century, research has identified a large number of neurotransmitters (>60 chemical substances; see Gazzaniga et al. 2010), each of which has specific functions (see Table 2.1 for a list of fifteen important neurotransmitters and their functions).

In the 1920s, the first of these chemical substances (*acetylcholine*) was discovered. Otto Loewi (1873–1961), a German pharmacologist, showed that it is possible to slow a frog's heart rate by experimentally controlling the amount of saline solution existing around the vagus nerve. The vagus nerve is important for transmitting information about the state of the viscera to the brain, thus being mainly afferent. Loewi's result provided confirmation that sympathetic regulation of cardiac function is mediated through chemical substances in the body, and was a discovery that led to Loewi being awarded the 1936 Nobel Prize in Physiology or Medicine.

Neurotransmitters fill and stimulate receptors in the postsynaptic neuron, thus blocking new signals until their effect is terminated. This termination may be caused by three major mechanisms (Gazzaniga et al. 2010). First, it is possible that a neurotransmitter is taken back into the presynaptic terminal buttons (reuptake).

Table 2.1 Neurotransmitters and important functions

Neurotransmitter	Important functions (Examples)
Acetylcholine	Motor control (muscles), learning, memory, dreaming
Adrenaline	Energy, arousal, stress, activation, muscle contraction
ACTH	Stress (precursor substance of cortisol)
Dopamine	Motor control (muscles), reward, motivation
Endorphin	Reward, pain reduction, relaxation
GABA	Anxiety, intoxication, inhibition of neural firing
Glutamate	Learning, memory, enhancement of neural firing
Glycine	Sleep, inhibition of neural firing
Histamine	Sleep, immune system function, pain perception
Melatonin	Sleep, dreaming, immune system function, learning, memory
Noradrenaline	Arousal, activation, stress
Oxytocin	Social bonding, trust, fear reduction, approach behavior
Serotonin	Emotion, impulsiveness, sleep, dreaming
Substance P	Pain perception, mood, anxiety
Vasopressin	Aggression, stress, distrust, avoidance behavior

Second, it also happens that an enzyme destroys the transmitter substance in the synaptic cleft (enzyme deactivation). Third, specific receptors monitor the amount of a neurotransmitter in the synapse, and once a specific threshold is exceeded a signal is sent to the presynaptic neuron to stop neurotransmitter release (autoreception).

In the context of neurotransmitters, two other important concepts are agonist and antagonist. An *agonist* is a chemical substance (e.g., a drug) that enhances the actions of a specific neurotransmitter. In contrast, an *antagonist* is a substance that blocks the actions of a specific neurotransmitter. There are different ways in which agonists and antagonists can exert their influence on neurotransmitter action (Gazzaniga et al. 2010). Agonist drugs can (i) increase the release of neurotransmitters, (ii) block the reuptake of neurotransmitters, and (iii) mimic a specific neurotransmitter in order to bind to receptors, thereby increasing the neurotransmitter's effects. In contrast, antagonist drugs can (i) block the release of neurotransmitters, (ii) destroy neurotransmitters in the synapse, and (iii) mimic a specific neurotransmitter in order to block the actual neurotransmitter from binding to receptors.

As an example, cocaine is an agonist drug because it blocks reuptake of the neurotransmitters serotonin, noradrenaline, and dopamine in specific brain areas (e.g., mesolimbic structures). Conversely, an analgesic (a substance used for pain relief) operates as an antagonist drug (e.g., morphine or other opiates; however, intake of such substances may result in physiological and psychological addiction). Note that drugs related to neurotransmitters are also used to treat diseases or to alleviate symptoms. L-DOPA, for example, is a precursor substance of the neurotransmitters dopamine, noradrenaline, and adrenaline (catecholamines), and it

is used as a neuroactive drug in the clinical treatment of Parkinson's disease (where loss of specific neurons results in dopamine deficiency). L-DOPA, among other effects, ameliorates tremor, a major symptom in Parkinson's disease.

2.3   The Human Brain

2.3.1   Major Structures of the Brain

The adult human brain has an average cranial capacity of ± 1400 cm^3 and an average weight of ± 1300 g. Brain tissue is soft, and feels like a hard-boiled egg. A visual inspection of the interior of the brain reveals that it consists of gray matter and white matter. *Gray matter* consists primarily of neural cell bodies (where information integration and processing take place) and is located in different areas of the brain, including the cerebral cortex, cerebellum, various subcortical structures (e.g., thalamus, hypothalamus, basal ganglia), and the brainstem. *White matter*, however, consists mainly of glial cells (which are responsible for holding other neurons in place, and supplying them with nutrients and oxygen) and myelinated axons (responsible for information transmission) (see also Fields 2008).

Together with the spinal cord, the brain forms the CNS. The spinal cord thickens at the base of the skull, where it transforms into the *brainstem*, a structure that can be separated anatomically into three parts (medulla oblongata, pons, and midbrain). Functionally, the brainstem controls the most basic functions in humans, such as heartbeat, breathing, and regulation of the sleep-wake cycle. Another part of the brain is the *cerebellum*, which is a protuberance connected to the back of the brainstem (see Fig. 2.5, left panel). The major function of the cerebellum is regulation of motor control and coordination.

The outer layer of the cerebral hemispheres is referred to as the *cerebral cortex*. Visually, this structure can be identified easily by its wrinkled appearance.
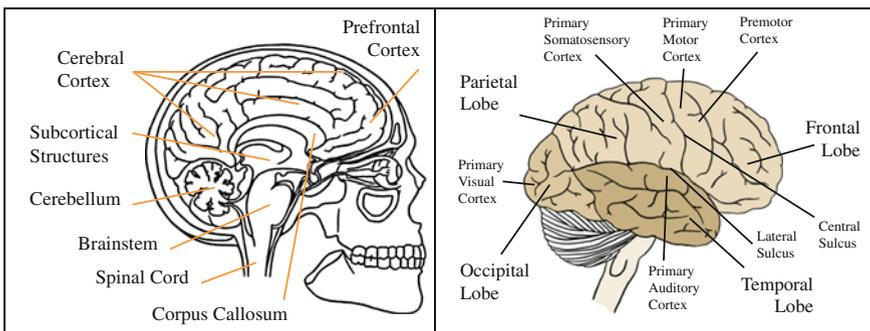
Fig. 2.5 Major structures of the brain (*left* sagittal view); Lobes of the Brain and Major Cortices (*right* lateral view)

Functionally, the cerebral cortex is of particular importance for perception, thinking, and consciousness, thereby serving to distinguish humans from most other species.

The cerebral cortex consists of four lobes, namely frontal, parietal, temporal, and occipital (see Fig. 2.5, right panel), and the hemispheres are connected by the *corpus callosum*, a structure that consists of a large number of axons that secure the information flow between left and right hemispheres (see Fig. 2.5, left panel). The *central sulcus* (also known as central fissure) separates the parietal lobe from the frontal lobe, as well as dividing the primary somatosensory cortex from the primary motor cortex. In contrast, the *lateral sulcus* (also known as lateral fissure) separates the temporal lobe from both the parietal lobe and the frontal lobe (see Fig. 2.5, right panel).

The *frontal lobe* has several important functions, two of which are conscious thinking (planning, reflection, and anticipation of possible future states) and movement: conscious thinking is implemented mainly in the *prefrontal cortex*, while movement is implemented in the *premotor cortex* and the *primary motor cortex*. Note that neurons in the motor areas are directly connected to the spinal cord (where muscles are controlled), and that activity in the left hemisphere controls the right extremities (e.g., hand), while activity in the right hemisphere controls the left extremities.

The *parietal lobe* has multiple functions, with integration of sensory information, as well as spatial navigation, among the most important. A major part of this lobe is the *primary somatosensory cortex*, a structure primarily responsible for the sense of touch. In this context, the *cortical homunculus*—a pictorial representation of anatomical structures, including the primary somatosensory cortex and the primary motor cortex (the brain areas supporting perception and exchange of sensory and motor information)—is essential, a concept developed by Wilder Penfield (1891–1976). Thus, a homunculus is a map of sensory and motor cortices of the brain, illustrating their connections to the limbs and organs of the human body. This map shows, for example, that sensations that are, organically, in proximity (e.g., lips and tongue) are also in proximity anatomically in the cortex; moreover, it illustrates that much more cortical tissue is devoted to organs for which humans have pronounced sensations (e.g., face and fingers). The concept of cortical homunculus is illustrated in Fig. 2.6 ("homunculus" originating from the Latin term for "little man").

The *temporal lobe* also has multiple functions, of which hearing has more notable relevance. This specific function is implemented in the *primary auditory cortex* (see Fig. 2.5, right panel). Moreover, important brain regions for the processing of emotions, as well as memory, are located in the temporal lobe, such as the amygdala and hippocampus. The Wernicke's area, also, is located in this lobe—a brain area important for speech comprehension (typically in the dominant hemisphere, which in a majority of people is the left hemisphere).

The *occipital lobe* is mainly related to vision. The largest segment of the visual areas in this lobe is the *primary visual cortex* (see Fig. 2.5, right panel; note that this area is also referred to as the striate cortex or V1). There are further visual areas
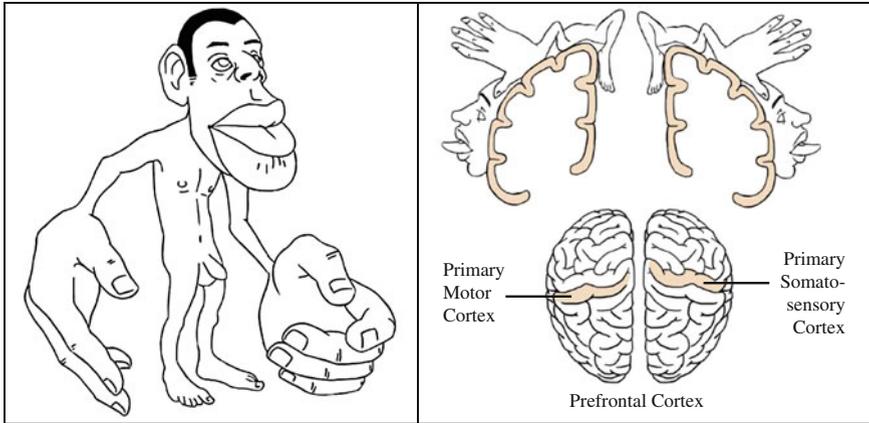
Fig. 2.6 Cortical homunculus (*left* "little man" illustration; *right* involved cortical areas)

(referred to as extrastriate cortices, namely V2, V3, V4, and V5). Basic visual information, particularly spatial relationships among objects, is typically relayed directly from the eye to V1 (via the lateral geniculate nucleus of the thalamus). Thus, processing of this basic information usually takes place in the striate cortex, while further visual attributes (e.g., form, direction, color, motion) are processed primarily in the extrastriate cortices.

Figure 2.5 (left) shows that both the cerebral cortex and subcortical structures are large and important areas of the human brain. Because these two areas contain a number of specific brain regions that are important for the neural implementation of mental processes that have relevance for IS research (e.g., higher cognitive processes and emotions), we will discuss these two areas in more detail.

2.3.2   The Cerebral Cortex

The *cerebral cortex* can be divided into 52 *Brodmann Areas* (*BA*), which are cortical areas defined on the basis of their cytoarchitecture (i.e., the structure and organization of cells). Even though this map of the cerebral cortex was developed a century ago by Korbinian Brodmann (1868–1918), revised versions are still used widely in brain research and clinical contexts. Figure 2.7 illustrates the locations of BA from both a lateral (left) and medial (right) view. Each BA is related to one or more functions or mental processes (see Table 2.2). Specific areas shown exist only in non-human primates (e.g., BA 15).
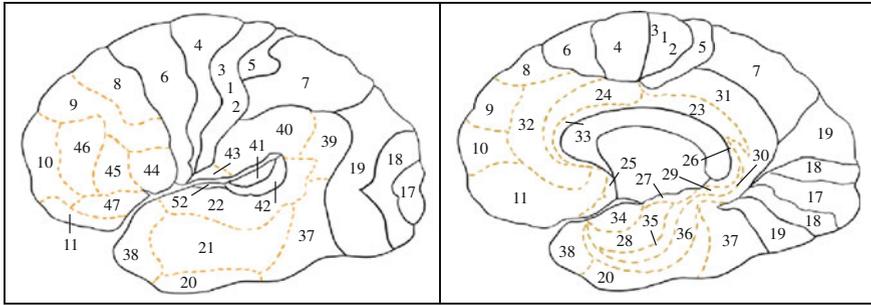
Fig. 2.7   Brodmann areas (*left* lateral view, *right* medial view)

Table 2.2   Selected Brodmann areas (BA), name of region, and functions/mental processes

| BA	Name of region	Function/mental process (Examples)
1, 2, 3	Primary somatosensory cortex	Sense of touch
4	Primary motor cortex	Planning of movement
6	Premotor cortex	Planning of movement
9, 46	Dorsolateral prefrontal cortex	Thinking, working memory, fairness
10	Ventromedial prefrontal cortex	Executive functions, abstract thinking
11, 12	Orbitofrontal cortex	Emotion, reward, decision-making
13, 14	Insular cortex	Homeostasis, emotion, disgust, risk
17	Primary visual cortex (V1)	Vision
18	Secondary visual cortex (V2)	Vision
19	Associative visual cortex (V3–V5)	Vision
22, 41, 42	Auditory cortex	Hearing, speech comprehension
24, 32, 33	Anterior cingulate cortex	Decision-making, conflict monitoring
37	Fusiform gyrus	Face recognition

2.3.3   Subcortical Structures

In contrast to the cerebral cortex, which mainly consists of visible areas on the surface of the brain, *subcortical structures* are not directly visible. These brain structures, however, are essential for understanding psychological functions. Major subcortical structures are the thalamus, hypothalamus, hippocampus, amygdala, cingulate gyrus, and the basal ganglia (see Fig. 2.8).

The *thalamus* has been labeled the "gateway to the brain" (e.g., Gazzaniga et al. 2010, p. 109) because it receives most of the incoming sensory information before the information reaches the cerebral cortex. Functionally, it is highly important for the regulation of alertness, attentiveness, sleep, and consciousness.

The *hypothalamus* has been labeled as the "master regulatory structure" in the brain (e.g., Gazzaniga et al. 2010, p. 109) because it receives input from many other brain and body structures in order to regulate a number of important physiological
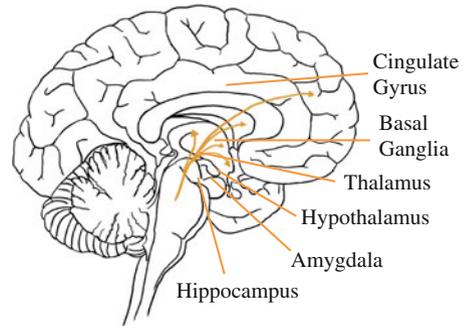
functions, such as regulation of body temperature, blood pressure, and blood glu-
cose levels. Moreover, this brain region links the nervous system to the hormone
system, a process mediated by the pituitary gland (also known as hypophysis). For
example, in stress situations, activity in the hypothalamus stimulates the release of
stress hormones such as adrenaline (also known as epinephrine), noradrenaline
(also known as norepinephrine), and cortisol (note that the influence of the
hypothalamus on these hormones is mediated by several other physiological pro-
cesses and substances; e.g., Tsigos and Chrousos 2002). Functionally, the
hypothalamus is also involved in regulation of basic drives such as hunger, thirst,
fatigue, sleep, and attachment behaviors.

The *hippocampus*, if viewed as a whole, has the shape of a curved tube, and is
often described as having the shape of a seahorse. The major functions of the
hippocampus are consolidation of information from short-term to long-term
memory, and spatial navigation. Research indicates that stress may result in
structural changes in the hippocampus, a fact that may also negatively affect
memory performance (e.g., Kim and Diamond 2002). Moreover, voxel-based
morphometry (VBM) evidence has shown that specific parts of London taxi drivers'
hippocampi are significantly larger, relative to those of control subjects (Maguire
et al. 2000). This suggests that the adult human brain may adapt to environmental
demands (processing a large amount of spatial information) in order to develop
specific skills (spatial navigation). Note the position that partial or complete reliance
on a navigation system during car driving may have an opposite effect.
Consequently, as is shown in an example based on the relationship between the
hippocampus and spatial navigation, the brain can be trained like a muscle.

The *amygdala* is a brain structure that is important for the neural implementation
of strong emotions (e.g., fear, anger), arousal, and reward, among others. Moreover,
the amygdala together with the hippocampus has been found to be specifically
related to emotion-based memory (Gazzaniga et al. 2009). Essentially, information
storage in the hippocampus is mediated by amygdala activity, so that arousal, rather
than the valence of emotion (positive or negative), mediates memory.
Consequently, arousing events are remembered longer than non-arousing events,
and the amygdala plays a key role in this specific memory function.

The *cingulate gyrus* is located above the corpus callosum, which has several different functions, such as emotion and cognitive conflict processing, as well as anticipation of reward (a fact that holds true particularly for the anterior cingulate cortex, ACC). Moreover, this brain region has been shown to be important in decision-making situations in general, and to play a key role in inferences regarding the mental states of other people (referred to as mentalizing).

The *basal ganglia* are related to various functions, such as motor control, reward processing, learning, and motivation. Among the several sub-components of the basal ganglia are the striatum (caudate nucleus and putamen), nucleus accumbens, and substantia nigra. The association of the *striatum* with value, pleasure, and reward, as well as with the anticipation of value and reward, is well established. Moreover, the relationship of the striatum to trusting intentions and social cooperation has been documented. Dopamine, an important neurotransmitter, is closely associated with the striatum. This hormone has been found to be correlated with pleasure, value, and reward in the brain, providing positive feelings and reinforcement that motivates proactive behavior (e.g., Schultz et al. 1997). The *nucleus accumbens* is also related to value, pleasure, and reward, though its associations extend to addiction. Finally, dysfunction of the basal ganglia is linked to several neurological diseases (e.g., Parkinson's disease), and is also associated with compulsive disorders such as compulsive purchasing behavior.

2.3.4 Locations in the Brain

Many brain research studies seek to relate specific mental processes or perceptions to activity in one or more brain areas. Similarly, IS scholars seek to gain a better understanding of the nature, antecedents, and consequences of relevant theoretical constructs (e.g., trust) by conducting brain imaging studies (particularly studies based on fMRI). Thus, it is crucial for IS scholars to develop an understanding of the terminology used in brain research. Two important categories of terms are those used to describe locations in the brain, as well as directions related to nervous system functioning.

Specific terminology used to describe locations in the body, brain, and spinal cord must have a reference point for the locations, such as other body parts or the face of a corresponding individual (e.g., Kolb and Whishaw 2009, pp. 52–54). The following terms are used extensively in brain research to describe locations in the brain such as lateral/medial, anterior/posterior, dorsal/ventral, superior/inferior, as well as others (e.g., rostral/caudal). Additional important neuroscience terms describe the direction of a cut through the brain, which can be frontal (coronal), horizontal, or sagittal. The figures in this section illustrate major planes of section (cuts) through the brain, along with corresponding descriptions of locations (Fig. 2.9) and descriptions of selected brain structures (Fig. 2.10) (Richard L. Russell; Carlson 2014, pp. 54–55). Furthermore, it is important to note that Figs. 2.9 and 2.10 (coronal and horizontal sections, left) illustrate the brain's gray and white matter.
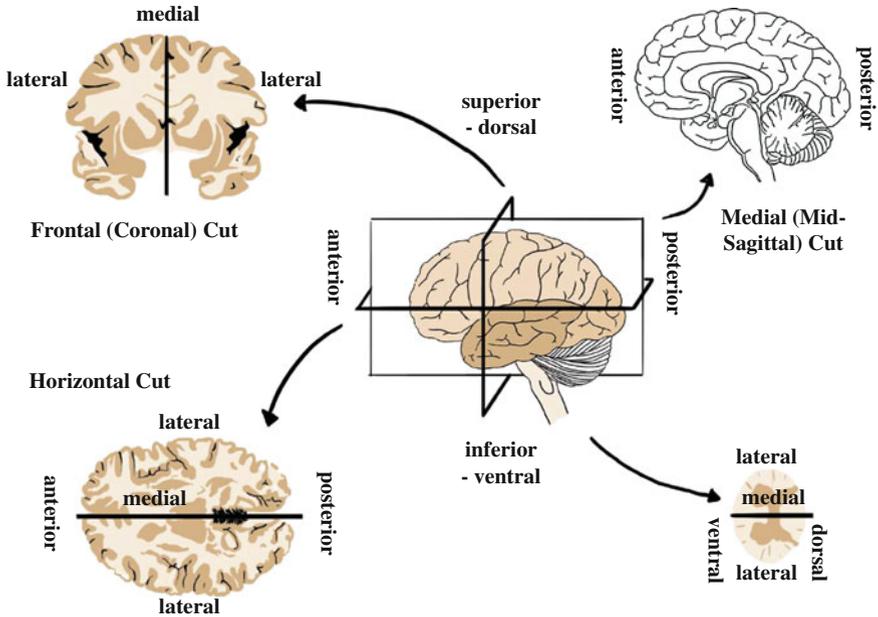
medial

lateral   lateral

superior
- dorsal

anterior   posterior

Frontal (Coronal) Cut

**Medial (Mid-
Sagittal) Cut**

anterior   posterior

Horizontal Cut

lateral

anterior   medial   posterior

inferior
- ventral

lateral

medial

ventral   dorsal

lateral

lateral

Fig. 2.9 Locations in the brain and different cuts through the brain

**Brainstem and
cerebellum**

Cortex

**Subcortical
structures**

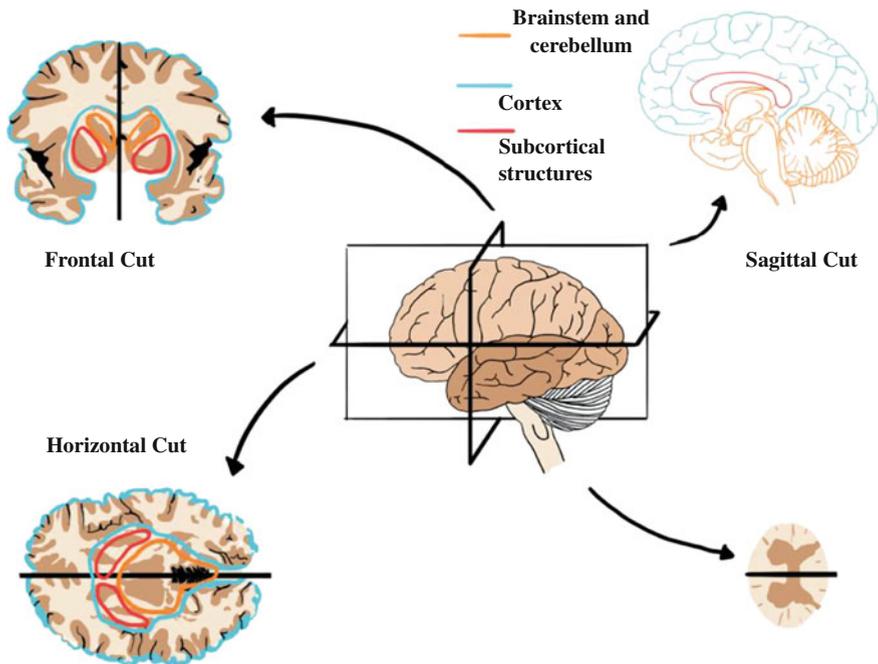**Frontal Cut**

Sagittal Cut

Horizontal Cut

Fig. 2.10 Selected brain structures and different cuts through the brain
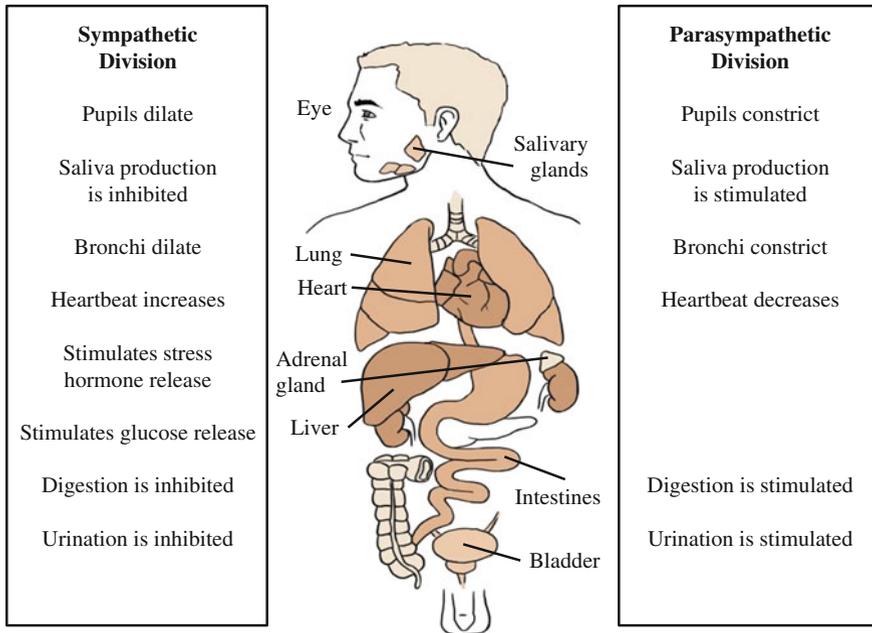
2.4   The Autonomic Nervous System

Many functions of the autonomic nervous system (ANS) are involuntary. However, some functions are at least partly under conscious control, such as breathing or swallowing. Most ANS activity is controlled by the brainstem (specifically the medulla oblongata) and the hypothalamus. The brainstem's most important ANS functions include cardiac and respiratory regulation, vasomotor activity (vasomotor refers to actions upon a blood vessel which change its diameter), and reflexes (e.g., vomiting, swallowing, sneezing). The hypothalamus' main ANS function is to integrate information from various other brain regions (e.g., other limbic structures) in order to instigate a cascade of events that ultimately leads to the release of stress hormones.

The ANS consists of two divisions: sympathetic and parasympathetic. While the former is responsible for implementation of a "fight-or-flight" response, the latter is the underlying structure of a "rest-and-digest" response. Thus, the sympathetic division is stimulatory, while the parasympathetic division is inhibitory (e.g., Kolb and Whishaw 2009).

In stressful situations, the sympathetic division of the ANS becomes active and stimulates a number of responses. These responses include biological reactions: pupil dilation (i.e., increased attention), skin conductance elevation (i.e., increased arousal), airway relaxation, heartbeat acceleration, intense glucose release, and muscle tension. Figure 2.11 (left) summarizes major physiological reactions of sympathetic activation. The primary function of these reactions is to prepare the body for the stressful situation in order to secure optimal performance. Moreover, bodily processes that are not crucial in stress situations are suppressed (e.g., salivation and digestion).

However, despite the fact that the described stress response is essential in order for humans to perform well, or even to survive, it is equally important to shut down these processes at some point in order to recover from a stressful event and its underlying biological processes. Hans Selye (1907–1982), in particular, has indicated in his study of the *General Adaptation Syndrome (GAS)* that prolonged activation of the sympathetic system will lead to a "stage of exhaustion" where irreversible damage occurs (e.g., loss of neurons in memory-related brain areas such as the hippocampus) and, if the stressor persists, the organism will die. To avoid this "stage of exhaustion," the parasympathetic division of the ANS becomes activated (e.g., Kolb and Whishaw 2009). Unlike the sympathetic system, its activation leads to reverse effects: pupil contraction (i.e., decreased attention), skin conductance reduction, airway constriction, heartbeat slowdown, halted glucose release, and muscle relaxation. Figure 2.11 (right) outlines major physiological reactions of parasympathetic activation.

Gazzaniga et al. (2010, p. 115) develop a useful method to describe the interplay between the sympathetic and parasympathetic divisions of the ANS. Through use of a concrete example, they instruct the reader to imagine hearing a fire alarm, and to note that, based on activation of the sympathetic system, signals are sent

Sympathetic Division		**Parasympathetic Division**
Pupils dilate	Eye	Pupils constrict
Saliva production is inhibited	Salivary glands	Saliva production is stimulated
Bronchi dilate	Lung	Bronchi constrict
Heartbeat increases	Heart	Heartbeat decreases
Stimulates stress hormone release	Adrenal gland	
Stimulates glucose release	Liver	
Digestion is inhibited	Intestines	Digestion is stimulated
Urination is inhibited	Bladder	Urination is stimulated

Fig. 2.11 Human autonomic nervous system

immediately from the brain to various parts of the body, as a warning to prepare for action. For example, adrenaline is released to increase heart rate, respiration rate, and blood sugar. Moreover, the pupils dilate in order to increase sensitivity to external stimuli (e.g., fire sources, potential escape routes). Also, blood flow to skeletal muscles increases in order to prepare the limbs for movement. As a result of sympathetic activation, a person is prepared to flee within seconds after perceiving a fire alarm. However, if the fire alarm is false and a person with authority or credibility explains that it was just a test alarm, the heart and respiration rates return to normal. Moreover, the muscles begin to relax and the person's attention and vigilance return to normal levels as well. The events that bring the physiology back to a baseline level are a consequence of parasympathetic activation.

Hormones play a central role in ANS function. As the glands or cells release hormones, the chemicals act as messengers in the body, conveying messages from one part of the body to another. A number of hormones are important in stress situations, including adrenaline, noradrenaline, and cortisol. These substances are related to activity of the sympathetic-adrenomedullary (SA) system and the hypothalamic-pituitary-adrenocortical (HPA) system (for a brief summary see Riedl 2013). In essence, in stress situations the sympathetic system (based on hypothalamus activity) stimulates the adrenal medulla (a part of the adrenal glands), which releases adrenaline and noradrenaline. Once released, these two hormones bind to receptors of various target organs, triggering sympathetic reactions (see Fig. 2.11,

left). The hypothalamus, however, also stimulates the release of the corticotropin-releasing hormone (CRH), influencing activation in the pituitary gland. This structure, in turn, induces a release of adrenocorticotropic hormone (ACTH), a substance that travels through the bloodstream to the adrenal glands, where it stimulates the release of cortisol into the bloodstream. Cortisol, among other functions, shuts down the original stress response by influencing activity in the hypothalamus and pituitary gland. Thus, cortisol contributes to the reestablishment of homeostasis, a state in which the body is in a stable and constant condition (see Fig. 2.11, right).

2.5 Plasticity of the Brain

Brain plasticity (also known as neuroplasticity) is a characteristic that makes alterations in the brain possible, as a function of experience (knowledge), drugs, or injury (e.g., Gazzaniga et al. 2010). In general, the brain constantly reorganizes itself based on the use intensity of its parts. This reorganization refers to changes in neural pathways and synapses. In actuality, what underlies experience (learning) is a change in the strength of connections between neurons.

Plasticity occurs on different levels, including cellular changes due to learning, as well as from alterations that are a consequence of injury (e.g., as a result of a stroke); changes resulting from injury are referred to as *cortical remapping*. A common saying in neuroscience is that "neurons that fire together also wire together." Thus, nearby neurons that often produce a simultaneous impulse are likely to become part of one single cortical map. Conversely, neurons that do not generate simultaneous impulses, or that only do so infrequently, are likely to form different maps. In other words, when two neurons fire simultaneously, the synaptic connection between them strengthens, making them more likely to fire together in the future, while not firing together weakens the connection between two neurons (Gazzaniga et al. 2010).

Another important concept in this context is *neurogenesis*, which is the process by which neurons are generated from stem cells. During pre-natal development, the constant generation of new neurons is a normal process. At birth, however, the total number of nerve cells in the brain of the newborn is estimated to total 100 billion, and this number decreases over the lifetime (both as a consequence of aging and because of other factors related to an adverse lifestyle). During the past decades, however, neuroscience has established as fact that neurogenesis can occur in specific parts of the brain (e.g., hippocampus). A major goal of current medical research is to use neurogenesis to develop treatments to combat neurodegenerative diseases such as Parkinson's and Alzheimer's disease.

2.6   Concluding Note

We have described selected fundamentals of human neurobiology and the brain in a way that characterizes this contribution as a primer, as a starting point for the IS researcher who seeks to develop a background for reading more specialized literature. It is hoped that this chapter provides a starting point for the IS researcher who seeks to develop a background for reading more specialized literature. Our approach centers on a belief that the NeuroIS researcher needs to develop an understanding of important concepts from genetics, neurobiology, and brain research. Without such a knowledge base, it is difficult, or even impossible, to read and understand contributions in reference disciplines, leaving the IS researcher to explain human behavior without the requisite fundamental knowledge. Therefore, sound knowledge is essential.

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