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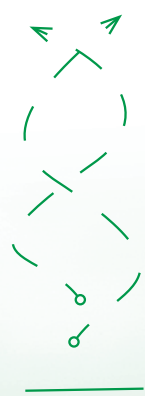

Cognitive Psychology: Mind and Brain

Edward E. Smith Stephen M. Kosslyn

First Edition

ALWAYS LEARNING

PEARSON

Pearson New International Edition

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Edward E. Smith Stephen M. Kosslyn

First Edition

PEARSON

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Glossary

achromatopsia (acquired): color blindness resulting from brain damage (typically to visual area V4); color vision and memory of color are lost.
action: a series of organized movements that is accomplished in order to reach a goal.
activity-based memory: a form of memory storage that occurs through a sustained or persistent increase in activity within specific neural populations.
affective primacy hypothesis: the idea, first proposed by Wundt (1907) and later elaborated by Zajonc (1984), suggesting that emotional stimuli are processed relatively automatically, making fewer demands on limited cognitive resources than do other types of stimuli.
agnosia: the inability to recognize familiar objects, even though there is no sensory deficit.
akinetopsia: motion blindness; that is, the loss of the ability to see objects move.
algorithm: a step-by-step procedure, invoking one process after another, that guarantees that a certain input will produce a certain output.
Allais paradox: in decision making, the apparent contradiction observed when the addition of the identical event to each alternative has the effect of changing the preference of the decision maker.
alternatives: in decision making, the different courses of action that are available.
ambiguity: in language, the property of having more than one interpretation of a sound, word, phrase, or sentence.
analogical reasoning: reasoning that involves using knowledge from one relatively known domain (the source) and applying it to another domain (the target).
anomia: a disturbance, caused by brain damage, in retrieving the name of an object or person.
anterograde amnesia: the inability consciously to remember information encountered *after* damage to the medial temporal lobes.
aphasia: a disruption in language or speech caused by brain damage.
apparent motion: the illusion created when visual stimuli in different locations appear in close succession.
approach–withdrawal model: a dimensional model that characterizes the component of an emotional reaction as either a tendency to approach the object, event or situation or to withdraw from it.
apraxia: a neurological disorder that impairs the ability to make voluntary movements.
arbitrariness: in language, the lack of direct resemblance between words and their referents.
arousal: the physiological responses (for example, heart rate, sweating, stress hormone release), the subjective assessment of intensity, and the mobilization of energy in response to an emotional stimulus.
articulation: the production of speech sounds.
articulatory rehearsal: the subcomponent of the phonological loop of working memory that is responsible for actively refreshing information in the phonological store.
articulatory suppression: the disruption of the phonological loop of working memory, and in particular the articulatory rehearsal process, caused by overtly producing irrelevant speech while maintaining information.
association: the case in which effects of an activity or variable on one task are accompanied by effects on another task. See also **dissociation**.
association area (convergence zone): a population of conjunctive neurons that associates feature information.

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Atkinson-Shiffrin model (modal model): a model of memory based on information processing, first developed in the 1960s, that emphasizes the role of short-term memory as an entryway for information to pass through before entering long-term memory.

atmosphere effect: in reasoning the tendency to accept a conclusion as valid if it contains the same quantifier—"some," "all," or "no"—as appears in the premises.

attention: the process that, at a given moment, enhances some information and inhibits other information.

attentional blink: the decrease in performance in reporting a second piece of information if it appears within a certain period of time after the appearance of a first piece of information.

attentional controller: a component of a neural-network model of conflict phenomena that adds activation to representations related to the current goal.

attitudes: relatively enduring affectively colored beliefs, preferences, and predispositions toward objects or persons, such as like, love, hate, or desire for a person or object.

automatic process: a process that can be initiated without intention and that can operate without attention.

background knowledge: knowledge that specifies how properties originate, why they are important, and how they are related to one another.

backward search: in solving a problem, moving from the goal state to the initial state.

Baddeley-Hitch model: the currently influential model of working memory; it emphasizes the need for short-term storage of information to enable complex cognitive activities, employing two short-term storage buffers and a control system.

basic emotions: six basic types of emotional reactions that appear to be universal across cultures: happiness, sadness, anger, fear, disgust, and surprise.

basic level: the level of a taxonomy used most often, learned most easily, and processed most efficiently.

behavioral method: a technique that measures directly observable behavior, such as the time to respond or the accuracy of a response.

belief bias: bias resulting when background knowledge about the world and personal beliefs influence memory to reshape it in a form consistent with expectations.

belief-bias effect: in reasoning, the tendency to accept a "believable" conclusion to a syllogism than an "unbelievable" one.

binding problem: the question of how we associate different features such as shape, color, and orientation so that we perceive a single object.

binocular rivalry: competition between individual images seen by each eye.

biological motion: the pattern of motion that is uniquely produced by living organisms.

bistable perception: the perception of alternating interpretations of ambiguous stimuli.

blocking (of memory): obstruction preventing retrieval of target information when other information is more strongly associated with the retrieval cue.

bottleneck: a restriction on the amount of information that can be processed at once, necessitating a selection of information to pass through the bottleneck.

Broca's aphasia (nonfluent aphasia): a form of aphasia characterized by nonfluent speech, often with fairly good comprehension but deficits in processing complex sentences.

Brown-Peterson task: a task to examine the duration of storage within short-term memory.

categorical syllogism: a syllogism in which the premises and conclusion relate different categories.

category-based induction: a form of induction that relies on the category of the instances involved.

category-specific impairments: in agnosia, the selective inability to retrieve certain categories of words, such as fruits or vegetables, while retaining the ability to recognize other word categories.

central executive: the control system component of the Baddeley-Hitch working memory model, which governs operations on information in the two storage buffer systems.

change blindness: the failure to detect changes in the physical aspects of a scene, thought to arise from the inability to select at any one time all the information present in a scene.

chunks: groupings of information in working memory, which increase the effective storage capacity by enabling multiple bits of information to be treated as single units.

circumplex model (of emotion): a model that describes the range of emotional responses as varying along the dimensions of arousal and valence.

classical conditioning: the process wherein a response that is elicited by an initial stimulus (the unconditioned stimulus) prior to learning comes to be elicited by a second stimulus (the conditioned stimulus) that predicts the onset of the unconditioned stimulus.

closed head injury: a brain injury caused by an external blow to the head that does not pierce the skull.

coarticulation: the overlapping in time of the articulation of speech sounds.

cocktail party effect: hearing your name or some other salient or relevant information above a din of background noise that would mask other information.

cognition (mental activity): the internal interpretation and transformation of stored information.

cohort: in language, the initial set of lexical candidates activated by the comprehender during the recognition of spoken words.

computer simulation models: computer programs that are designed to mimic specific aspects of mental processing.

conceptual priming: facilitated processing of the meaning of a stimulus, due to processing a related stimulus (priming is a form of nondeclarative memory).

conditional syllogism: a syllogism that represents the condition relationship between variables; the first premise is of the form "if *p*, then *q*."

confirmation bias: in reasoning the predisposition to seek out, interpret, and weight information in ways that are consistent with preexisting beliefs and expectations.

conflict monitor: a component of a neural-network model of conflict phenomena that monitors the amount of conflict in processing.

conjunctive search: a type of visual search in which the target differs from the distractors in the display by at least two features; for example, if the target is a shaded circle, some distractors may be shaded squares and others unshaded circles.

consequences: the eventual benefits or losses that are incurred by a decision maker choosing a particular alternative.

consistency bias: bias resulting from the (often erroneous) belief that one's attitudes are stable over time; memories are therefore unconsciously adjusted to bring the past in line with the present.

consolidation: the process that modifies memory representations such that they become more stable over time.

content errors: errors in deductive reasoning that result when the content of the scenario in the syllogism is used instead of logical form.

content morphemes: morphemes that convey meaning but do not convey information about the structure of a sentence (e.g., *cat, run*).

content-based organization: a theoretical account in which maintenance in working memory is thought to occur in different regions of the prefrontal cortex according to the type of information (e.g., visual, spatial, or object) being stored.

context-dependent effect: the phenomenon that memory retrieval is typically better when the external or physical environment—the context—at retrieval matches that at encoding.

convergence zone (association area): a population of conjunctive neurons that associates feature information.

converging evidence: different types of results that imply the same conclusion.

critical periods: biologically determined periods early in life during which the animal is ready to develop particular abilities or responses; if a critical period is missed, the abilities or responses cannot be learned or can be learned only with great difficulty.

cue dependent: relying on hints and clues from the external and internal environment.

decay theory: the hypothesis that forgetting is caused by the spontaneous weakening of memory representations with time.

decision: the selection of one option or course of action from a number of possible alternatives.

decision utility: the anticipation, at the time a decision is made, of the expected subjective value or worth of a particular outcome.

decision tree: a graphical tool for decision making showing the available various courses of action, the likely outcomes, and the potential consequences of each possible choice.

decision weights: a decision maker's estimates of the likelihood of various outcomes of a decision.

declarative memory (explicit memory): form of long-term memory that can be consciously recollected and described ("declared") to other people; includes memory for facts and events.

delayed response task: a task used to study simple forms of working memory: a briefly presented cue is followed by a short delay period, during which the cue information must be held in short-term storage in order to enable the appropriate response to a later signal.

descriptive theories: theories of decision making that focus on how people actually make choices, regardless of how well the decision conforms to rational principles.

disambiguation region: the point in a sentence at which the structure and intended interpretation are made clear.

discourse: a coherent group of written or spoken sentences.

disjunctive (or feature) search: a type of visual search in which the target differs from the distractors in the display by a single feature.

dissociation: the case in which an activity or variable affects the performance of one task or aspect of a task but not another; a dissociation is evidence for the existence of a specific process. See also **association**.

distractors: items that appear (such as in a visual search experiment) that are not the target item that is being sought.

distributed practice: study trials separated by other stimuli.

divided attention: focusing on more than one source of input at any one time.

dorsal pathway: a visual pathway from the occipital lobes to the parietal lobes, which processes spatial information, such as where items are located.

double dissociation: the case in which an activity or variable affects one process but not another and a second activity or variable has the reverse effects.

duality of patterning: a feature of a communication system that enables a small number of meaningless units to be combined into a large number of meaningful units.

dual-process theories (of recognition): theories based on the hypothesis that recollection and familiarity can both support recognition that a stimulus was previously encountered.

dual-task coordination: the process of simultaneously performing two distinct tasks, each of which typically involves storage of information in working memory.

dual-task interference: interference in performance on one task while performing a second at the same time, compared with when the first task is performed alone.

dynamic inconsistency: in decision making, the observed tendency for preferences between outcomes to reverse depending on immediate availability versus a future payoff.

dynamic representation: refers to the ability of the cognitive system to construct, and to call on as necessary, many different representations of a category, each emphasizing the knowledge currently most relevant.

elaboration: the act of processing a stimulus by considering its meaning and relating it to other information stored in memory.

elimination by aspects: a choice strategy whereby a decision maker sets a cutoff for a particular aspect of the alternatives and eliminates all options that do not make the cutoff; then another aspect is selected, a cutoff set, and more alternatives eliminated until only one alternative remains.

Ellsberg paradox: a decision maker's choice of certainty over ambiguity even when the result is an inconsistent pattern of choice.

emotion: a relatively brief episode of synchronized responses (which can include bodily responses, facial expression, and subjective evaluation) that indicates the evaluation of an internal or external event as significant.

emotional classical conditioning: a means by which neutral stimuli can acquire emotional properties by simple association in time between the experience of the neutral event and an emotional event, so that the neutral event is perceived to predict the emotional event.

emotional learning: learning that results in objects and people being associated with an emotion.

encoding: the processes by which information or perceived events are transformed into a memory representation.

encoding specificity principle: our ability to remember a stimulus depends on the similarity between the way the stimulus is processed at encoding and at retrieval.

encoding variability: the encoding of different aspects of a stimulus as different features are selected for encoding in subsequent encounters.

endogenous attention: a form of attention in which top-down information drives the selection of information in the input.

endowment effect: the tendency for an item to acquire extra value by virtue of our possessing it; the effect has been used to explain why sellers often put a higher price on items than buyers do.

episodic buffer: a third storage buffer, recently added to the Baddeley-Hitch model, which may serve as a storage site in which complex, multimodal information (such as temporally extended events or episodes) can be stored and integrated.

episodic memory: memory of individual events that is associated with a particular spatial and temporal context.

event-related brain potentials (ERPs): electrical activity in the brain linked to a particular stimulus (or response).

executive attention: the type of attention that acts on the contents of working memory and directs subsequent processing.

executive processes: processes that modulate the operation of other processes and that are responsible for the coordination of mental activity.

exemplar variation: the differences among many possible examples of objects in a category.

exemplars: individual category members.

exogenous attention: a form of attention in which information in the input captures attention and is selected in a bottom-up fashion.

expected utility: the value or worth of a particular outcome weighted by the likelihood of that outcome's occurring.

expected utility model: a theory of decision making that assumes rational behavior on the part of the decision maker in evaluating the likelihood of alternatives, assessing the consequences, assigning utilities, and choosing the option with the highest utility.

experienced utility: the value or worth placed on a particular outcome at the time the outcome occurs.

explicit memory tests: memory tasks that make direct (that is, explicit) reference to memory for the past, such as recall and recognition.

extinction: the decrease in a learned response that occurs when a previously neutral stimulus, which has acquired properties through classical conditioning, is presented enough times without the occurrence of the unconditioned stimulus that the participant learns that this conditioned neutral stimulus no longer predicts the occurrence of the unconditioned stimulus.

face superiority effect: the finding that people are better able to discriminate between two features of a face (e.g., a wide nose and a narrow nose) when they are shown within the context of the rest of a face, than when the parts are presented alone.

fast-and-frugal strategy: a choice strategy whereby a decision maker chooses on the basis of specific aspects of each option.

feature (in perception): a meaningful sensory aspect of a perceived stimulus.

flashbulb memories: a term used to refer to memories for shocking or otherwise emotionally charged events, which are often described as recollected with a high level of confidence and apparent detail, like a picture taken with a flashbulb.

fluent aphasia (Wernicke's aphasia): a form of aphasia characterized by fluent but often meaningless speech, many made-up words or other speech errors, and poor comprehension.

focused attention: focusing on one source of input (e.g., a phone call) to the exclusion of others (e.g., watching a television program).

forgetting: the inability to recall or recognize previously encoded information.

form errors: errors in deductive reasoning that result from the structural form or format of the premise–conclusion relationship.

format (of a representation): the form of the code being used by a representation; the means by which it serves to convey information.

forward search: in solving a problem, moving from the initial state to the goal state.

fovea: the central part of the retina, which has the greatest visual acuity.

frame: a structure that specifies a set of relations that links objects in the environment. See also **semantic network**.

framing effects: the influence of the various ways a problem may be put, which can alter a decision maker's choice.

Freudian slip: a speech error in which the speaker chooses a word that means the opposite of what was intended.
frontal executive hypothesis: the proposal that every executive process is primarily mediated by the prefrontal cortex.
function morpheme: a morpheme that conveys syntactical information, such as the *-s* plural morpheme.
function words: words that convey information about the syntactical structure of a sentence, for example articles, auxiliary verbs, and conjunctions.
garden path sentence: an ambiguous sentence that initially seems to have one meaning but then is disambiguated with a different meaning.
generate and test (random search): attempting to solve a problem by a process of trial and error.
generation effect: the phenomenon that information that is retrieved or generated from memory is more likely to be remembered than information that is presented externally.
generative capacity (in language): the uniquely human ability to recombine morphemes, words, and sentences to convey an infinite number of thoughts.
geons: a set of 24 relatively simple geometrical three-dimensional shapes that can be combined to represent many common objects.
goal state: the solution to a problem.
goal-maintenance model: a theoretical account of working memory in which the prefrontal cortex actively maintains goal-related information so that this information can serve as a top-down influence that coordinates perception, attention, and actions necessary to attain the goal.
grammar: the implicit knowledge that one has of the structure of a language.
grammatical encoding: the second level in a model of the speech production process; at this level the speaker (or writer) chooses words to convey meaning and the syntactic structure of the sentence to be uttered.
grouping principles: conditions, such as proximity and similarity, that lead the visual system to produce perceptual units.
hemispatial neglect: an attention deficit in which the impairment leads the patient to ignore information appearing on the side of space opposite the damaged side of the brain.
heuristics: simple, efficient, quick rules of thumb that usually, but not always, give the correct answer to a problem and are used to make decisions and judgments; the rules work well in most circumstances, but in certain cases can lead to systematic biases.
hill climbing: a heuristic for solving a problem by choosing successive moves one at a time that most closely resemble the goal state.
ill-defined problems: problems in which the initial state and the goal state are not clearly known at the outset.
illusory conjunctions: incorrect combinations of features; for example, in a visual search task, reporting that the target was a shaded circle when the display contained shaded squares and unshaded circles.
imitation: the ability to understand the intent of an observed action and then to reproduce it.
immediacy: in language the principle that we interpret words as we encounter them.
implicit memory tests: memory tasks that make indirect (that is, implicit) reference to memory; the memory is revealed implicitly through a change in behavior rather than through recall or recognition of the contents of memory.
incidental learning: learning that occurs not as a result of a purposeful attempt to learn, but as a byproduct of performing a particular task.
inductive reasoning: any thought process that uses knowledge of specific instances to draw further inferences (which are not necessarily correct).
information processing: the ways in which information is stored, manipulated, and transformed.
initial state (start state): the state of a problem when it is first faced by the problem solver.
insight problem: a problem to which the solution comes suddenly.
instrumental conditioning (operant conditioning): a means of learning in which a behavior or response increases or decreases in frequency depending on the outcome of that behavior—on whether it yields a reward or a punishment.
intentional learning: learning that occurs as a result of a purposeful attempt to learn.
intentions: mental plans designed to achieve a goal through action.

interference theories (of forgetting): theories based on the hypothesis that memories compete during retrieval, and forgetting occurs because other associates of a cue interfere with retrieval of the desired memory.

intonation: the "melody" of speech that results from the rise and fall of pitch and variations in stress.

introspection: the process of internal perception, that is, looking within oneself to assess one's mental events.

kinematic pattern: the pattern of motion associated with a specific action or set of movements.

knowledge: in the inclusive sense used in cognitive psychology, information in memory about the world, ranging from the everyday to the formal; often further defined as information about the world that is likely to be true and that one has justification for believing.

levels of analysis: the various degrees of abstraction we can use to describe an object or event.

levels-of-processing theory: theory based on the hypothesis that processing different aspects of a stimulus—perceptual, phonological, semantic—corresponds to increasingly deeper processing and increasingly more effective encoding.

lexical accessibility: the ease with which a word can be retrieved.

lexicon: one's collective mental representations of known words.

long-term memory: information that is acquired in the course of an experience and that persists so that it can be retrieved even long after the experience is past.

loss aversion: decision behavior to avoid a loss, even if the result is a less than optimal choice.

massed practice: repeatedly studying the same information without interleaving other information between study trials.

matching bias: in reasoning the tendency to accept a conclusion as valid if it contains the syntactic structure of the premises.

meaningful entity: an object or event that plays an important role in an organism's survival and pursuit of its goals.

means–ends analysis: a problem-solving strategy that breaks the problem into subproblems; if a subproblem at the first stage of analysis is not solvable, then the problem is further broken into subproblems until a soluble subproblem is found.

memory: the set of representations and processes by which information is encoded, consolidated, and retrieved.

mental activity (cognition): the internal interpretation or transformation of stored information.

mere exposure: the acquisition of a preference or attitude through familiarity alone.

message level: the first level in a model of the speech production process; at this level the speaker (or writer) formulates a nonlinguistic message to be conveyed.

mimicry: the tendency to adopt the behaviors, postures, or mannerisms of others without awareness or intent.

mirror neurons: cells in the premotor cortex that discharge both during the execution of a given action as well as during the observation of the same action performed by another individual.

misattribution: ascribing recollected information to an incorrect time, place, person, or source.

misinformation effect: misremembering of an original event in line with false information subsequently introduced.

modal model (Atkinson-Shiffrin model): a model of memory based on information processing, first developed in the 1960s, that emphasizes the role of short-term memory as an entryway for information to pass through before entering long-term memory.

modality switching: a process in which one shifts attention from one modality to another, for instance, from vision to audition.

monitoring: assessing one's performance on a task while the task is being performed.

mood: a low-intensity, diffuse, and long-lasting affective state.

mood-congruent memory effect: the tendency of mood to influence the type of information that is retrieved so that it is congruent with the present affective state; negative information is more likely to be retrieved during negative moods and positive information is more likely to be retrieved during positive moods.

morpheme: the smallest unit of meaning in a language; *cats* has two morphemes, *cat* and *–s*.

motivation: the propensity to action.

motor anticipation: the phenomenon by which a motor response is tuned prior to producing the response.
motor cognition: mental processing in which the motor system draws on stored information to contribute to the preparation and production of our own actions, as well as to anticipate, predict, and interpret the actions of others.
motor imagery: imagining making an intended action without actually producing it.
motor priming: the effect whereby watching an action automatically facilitates a similar action by oneself.
motor program: the representation of a sequence of movements that is planned in advance of actual performance.
movement: a voluntary displacement of a body part in physical space.
***N*-back task:** a task used to study the effects of increases in working memory load by requiring participants to judge for each presented item whether it matches an item presented *N* items back in the series.
neighborhood density: the number of words in a given language with similar sounds and articulations.
neural-network models: models that rely on sets of interconnected units, each of which is intended to correspond to a neuron or a small group of neurons.
nondeclarative memory (implicit memory): nonconscious forms of long-term memory that are expressed as a change in behavior rather than as conscious recollection.
nonfluent aphasia (Broca's aphasia): a form of aphasia characterized by nonfluent speech, often with fairly good comprehension but deficits in processing complex sentences.
normative theories (prescriptive theories): in decision making, theories that describe how we *should* decide in order to make rational choices.
ontological types: categories for the general kinds of things in the world.
output interference: interference, leading to forgetting, during the act of retrieval because initially retrieved memories are strengthened and, thus, block retrieval of other memories.
pattern completion: a retrieval process in which a cue that is part of a stored memory serves to reactivate other aspects of the stored memory, resulting in retrieval of other information present during encoding of the event.
perception–action cycle: the transformation of perceived patterns into coordinated patterns of movements; the mutual functional interdependence between perception and action in the outside world.
perception-to-action transfer: the effect that watching an action facilitates the later ability to perform that action.
perceptual priming: facilitated processing of perceptual aspects of a stimulus due to processing a prior stimulus (priming is a form of nondeclarative memory).
phoneme: the minimal unit of sound that distinguishes words in a given language.
phoneme restoration effect: a perceptual phenomenon in which a missing or distorted phoneme is supplied by the listener.
phonetic alphabet: an alphabet of symbols in which the speech sounds of all languages can be represented.
phonological encoding: the third level in a model of the speech production process; at this level, prior to articulation, the phonological representation of the utterance is developed.
phonological loop: the storage buffer component of the Baddeley-Hitch working memory model that is responsible for maintaining verbal information.
phonological similarity effect: the reduction in working memory performance that occurs when simultaneously stored verbal items that have similar sounds must be serially recalled.
phonological store: the subcomponent of the phonological loop responsible for short-term storage of verbal information in the form of a sound-based (phonological) code.
phrase structure tree: a diagram of a sentence that illustrates its hierarchical syntactic structure.
potentiated eyeblink startle: eyeblink startle is potentiated, or increased, in the presence of a negative stimulus and is decreased in the presence of a positive stimulus.
prescriptive theories (normative theories): in decision making, theories that describe how we *should* decide in order to make rational choices.
primary memory: the term used by William James to describe a separate memory system that provides a storage site that enables information to remain accessible to consciousness.
primary reinforcer: an emotionally evocative stimulus that is inherently positive or negative, such as food or shock; for these stimuli the reinforcing properties occur naturally and do not need to be learned. See also **secondary reinforcer**.

priming: the facilitation of processing a stimulus or task by a preceding stimulus or task.

proactive interference: the case in which previous learning results in difficulty remembering newly learned information.

problem solving: the act of using a set of cognitive processes to reach a goal when the path to that goal is not obvious.

problem space: the set of states, or possible choices, that faces the problem solver at each step in moving from an initial state to a goal state.

procedural invariance: in decision making, the principle that a consistent preference should be expressed between options, even when they are presented in different form.

process: a transformation of information that obeys well-defined principles to produce a specific output when given a specific input.

process models: models that specify a sequence of processes that convert an input to an output; each process typically is treated as a "black box."

process-based organization: the idea that different working memory processes (storage and executive control) are carried out in different regions of the prefrontal cortex.

processing system: a set of processes that work together to accomplish a task, using and producing representations as appropriate.

property list: a list of the characteristics of the entities belonging to a category.

propositions: assertions that can be expressed in clauses in sentences.

prospect theory: a modern descriptive theory of decision behavior that updates the standard economic model of expected utility theory by assuming that we experience losses more keenly than gains of the same magnitude, that we are risk averse for gains and risk seeking for losses, that we use decision weights instead of objective probabilities, and that our decisions are often made from the perspective of a reference point.

prototype: the collection of properties most likely to be true of members of a category.

psycholinguistics: the study of the comprehension, production, and acquisition of language.

psychophysiology: the study of the relationship between mental states, typically affective states, and physiological responses.

random search (generate and test): attempting to solve a problem by the process of trial and error.

reasoning: the cognitive procedures we use to make inferences from knowledge.

recapitulation: the reinstatement during retrieval of the pattern of activation that was present during encoding.

receptive field (of a cell): the region of the visual field in which a stimulus will affect the activity of the cell.

reciprocal imitation: taking turns in imitation, as a mother and baby engaging in communicative exchanges.

recognition: the process of matching organized sensory input to stored representations in memory.

reconstructive memory: memory that is a reconstruction of the past rather than a reproduction of it (and is thus is susceptible to bias).

recursion: the successive embedding of grammatical phrases within sentences, leading to the infinite creativity of human language.

reference point: the psychological position from which we view the consequences of a decision.

repetition blindness: the failure to detect the subsequent appearance of a stimulus when stimuli are presented in a rapid sequence.

repetition suppression: the phenomenon observed in nonhuman primates and rats that the firing rate of neurons is less in subsequent encounters with a stimulus than in the initial encounter.

representation: a physical state that was created to convey information, specifying an object, event, or category or its characteristics or relations.

response bottleneck: a stage of processing in which a response (e.g., a button press) to a stimulus is selected in competition with other possible responses (e.g., a foot pedal response) for execution.

response inhibition: the suppression of a partially prepared response.

retention interval: the time between encoding and retrieval of an event.

retrieval-induced forgetting: forgetting that occurs when a memory is suppressed during the retrieval of another memory.

retroactive interference: the case in which new learning impairs the ability to remember previously learned information.

retrograde amnesia: the forgetting of events that occurred *before* brain damage.

reverberatory loop: a hypothesis about short-term storage in working memory in which a circuit of connected neurons recirculates activity among themselves, with each neuron both sending and receiving signals regarding the information being stored.

risk averse: describes the preference for receiving a small, certain gain to the chance of getting a larger, but uncertain, gain.

risk seeking: describes the preference for receiving a larger, but uncertain, gain to the chance of getting a small, certain gain.

rule: in categorization, a precise definition of the criteria for a category.

saccade: a quick eye movement during reading.

satisficing: a choice strategy whereby a decision maker finds not necessarily the best possible option, but rather one that is "good enough" on a number of dimensions; a common strategy in consumer choice.

schema: a structured representation that captures the information typically true for a situation or event.

secondary reinforcer: an emotionally evocative stimulus that is not inherently positive or negative, but rather acquires its reinforcing properties through learning (money is a prototypical example). See also **primary reinforcer**.

semantic memory: general knowledge about the world, including words and concepts, their properties and interrelations.

semantic network: a structure that diagrammatically specifies, by directional arrows, a set of relations that links objects or events. See also **frame**.

sense of agency: awareness of being the initiator or source of a movement, action, or thought.

sequencing: the ability to order information or actions to achieve a goal.

shared motor representations: representations that both control our own actions and specify actions made by other people; shared motor representations are critical in planning because they permit observational learning.

short-term memory: an alternative term for the storage component of working memory that emphasizes the limited duration of this storage system, which distinguishes it from the more permanent long-term memory.

simulation: in perception, the reactivation, in a statistical pattern, of image and feature information even after the original scene is no longer present; in reasoning and planning, the construction and "running" of a mental model of an object or situation, used to anticipate the consequences of an action or transformation.

skin conductance response: an indication of autonomic nervous system arousal assessed by passing a small electrical current through the skin and measuring changes in resistance to the current as a result of subtle changes in the sweat glands; often used as an indirect assessment of an emotional reaction.

sound exchange error: a speech error in which two sounds change places.

spaced practice: studying the same information but interleaving other information between study trials.

spacing effect: the phenomenon that memory for information is better when study trials are spaced rather than massed.

spatial rehearsal: the process of mentally refreshing spatial locations stored in the visuospatial component of working memory, possibly by covert movement of the eyes or body toward the stored locations.

spectrogram: the visual display produced on a spectrograph, an instrument used in acoustic phonetics for speech analysis; time is shown on one axis and the frequency of sound on the other.

start state (also known as initial state): the state of a problem when it is first faced by the problem solver.

state-dependent effect: the phenomenon that retrieval is typically better when aspects of our internal states at retrieval match those at encoding.

stimulus–response compatibility: a measure of the degree to which the assignment of correct responses to stimuli is consonant with the way people would act naturally. In a stimulus–response compatibility task, the "naturalness" of the assignment of stimuli to responses is varied.

stimulus–response habits: habits that emerge through the slow accumulation of knowledge about the predictive relationship between a stimulus and a response.

Stroop task: a test of attentional function in which color names are presented in different-colored ink; the participant's task is to name the color of the ink.

structural ambiguity: a linear string of words that is consistent with more than one syntactic structure and meaning.

subjective (or illusory) contour: a contour that is not physically present in the stimulus but is filled in by the visual system.

suppression: the active weakening of a memory.

switching attention: moving the focus of attention from one entity to another.

switching cost: the additional time taken when it is necessary to switch attention from one task or attribute to another, as opposed to keeping the attention focused on the same task or attribute.

syllogism: an argument in deductive reasoning that consists of two statements (the major premise and minor premise) and a conclusion.

syntax: the relationship between the types of words (such as nouns and verbs) in a sentence; this structure specifies the roles of the entities named by words (e.g., subject, object).

taxonomy: a set of nested categories that vary in abstraction, with each nested category a subset of its higher order category.

template: a pattern that can be used to compare individual items to a standard.

temporal discounting: the tendency to discount or devalue outcomes, both gains and losses, pleasant and unpleasant, that occur further in the future.

thinking: the process of mentally representing information and transforming these representations so that new representations, useful to our goals, are generated.

tilt aftereffect: a bias in perceiving orientation that results when right-tilting or left-tilting neurons are fatigued.

transfer appropriate processing: the principle that processing at encoding is effective to the extent that it overlaps with the processing to be performed at retrieval.

transitivity: in decision making, the principle that if object A is preferred to object B, and object B is preferred to object C, then object A must be preferred to object C.

triangle model: a theory of the lexicon, used to describe word representation, with three major components: spelling (orthography), sound (phonology), and meaning.

valence: the subjective quality, positive or negative, of the emotional reaction to a specific object or event.

ventral pathway: a visual pathway from the occipital lobes to the bottom parts of the temporal lobes that processes information that leads to the recognition of objects.

verbal protocol analysis: a procedure in which the thought process of a problem solver in the course of working on a problem is spoken aloud, recorded, and analyzed.

viewpoint dependence: sensitivity to the appearance of an object as viewed from a particular position.

visual field: the portion of the world that is visible at the present moment.

visuospatial scratchpad: the storage buffer component of the Baddeley-Hitch working memory model that is responsible for maintaining visuospatial information.

vocal tract: the set of anatomical structures that participate in speech production, principally the larynx (which includes the vocal cords), mouth, and nose.

weight-based memory: a form of memory storage that occurs by strengthening (or weakening) the connections, or weights, between neural populations.

well-defined problems: problems in which the initial state and the goal state are clearly defined and the possible moves (and the constraining rules) are known.

Wernicke's aphasia (fluent aphasia): a form of aphasia characterized by fluent but often meaningless speech, many made-up words or other speech errors, and poor comprehension.

word superiority effect: the phenomenon in which a letter is seen better in the context of a word than alone; surrounding letters may suggest a word, and thus influence the perception of the central letters.

word-exchange error: a speech error in which two words change places.

word-length effect: the reduction in working memory performance that occurs when storing items that take a long time to say out loud.

working memory: the system that enables the short-term storage and mental manipulation of information.

working memory capacity (working memory span): a measure that describes the maximum amount of information an individual can store in working memory.

How the Brain Gives Rise to the Mind

Learning Objectives

1. A Brief History: How We Got Here
    - 1.1. In the Beginning: The Contents of Consciousness
    - 1.2. Psychology in the World
    - 1.3. Behaviorism: Reaction against the Unobservable
    - 1.4. The Cognitive Revolution
2. Understanding the Mind: The Form of Theories of Cognition
    - 2.1. Mind and Brain
    - 2.2. Mental Representation
    - 2.3. Mental Processing
    - 2.4. Why the Brain?

DEBATE: What Is the Nature of Visual Mental Imagery?

3. The Cognitive Brain
    - 3.1. Neurons: The Building Blocks of the Brain
    - 3.2. Structure of the Nervous System
        - 3.2.1. The Peripheral Nervous System
        - 3.2.2. The Cerebral Cortex
        - 3.2.3. Subcortical Areas
4. Studying Cognition
    - 4.1. Converging Evidence for Dissociations and Associations
    - 4.2. Behavioral Methods
    - 4.3. Correlational Neural Methods: The Importance of Localization
    - 4.4. Causal Neural Methods
    - 4.5. Modeling
    - 4.6. Neural-Network Models
5. Overview

Revisit and Reflect

You've just taken your seat and are about to begin your first job interview. You are sitting on one side of an immaculately clean desk, facing a well-dressed woman on the other side. You're asking yourself: Why am I doing this? Do I really want to go through all this stress when I may not get the job—and even if I do get it, I might not even like it?

From Chapter 1 of *Cognitive Psychology: Mind and Brain*, First Edition. Edward E. Smith/ Stephen M. Kosslyn. Copyright © 2007 by Pearson Education, Inc. All rights reserved.

Well, why are you? Perhaps it was the only opportunity available, and you don't have the luxury of waiting for a better opportunity. But why this type of job, rather than some other type of job? Because you've heard other people talk about it, and it sounded interesting? Or perhaps you saw an article in a newspaper or magazine, picked it up, and read about someone who has this job. Whatever the impetus for your looking into it, the job had to pay enough for you to live and had to have a future. Nobody likes being evaluated, but that's just part of the process. So, there you are, at the interview, wondering what else you could have done, where else you could be instead.

Resolving a life-altering question such as whether or not to try to get a particular job is an enormously complicated activity. If you want to understand all the cogitation that led up to your deciding to apply for the job and that is used during the interview—and, should you be offered the job, that allows you to decide whether or not to take it—you will need to understand the following:

- *perception,* the processing of information from the senses, which you require in order to hear and read about the job and, of course, to listen to the interviewer and watch her face for telltale signs as to how you are doing;
- *emotion,* such as the anxiety surrounding the interview and your enjoyment of the work in question; emotion can arise when you perceive something (like the warm smile of the interviewer at the end of your discussion), and—perhaps paradoxically—is a central aspect of much of cognition;
- *representation in long-term memory,* your actual memories of previous summer jobs and relevant classroom experiences, as well as your memories of your leadership roles in clubs and your memories of your skills;
- *encoding,* which occurs when you enter new information into memory, such as when you describe to yourself what you see in the workplace (which you later can reflect on when thinking about whether you would really want the job), and *retrieving information from long-term memory* (critical if you are going to answer the interview questions, and also when you later want to think about the pros and cons of what you learned during the interview);
- *working memory,* which allows you to hold information in awareness and think about it (important if you try to scope out any themes that are emerging from the questions);
- *attention,* which allows you to focus on specific information, including both the interviewer's words and her nonverbal signals, and which allows you to filter out irrelevant information (such as the sounds of cars outside);
- *executive processes,* which manage your other mental events, allowing you to pause before you speak and to inhibit yourself from saying the wrong thing, and which enable you to act on your decisions;
- *decision making, problem solving,* and *reasoning,* which allow you to figure out which jobs you might like and how best to apply for them, as well as what to say during the interview;
- *motor cognition* and *mental simulation,* which involve setting up your responses, mentally rehearsing them, and anticipating the consequences of your behaviors

(useful for preparing for the interview in advance and anticipating the interviewer's likely response to points you make);

- and—of course—*language*, which is what you use to understand the questions and reply to them; what you say ultimately will make or break your interview.

This chapter is about all these mental activities—for that is in fact what they are—and more.

Mental activity, also known as **cognition**, is the internal interpretation or transformation of stored information. You acquire information through your senses and you store it in memory. Cognition occurs when you derive implications or associations from an observation, fact, or event. For example, you might realize that you would have to move to a new city for one job but not another and then consider the pros and cons of the night life of that new city. Similarly, when you consider whether or not to apply for a particular job, you weigh facts and considerations about the salary, cost of living, possible promotions, skills you can learn that might help you move onto a better job, and so on. Mental activity, in one form or another, is what allows you to play out in your head the various ramifications of such facts and considerations.

How can we study mental activity? We seem to think effortlessly, and often can easily talk about our beliefs and desires. Perhaps you know that you want a certain type of job because you've majored in that subject and focused like a laser beam on such employment ever since high school—end of story. But how can you come to realize whether a particular job situation is a good fit for your own personal circumstances? In fact, how is it that you, and not your pet dog or cat, has the concept of a "job"? And what do you mean by the "mind"? Do you mean "consciousness," that is, what you are aware of? If so, then what is responsible for the presence of some thoughts in consciousness but not others? Neither you, the authors, nor any other human beings are aware of most mental activities. So how can we come to understand them?

This chapter sets the stage for our investigation, first describing the nature of theories of mental activities and then looking at ways in which scientists have come to develop and evaluate such theories in detail. We specifically address four questions:

1. How did the field of cognitive psychology arise?
2. What is a scientific theory of cognition, and what roles does knowledge about the brain play in such theories?
3. What are the major structures of the brain, and what roles do they play in our skills and abilities?
4. What methods are used to study cognition?

1. A BRIEF HISTORY: HOW WE GOT HERE

Most of the topics in this chapter, in one guise or another, are old hat for philosophers, who have picked over numerous and varied theories of the mind for well over two thousand years. For example, the Greek philosopher Plato (427–347 B.C.) believed that memories are like etchings on a wax tablet—and that people differ in the hardness and purity of the "wax," which would explain why some people have better memories than others. This notion is interesting in part because there is no clear-cut distinction between the physical substance (the wax) and its function (to

retain memories). The French philosopher and mathematician René Descartes (1596–1650) gave us the famous distinction between mind and body, asserting that mind is qualitatively distinct from body, as different as heat is from light. This distinction has permeated our culture and now seems obvious to many, but in fact research is now revealing that it is not as clear-cut as it may seem (as we shall see when we consider the effects of mind on body—and vice versa—when we discuss emotion). John Locke (1632–1704), writing in England, considered what the contents of the mind might be like and argued that thought is a series of mental images. Bishop George Berkeley (1685–1753) begged to disagree, arguing in part that abstract concepts—such as "justice" and "truth"—could not be conveyed effectively by images. Such discussions set the stage for many contemporary research programs, such as those aimed at discovering the various ways in which we can store information, which—as Berkeley argued—cannot be limited to mental images.

Although philosophers raised many fascinating ideas and often identified key issues that are still with us today, their methods simply were not up to the task of resolving many questions about mental activity. Philosophy rests on argument (that's why logic is taught in philosophy departments), but sometimes the available facts are not sufficient to allow argument alone to answer a question. Science, unlike philosophy, relies on a method that produces new facts, and by so doing allows all participants to agree on the answer to a question. The scientific study of the mind began in the late nineteenth century, which by the standards of science means that it is still in its infancy.

1.1. In the Beginning: The Contents of Consciousness

We can mark the birth of the scientific study of mental activity with the establishment of the first modern psychology laboratory in 1879, in Leipzig, Germany. The head of that laboratory was Wilhelm Wundt (1832–1920), who focused on understanding the nature of consciousness (Figure 1). Wundt's guiding idea was that the contents of consciousness—the things we are aware of—can be approached by analogy to the way chemists approach the structure of molecules: (1) by characterizing basic sensations (such as feeling heat or cold, or seeing red or blue) and feelings (such as fear and love), and (2) by finding the rules whereby such elements are combined (such as the ways simple sensations are combined to form the perception of seeing an entire object, with its shape, texture, and color). An American student of Wundt, Edward Titchener (1867–1927), extended this approach to cover not only sensations and feelings but all mental activity.

The early psychologists of Wundt's school made at least two major contributions. First, they showed that mental activity can be broken down into more basic operations (such as the perception of color, shape, and location); this strategy of "divide and conquer" has withstood the test of time. Second, they developed objective methods for assessing mental activity, such as measuring the amount of time people need to make certain decisions.

However, these scientists also relied heavily on **introspection**, the process of internal perception, that is, looking within oneself to assess one's mental activity. To

FIGURE 1 **Wilhelm Wundt (standing, with gray beard) and colleagues**

The first psychology laboratories focused on understanding the nature of mental activity, but used introspection in ways that later proved unreliable.

(Archives of the History of American Psychology—The University of Akron.)

experience introspection, try to answer this question: What shape are a cat's ears? Most people report that they visualize the animal's head and "look" at its ears. Did you have this experience? Not everyone does. What can we conclude when people disagree about their introspections? And now consider, what color were the ears, what texture? Were these characteristics present in your mental image? Are you sure? What do we do when people who report on their own mental activity aren't certain?

Wundt trained observers to be sensitive to their reactions to stimuli, noticing subtle changes in the duration, quality, or intensity when stimuli were changed slightly (for example, having a different shade of color or tone). Nevertheless, this reliance on introspective reports turned out to be their Achilles' heel; no amount of training could solve another difficulty. Oswald Kulpe (1862–1915), another German philosopher-scientist, demonstrated that mental images do not always accompany mental activity. A mental image is signaled by the experience of perceiving when the appropriate sensory input is absent; a mental image creates the experience of "seeing with the mind's eye" (or "hearing with the mind's ear," and so on). Some types of mental activity, such

as those occurring in your head as you understand these words, are unconscious—they are not accompanied by mental images. Kulpe and his colleagues found, for example, that when participants were asked to heft two weights and decide which was the heavier, they could do this, but they had no idea how they reached their decisions. Participants reported that they had kinesthetic images of the weights (that is, they had the "feeling" of lifting them), but the decision process itself left no trail in consciousness. Similarly, you will be aware of your decision to apply for a particular job and not to apply for others, but you may not be aware of just *how* you made that decision.

1.2. Psychology in the World

At about the same time that Wundt's laboratory was up and running, another approach to scientific psychology was developed, primarily in America, by William James (1842–1910). These "functionalist" psychologists, as they became known, focused not on the *nature* of mental activity, but rather on the *functions* of specific mental activities in the world. The idea was that certain practices or approaches are better suited than others to accomplishing certain tasks, and that we should change our thoughts and behavior as we discover those that are increasingly "better adapted" to our environment. For example, if you discover that you learn better by listening to lectures than by reading the text, you should be sure to attend all the lectures. But more than that, you should note what it is about lectures (the chance to ask questions? the visual aids?) that engages you and try to select courses in which the lectures have those characteristics.

The functionalist approach produced firm foundations for future studies. In particular, in proposing theories of the functions of behaviors and mental activities, it relied in large part on ideas about evolution proposed by Charles Darwin—and this evolutionary perspective has flourished (e.g., Pinker, 1997, 2002). Conceiving of mental activities and behavior in an evolutionary context has led researchers to study animal behavior, which has continued to be a valuable source of insights into some mental functions, especially with regard to their relationship to the brain (Hauser, 1996).

1.3. Behaviorism: Reaction against the Unobservable

The early psychologists sensibly tried to model their new science on the success stories of the day, the methods of physics, chemistry, and biology. But different psychologists took different lessons from the successes of other sciences, and some declared that psychology should not attempt to understand hidden mental events but rather should focus purely on the immediately observable: stimuli, responses, and the consequences of those responses (Figure 2). This was the central doctrine of the behaviorists, who avoided discussion of mental activity. Behaviorist theories specify ways in which stimuli lead to responses, and ways in which the consequences of responses set up associations between stimuli and responses. Some of the behaviorists, among them Clark L. Hull (1884–1952), were willing to propose internal events that are inferred directly from behavior, such as motivation, even though these events were not themselves immediately observable. However, many later behaviorists, notably B. F. Skinner (1904–1990) and his followers, went so far as to

FIGURE 2 Observing rat behavior

Behavioral methods, if not the theory that initially led to their pursuit, have proved important to the study of cognition.

(Photograph by Richard Wood. Courtesy of Index Stock Imagery, Inc. Royalty Free.)

reject absolutely all discussion of internal events. In all cases, however, the approach of the behaviorists had severe limits; in fact, it simply could not explain the most interesting human behaviors, notably language (Chomsky, 1957, 1959). Behaviorism also failed to provide insights into the nature of perception, memory, decision making.

Nevertheless, the behaviorists contributed a host of rigorous experimental techniques that have since been put to good use in the study of cognition. In addition, the behaviorists made many discoveries, particularly about the nature of learning, that now must be explained by all theories in psychology. Moreover, behaviorist approaches led to sophisticated views of how animals use information to make choices, which in turn have inspired much contemporary work (e.g., Grafen, 2002; Herrnstein, 1990).

1.4. The Cognitive Revolution

Today the study of mental activity is again respectable. As the limitations of behaviorism became widely appreciated, researchers became open to other approaches—but this backlash against behaviorism would have had much less of an effect if not for key technological changes, which led to a new way to envision mental activity.

This new approach, developed in the late 1950s and early 1960s, was directly tied to the development of the computer (Gardner, 1985) and so dominated the field that this period of transition is now known as the *cognitive revolution*. The behaviorists had simply described stimulus–response–consequences relations. Now researchers seized on the computer as a model for the way in which human mental activity takes place; the computer was a tool that allowed researchers to specify the internal *mechanisms* that produce behavior. Psychologist/computer scientists Herbert A. Simon and Alan Newell and linguist Noam Chomsky played a central role in this revolution, providing examples of how progress could be achieved by comparing the mind to a computing machine (Figure 3).

The cognitive revolution blossomed when researchers developed new methods to test predictions from computational models, which often specified the order in which specific mental activities purportedly take place. These methods were an important part of the cognitive revolution because they allowed mental activity to be studied more objectively than did introspection, thereby allowing many researchers

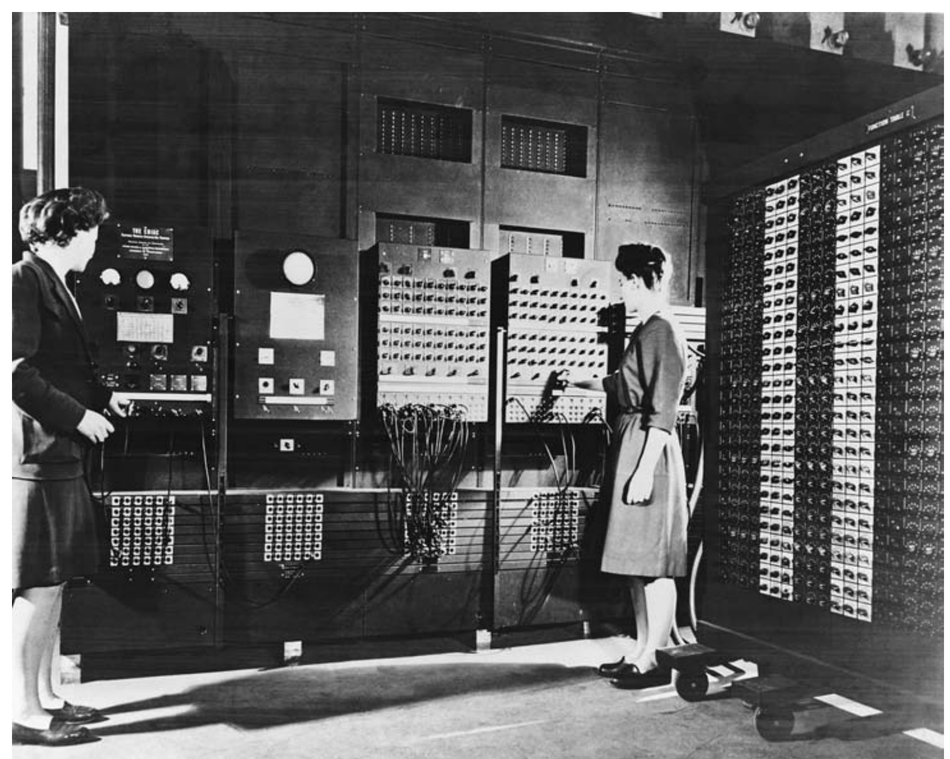


FIGURE 3 **BINAC, the Binary Automatic Computer, developed in 1949**

Computer technology has evolved so quickly that complex models of mental activity can now be programmed into an ordinary desktop machine.

(Courtesy of Corbis/Bettmann.)

to move beyond behaviorism without giving up a desire for empiricism, the discovery of new facts via systematic observation.

One reason why the computer was so important as a model is that it demonstrated, once and for all, why researchers need to think about internal events, not just observable stimuli, responses, and consequences of responses. For example, imagine that your word-processing program has started printing EVERYTHING YOU TYPE IN UPPERCASE. What do you do? First, you would probably look to see if the shift key is stuck. Any good behaviorist would approve of this: you are looking at stimuli and responses. But say it isn't stuck. Now what? Now you suspect that something has gone wrong inside. For some reason, the key presses aren't being *interpreted* correctly. To fix the problem, you must examine the program itself to see exactly what it is doing. Studying stimuli and responses is only the beginning; a true understanding of what's going on, in people and in computers, requires going inside, looking at the mechanism that underlies what you can observe directly.

Finally, in recent years biology has come to be a major part of the mix. To see why, we need to consider the nature of mental activity in more detail, to which we turn in the following section.

Comprehension Check:

1. What are the differences between behaviorism and the cognitive approach?
2. Why did the "cognitive revolution" occur?

2. UNDERSTANDING THE MIND: THE FORM OF THEORIES OF COGNITION

The cognitive revolution led to a detailed conception of the form of a theory of mental activity, but to say that mental activities are like computer programs is a leap. Consider the machines that run computer programs versus the "machine" that produces mental activity—that is, the brain. Certainly, computers and brains look very different and are composed of different materials. Moreover, computer programs are separate from the computers that run them; the same program can run on many different machines. But the mental activities taking place in your head right now are yours and yours alone. Why should we assume that programs for computers have anything to do with mental activities produced by brains? Clearly the analogy is restricted to only certain aspects of computer programs. But which ones?

2.1. Mind and Brain

The distinction between a computer's software—its programs—and its hardware is a good first step because it focuses us on how computers operate, not simply on their physical natures. But the idea that mental activity is like software and the brain itself is like hardware isn't quite right. If a computer program is useful, it sometimes is converted into a chip and thus "becomes" a piece of hardware. Once converted, what used to be a program (that is, the instructions to the computer) is now etched as physical

pathways in the chip; the program as such no longer exists—you cannot identify parts of the chip with the different instructions in the computer program. For example, in a program we could write one instruction to make the computer add 10 numbers, and then another to have it divide the sum by 10 to find the average. In a chip, such instructions would not exist; instead circuits would accomplish the same goals. Even so, the chip can be described as doing what the program does: adding the numbers and dividing by the number of digits to find the average. Here's the important point: in spite of the fact that software—a program—does not exist, we can still describe what the hardware is doing using the same vocabulary we used to describe the program.

The crucial distinction is not between software and hardware per se, but rather between **levels of analysis**, the various degrees of abstraction we can use to describe an object. Different levels of analysis typically rely on different vocabularies. Let's start with the computer: on one level, we can describe the computer in terms of its physics, noting how electricity changes magnetic fields, observing how heat is produced and dissipated, and the like. On another level, we can describe the computer in terms of its function, that is, in terms of *what the computer is doing:* it receives input in the form of symbols, converts the symbols into a special code, stores this information, and operates on this information (adding, sorting lists, comparing input to stored information, and so on). At this level, instead of relying on the language of physics, we depend for accurate description on the language of **information processing**, that is, the storage, manipulation, and transformation of information. In cognitive psychology, mental activity is often described in terms of information processing. When you are sitting there, smiling and trying to look relaxed as a job interview is progressing, your brain is working hard to allow you to come up with the most effective responses. To understand all of what goes into each of your responses and questions, we need to understand information processing.

A critical aspect of the idea of levels of analysis is that a description at one level cannot be replaced by one at another level; the levels may provide equally valid analyses, and even reinforce one another, but they are not interchangeable. In particular, the analysis of mental activity—the level of information processing—cannot be replaced by the level of a physical description of the brain. Why not? Consider some analogies. Can you replace a description of a building's architecture with a description of its bricks, boards, and other building materials? No. Can you replace a description of the function of a pair of scissors with a description of the arrays of atoms in its blades? Clearly not. How about the human hand: would a description of bones, tendons, and muscles replace descriptions of grasping, stroking, and poking? No. The computer—and the brain—are no different from these examples: for a full understanding we must distinguish between a functional level of analysis (what the architectural features of a building must achieve, the actions a pair of scissors and a hand perform) and a physical level of analysis (in which we characterize the physical properties of the parts that make up all these objects).

Descriptions at the different levels of analysis cannot be replaced by one another because they specify qualitatively different kinds of things. And that is why we cannot dispense with a description of the information processing that accomplishes mental activity and instead simply discuss the physical brain that gives rise to it.

Does this mean that studying the brain has no place in the study of cognition? Not at all! Although we cannot replace one level of analysis with another, we can gain insights into characteristics of one level from the others. You probably couldn't make a working pair of scissors out of wet cardboard: it's important to know about the physics of materials to understand how a blade can hold an edge (and why some materials do so better than others). Similarly, the physical structure of the hand is what allows it to do all those marvelous things: no palm, no fingers, and no thumb mean no grasping, no stroking, and no poking. Researchers have realized that conceiving of mental activity by analogy to the computer was a good start, but to understand mental activity fully we need to consider the neural mechanisms that give rise to them, which ultimately requires understanding how the brain gives rise to mental activity. Knowledge about the brain, that most complex of organs, helps us understand cognition, feelings, and behavior. To see how, we first must consider in more detail the nature of the information processing that underlies mental activity.

2.2. Mental Representation

All our mental activity is *about* something—a possible job you could choose, a friend's face you see across the way, fond thoughts of last night's date. Cognitive psychologists try to specify how information is internally represented. A **representation** is a physical state (such as marks on a page, magnetic fields in a computer, or neural connections in a brain) that conveys information, specifying an object, event, or category or its characteristics. Representations have two distinct facets. On the one hand, there's the *form* of a representation, the means by which it conveys information—in other words, its **format**. For example, a drawing (that is, a depiction) and a verbal description (of the sort found in a text) are different formats (Figure 4). Drawings represent something by means of a graphic resemblance between the lines in the drawing and the corresponding portions of the depicted object or scene; descriptions (such as these words) represent something by means of conventions that allow symbols (letters and punctuation marks) to be combined in certain ways but not others (*word* is an acceptable order of symbols for written English, but "odwr" is not; Kosslyn, 1980, 1994). On the other hand, there's the *content,* the meaning, conveyed by a particular representation. The same content can usually be conveyed in more than one format: spoken words and Morse code are different formats that can convey the same content. (Your decision to apply for a particular job often may depend on information you acquired in at least two formats, written and spoken words.)

2.3. Mental Processing

Does a tree falling in the forest make a sound if nobody is there to hear it? The answer, at least for psychologists, is clear: no. "Sound" is a psychological quality, which is not the same thing as compressed air waves. A brain must be present in order to *register* the pattern of compression in the waves, and it is the neural impulses in the brain that give rise to our experience of sound. No brain, no sound. Similarly,

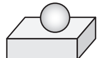
"A BALL IS ON A BOX"	
Description (Propositional Representation)	Depiction (Quasi-Pictorial Representation)
ON (BALL, BOX)	
1. Relation (e.g., ON)	1. No distinct relation
2. Argument(s) (e.g., BALL, BOX)	2. No distinct arguments
3. Syntax (rules for combining symbols)	3. No clear syntax
4. Abstract	4. Concrete
5. Does not occur in spatial medium	5. Occurs in spatial medium
6. Arbitrarily related to represented object	6. Resemblance used to convey Information

FIGURE 4 **Examples of different formats**

The same content can be represented either by descriptions (abstract, language-like propositional representations) or depictions (picture-like representations). Some of the differences between the two types of formats are listed. A "relation" specifies how entities are combined, and an "argument" is an entity that is affected by a relation.

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to understand how representations work we need to consider something else, namely, the processes that operate on them. French words convey information to speakers of French, and smoke signals convey information to combustion-literate Americans, because they know how to interpret them; to others, they are meaningless. Similarly, these black swiggles on the page in front of you have meaning only because you've learned how to *process* them appropriately. A **process** is a transformation of information that obeys well-defined principles to produce a specific output when given a specific input. For a computer, you can provide an input by pressing the key labeled "4" and a process produces an output, the pattern "4" on the screen. The process connects an input to an output.

Think about your computer's word-processing program. If there were no way to keyboard text, no way to cut-and-paste or delete, no way to save and retrieve what you've written, what good would it be? The representations of the words in random access memory (RAM) and on the hard disk are useful only because they can be processed. Similarly, a *mental representation* is a representation that conveys meaning within a processing system—a system that includes various processes that intepret and operate on representations, doing various things to them. Mental representations would not represent anything if they did not occur within a processing system. For example, if representations were never accessed and operated on by processes that use them in specific ways (such as by interpreting their meaning or finding other representations that are associated with them), for all intents and purposes they would not exist. To be more specific, a **processing system** is a set of processes that work together to accomplish a type of task, using and producing representations as appropriate. A processing system is like a factory that takes metal, plastics, and paint as

input and produces cars as output. Many separate operations are performed in the factory, but they all work together to achieve a common goal.

A key idea is that a complex activity cannot be accomplished by a single process, but rather needs to be carried out by a set of processes, each of which accomplishes a different aspect of the overall job (think again about the analogy to an automobile factory). No large computer program is a single uninterrupted list of code. Rather, programs are written in modules, which interact in different ways depending on the nature of the input and the required output. Such is also true of the information processing that underlies mental activity (Marr, 1982; Simon, 1981).

An **algorithm** is a step-by-step procedure that guarantees that a certain input will produce a certain output. A good recipe is an algorithm: follow a list of procedural steps involving certain amounts of flour, eggs, milk, sugar, and butter, the actions of stirring, kneading, and baking, and you'll have a nice cake. *Serial algorithms* specify sequences of steps, with each step's sequence depending on the one before. In contrast, *parallel algorithms* specify operations that are performed at the same time, just as you can make the frosting for a cake at the same time the pan of batter is cooking in the oven. Some algorithms involve both serial and parallel processing. An algorithm that accomplishes a mental process combines specific operations, using and creating representations as needed. By analogy, when you stir the eggs, milk, sugar, and butter into the flour, you create something new: dough. This is like creating a new representation, which is a prerequisite to performing particular processing, such as kneading, and then, after such processing, baking.

2.4. Why the Brain?

At its inception, cognitive psychology was concerned only with function, only with characterizing mental activity (Neisser, 1967). More recently, cognitive psychology has come to rely on facts about the brain. This development has occurred for two main reasons, which concern the concepts of identifiability and adequacy. *Identifiability* refers to the ability to specify the correct combination of representations and processes used to accomplish a task. The problem is that, in principle, different sorts of information processing can produce the same result; thus, additional sorts of evidence—such as knowledge of specific brain activity—are necessary to discover how mental processing in fact takes place. The goal of any theory in science is to discover the facts of the matter, to understand the principles and causes that underlie phenomena. Just as you can correctly or incorrectly describe the way a particular computer program operates, you can correctly or incorrectly describe mental representations, processes, and the ways they are used during a specific mental activity. You can get it right or get it wrong.

It is difficult to disagree with the idea that some theories (or aspects of theories) are correct and some are incorrect, but identifiability is much easier said than achieved. One reason this black-and-white approach has proven difficult to realize is that theories in cognitive psychology can be undermined by *structure–process trade-offs*. This is a key idea, so let's pause to consider an example.

Saul Sternberg (1969b) developed a method to examine how information is accessed in memory. He gave people sets of digits, each set containing one to six items.

He then presented single items and asked the participants to decide as quickly as they could whether those items had been in the set. For example, the participants first would memorize “1, 8, 3, 4” and would later be asked to decide whether “3” was in the set, whether “5” was in the set, and so on. A key result was that the time to respond increased linearly for increasingly large memorized sets; that is, an equal increment of time was added for each additional item included in the set. This led Sternberg to hypothesize that people hold *lists* of items in memory and *serially scan* these lists (when asked whether “3” was in the set, they go through and check each item in the list of numbers they are holding in their memory). The theory thus specified a representation (a list) and an accompanying process (serial scanning). However, it wasn’t long before others (e.g., Monsell, 1978; Townsend, 1990; Townsend & Ashby, 1983) formulated alternative theories that varied the representation and compensated for this change by varying the accompanying process. For example, instead of a list, the items could be stored as an *unordered collection*, like pool balls sitting in a bowl. Instead of searching them one at a time, they could be searched *in parallel,* all at the same time (Figure 5). But how would this theory explain the increase in time for larger sets? The essential idea is that—as in everything else in nature—there is variation in the time to examine each item, whether it’s examining them one at a time in a list or in parallel as a group. Think about the amount of time people spend in a job interview: some interviews finish up very quickly (for better or worse!), some end up dragging on at length. Just as in interviews, some comparisons of remembered information are faster than others. And here’s the trick that makes this alternative theory work: the larger the number of items to be considered, the more likely it is that one of the comparisons will be particularly slow, just as it is more likely that there will be a particularly long interview as the number of people interviewed increases. Thus, if all items must be checked before a decision is made, then the more items, the more time in general will be required until all comparisons are complete.

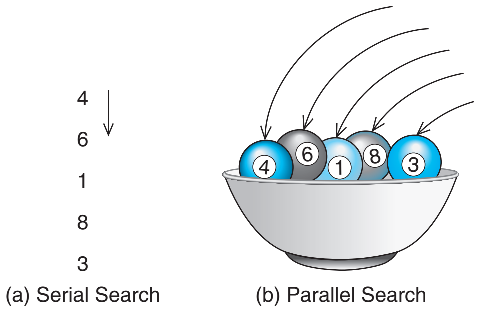


FIGURE 5 **Two theories of memory scanning**

(a) A set of digits can be ordered into a list and scanned serially, one digit at a time. (b) Alternatively, the representation can be changed, creating an unordered collection, and the process can then be changed to compensate for the change in representation—with all digits examined in parallel. This structure–process trade-off can produce models that can mimic each other, both predicting increased times when larger sets of digits must be searched.

In short, the two theories, list-with-serial-scan and collection-with-parallel comparison, can mimic each other. The point: we can change the theory of the representation, and compensate for that change by altering the theory of the process. The representation and process trade off against each other, with change in one compensating for change in the other.

Anderson (1978) proved mathematically that information-processing theorists can always use this sort of structure–process trade-off to create a theory that mimics another theory. The problem is that all the characteristics of both the representations and the processes are up for grabs; a theorist can change one aspect and then can adjust the other aspects of the theory arbitrarily—nothing is nailed down in advance. Anderson also pointed out, however, that the brain can serve to limit this arbitrariness. A theorist *cannot* make up properties of the brain willy-nilly to account for data. Cognitive theories are limited by facts about the brain; the facts don't dictate the theories, but they limit the range of what can be proposed. Facts about the brain anchor theories so that theorists cannot always use structure–process trade-offs to invent alternative accounts for sets of data; the accompanying *Debate* box illustrates an example of the way such facts can help us understand mental activity.

Turning to the brain helps us to grapple with the challenge of identifiability. But this is not all that can be gained by considering the brain when formulating theories of mental activity. Facts about the brain can help us test the *adequacy* of a theory, which lets us know whether a theory is—to that point—valid.

How do we know when a theory, taken on its own terms (and not compared to another, competing theory), is worth its salt? At first glance, this seems obvious: a theory should be taken seriously if it explains all relevant phenomena and makes correct predictions. That standard holds to evaluate a final, complete theory—but it is not clear that such theories ever really exist! What about theories that are just being worked out now, as is true in almost all of cognitive psychology? How do we know whether we are on the right track? Clearly, the theory must be testable, and it must be capable of being disproved; if a theory can explain any result *and* its opposite, it explains nothing at all.

In addition, in psychology we can use facts about the structure and function of the brain to help us evaluate theories; such facts can provide strong justification and support for a theory (what Chomsky, 1967, called *explanatory adequacy*). For example, a cognitive theory might claim that nouns and verbs are stored separately, and this theory might perhaps be based on differences in how easily the two categories can be learned. If researchers can then show that the brain "respects" this distinction, perhaps by showing that different parts of the brain are active when people produce or comprehend the two types of words, the theory is supported. And it is supported more strongly than it would be if you simply collected more data on learning, of the sort that were used to formulate the theory in the first place. We use facts about the brain in this way, as a separate source of justification and support for cognitive theories. If a theory incorporates two distinct processes, this theory gains support when researchers show that different parts of the brain carry out each process.

What Is the Nature of Visual Mental Imagery? DEBATE

Perception occurs after our sense organs (e.g., our eyes and ears) register a stimulus that is physically present and our brain allows us to organize the sensory input; mental imagery occurs when you have a similar experience of perception, but is based on information you previously stored in memory. For example, can you recall how many windows there are in your bedroom? To answer, most people visualize their room, which is an example of using mental imagery. Although mental imagery may seem similar to perception, it clearly is not the same thing; we can change our images at will (for instance, by adding or deleting windows), and the images fade very quickly.

The "imagery debate" concerns the nature of the representations used during mental imagery, and has focused on visual mental imagery (although the issues apply equally well to other forms of imagery, such as the auditory images you have when you "hear" a song in your mind). This debate began when Zenon Pylyshyn (1973) claimed that mental imagery relies entirely on the same sorts of descriptive representations that are used in language. Kosslyn and Pomerantz (1977) marshaled both theoretical arguments and empirical results in an attempt to counter Pylyshyn's assertion and to support the idea that imagery relies in part on depictive representations. In depictive representations, each point in the representation corresponds to a point on the object being depicted such that the distances between points in the representation correspond to the distances between the corresponding points on the object. Pictures are an example of a depictive representation. Many exchanges followed, without conclusion. Every finding produced by the depictive camp was quickly undermined by the descriptive camp. Structure–process tradeoffs ran rampant (Anderson, 1978; Kosslyn, Thompson & Ganis, 2006).

Today, the debate finally appears to be going somewhere, thanks to new knowledge of key facts about the brain mechanisms used in vision. In the monkey brain, some areas involved in visual processing are *topographically organized,* and new methods have shown that the human brain also has such visual areas (e.g., Sereno et al., 1995). These brain areas (such as areas 17 and 18, as the regions are known) literally use space on the surface of the brain to represent space in the world. When you see an object, the pattern of activity on your retinas is projected back into the brain, where it is reproduced (although with some distortions) on the surface of the brain. There literally is a "picture in your head"; brain areas support genuinely depictive representations. And at least two of these topographically organized areas (the largest ones) are also activated when participants close their eyes and visualize objects clearly enough that they could "see" fine details (Kosslyn & Thompson, 2003). Moreover, the size and orientation of the image affects activation in these areas in very much the same way as when people actually see objects at different sizes or orientations (Klein et al., 2003; Kosslyn et al., 1995). In fact, temporarily disrupting neural functioning in these areas temporarily disrupts both visual perception and visual mental imagery—and does so to the same extent (Kosslyn et al., 1999).

However, some patients with brain damage in these areas apparently still retain at least some forms of imagery (e.g., Behrmann, 2000; Goldenberg et al., 1995), and thus the precise role of these brain areas in imagery has yet to be established. If future research conclusively shows that at least some forms of imagery rely on depictive representations in topographically organized brain areas, the debate will either end or be forced to change direction.

Comprehension Check:

1. What is the relationship between mental activity and brain activity?
2. Why is information about the brain important for theorizing about mental activity?

3. THE COGNITIVE BRAIN

Volumes and volumes have been written about the brain, but fortunately we need not concern ourselves here with most of this avalanche of information. Rather, we need focus only on those aspects that can be brought to bear on theories of mental activity. Although we note the major functions of different brain structures, we must emphasize from the outset that virtually all cognitive functions are *not* carried out by a single brain area; rather, systems of brain areas working together allow us to perform specific tasks. Nevertheless, each brain area plays a role in some functions and not others—and knowing these roles will help in understanding later discussions.

3.1. Neurons: The Building Blocks of the Brain

What do neurons have to do with mental processes? That's a bit like wondering what the properties of bricks, boards, and steel have to do with architecture. It is true that architecture cannot be reduced to these components, but they nevertheless influence architecture. For example, London, England, is relatively flat and spread out because most of it was built before steel was readily available—and you cannot build skyscrapers with just brick because the weight of upper stories becomes so great that the walls at street level cannot support them. Although the building materials do not *dictate* the way they are used, they place limitations—*constraints*—on the types of possible architectures. So too with the components of nervous systems. The nature of our neurons and the ways they interact feed into theories of how large groups of neurons can function in mental activity.

Brain activity arises primarily from the activities of neurons. *Sensory neurons* are activated by input from sensory organs such as the eyes and ears; *motor neurons* stimulate muscles, causing movements. *Interneurons,* the vast majority of the neurons in the brain, stand between sensory and motor neurons or between other interneurons; often interneurons are connected to other interneurons, forming vast networks. In addition to 100 billion neurons or so, the brain also contains *glial cells*. Glial cells initially were thought to be involved solely in the care and feeding of neurons, but now are recognized to play a critical role in the way connections among neurons are set up (Ullian et al., 2001). They also modulate chemical interactions among neurons (Newman & Zahs, 1998). There are about 10 times as many glial cells as neurons in the brain.

The crucial parts of a neuron (Figure 6) are its dendrites, axon, and cell body. The *dendrites* receive input from other neurons, as does the *cell body,* and the *axon* transmits output to other neurons. The axon is usually covered with myelin, a fatty insulator that improves transmission. Typical neurons have thousands of dendrites, and the axon branches at the end so that each neuron can in turn affect thousands of other neurons. The connection between neurons is called a *synapse,* and the gap in the synapse is called the *synaptic cleft.* Most neurons affect others by releasing specific *neurotransmitters* at the tip of the axon via small structures known as *terminal*

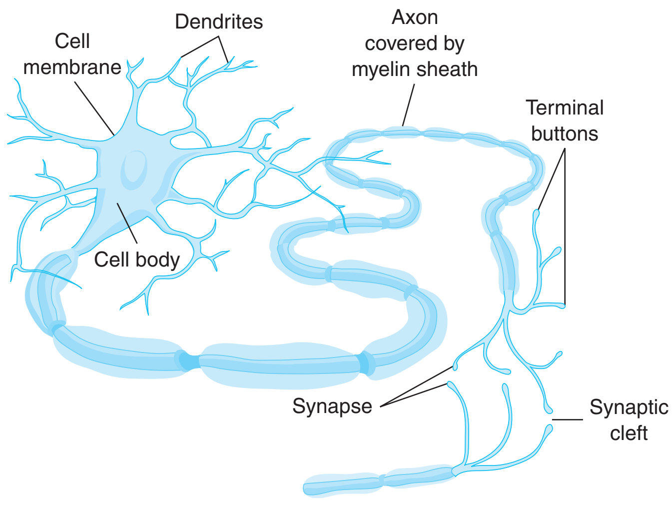


FIGURE 6 **Structure of a neuron**

Neurons have distinct parts that perform distinct roles in information processing.

buttons. Neurotransmitters cross the synaptic cleft, moving from the axon of one neuron to the dendrites (or, sometimes, directly on the cell membrane, the outer covering of the cell body itself) of another.

The effects of a neurotransmitter depend on the *receptors* present on the receiving end. The standard analogy is to a lock and key: the chemical corresponds to a key, and the receptor to a lock. When the appropriate "messenger molecule," the neurotransmitter, binds to a receptor, it can excite the neuron (making it more active) or inhibit it (damping down its activity). The same neurotransmitter can have different effects depending on the nature of the receptor. If the excitatory input reaching a neuron is sufficiently greater than the inhibitory input, the neuron will produce an *action potential;* that is, it will "fire." Neurons obey an all-or-none law: either they fire or they don't.

3.2. Structure of the Nervous System

The nervous system is traditionally considered to have two major parts, the *central nervous system* (CNS) and the *peripheral nervous system* (PNS). The CNS consists of the brain and spinal cord; the PNS consists of the skeletal nervous system and the *autonomic nervous system* (ANS). We start with the more basic, and (in evolutionary terms) older, PNS and then turn to the brain itself.

3.2.1. The Peripheral Nervous System

The skeletal system governs *striated* (that is, very finely "striped") muscles, which are under voluntary control. The skeletal system plays a major role in motor cognition and mental simulation. In contrast, most of the functions of the

ANS are carried out by smooth muscles, but the ANS also controls some glands. Smooth muscles, found in the heart, blood vessels, stomach lining, and intestines, are usually not under voluntary control. The ANS plays a key role in emotion and it also affects how memory works.

The ANS is traditionally divided into two major parts, the sympathetic and parasympathetic nervous systems. The *sympathetic nervous system* prepares an animal to respond more vigorously and accurately during an emergency. Among other things, it:

- increases the heart rate (so more oxygen and nutrients are delivered to organs),
- increases the breathing rate (thus providing more oxygen),
- dilates the pupils (resulting in greater sensitivity to light),
- causes the palms of the hands to become moist (thus providing better grip),
- reduces digestive functions, including salivation (putting them "on hold"), and
- relaxes the bladder (suspending another function that isn't crucial in an emergency).

These changes prepare an organism for successful challenge or successful escape, and are often called the *fight-or-flight response*. Why should we care about this response in a chapter on cognition? For one thing, the events surrounding this response can actually improve memory, while at the same time they can disrupt reasoning.

We modern human beings have the same sympathetic nervous system that served our ancestors well, but now its responses can be activated by stimuli very different from those encountered in previous eras. If during a job interview you are asked to explain some weak spot on your résumé, you may not find the features of the fight-or-flight responses so adaptive—it is not easy making your explanation when your heart is pounding and you have a dry mouth!

The *parasympathetic nervous system* in many ways counters the sympathetic nervous system. Whereas the sympathetic system tends to rev things up, the parasympathetic system dampens them down. Moreover, whereas the sympathetic system causes a whole constellation of effects (producing arousal in general), the parasympathetic system targets single organs or small sets of organs. In a job interview, you are grateful when the interviewer moves onto another part of your résumé where you are on rock-solid ground—and the parasympathetic system then dampens down the fight-or-flight response you were struggling to contain.

3.2.2. The Cerebral Cortex

Now let's consider the central nervous system, specifically the brain—the seat of mental activity. Imagine that you are in a neuroanatomy lab, dissecting a human brain. The first thing you see, covering the surface of the brain, is the topmost of three membranes, called the *meninges*. Putting on surgical gloves (an absolute necessity to guard yourself against viruses), you peel back the meninges to uncover a rich network of blood vessels clinging to the surface of the brain, like ivy clinging to a wall. The surface of the brain contains most of the cell bodies of neurons, which

are a gray color, hence the term "gray matter." These cells are in a layer about 2 millimeters deep, which is called the *cerebral cortex*. The cortex of the brain is noticeably wrinkled; the wrinkles allow more cortex to be crammed into the skull. Each up-bulging fold is called a *gyrus,* and each crease a *sulcus*. The various gyri and sulci have individual names, and many have been identified as playing a role in particular mental activities.

In your neuroanatomy lab you are equipped with a scalpel as well as surgical gloves. Now slice into the brain and examine its interior. The interior is packed with white fibers (the color giving rise to the term "white matter"), which connect the neurons. Keep exploring deeper to find the *subcortical structures* (so called because they lie beneath the cortex), which contain gray matter, and—at the very center of the brain—a series of connected cavities, the *ventricles*. The ventricles are filled with the same fluid that runs inside the spinal cord.

The brain is best considered not as a single entity but rather as a collection of components that work together, in the same way that the hand is a collection of separate bones, tendons, and muscles, all of which depend on one another to carry out the functions of the hand. One of the first things you have noticed in the neuroanatomy lab is that the brain is divided into two halves, the left and right *cerebral hemispheres*. Although the same physical structures are duplicated in the two cerebral hemispheres, they can differ both in their size and their functions. The hemispheres are connected in the interior of the brain by a massive collection of nerve fibers (some 250 to 300 million of them), called the *corpus callosum,* as well as several smaller, less important connections.

Modern neuroanatomy divides each hemisphere into four major parts, or *lobes:* the *occipital,* at the posterior (rear) of the brain; the *temporal,* directly under the temples; the *parietal,* at the superior (upper) posterior part of the brain; and the *frontal,* at the anterior (front) part of the brain, right behind the forehead (Figure 7). The lobes are named after the bones of the skull that cover them, and hence this organization of the brain is somewhat arbitrary—so you won't be surprised to find that mental activities are not neatly assigned to one or another lobe. Nevertheless, at least some mental representations and processes occur mainly in a specific lobe, and we can make some generalizations about the different functions of the various lobes. But always keep in mind that the lobes work together, like the bones, tendons, and muscles of the hand.

The occipital lobes process only visual input, both from the eyes and from memory (at least in some cases, in mental imagery). If you were to slip while roller skating and fall on the back of your head, you would probably "see stars." This visual effect (which is not worth the pain of inducing it) occurs because the impact causes compression of the neurons in the occipital lobes. Curiously, if you stare straight ahead, the left occipital lobe receives inputs from the right side of space, and the right occipital lobe receives inputs from the left side of space. Why? The back of the eye, the retina, is actually part of the brain that's been pushed forward during development (Dowling, 1992); hence the left side of each eye (not just the left eye) is connected to the left part of the brain, and the right side of each eye (not just the right eye) is connected to the right side of the brain. When you stare straight ahead, light

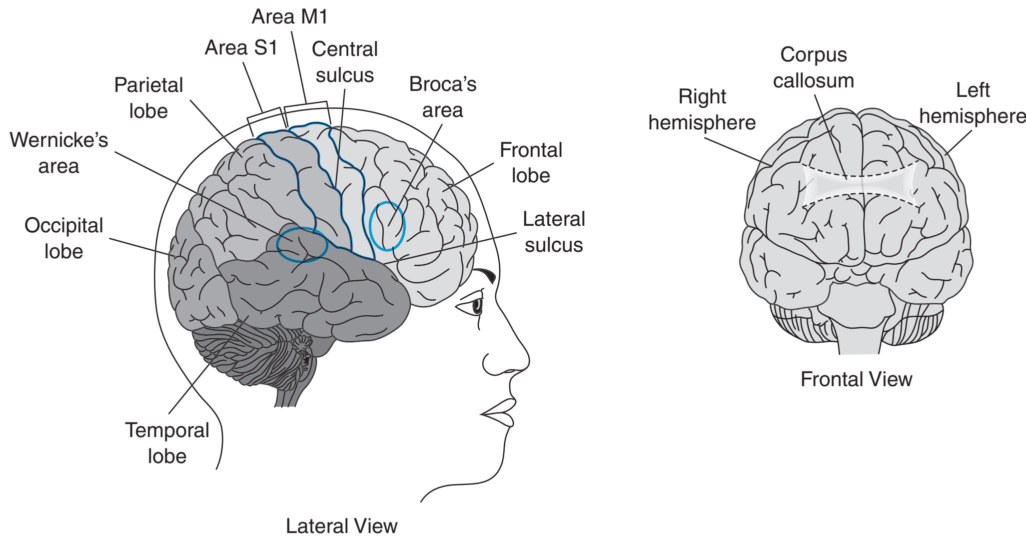


FIGURE 7 The major lobes and landmarks of the brain

The anatomical landmarks of the brain only imperfectly correspond to distinct functions, but these landmarks nevertheless are useful ways to describe brain location. Specific terms are used to describe locations in the brain: *Medial* means closer to the midline; thus, the medial views show the inside of the brain. *Lateral* means toward the side, farther away from the midline; thus the lateral views show the outside surface of the cerebral cortex. The terms *dorsal* (the "back" side) and *ventral* (the "stomach" side) are also used. Because we stand fully upright, these terms have no literal meaning with reference to the human brain, but by convention *dorsal,* like *superior,* describes "above," and *ventral,* like *inferior,* describes "below."

from your left strikes the right sides of each eye, and light from your right strikes the left sides of each eye. Vision, like all cognitive functions, is itself carried out by a set of distinct representations and processes. In fact, the occipital lobes contain numerous different areas, each of which plays a key role in a different aspect of vision: for example, some areas primarily process motion, others color, and others shape. If the occipital lobes are damaged, partial or complete blindness results.

The temporal lobes are involved in many different sorts of functions. One of them is the retention of visual memories. In addition, they receive input from the occipital lobes and match visual input to visual memories. When you've already stored an image of what you currently are seeing, this matching process makes the stimulus seem familiar. The temporal lobes also process input from the ears, and the posterior portion of the left temporal lobe contains *Wernicke's area,* which is crucial for comprehending language. At the anterior (i.e., front) portion of the temporal lobes are a number of areas that are critical for storing new information in memory, and areas involved in deriving meaning and in emotion.

The parietal lobes are crucially involved in representing space and your relationship to it. The most anterior gyrus of the parietal lobes, the *somatosensory cortex* (area S1),

represents sensations on different parts of the body; S1 is organized so that the different parts of the body are registered by different portions of cortex. In addition, the left-hemisphere S1 registers sensations on the right side of the body, and vice versa for the right hemisphere. The parietal lobes also are important for consciousness and attention. Moreover, they are also involved in mathematical thinking. Albert Einstein (1945) reported that he relied on mental imagery when reasoning, and often imagined "what would happen if. . . ." This is interesting: after his death researchers discovered that his parietal lobes were about 15 percent larger than normal (Witelson et al., 1999).

The frontal lobes are generally involved in managing sequences of behaviors or mental activities. They play a major role in producing speech; *Broca's area* is usually identified with the third frontal gyrus in the left hemisphere, and this area is crucial for programming speech sounds. Several other areas in the frontal lobes are involved in controlling movements. The most posterior gyrus in the frontal lobes is called the *primary motor cortex* (area M1; also called the *motor strip*); this area controls fine motor movements, such as those necessary to type up your résumé. Like S1, M1 is organized so that different parts of the cortex correspond to different parts of the body. The left-hemisphere M1 controls the right part of the body, and vice versa. The frontal lobes are also involved in looking up specific information stored in memory, in planning and reasoning, in storing information briefly in memory so that it can be used in reasoning, in some emotions, and even in personality (Davidson, 1998, 2002). The frontal lobes obviously are crucial in helping you decide what sort of job to pursue, and will play crucial roles in allowing you to do well in your chosen career.

Although many functions are duplicated in the corresponding lobes in the two hemispheres (just as they are in our two lungs and two kidneys), in some cases the lobes function differently on the left and right sides. For example, the left-hemisphere parietal lobe produces representations that describe spatial relations (such as, "one object is *above* another"), whereas the right produces representations of continuous distances (Laeng et al., 2002). However, even when the hemispheres are specialized differently, in most cases the difference is a matter of degree, not of kind. Other than for some language functions, both hemispheres generally can carry out most functions, but perhaps not equally well (Hellige, 1993).

3.2.3. Subcortical Areas

The subcortical areas of the human brain (Figure 8) often appear very similar to those of other animals, and research suggests that these areas perform similar functions in various species. This is not to say that these areas perform simple functions: they typically carry out complex functions that either are essential for life or fundamental to the survival of the organism.

The *thalamus* is usually regarded as a kind of switching station. The sensory organs, such as the eye and the ear, as well as parts of the brain involved in controlling voluntary movements, send fibers to the thalamus, and the thalamus in turn sends fibers widely throughout the brain. The thalamus is ideally situated to regulate the flow of information in the brain, and it does: *attention* is the selective aspect of information processing, and parts of the thalamus play a crucial role in attention. The *pulvinar nucleus* (a nucleus, in neuroanatomy, is a cluster of cells) is involved in focusing attention. The thalamus is also important in regulating sleep.

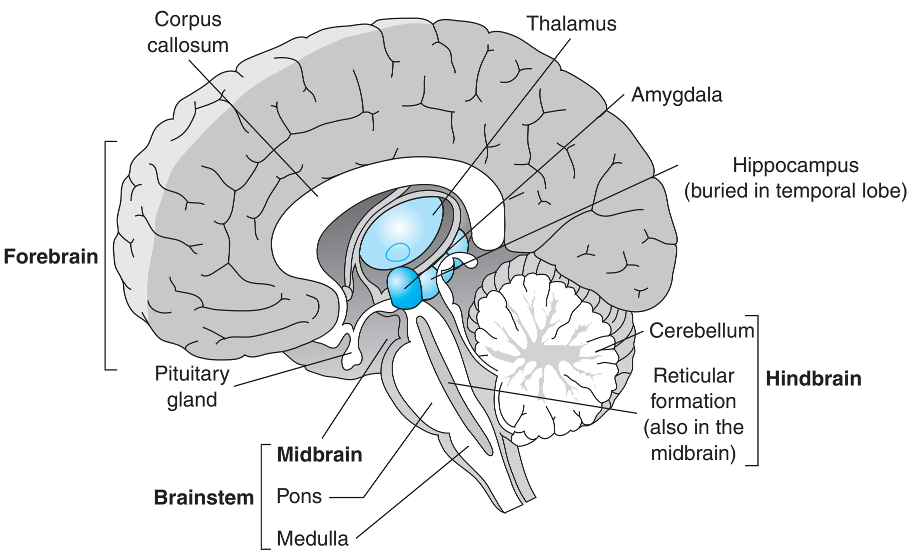


FIGURE 8 The major subcortical areas of the brain

The mammalian brain is divided into the *forebrain, midbrain,* and *hindbrain.* In nonhuman mammals, these are essentially in front-to-back order. In humans, *hindbrain* seems a misnomer, both because of human posture and the evolutionary expansion of the forebrain over the midbrain and the hindbrain.

Directly under the thalamus lies the *hypothalamus*, which controls many bodily functions, including maintaining a constant body temperature and blood pressure, eating and drinking, keeping the heart rate within appropriate limits, and regulating sexual behavior. Some of these functions are accomplished by various hormones (which are chemicals that affect various organs, and can even modulate the activity of neurons) regulated by the hypothalamus.

The *hippocampus* is located at the anterior of the temporal lobes, tucked inside. Its internal structure and connections to other areas allow it to play a central role in entering new information into memory. The hippocampus itself is not the repository of new memories; rather, it governs processes that allow memories to be stored elsewhere in the brain (such as in other regions of the temporal lobe).

The *amygdala* (named, based on its shape, for the Greek word for "almond") nestles next to the hippocampus, and for good reason. The amygdala is central both in the appreciation of emotion in others and in the production of behaviors that express our own emotions, especially fear. The amygdala can modulate the functioning of the hippocampus, a relationship that helps you store vivid memories of highly emotional information. The amygdala and hypothalamus serve to connect the CNS to the PNS. Both structures are central to triggering fight-or-flight responses.

The amygdala and hippocampus, along with several other subcortical structures, are part of the *limbic system*. At one time researchers believed that the limbic system regulated emotion, but this turned out to be incorrect. Not only are some parts of the limbic system used in other ways (such as in encoding new memories),

but also other structures (such as the frontal lobes) are involved in emotion (Davidson, 2002; LeDoux, 1996).

The *basal ganglia* are absolutely critical for day-to-day life, allowing us to plan movements and to develop habits. Can you imagine what life would be like if you had to think through everything you do every time you do it? Think about the difference between the second time you went to a particular classroom in a basement of an unfamiliar building (which you now remember from the previous visit) and the tenth time you sauntered in: without the basal ganglia, every visit would be like that effortful, alert, second time. The basal ganglia lie at the outer sides of the thalami. The *nucleus accumbens,* a structure that is near the basal ganglia and sometimes considered to be part of it, plays an important role in learning. As the behaviorists emphasized, animals will learn a behavior when it produces a pleasant consequence. (If you make eye contact with the interviewer and receive a warm smile in return, you are likely to make eye contact again later in the interview.) This happy consequence is called a *reward*. The nucleus accumbens signals other brain areas when reward occurs (Tzschentke & Schmidt, 2000), both when it is actually received and when an animal only anticipates receiving it (Hall et al., 2001; Knutson et al., 2001; Pagnoni et al., 2002). By studying the brain, then, researchers have discovered that a mental state—anticipation—can affect the brain in a way that in turn enhances learning.

The *brainstem* is located at the base of the brain, and contains many structures that receive information from and send information to the spinal cord. A set of small structures, collectively known as the *reticular formation,* is involved in sleep and alertness. Some of the neurons in this structure produce *neuromodulators,* which are chemicals that affect far-flung portions of the brain. (These chemicals do just what their name suggests: they alter, or modulate, the functions of neurons.) The *pons* ("bridge" in Latin) connects the brainstem to the cerebellum, and contributes to functions that both structures perform, such as controlling sleep and forming facial expressions.

Finally, the *cerebellum* is concerned with physical coordination. It is also involved in some aspects of attention and in the estimation of time. The surface area of the cerebellum is about the same as the surface area of the cerebral cortex, which implies that this structure is engaged in many complex processes; researchers have only begun to comprehend its functions.

✓ Comprehension Check:

1. What are the four lobes of each hemisphere of the brain?
2. What roles are played by the major subcortical structures?

4. STUDYING COGNITION

Cognition is investigated in several fields, each of which uses a different approach. When first conceived, *cognitive psychology* focused exclusively on the level of information processing (e.g., Lindsay & Norman, 1977; Neisser, 1967). *Artificial intelligence* (AI), concentrating at the same level of analysis, is the field in which

researchers attempt to program computers to perform cognitive tasks. Many AI researchers believe that cognition is so complicated that figuring out how to build a processing system that performs comparably to humans will lend insight into human cognition (Minsky, 1986). Neither early cognitive psychology nor AI pays much attention to the way such information processing takes place in the brain. But even computer buffs have noted that it isn't quite right to assume that information processing is independent of the machine itself: some programs rely on specific features of the hardware, such as the presence of a certain amount of RAM or a particular graphics or sound card. Studying the hardware can lead to insights about what the machine does and how it functions.

In fact, taking this view further, other researchers argue that understanding the hardware in sufficient detail allows you to understand its function. *Neuroscience* aims to understand the "wetware," the brain itself, which also must be understood at different levels of analysis. At one extreme, we must understand the nature of the genetic and molecular events that regulate cells in order to know how individual neurons work; at the other extreme, we must understand the functions of lobes and interactions among the different brain regions in order to know how the brain as a whole operates. Theories of such large-scale interactions among brain areas meld into theories of information processing (cf. Dowling, 1992).

Cognitive neuroscience stands at the intersection of neuroscience and cognitive psychology. The guiding idea is "the mind is what the brain does." Cognition is information processing, but information processing carried out by a brain with specific characteristics. Thus, cognitive neuroscience uses knowledge of the brain, such as the existence of brain areas that are specialized for different processes, in theories of processing systems. However, as indicated by the name of the approach, in which *neuroscience* is the noun that's modified by *cognitive,* cognitive neuroscience is focused on understanding the brain itself—what different parts of it do and how they interact.

In this chapter we focus on the subject matter of cognitive psychology—the study of mental activity—and draw on related fields to further the investigation. Our goal is twofold: to integrate what has been learned about cognition from the various approaches and to integrate the brain into the traditional laboratory approaches of cognitive psychology. As we conceive it, the goal of the new cognitive psychology is to understand mental activity so well that you could program a computer to mimic the way the brain functions when we perform tasks.

4.1. Converging Evidence for Dissociations and Associations

The first thing you will notice as we continue is that there are a lot of different methods. No one method is ideal; they all have limitations and potential problems. But—and this is a critical point—they have *different* limitations and potential problems. Using several different methods has two desirable outcomes. First, a more complete picture can be painted. For example, some sorts of neuroimaging (also called brain scanning) require a relatively long time to obtain an image, but can detect changes in relatively small parts of the brain, and the opposite is true of other neuroimaging methods. By using both types of methods, researchers can learn about different

aspects of the same phenomenon. Second, the results from any one study are rarely conclusive; findings from any method are typically open to more than one interpretation. But if the results from different methodologies all point in the same direction, the weaknesses of any one method are compensated by the strengths of another. Thus, **converging evidence**, different types of results that imply the same conclusion, lies at the heart of successful investigations in cognitive psychology.

Many of the methods in cognitive psychology are used to accomplish two general types of goals. The first is to establish a **dissociation**, that is, to establish that an activity or a variable affects the performance of one task (or aspect of one task) but not of another. A dissociation, therefore, is evidence for the existence of a specific process. For example, Alan Baddley (1986) has argued that people can use at least two distinct types of "working memory" structures, one that briefly holds visual-spatial information and one that briefly holds articulatory-verbal information. If you look up a phone number and keep it in mind as you cross the room to the telephone, you are holding that information in the articulatory-verbal working memory. In contrast, if you are given a map of how to find the office where a job interview will take place, you might hold that map in visual-spatial working memory after you enter the building and begin to walk down the halls. The primary evidence for the existence of these two types of memory structures is a dissociation between the two kinds of memories in the effects of different sorts of interference. Having to count backward disrupts the ability to retain articulatory-verbal information, but not visual-spatial information; in contrast, having to trace a route through a maze has the opposite effect. In this example, we have a **double dissociation**: in this case, an activity or variable affects one process but not another and a second activity or variable has the reverse properties (e.g., Sternberg, 2003). Double dissociations are powerful evidence for the existence of two distinct processes, and they can be obtained with virtually any of the methods used in cognitive psychology.

In addition to dissociations, cognitive psychologists try to document associations. An **association**, in this sense, occurs when the effects of an activity or variable on one task are accompanied by effects on another task. Such shared effects indicate that common representations or processes are being affected. For example, if someone suffered brain damage that led to the inability to recognize faces, you might want to test whether that patient also had difficulty forming mental images of faces. In fact, if patients have one problem, they often have the other. This association suggests that a common representation or process is shared by perception and mental imagery.

So much for goals and general approaches. How do we actually get on with it? How do we actually collect observations—data—and formulate theories? Researchers in cognitive psychology ask a wide variety of questions about information processing, and many different methods can be used to answer them. In this chapter you will see how different methods complement one another, and how researchers have used methods in clever ways to discover some of the secrets of one of Nature's most intricate and intriguing creations—the human mind. So to get oriented, let's open the toolbox and see what's inside.

4.2. Behavioral Methods

A **behavioral method** measures directly observable behavior, such as the time to respond or the accuracy of a response. Researchers attempt to draw inferences about internal representation and processing from such directly observable responses. Table 1 summarizes the main behavioral measures and methods used in cognitive psychology and their primary advantages and disadvantages. We pause briefly here to consider some observations about the most important behavioral methods.

First, the accuracy with which participants perform a task is used to address a wide variety of types of processing, ranging from those that require making a discrimination (either perceptually or from memory) to those that require recall. With all accuracy measures, however, researchers must be on guard against two possible hazards:

1. If the task is too easy, participants may exhibit *ceiling effects*, where no differences are seen in the responses because the participants all score the highest

TABLE 1 Major Behavioral Measures and Methods Used in Cognitive Psychology

Measure or Method	Example	Advantages	Limitations
Accuracy (percent correct or percent error)	Memory recall, such as trying to remember the main job requirements during an interview	Objective measure of processing effectiveness	Ceiling effects (no differences because the task is too easy); floor effects (no differences because the task is too hard); speed–accuracy trade-off ("jumping the gun")
Response time	Time to answer a specific question, such as whether you know the requirements of a certain job	Objective and subtle measure of processing, including unconscious processing	Sensitive to experimental expectancy effects and to effects of task demands; speed-accuracy trade-off
Judgments	Rating on a seven-point scale how successful you felt an interview was	Can assess subjective reactions; easy and inexpensive to collect	Participant may not know how to use the scale; may not have conscious access to the information; may not be honest
Protocol collection (speaking aloud one's thoughts about a problem)	Talking through the pros and cons of various job possibilities	Can reveal a sequence of processing steps	Cannot be used for most cognitive processes, which occur unconsciously and in a fraction of a second

possible score. For example, if you want to know whether emotion boosts memory and you test only two highly emotional items and two neutral ones, the participants will recall all the items so well that no difference will emerge. But that result does not mean that no difference exists, merely that your test was too easy to demonstrate it. Similarly, if the task is too difficult, participants may exhibit *floor effects,* where no differences are seen among responses because the participants are doing terribly on all the conditions.

2. Participants can make errors because they are jumping the gun, that is, responding before they are ready. This pattern of responses produces a *speed–accuracy trade-off* in which errors go up as response times go down. Such a trade-off can be detected only if response times are assessed at the same time as accuracy. Therefore, as a rule, the two measures should be taken together. Incidentally, this problem is not limited to the laboratory: such speed–accuracy trade-offs can occur in real life, which is why you should be sure to reflect on your decisions: there's truth in "haste makes waste."

Second, a large amount of research in cognitive psychology rests on measures of the amount of time participants take to respond when making a judgment. In general, participants should require more time to respond when a task requires more cognitive processing.

Finally, some researchers also collect judgments of various sorts (such as ratings of confidence that a participant recalls information correctly) and others collect protocols (such as records of what participants say they are doing as they work through a problem).

In general, purely behavioral methods are prone to a number of problems:

1. Participants sometimes change their speed of responding after figuring out what the investigator expects, trying, perhaps unconsciously, to cooperate. The influence of the investigator on the participant's responses is known as *experimental expectancy effects*.
2. Participants may respond to *task demands,* aspects of the task itself that participants believe require them to respond in a particular way. For example, results of mental imagery scanning experiments might reflect such task demands (Pylyshyn, 1981, 2002, 2003). In these experiments, participants are asked to scan an object in their visual mental image, with their eyes closed, until they have focused on a specific target (at which point they press a button). Response times typically increase with the distance scanned (for a review, Denis & Kosslyn, 1999). This result could be explained if participants *interpret the task* as requiring them to mimic what would happen in the corresponding perceptual situation, and thus take more time when they think they should be scanning longer distances. Task demands can be ruled out, but this requires clever experimentation. For example, the scanning results have been obtained even when no instructions to scan, or even to use imagery, are employed (Finke & Pinker, 1982, 1983).

3. Behavioral methods are necessarily incomplete. They cannot give us a rich picture of underlying processing, in part because of structure–process trade-offs. These methods are probably most useful when employed to test a specific theory that makes specific predictions about the specific measures being collected.

4.3. Correlational Neural Methods: The Importance of Localization

Cognitive psychology has become extraordinarily exciting during the past decade because researchers have developed relatively inexpensive, high-quality methods for assessing how the human brain functions. These methods are *correlational:* although they reveal the pattern of brain activity that accompanies information processing, they do not show that activation in specific brain areas actually results in the task's being carried out. Correlation does not necessarily imply causation. Some of the activated brain areas could be just along for the ride—activated because they are connected to other areas that do play a functional role in processing. One of the main virtues of these methods is that they allow researchers to begin to *localize* mental activity, to show that particular parts of the brain either give rise to specific representations or carry out specific processes.

Such data can establish both dissociations and associations, thereby giving insight into the nature of representations and processes used during mental activity. On the one hand, if two tasks activate different brain areas (a dissociation), this is evidence that they are accomplished at least in part by separate representations or processes. For example, the parts of the brain used when one holds verbal information in working memory (sometimes refered to as "short-term memory") are different from those used when one recalls previously stored information (Nyberg et al., 1996; Smith, 2000), showing that working memory is not just an activated portion of the information previously stored in memory. On the other hand, if the same brain area is activated in two tasks (an association), this is evidence that at least some of the same representations or processes may be used in the two tasks. For example, once part of the parietal lobe was shown to be involved in representing space, Dehaene and colleagues (1999) could interpret activation in this region when participants compare relative magnitudes of numbers. They argued that people use a "mental number line" in this task. Their interpretation was then supported with a variety of additional forms of evidence. However, this sort of inference must be made with great caution: what appears to be activation of the same area in two different tasks may in fact be activation in two different, nearby areas, but the technique is too insensitive to register the difference. As usual, we must be very careful in affirming the null hypothesis; that is, in claiming that a failure to *find* a difference means that there is in fact no difference.

We can evaluate the various correlational neural methods on four dimensions: (1) *spatial resolution,* how precisely they localize the brain area that produces a signal; (2) *temporal resolution,* how precisely they track changes in brain activity over time; (3) *invasiveness,* the degree to which they require introduction of foreign substances into the brain; and (4) *cost,* both for the equipment (and any special facilities) and for its use in each participant test. The three most important neuroimaging

TABLE 2 Correlational Neuroimaging Methods

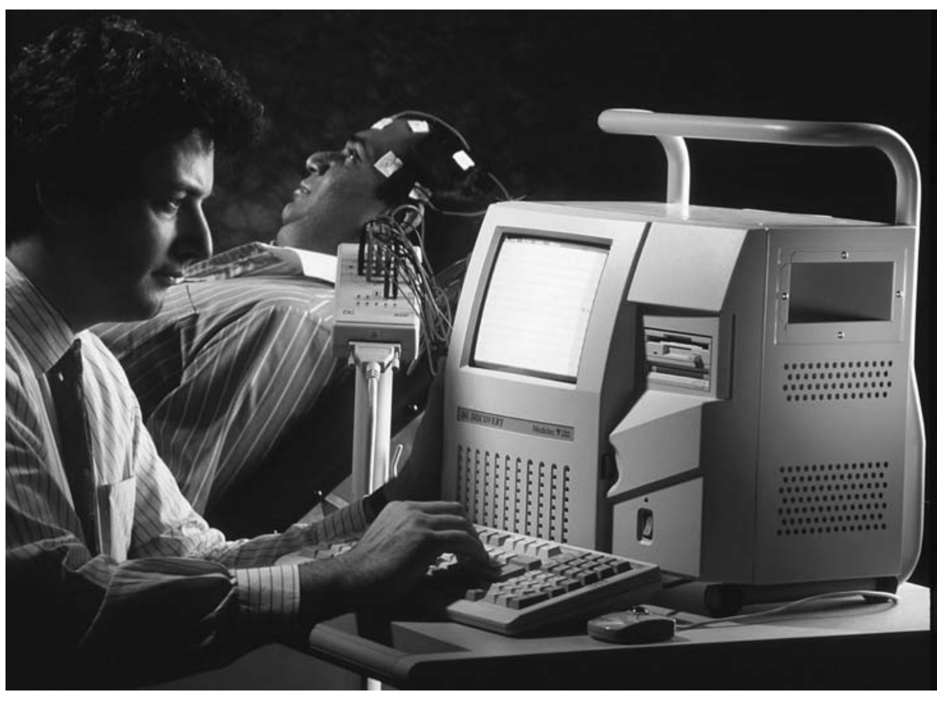
Method	Example	Spatial Resolution	Temporal Resolution	Invasiveness	Cost (Initial; Use)
Electrical (electroencephalography, EEG; event-related potentials, ERP)	Track stages of sleep (EEG), brain response to novelty (ERP)	Poor (perhaps 1 inch)	Excellent (milliseconds)	Low	Low purchase cost; low use cost
Magnetoencephalography (MEG)	Detect activity in auditory cortex to tones of different pitches	Good (under 1 centimeter), but only in sulci, not in gyri (because of the way dendrites line up)	Excellent (milliseconds)	Low	High purchase cost (and needs a special magnetically shielded room); medium use cost (needs servicing so superconductors remain extremely cold)
Positron emission tomography (PET)	Detect activity in language areas as participants speak	Good (about 1 centimeter, but in theory higher)	Poor (an image every 40 seconds)	High (must introduce radiation)	High purchase cost (needs a cyclotron plus the PET camera); high use cost (about $2,000 per participant)
Magnetic resonance imaging (MRI) and functional magnetic resonance imaging (fMRI)	Show structure of the brain (for MRI), show activity in brain areas, same as PET (for fMRI)	Superb (millimeter range); fMRI often about 0.5 centimeter	Depends on level of resolution; typically several seconds	Low	High purchase cost (needs a specially shielded room); medium use cost (needs servicing)
Optical imaging	Show activity in brain areas, same as PET	Poor at present (about 2 centimeters)	Depends on level of resolution; typically several minutes	Medium/low (light is shined through the skull)	Low purchase cost; low use cost

methods for cognitive psychology currently are event-related potentials (ERP), positron emission tomography (PET), and functional magnetic resonance imaging (fMRI), and so it is worth considering them briefly in more detail. Table 2 summarizes these methods.

The oldest correlational methods record brain activity from the scalp. *Electroencephalography* (EEG) uses electrodes placed on the scalp to record fluctuations in electrical activity over time (Figure 9a). These "brain waves" are analyzed to reveal how much activity is present in different "bands," which are sets of frequencies. For example, the "alpha rhythm" is 8 to 12 Hz (that is, 8 to 12 cycles per second), and the amplitude of waves in this range increases when a participant becomes relaxed. Recording *event-related potentials* also relies on scalp electrodes, but here they are used to observe fluctuations in activity in response to a specific stimulus. Investigators note changes in electrical activity, positive or negative, that occur specific amounts of time after a stimulus has been presented. For example, the "P-300" is a positive fluctuation that occurs about 300 milliseconds after a stimulus; this fluctuation is thought to reflect detection of novelty. These methods have several drawbacks:

1. Both EEG and ERP are disrupted by slight movements because muscles produce electric activity when they twitch.
2. Both techniques have relatively poor spatial resolution, in part because electrical waves travel over the surface of the brain and the scalp, and in part because the electrical activity at any point on the scalp is a composite of activity that has originated from various places in the brain. It is as if you were measuring the amount of water falling into paper cups during a rainstorm, and trying to figure out how much water the cloud immediately overhead held; the water you collect came from multiple parts of the cloud (the wind affects where raindrops land) as well as from multiple altitudes. Researchers are working on techniques to use recordings at multiple electrodes to try to zero in on the source of electric activity, but these techniques are still being developed. At present, the spatial resolution of electric techniques is probably about 1 inch, but this is a rough estimate. In spite of their poor spatial resolution, these techniques have several virtues: they have excellent temporal resolution, they are not invasive, and both purchase and use of the equipment are relatively inexpensive.

A relatively recent variant of ERP, *magnetoencephalography* (MEG), records magnetic rather than electric fields (Figure 9b). Unlike electrical fields, magnetic fields are not distorted as they pass through bone and they do not travel over the surface of the brain or the scalp. MEG has relatively good spatial resolution (probably under a centimeter), but because of the way dendrites are arranged in cortex it primarily detects activity in sulci, not on gyri. It has superb temporal resolution (detecting fluctuations of a few milliseconds) and is not invasive. However, MEG is expensive; the machine must be housed in a special magnetically shielded room, and the detectors must be serviced regularly. (They need to be extremely cold, so that superconductors can detect the faint magnetic fields in the brain.)



(a)

FIGURE 9 Recording the brain

(a) An EEG machine, which records electrical activity.
(Photograph by Deep Light Production. Courtesy of Photo Researchers, Inc.)

PET provides a different type of information than what we can learn from ERP and thus is very useful as a complementary technique (Figure 10a). The most common use of PET in cognitive psychology relies on a radioactive isotope of oxygen, ^{15}O. Water in which some of the oxygen is in the form of this isotope is injected into a participant who is performing a task. When a part of the brain becomes active, it draws more blood to it (rather like the way a washing machine draws more water from the main when the machine is turned on). As more blood flows to an area, more of the radioactively tagged water goes along with it. Detectors surrounding the head record the amount of radioactivity, and computers later reconstruct a three-dimensional image from this information. This technique can detect activity in structures smaller than 1 centimeter across (in theory as small as 2 millimeters, but in practice perhaps three times larger than that). Among the drawbacks are the following:

1. Although the levels of radiation are very low (10 scans deliver about the same amount of radiation as what an airline pilot typically receives in a year and a half), the technique is still invasive.
2. The temporal resolution is relatively poor; it takes at least 40 seconds to obtain an image.

(b)

FIGURE 9 *(continued)*

(b) A MEG machine, which records magnetic activity, in use.

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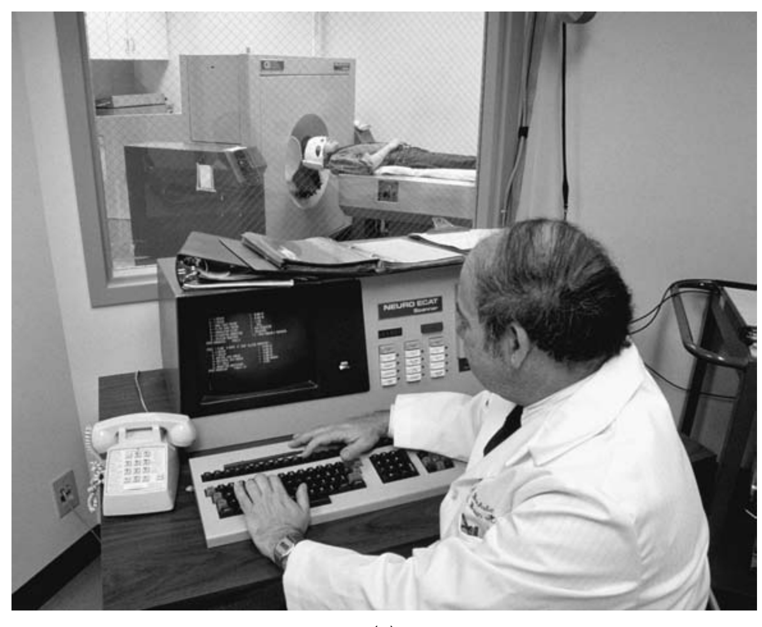
3. PET is expensive, requiring radioactive material that is manufactured immediately before use (because the radiation decays quickly) and special machines to perform the scans.

Another technique has recently come to replace most of the research that used to be done with PET. This technique grew out of magnetic resonance imaging (MRI). So, let's first look at MRI, and then consider the newer functional magnetic resonance imaging methods that assess brain activity. The American Paul C. Lauterbur and the Englishman Peter Mansfield won the 2003 Nobel Prize in Physiology or Medicine for their roles in developing MRI. Their discoveries not only changed the face of medicine for all time but also dramatically improved our ability to understand the brain. The original use of MRI was to assess brain structure, not function. For example, this technique has revealed that musicians who play string instruments (such as violins) have a larger area M1 in their right hemispheres (controlling their left hands) than is present for other members of an orchestra (Münte et al., 2002). MRI uses magnetic fields to



(a)

(b)

FIGURE 10 **Neuroimaging methods**

PET and fMRI are probably the most common neuroimaging methods used today. (a) A PET scan in progress.

(Photograph by Spencer Grant. Courtesy of PhotoEdit Inc.)

(b) An MRI machine.

(Photograph by Geoff Tompkinson. Courtesy of Photo Researchers, Inc.)

alter the orientations of specific atoms in a substance. A strong reference magnet is turned on, causing all the atoms to line up with it (atoms have a north and south pole, and line up accordingly with a large magnet). A quick pulse of radio waves is then used to disorient the atoms, which give off detectable signals when they return to normal. (This pulse is created by magnets that are so strong that they flex when they are turned on, and they displace air, which creates a sound, just as a loudspeaker pushes air to create sound. But in the case of MRI, the sound is a loud knocking noise.) The MRI records a signal as the atoms return to their original alignment; the recorded current is then amplified and used to create an image. Gray matter and white matter can be identified by the way their component atoms resonate to different frequencies of radio waves. MRI has extraordinarily good spatial resolution (less than 1 millimeter, in principle), good temporal resolution (an image can be created in a few seconds), and it is noninvasive. But the machines are very expensive and require special facilities (Figure 10b).

Functional magnetic resonance imaging is based on the same principles as structural MRI. However, instead of charting the structure of the brain, fMRI tracks activity in different parts of the brain. The most common fMRI technique is called BOLD, for *blood oxygenation level dependent*. Red blood cells contain iron (in the hemoglobin), which can have oxygen bound to it or can have oxygen stripped off when it is used up in metabolism. When a brain area begins to function, it draws more oxygenated red blood cells than it actually needs, and thus oxygenated red blood cells pile up. The iron-with-oxygen and the iron-without-oxygen affect the nearby hydrogen atoms in water (the major constituent of blood) differently. And that's the key: the magnetic pulse sequence is designed to reveal where oxygenated red blood cells have piled up, which is an indirect measure of activity in that brain area. fMRI has about the same spatial resolution as structural MRI (at least 1 millimeter) and is noninvasive. Nevertheless, this technique does have drawbacks, including these:

1. fMRI can detect changes that occur over the course of about 6 seconds, which is much less precise than ERP or MEG.
2. The machines (and the necessary specially shielded rooms) are expensive.
3. The machines are very noisy (which can make participants uncomfortable and therefore make certain studies hard to do).
4. The tube in which participants lie is very narrow, which some people find disturbing.

Finally, it is worth mentioning a very new member of the neuroimaging toolbox, which holds promise of becoming increasingly popular in the near future. *Optical imaging* takes advantage of two facts about light: first, the skull is transparent to near-infrared light; second, some frequencies of such light are absorbed more by oxygenated hemoglobin than by hemoglobin stripped of its oxygen (Obrig & Villringer, 2003). The *diffuse optical tomography* (DOT) method positions a collection of very weak lasers at different locations on the skull and shines light onto the cortex; the reflected light is measured by detectors placed on the scalp. Each laser flickers at a distinct rate, and thus it is possible to calculate where the reflected light originated. This technique allows researchers to track blood flow in the cortex. It is relatively inexpensive to build the machines and costs almost nothing to use them.

Although the technique is in a sense invasive, it is very safe; the level of light reaching the cortex is less than what an uncovered bald head receives outdoors on a sunny day (the technique has been approved for use with very young infants). The major drawbacks are as follows:

1. Light penetrates only 2 or 3 centimeters before it becomes too diffuse to be recorded accurately, and thus no subcortical areas can be assessed and only about 80 percent of the cortex can be reached.
2. This technique has about the same temporal resolution as BOLD fMRI, and the spatial resolution depends on the number and placement of the lasers and detectors.

In general, neuroimaging techniques suffer from a number of weaknesses, which should make you cautious when interpreting their results:

- First, we cannot tell the difference between results caused by excitatory or inhibitory activity.
- Second, more activation does not necessarily mean more processing. A champion runner can run a mile faster than a couch potato and use less energy in the process; similarly, if you are an expert at specific processes, you may be able to accomplish them with less brain processing.
- Third, the same functional area can lie in slightly different anatomical regions in different brains, which makes averaging over participants difficult.
- Fourth, the brain is always "on," even during sleep. Thus, researchers always must compare two conditions and observe how activation changes from one to the other. The problem is that we do not know exactly what processing takes place during either a "test" or "baseline" comparison condition, and so the difference between the two conditions can be difficult to interpret.
- Fifth, if no difference in activation between two tasks is found in a brain area, this can mean that the process was active in both tasks, not active in either task, or the difference was too subtle to detect. This last possibility is particularly worrisome because blood vessels can expand only so much, and therefore increases in blood flow with neural activity cannot be linear—they cannot increase by the same increment for each additional increment of processing. If an area is relatively active in two conditions, the difference in blood flow between them may not reflect the difference in processing.
- Finally, processes need not be implemented in distinct neural tissue. For example, area 17 contains neurons that process color, and these neurons are interspersed among those that process shape (Livingstone & Hubel, 1984). If we average over a centimeter or so (the resolution used in most PET and fMRI studies), we cannot distinguish these two classes of neurons. In short, "converging evidence" must be our watchword!

4.4. Causal Neural Methods

Researchers have depended on other types of studies to establish causal connections between brain activation and performance. Such methods, summarized in Table 3,

TABLE 3 Causal Neural Methods Used in Cognitive Psychology

Method	Example	Advantages	Limitations
Neuropsychological studies (of patients with localized or diffuse brain damage)	Examine deficit in understanding nouns but not verbs	Tests theories of causal role of specific brain areas; tests theories of shared and distinct processing used in different tasks; relatively easy and inexpensive to collect	Damage is often not limited to one area; patients may have many deficits
Transcranial magnetic stimulation (TMS)	Temporarily disrupt occipital lobe and show that this has the same effects on visual perception and on visual mental imagery	Same as for neuropsychological studies, but the transient "lesion" is more restricted, and the participant can be tested before and after TMS	Can be used only for brain areas near the surface (TMS affects only tissue about 1 inch down)
Drugs that affect specific brain systems	Disrupt the action of noradrenaline, which is crucial for the operation of the hippocampus	Can alter the processing of specific brain systems; typically is reversible; can be tested in advance with animals	Many drugs affect many different brain systems; the temporal resolution may be very poor

show that activity in a particular brain area actually gives rise to specific representations or carries out specific processes.

If a part of the brain plays a key role in performing a specific task, then a patient should have difficulty performing that task if that part of the brain has been damaged. Following this logic, researchers have tried to use deficits in performance of particular tasks (such as reading, writing, or arithmetic) following brain damage to infer the causal role of specific parts of the brain. People suffer brain damage primarily for one or the other of five reasons:

- They have a stroke, an event that occurs when blood flow—with its life-sustaining oxygen and nutrients—to the brain is disrupted. When this happens, neurons in part of the brain may die.
- Surgery to remove a tumor may also have removed specific parts of the brain.
- They have suffered various sorts of head injuries that can damage the brain. (In a car, use the seat belt! On a bike, wear a helmet!)
- They have a brain-damaging disease. Alzheimer's disease, for example, initially selectively impairs parts of the brain involved in memory.
- They have ingested brain-damaging toxins. Drinking too much alcohol for too long, for example, can lead to bad dietary habits, which in turn damage specific parts of the brain involved in memory. (The problem is not the alcohol per se, but rather how drinking too much affects nutrition.)

Researchers have studied patients with brain damage in order to discover which cognitive abilities are disrupted and which are left intact. Their goal is to document dissociations and associations (Caramazza, 1984, 1986; Shallice, 1988). In these studies, a dissociation is said to occur when one ability is impaired while another is spared, and an association is said to occur when two tasks are always disrupted together (suggesting that the two tasks rely on at least one common underlying representation or process). However, associations can also occur because nearby brain areas are damaged together (or neurons that have different functions are present in the same area).

In general, it can be difficult to relate changes in performance after brain damage to the normal function of damaged areas. Why?

1. Brain damage typically affects a large area of neural tissue, and also affects connections among brain areas.
2. Such damage does not leave the rest of the brain as it was before the injury; rather, the brain compensates in various ways. Gregory (1961) offers a useful metaphor: if you remove a resistor from a radio and it begins to howl, this does not mean that the resistor was a howl suppressor. Removing the part changes the way the entire system works.

Nevertheless, if one has a theory of what a specific brain area does, then damage to that area provides a strong test of the role of that area: if an area does play a causal role in a particular type of performance, then damage to that part of the brain should disrupt such tasks (Fellows et al., 2005).

A new technique sidesteps many of the difficulties encountered when studying people with brain damage. *Transcranial magnetic stimulation* (TMS) temporarily disrupts normal brain activity in a relatively small area, perhaps 1 cubic centimeter (Walsh & Pascual-Leone, 2003). TMS involves placing a coil on the participant's skull and briefly running a large current through the coil (Figure 11). The current produces a magnetic field, which in turn temporarily disrupts neural activity of brain areas beneath the coil. There are two main variants of this technique. In the single-pulse version, a pulse is delivered a specific amount of time after a stimulus is presented. This method can be used to discover the duration of particular processes, as well as their causal roles in a specific task. In the other version, known as repetitive TMS (rTMS), a series of magnetic pulses is delivered to a brain area before a task is performed. If enough pulses are delivered, the neurons eventually become less responsive and continue to be sluggish for a period thereafter. Thus, researchers can deliver rTMS to a particular part of the cortex and then observe performance in specific tasks. This technique in some ways induces a temporary lesion, but does not disrupt connections. For example, if TMS is delivered to Broca's area, the result is difficulty in producing speech immediately afterward. It is not always clear, however, exactly which areas are affected by the pulses, nor is it clear whether affecting one area also affects another to which it is connected. The method has drawbacks:

1. The effects of stimulating one area can be transmitted to other areas, which can make it difficult to infer which area is in fact responsible for observed effects.
2. If not used according to safety guidelines, rTMS can produce seizures.

FIGURE 11 Investigation by transcranial magnetic stimulation

A TMS test, as shown here, can be administered easily in a laboratory; it can temporarily impair very specific cognitive processing.
(Courtesy of Julian Paul Keenan, PhD.)

3. The technique affects only the cortex, and only the portions of it that lie directly beneath the skull.
4. Muscles at the sides of the forehead twitch when TMS is applied to that area, which can be uncomfortable.

Finally, another method involves administering drugs that affect the workings of specific brain systems. This technique provides another way to demonstrate that particular brain systems play a causal role in particular types of performance. For example, Cahill and colleagues (1994) showed participants pictures that either illustrated neutral events (such as walking past a junk yard) or aversive events (such as being in a horrible accident). One hour after seeing the pictures, they gave the participants one of two pills: half the participants took a drug that interferes with noradrenaline, a neurotransmitter that is crucial for the operation of the hippocampus; this drug thus impaired the operation of that brain structure, which is crucial for entering new information into memory. The other half of the participants received a placebo, a medically inert substance. (The participants did not know whether they received the active drug or a placebo.) A week later, the participants were tested—without being warned in advance that such a test was in the works—on their memory for the pictures. The group that received the placebo recalled more pictures of emotional events than pictures of neural events. Why? The answer may be that the group that received the drug that blocks noradrenaline did not show the typical memory advantage for emotional events, which is evidence that the

hippocampus (along with the amygdala) plays a role in our enhanced memory for emotional material. However, this method also has drawbacks:

1. Drugs often affect many different brain systems.
2. Drugs may take a relatively long time to operate and their effects may linger for a relatively long time.

In general, the causal methods are most effective when used in combination with neuroimaging techniques, which can establish that certain areas are active during a task; those areas then can be specifically examined (in patients with brain damage or by TMS or specific drugs). Advances in localizing activation in individual participants are allowing researchers to use TMS with increasing precision, and this technique is likely to play an increasingly large role in research.

4.5. Modeling

Mental activity also can be studied by constructing models. Models can not only tell you whether a set of principles or mechanisms can in fact explain data, but they can also make new predictions. What's the difference between a theory and a model? A theory proposes a set of abstract principles that can account for a range of phenomena; a model is a specific, concrete version of a theory. Models have three types of characteristics (Hesse, 1963):

1. those that are relevant to a theory, such as the shape of a model airplane's wings or the order in which processes are carried out in a computer program;
2. those that are clearly not relevant to a theory, such as the color of a model airplane or the actual time a computer program requires to perform a process; and
3. those that are not clearly in either category, such as the shape of the belly of a model airplane and the role of the central processing unit in executing routines in a computer model. Sometimes research is focused on the third category, attempting to assign these characteristics to one of the first two categories.

In psychology, models are often implemented as computer programs. Such **computer simulation models** are intended to mimic the underlying mental representations and processes that produce specific types of human performance. Computer simulations must be distinguished from programs in artificial intelligence, which are intended to produce "intelligent" behavior but may incorporate underlying processes far different from those used by humans. In addition, we must note that models of mental activity are not always implemented in computer programs; they can also be realized as a set of equations or simply formulated verbally or with diagrams.

At its inception, cognitive psychology relied primarily on **process models**, which specify a sequence of processes that convert an input to an output. Such models can be illustrated with a flowchart, and are sometimes called "box and arrow" models. Figure 12 presents an example of a model to explain how people decide whether

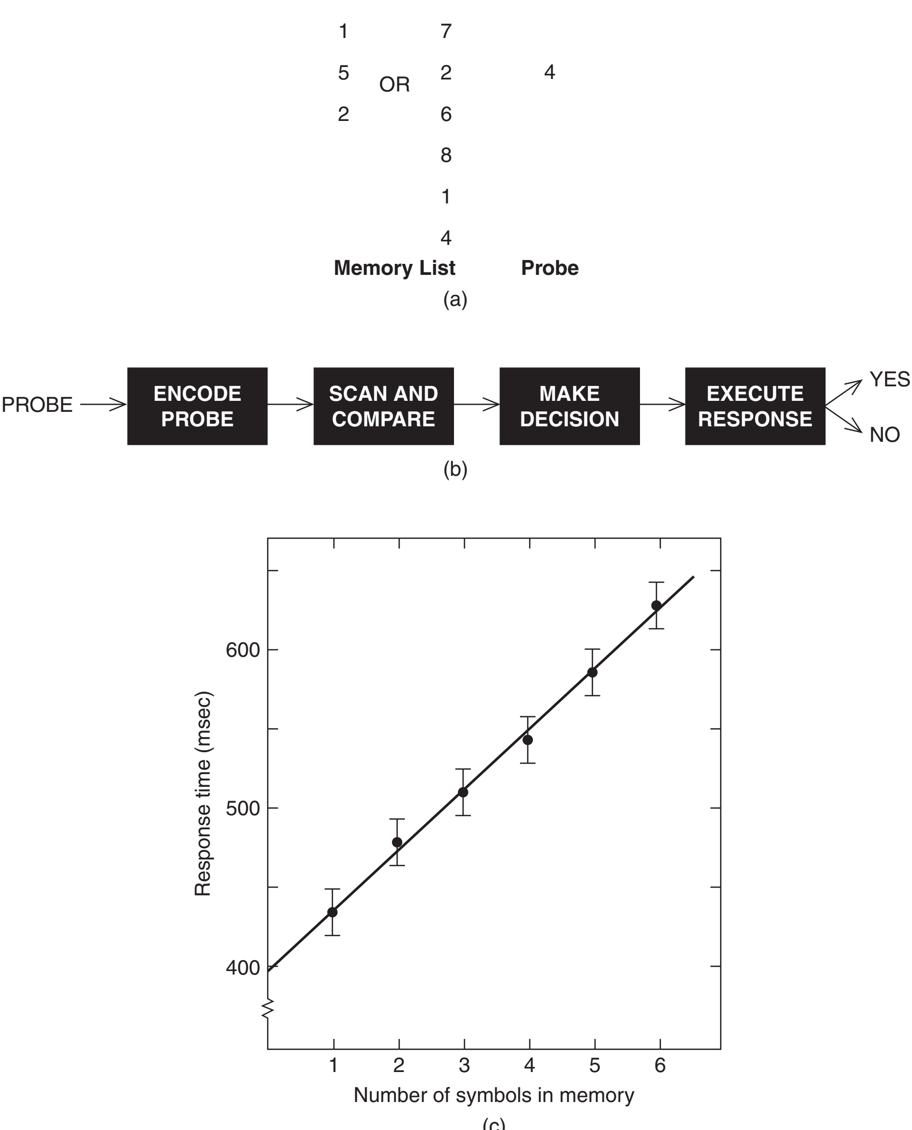


FIGURE 12 **Sternberg's process model**

(a) The first task is to memorize a short list of items—here, numbers. Then a probe item, say, "4," is presented that may or may not have been on the list. The task is to decide whether it was or was not. (b) The probe item is encoded and thus entered into memory. The list stored in memory is scanned and the probe compared to each item on the list; if the list is scanned an item at a time, then the longer the list, the more time should be required to scan it. Next, a decision is made about how to respond. Finally, the actual response is executed, leading the participant to press either the YES or the NO key. (c) The prediction was confirmed: more time was required to scan longer lists.

a stimulus was on a list they just studied. (We earlier considered this task when discussing structure–process trade-offs.) Most of these models specify each process in terms of its input and output, but the internal workings of each process are not specified in detail—they remain in a metaphoric "black box." Process models are often used to explain and predict response times on the basis of the relative number of operations the model would perform to accomplish a task. In addition, because such models specify distinct processes, they are also used to explain and predict patterns of deficits following brain damage (Caramazza, 1984, 1986); the central idea here is that some processes can be impaired selectively by damage. But process models also have drawbacks as investigative tools:

1. They typically assume serial processing, one step at a time in sequence, and rarely model parallel processing, in which processes occur simultaneously.
2. *Feedback,* the effect of a process later in the sequence on one earlier in the sequence, typically occurs only after the processes leading up to it are complete. The brain is not like this; later areas send output to earlier ones well before earlier processing is complete.
3. They typically do not learn, and learning clearly shapes mental activity from the earliest ages.

4.6. Neural-Network Models

Neural-network models, also called connectionist models, were created in part in response to the weaknesses of process models. As their name implies, these models take into account key properties of how the brain works (Plaut et al., 1996; Rumelhart et al., 1986; Vogels et al., 2005). **Neural-network models** rely on sets of interconnected units, each of which is intended to correspond to a neuron or a small group of neurons. Units are not the same thing as neurons, but rather they specify the input–output process a neuron or group of neurons performs. The simplest models include three layers of units, as illustrated in Figure 13. The *input layer* is a set of units that receives stimulation from the external environment. The units in the input layer are connected to units in a *hidden layer,* so named because these units have no direct contact with the environment. The units in the hidden layer in turn are connected to those in the *output layer.* In the simplest models, each unit can be "on" or "off," as designated by 1 or 0. The heart of these networks is their connections (hence the alternative name "connectionist"). Each connection from an input unit either excites or inhibits a hidden unit. Furthermore, each connection has a *weight,* a measure of the strength of its influence on the receiving unit. Some networks include feedback loops, for example, with connections from hidden units to input units. Here is a crucial point: the pattern of weights in the entire network serves to represent associations between input and output. Neural networks not only use parallel processing, they rely on *distributed* parallel processing, in which a representation is a pattern of weights, not a single weight, node, or connection.

Neural nets have several interesting properties. For one, they learn. The weights typically are set randomly at first, and various training techniques are used to allow

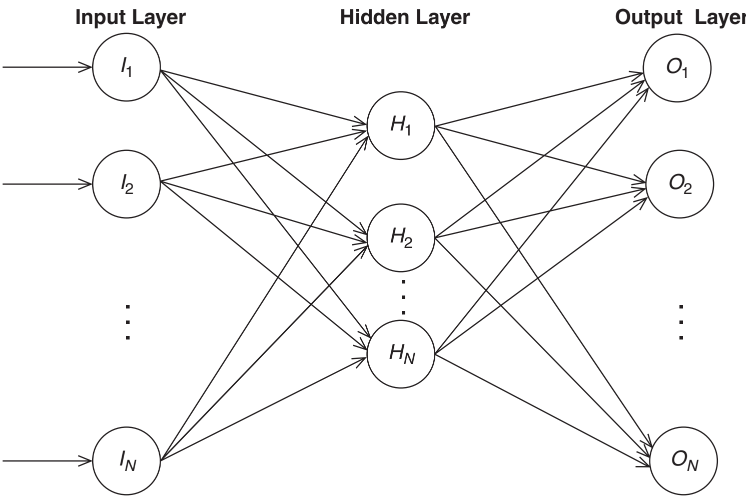


FIGURE 13 A simple feed-forward neural network

Three inputs are shown; there may be many more between the second (I_2) and the Nth (I_N). More complex networks not only can have feedback loops, but the connections between units can be organized in specific ways.

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the network to set the weights automatically so that input produces appropriate output. For another, they generalize: when a neural network is given a set of inputs that is similar, but not identical, to one on which the net was trained, it still can respond appropriately. Moreover, when damaged they degrade gradually. In a standard computer program, by contrast, if even one command is wrong, the entire program crashes. In a neural net, units or connections can be removed and—up to a point—the net will still function, although not as well. And sometimes it will function well in some ways but not in others. This is similar to what happens in a brain.

Finally, neural networks are useful because they help us understand the difference between a neural code and a mental representation. The neural code consists of a specific level of activity for each neuron (or, in these models, for each node) and a specific strength for each of the connections among neurons (or among nodes, in the models). But simply knowing the state of each individual node and connection won't tell you how and why particular inputs produce particular outputs; you need to consider the system as a whole in order to understand how it represents and processes information. Neural codes are like the bricks in a building, and the mental representations are like the architectural features that emerge from arranging bricks in certain ways.

We have just considered the basic methods, but researchers have cleverly extended and developed these methods as needed to address specific issues.

Comprehension Check:

1. What are the major methods used to study mental activity?
2. What roles do studies of the brain play in revealing facts about mental activity?

5. OVERVIEW

Recall how we opened this chapter; the questions remain: how will you decide to apply for certain jobs, and how will you cope with the interviews? In what follows, we will look at the wide variety of mental activities you will need to land a job and perform it effectively.

You probably read or heard about the opportunity to apply for a job: perception is a necessary first step for many mental activities that are concerned with objects and situations in your environment.

One result of processing information from the senses is that attention is shifted, allowing you to take in additional information of particular interest. Once you started the interview, you were probably alert for even the smallest evidence of heightened interest in the interviewer's face. And you probably chose to ignore any grumbling in your stomach or uncomfortable tugging of your clothing. Attention is the activity whereby some information processing is facilitated and other information processing is inhibited.

However, much mental activity does not focus on stimuli that are currently being perceived, but rather relies on previously stored representations of such stimuli. When you learned about the job, you interpreted that information in terms of what you already knew and what you remembered about similar jobs or related activities. We store not only what we actually perceive, but also our interpretations and responses to stimuli.

How did relevant information come to be stored in long-term memory? If information could not be accessed, for all practical purposes it would not exist; information retrieval is a crucial component of virtually all forms of reasoning, language, and other mental activities.

Once retrieved, information is often stored and operated on in working memory, the contents of which are presumably in consciousness. If you had the experience of "turning over in your mind" the various pros and cons of taking a job, you were using working memory.

What determines how you use working memory? But this "CEO of the mind" isn't a little corporate boss nestled in your brain; rather, the brain has a system of processes that operates on input in an effort to produce output that will help you achieve your goals.

Goals—where do they come from? Emotional reactions are one source of our goals. You probably had a reaction of liking (or in some cases not liking) activities like those required in particular jobs (for example, you might enjoy writing and finding out what's going on, which makes you suspect that working for a newspaper might be for you). Human beings are not cold, calculating computers; we have emotional reactions to most stimuli, and these emotional reactions affect much of how we subsequently process information.

How will you finally decide to accept a particular job? Why will you choose it over possible alternative jobs? Part of what executive processes must do is organize other processes that make decisions.

Often obstacles prevent the immediate achievement of a goal; perhaps in order to apply for a particular job you needed to take specific courses as a student—but taking these courses presented a conflict with some other activity, so you had to shift your schedule around. Your decision making ("I'm going to take this course") may have been to some extent based on problem solving ("If I take this course, how can I persuade my roommate to switch our weekly review sessions?"). The obstacle poses a problem to be solved.

Use knowledge about movements to organize what you see and how you think.

When you actually have an interview, you of course must listen and speak—which are arguably the most complex of all human mental activities.

Let's begin.

Revisit and Reflect

1. *How did the field of cognitive psychology arise?*

   Cognitive psychology began as a science in 1879, in the laboratory of Wilhelm Wundt in Germany. The early methodologies were flawed, however (in part because of an overemphasis on the use of introspection), which eventually led the behaviorists to reject the study of the mind altogether. The behaviorists focused solely on immediately observable events, but this approach proved too limiting. It failed to lend insight into many important phenomena, such as language and perception, and could not characterize the mechanisms that actually produce

behavior. The cognitive revolution occurred when the computer provided new ways to conceptualize mental activity, and new methodologies provided new ways to test theories of mental activity. These advances allowed scientists to go beyond stimuli, responses and consequences of responses, and led them to begin to understand the mechanisms responsible not only for behavior, but for perception, language, and cognition in general.

Think Critically

- What knowledge about mental activity could help you do better in this course?
- Would it be useful to know how to improve your memory? What about your decision-making abilities?
- In what ways does integrating the study of the brain into the study of the mind affect what you might be able to do with knowledge about the mind?
- In what ways could you use such information to test the efficacy of new drugs that are supposed to improve cognitive processing?

2. *What is a scientific theory of cognition, and what roles does knowledge about the brain play in such theories?*

Theories of cognition have often been likened to descriptions of software, as opposed to the hardware of the computer itself. This is an oversimplification. Theories of cognition are cast at a specific level of analysis, namely, in terms of how the brain functions to process information. You cannot replace a theory of cognition with a theory of neural activity any more than you can replace a description of a building's architecture with one of its constituent bricks and boards.

A processing system can be understood in terms of its representations and processes; representations serve to store information, and processes interpret or transform stored information. The traditional cognitive psychology was grounded entirely in inferences drawn from studies of behavior. These methods could not distinguish between many alternative theories, in part because of structure–process trade-offs. Considering facts about the brain not only provides additional constraints, which facilitates theorizing, but also provides additional reasons to develop theories in specific ways. Moreover, by grounding theories in the brain, a set of new and powerful methods becomes appropriate for evaluating such theories.

Think Critically

- Do you think a computer could ever be programmed to have a "mind"? Why or why not? If your answer is no, what do you think would be missing?
- Say we could program a computer to mimic your thinking processes. Would you have any use for such a computer? Could it be more than a fancy telephone answering machine?
- Would you be comfortable allowing such a computer program to choose your job interviews for you? Which sorts of things would you be most reluctant to delegate to that program? Why?