NBL 356-656 Module 9 Review Q&A

For the following questions, since some of this information is derived from Wikipedia articles and YouTube videos, I’ve highlighted the information that you are responsible for in Quiz 9.

1. *Define long term memory consolidation and the two types. What is the standard two stage memory system model? What is the role of the hippocampus and cortex in memory consolidation? What is “multiple trace theory?”*

Long term memory consolidation is the encoding of memories from its shorter-term store (such as the hippocampus) into its long term storage circuit (such as the neocortex.) The two types of consolidation are synaptic (or cellular) and systems consolidation.

From Wikipedia, “Synaptic consolidation is one form of memory consolidation seen across all species and long-term memory tasks. Synaptic consolidation is achieved faster than systems consolidation. LTP, one of the best understood forms of synaptic plasticity, is thought to be a possible underlying process in synaptic consolidation.”

“Systems Consolidation is the second form of memory consolidation. It is a reorganization process in which memories from the hippocampal region, where memories are first encoded, are moved to the neocortex in a more permanent form of storage. Systems consolidation is a slow dynamic process which can take weeks to months to years to be fully formed in humans, unlike synaptic consolidation that only takes minutes to hours for new information to stabilize into memories.” Systems consolidation may involve circuit-wide changes in which all the neurons or all their synapses undergo some type of similar biochemical change that coordinates and stabilizes their activity as a neural circuit.

From Wikipedia, “The standard two-stage memory model that has been originally elaborated for declarative memory assumes that new memories are transiently encoded into a temporary store (represented by the hippocampus in the declarative memory system) before they are gradually transferred into a long-term store (mainly represented by the neocortex), or are forgotten.” Multiple trace theory (MTT which is controversial in memory research and not uniformly accepted by the memory research community) proposes that although semantic or context-free memories become independent of the hippocampus over time, episodic or contextually-rich memories always depend on the hippocampus. MTT claims that memories are stored jointly in hippocampal and extrahippocampal circuits.\* for more see below at end.

1. *The glutamate, Ca2+, activated kinase/phosphatase, and activated transcription factor signals are all transient (lasting only seconds, minutes, or a few hours), and proteins are constantly turning over (through degradation and synthesis.) However, LTP can last for many hours to days to months, and long term memory can last for decades. Thus an overarching question in memory is “What are the biochemical/molecular mechanisms that underlie the persistence of LTP, and the stability of long term memory?” One hypothesis is that there is a self-perpetuating signal or stable mechanism in the neuron. Three ideas are, A) a self-perpetuating kinase, B) the prion idea and C) epigenetic modifications. Briefly explain the basics of these concepts. Can you think of an alternative idea D) about how memory could persist? Could several mechanisms be involved?*

A) Calmodulin dependent kinase II which is a protein kinase that depends on Ca2+/calmodulin for its initial activation. However, it can undergo autophosphorylation (and transphosphorylation of nearby CamKIIs), which renders it activated and does not require Ca2+/calmodulin any more, and so it remains active even after the Ca2+ signal has decreased. CamKII also can transphosphorylate other CamKIIs, so they could perpetuate the active CamKII-dependent processes over time.

B) For a protein that acts like a “prion” protein, the idea is the prion protein adopts an alternative and different secondary amino acid structure (such as beta sheets) that is different from the original structure. The two proteins are identical in their primary amino acid structure but differ in their secondary structure. In the original prion protein discovery, this different secondary structure of the prion protein is toxic to neurons and causes their degeneration, as seen in CJD and BSE. Also, the alternative secondary structured protein can bind the original protein and convert it to the alternative secondary structure. Thus it could perpetuate the conversion. For memory, the idea would be that the prion protein, when it is converted to the different structure, would have a change in activity and regulate for example, transcription.

C) Epigenetics involves the covalent modification of DNA and the DNA binding proteins (the histones), which are fairly stable and/or self perpetuating modification, and lead to the persistent activation or inhibition of memory regulatory genes (PRPs).

D) An alternative idea could be something like a Ca2+ dependent activation of a protease. Similar to the CamKII or prion self-perpetuation ideas, if the protease could auto-cleave itself and trans-cleave other similar proteases, it could then become activated and independent of the initial signal, and could perpetuate the activation. The activated protease could then cleave, and activate specific transcription factors involved in the transcription of memory regulatory genes. (cleave=proteolyze).

1. *What are the types of epigenetic modifications? How can epigenetics cooperate with transcription factors to control transcription?*

Epigenetics had been shown to be the mechanism underlying cellular differentiation. It is stable, self perpetuating, and heritable (after proliferation, the progeny cells have the same epigenetic modifications and cells maintain their differentiation and phenotype even after proliferation). The long-term nature of epigenetics, and its role in transcriptional regulation made it an ideal candidate mechanism to be involved in long term memory storage.

DNA methylation involves the covalent incorporation of a methyl group in cytosines, usually in the context of a CpG island. (Adenines have also been shown to be methylated.) When located in a gene promoter, DNA methylation typically acts to repress gene transcription, though there have some examples of DNA methylation leading to increased gene transcription.

From Wikipedia: “Histone acetylation and deacetylation are the processes by which the lysine residues within the N-terminal tail protruding from the histone core of the nucleosome are acetylated and deacetylated as part of regulation of transcription. These reactions are typically catalyzed by enzymes with "histone acetyltransferase" (HAT) or "histone deacetylase" (HDAC) activity. Acetylated histones, octameric proteins that organize chromatin into nucleosomes and ultimately higher order structures, represent a type of epigenetic marker within chromatin. Acetylation removes the positive charge on the histones, thereby decreasing the interaction of the N termini of histones with the negatively charged phosphate groups of DNA. As a consequence, the condensed chromatin is transformed into a more relaxed structure that is associated with greater levels of gene transcription.”

1. *Briefly describe SWS and REM sleep and proposed role of sleep stages in memory consolidation. What is it about sleep that makes it an ideal state for memory encoding and storage?*

It has been proposed that for declarative memory encoding, 1) synaptic consolidation in the hippocampus occurs when an organism is awake, when information is detected, attended to, its relevance/salience is determined and information is associated, and then 2) systems consolidation occurs during SWS sleep during which the memory is transmitted/transferred from the hippocampus to the circuits in the neocortex, and then 3) synaptic consolidation within the neocortex occurs during REM sleep. For procedural memory, the role of REM sleep appears to be more important.

One well accepted idea is that sleep provides an ideal state for memory encoding/consolidation because during sleep there is no incoming activity into the hippocampus or neocortex, and there is need for recall of previously stored memory for short term/working memory. Therefore there is no interference of other hippocampal or neocortical activity that could disrupt the processes of synaptic and systems consolidation.

From Wikipedia, “Slow-wave sleep (SWS), often referred to as deep sleep, consists of Stage three (combined stages 3 and 4) of non-rapid eye movement (REM) sleep. Initially, SWS consisted of both Stage 3 (N3), which has 20-50 percent delta wave activity, and Stage four (N4), which has more than 50 percent delta wave activity. However, as of 2008, the American Academy of Sleep Medicine has discontinued the use of Stage four as a separate stage. Thus, the two stages are now combined as "Stage three". An epoch (30 seconds of sleep), which consists of 20% or more slow-wave (delta) sleep, is now considered to be stage three. This period of sleep is called slow-wave sleep because the EEG activity is synchronized, producing slow waves with a frequency range of 0.5-2 Hz and peak-to-peak amplitude greater than 75 µV. The first section of the wave signifies a "down state," which is an inhibition or hyperpolarizing phase in which the neurons in the neocortex are silent. This is the period when the neocortical neurons are able to rest. The second section of the wave signifies an "up state," which is an excitation or depolarizing phase in which the neurons fire briefly at a high rate. The principal characteristics during slow-wave sleep that contrast with REM sleep are moderate muscle tone, slow or absent eye movement, and lack of genital activity.”

“Rapid eye movement sleep (REM sleep, REMS) is a unique phase of sleep in mammals and birds, distinguishable by random/rapid movement of the eyes, accompanied with low muscle tone throughout the body, and the propensity of the sleeper to dream vividly. The REM phase is also known as paradoxical sleep (PS) and sometimes desynchronized sleep because of physiological similarities to waking states, including rapid, low-voltage desynchronized brain waves. Electrical and chemical activity regulating this phase seems to originate in the brain stem and is characterized most notably by an abundance of the neurotransmitter acetylcholine, combined with a nearly complete absence of monoamine neurotransmitters histamine, serotonin, and norepinephrine. REM sleep is physiologically different from the other phases of sleep, which are collectively referred to as non-REM sleep (NREM sleep, NREMS, synchronized sleep). REM and non-REM sleep alternate within one sleep cycle, which lasts about 90 minutes in adult humans. As sleep cycles continue, they shift towards a higher proportion of REM sleep. The transition to REM sleep brings marked physical changes, beginning with electrical bursts called PGO waves originating in the brain stem. Organisms in REM sleep suspend central homeostasis, allowing large fluctuations in respiration, thermoregulation, and circulation, which do not occur in any other modes of sleeping or waking. The body abruptly loses muscle tone, a state known as REM atonia.”

*5. Describe memory reconsolidation and its characteristics.*

Memory reconsolidation is a process in which memory that is recalled/retrieved is stored again. Memory reconsolidation does not merely involve restoring the exact same memory, however. During recall, the memory can be modified, allowing information to be added or removed. During recall, memory information is transmitted to the short-term working memory centers, where it can become unstable and able to be modified. Not only does this involve activation of the cortical circuits that store this memory, but it involves the re-encoding of previously stored information. During slow-wave sleep and REM sleep, systems consolidation occurs. Thus, in the same manner that the original memory was stored, synapses that were activated as a result of the new information undergo LTP and this information is gradually transmitted to the memory traces in the cerebral cortex that held the original memory, creating new connections between existing neurons.

6. *What is a cognitive map? What are schemas?*

All of the following information is directly from Wikipedia:

A **cognitive map** is a type of mental representation which serves an individual to acquire, code, store, recall, and decode information about the relative locations and attributes of phenomena in their everyday or metaphorical spatial environment. The concept was introduced by Edward Tolman in 1948. The concept was used to explain the behavior of rats that appeared to learn the spatial layout of a maze, and subsequently the concept was applied to other animals, including humans. The term was later generalized by some researchers, especially in the field of operations research, to refer to a kind of semantic network representing an individual's personal knowledge or schemas.

In psychology and cognitive science, a **schema** (plural schemata or schemas) describes a pattern of thought or behavior that organizes categories of information and the relationships among them. It can also be described as a mental structure of preconceived ideas, a framework representing some aspect of the world, or a system of organizing and perceiving new information. Schemata influence attention and the absorption of new knowledge: people are more likely to notice things that fit into their schema, while re-interpreting contradictions to the schema as exceptions or distorting them to fit. Schemata have a tendency to remain unchanged, even in the face of contradictory information. Schemata can help in understanding the world and the rapidly changing environment. People can organize new perceptions into schemata quickly as most situations do not require complex thought when using schema, since automatic thought is all that is required.People use schemata to organize current knowledge and provide a framework for future understanding. Examples of schemata include academic rubrics, social schemas, stereotypes, social roles, scripts, worldviews, and archetypes. In Piaget's theory of development, children construct a series of schemata based on the interactions they experience, to help them understand the world.

*7. What are the definitions of place cells, grid cells, boundary/border cells, head direction cells and speed cells and where are they located?*

All of the following information is directly from Wikipedia:

A **place cell** is a kind of pyramidal neuron within the hippocampus that becomes active when an animal enters a particular place in its environment, which is known as the place field. Place cells are thought, collectively, to act as a cognitive representation of a specific location in space, known as a cognitive map. Place cells work with other types of neurons in the hippocampus and surrounding regions to perform this kind of spatial processing. They have been found in a variety of animals, including rodents, bats, monkeys and humans. Place cell firing patterns are often determined by stimuli in the environment, including visual landmarks, olfactory and vestibular stimuli. Place cells have the ability to suddenly change their firing pattern from one pattern to another, a phenomenon known as remapping. This remapping may occur in either some of the place cells, or in all place cells at once. It may be caused by a number of changes, such as a change in the odor of the environment. Place cells are thought to play an important role in episodic memory. They contain information about the spatial context a memory took place in. Additionally, they seem to perform consolidation by exhibiting replay, the reactivation of the place cells involved in a certain experience at a much faster time scale. Place cells show alterations with age and disease, such as Alzheimer's disease, which may be involved in a decrease of memory function.

A **grid cell** is a type of neuron within the entorhinal cortex that fires at regular intervals as an animal navigates an open area, allowing it to understand its position in space by storing and integrating information about location, distance, and direction. Grid cells have been found in many animals, including rats, mice, bats, monkeys, and humans. Grid cells were discovered in 2005 by Edvard Moser, May-Britt Moser, and their students Torkel Hafting, Marianne Fyhn, and Sturla Molden at the Centre for the Biology of Memory (CBM) in Norway. They were awarded the 2014 Nobel Prize in Physiology or Medicine together with John O'Keefe for their discoveries of cells that constitute a positioning system in the brain. The arrangement of spatial firing fields, all at equal distances from their neighbors, led to a hypothesis that these cells encode a neural representation of Euclidean space. The discovery also suggested a mechanism for dynamic computation of self-position based on continuously updated information about position and direction. Grid cells derive their name from the fact that connecting the centers of their firing fields gives a triangular grid. To detect grid cell activity in a typical rat experiment, an electrode which can record single-neuron activity is implanted in the dorsomedial entorhinal cortex and collects recordings as the rat moves around freely in an open arena. The resulting data can be visualized by marking the rat's position on a map of the arena every time that neuron fires an action potential. These marks accumulate over time to form a set of small clusters, which in turn form the vertices of a grid of equilateral triangles. The regular triangle pattern distinguishes grid cells from other types of cells that show spatial firing. By contrast, if a place cell from the rat hippocampus is examined in the same way, then the marks will frequently only form one cluster (one "place field") in a given environment, and even when multiple clusters are seen, there is no perceptible regularity in their arrangement.

**Boundary cells** (also known as **border cells** or boundary vector cells) are neurons found in the hippocampal formation that respond to the presence of an environmental boundary at a particular distance and direction from an animal. The existence of cells with these firing characteristics were first predicted on the basis of properties of place cells. Boundary cells were subsequently discovered in several regions of the hippocampal formation: the subiculum, presubiculum and entorhinal cortex. Firing of a boundary cell recorded in rat subiculum in 1 x 1 metre square-walled box with 50 cm-high walls. A 50 cm-long barrier inserted into box elicits second field along north side of barrier in addition to original field along south wall. Left: Firing rate map, one of 5 colours in locational bin indicates spatially-smoothed firing rate in that bin (autoscaled to firing rate peak, dark blue: 0-20%; light blue: 20-40%; green: 40-60%; yellow: 60-80%; red: 80-100%. The maximum firing rate is 14.2 Hz). Right: path taken by rat is shown in black, locations where spikes were recorded indicated by green squares. O'Keefe and Burgess had noted that the firing fields of place cells, which characteristically respond only in a circumscribed area of an animal's environment, tended to fire in 'corresponding' locations when the shape and size of the environment was altered. For example, a place cell that fired in the northeastern corner of a rectangular environment might continue to fire in the northeastern corner when the size of the environment was doubled. To explain these observations, the Burgess and O'Keefe groups developed a computational model (Boundary Vector Cell - or BVC - model) of place cells that relied on inputs sensitive to the geometry of the environment to determine where a given place cell would fire in environments of different shapes and sizes. The hypothetical input cells (BVCs) responded to environmental boundaries at particular distances and allo-centric directions from the rat. Separate studies emerging from different research groups identified cells with these characteristics in the subiculum, entorhinal cortex and pre- and para-subiculum where they were described variously as "BVCs", "boundary cells" and "border cells". These terms are somewhat interchangeable; the critical defining functional characteristics of associated with the different labeling schemes are rather arbitrary and any functional differences in cells found in different anatomical regions are not yet fully clear. For example, neurons classified as "border cells" may include some that fire at short range to any environmental boundary (regardless of direction). Additionally, the BVC model predicted the existence of a small proportion of cells with longer range tunings (i.e., firing parallel to, but at some distance from boundaries) and few such cells have been described to date. In general, although the general predictions of the BVC model regarding the existence of geometric boundary sensitive inputs were confirmed by the empirical observations it prompted, the more detailed characteristics such as the distribution of distance and direction tunings remain to be determined. In medial entorhinal cortex border/boundary cells comprise about 10% of local population, being intermingled with grid cells and head direction cells. During development MEC border cells (and HD cells but not grid cells) show adult-like firing fields as soon as rats are able to freely explore their environment at around 16-18 days old. This suggests HD and border cells, rather than grid cells, provide the first critical spatial input to hippocampal place cells.

**Head direction (HD) cells** are neurons found in a number of brain regions that increase their firing rates above baseline levels only when the animal's head points in a specific direction. They have been reported in rats, monkeys, mice, chinchillas and bats, but are thought to be common to all mammals, perhaps all vertebrates and perhaps even some invertebrates, and to underlie the "sense of direction". When the animal's head is facing in the cell's "preferred firing direction" these neurons fire at a steady rate (i.e., they do not show adaptation), but firing decreases back to baseline rates as the animal's head turns away from the preferred direction (usually about 45° away from this direction). HD cells are found in many brain areas, including the cortical regions of postsubiculum (also known as the dorsal presubiculum), retrosplenial cortex, and entorhinal cortex, and subcortical regions including the thalamus (the anterior dorsal and the lateral dorsal thalamic nuclei), lateral mammillary nucleus, dorsal tegmental nucleus and striatum. It is thought that the cortical head direction cells process information about the environment, while the subcortical ones process information about angular head movements. A striking characteristic of HD cells is that in most brain regions they maintain the same relative preferred firing directions, even if the animal is moved to a different room, or if landmarks are moved. This has suggested that the cells interact so as to maintain a unitary stable heading signal (see "Theoretical models"). Recently, however, a subpopulation of HD neurons has been found in the dysgranular part of retrosplenial cortex that can operate independently of the rest of the network, and which seems more responsive to environmental cues. The system is related to the place cell system, located in the hippocampus, which is mostly orientation-invariant and location-specific, whereas HD cells are mostly orientation-specific and location-invariant. However, HD cells do not require a functional hippocampus to express their head direction specificity. They depend on the vestibular system, and the firing is independent of the position of the animal's body relative to its head. Some HD cells exhibit anticipatory behavior: the best match between HD activity and the animal's actual head direction has been found to be up to 95 ms in future. That is, activity of head direction cells predicts, 95 ms in advance, what the animal's head direction will be. This possibly reflects inputs from the motor system ("motor efference copy") preparing the network for an impending head turn. HD cells continue to fire in an organized manner during sleep, as if animals were awake. However, instead of always pointing toward the same direction—the animals are asleep and thus immobile—the neuronal "compass needle" moves constantly. In particular, during rapid eye movement sleep, a brain state rich in dreaming activity in humans and whose electrical activity is virtually indistinguishable from the waking brain, this directional signal moves as if the animal is awake: that is, HD neurons are sequentially activated, and the individual neurons representing a common direction during wake are still active, or silent, at the same time.

**Speed cells** are neurons whose firing rates depend on an animal's speed through its environment. Together with place cells, grid cells, boundary cells, and head direction cells, they form a part of a larger set of neurons that are involved in cognitive mapping of the surrounding environment. Speed cells are found in the entorhinal cortex.

*8. What is the definition of consciousness?*

Consciousness, at its simplest, is "sentience or awareness of internal or external existence". Despite centuries of analyses, definitions, explanations and debates by philosophers and scientists, consciousness remains puzzling and controversial, being "at once the most familiar and most mysterious aspect of our lives". Perhaps the only widely agreed notion about the topic is the intuition that it exists. Opinions differ about what exactly needs to be studied and explained as consciousness. Sometimes, it is synonymous with 'the mind', and at other times, an aspect of it. In the past, it was one's "inner life", the world of introspection, of private thought, imagination and volition. Today, it often includes some kind of experience, cognition, feeling or perception. It may be 'awareness', or 'awareness of awareness', or self-awareness. There might be different levels or orders of consciousness, or different kinds of consciousness, or just one kind with different features. Other questions include whether only humans are conscious or all animals or even the whole universe. The disparate range of research, notions and speculations raises doubts whether the right questions are being asked. Examples of the range of descriptions, definitions or explanations are: simple wakefulness, one's sense of selfhood or soul explored by "looking within"; being a metaphorical "stream" of contents, or being a mental state, mental event or mental process of the brain; having phanera or qualia and subjectivity; being the 'something that it is like' to 'have' or 'be' it; being the "inner theatre" or the executive control system of the mind. As Professor Dave explains, “Consciousness is or means having a first person subjective experience.”

9. What is the “hard problem of consciousness?”

The hard problem of consciousness is the problem of explaining why and how we have qualia or phenomenal experiences. That is to say, it is the problem of why we have personal, first-person experiences, often described as experiences that feel "like something." In comparison, we assume there are no such experiences for inanimate things like, for instance, a thermostat, toaster, computer, or, theoretically, a sophisticated form of artificial intelligence. The philosopher Dr. David Chalmers, who introduced the term "hard problem of consciousness," contrasts this with the "easy problems" of explaining the physical systems that give us and other animals the ability to discriminate, integrate information, report mental states, focus attention, and so forth. Easy problems are (relatively) easy because all that is required for their solution is to specify a mechanism that can perform the function. That is, even though we have yet to solve most of the easy problems (our understanding of the brain is still preliminary), these questions can probably eventually be understood by relying entirely on standard scientific methods. Dr. Chalmers claims that even once we have solved such problems about the brain and experience, the hard problem will "persist even when the performance of all the relevant functions is explained".

*10. What are neural correlates of consciousness (NCCs) and what are the two current leading theories?*

The neural correlates of consciousness are the minimal neuronal mechanisms jointly sufficient for one conscious perception. The idea is that for every conscious percept, there will be an NCC. Inducing the NCC will induce the perception. Inactivating the NCC will eliminate the perception. One fact that most neuroscientist agree on it that there is no one location in the brain where consciousness takes place. The two current theories are the global workspace theory (GWT), championed by Stanislas Dehaene of the Collège de France in Paris, and the integrated information theory (IIT), proposed by Giulio Tononi of the University of Wisconsin in Madison. The GWT says the brain’s prefrontal cortex, which controls higher order cognitive processes like decision-making, acts as a central computer that collects and prioritizes information from sensory input. It then broadcasts the information to other parts of the brain that carry out tasks. Dehaene thinks this selection process is what we perceive as consciousness. By contrast, the IIT proposes that consciousness arises from the interconnectedness of brain networks. The more neurons interact with one another, the more a being feels conscious—even without sensory input. IIT proponents suspect this process occurs in the back of the brain, where neurons connect in a gridlike structure.

“Rival theories face off over brain’s source of consciousness $20 million project puts competing ideas to the test.” In a recent competition funded by Templeton World Charity Foundation (TWCF) the two theories will be tested. Dr Tononi, of the University of Wisconsin, Madison, thinks consciousness is a direct consequence of the interconnectedness of neurons within brains. IIT argues that the more the neurons in a being’s brain interact with one another, and the more complex the resulting network is, the more the being in question feels itself to be conscious. Because the parts of a human brain where neuronal connectivity is most complex are the sensory processing areas (in particular, the visual cortex) at the back of the organ, these, IIT predicts, are where human consciousness will be seated. Dr Dehaene, who works at the Collège de France, in Paris, reckons by contrast that the action, when it comes to consciousness, involves a network of brain areas—particularly the prefrontal cortex. This part of the brain receives sensory information from elsewhere in the organ, evaluates and edits it, and then sends the edited version out to other areas, to be acted on. It is the activity of evaluating, editing and broadcasting which, according to GWT, generates feelings of consciousness.

One difference between IIT and GWT, accordingly, is that the former is a “bottom up” explanation, whereas the latter is “top down”. Supporters of IIT think consciousness is an emergent property of neural complexity that can exist to different degrees, and could, in principle, be measured as a number (for which they use the Greek letter phi). GWT-type consciousness, by contrast, is more of an all-or-nothing affair. Distinguishing between the two would be a big step forward for science. It would also have implications for how easy it might be to build a computer that was conscious.

**Global workspace theory** (GWT) is a simple cognitive architecture that has been developed to account qualitatively for a large set of matched pairs of conscious and unconscious processes. It was proposed by Bernard Baars. GWT resembles the concept of working memory, and is proposed to correspond to a "momentarily active, subjectively experienced" event in working memory (WM)—the "inner domain in which we can rehearse telephone numbers to ourselves or in which we carry on the narrative of our lives. It is usually thought to include inner speech and visual imagery." In order to be conscious of something it must be globally available across much of the brain to many different cognitive processes such as attention and memory. A state is conscious when and only when it (or its content) is present in the global neuronal workspace making the state (content) globally accessible to multiple systems including long-term memory, motor, evaluational, attentional and perceptual systems.

GWT can be explained in terms of a "theater metaphor". In the "theater of consciousness" a "spotlight of selective attention" shines a bright spot on stage. The bright spot reveals the contents of consciousness, actors moving in and out, making speeches or interacting with each other. The audience is not lit up—it is in the dark (i.e., unconscious) watching the play. Behind the scenes, also in the dark, are the director (executive processes), stage hands, script writers, scene designers and the like. They shape the visible activities in the bright spot, but are themselves invisible. Baars argues that this is distinct from the concept of the Cartesian theater, since it is not based on the implicit dualistic assumption of "someone" viewing the theater, and is not located in a single place in the mind.

GWT involves a fleeting memory with a duration of a few seconds (much shorter than the 10–30 seconds of classical working memory). GWT contents are proposed to correspond to what we are conscious of, and are broadcast to a multitude of unconscious cognitive brain processes, which may be called receiving processes. Other unconscious processes, operating in parallel with limited communication between them, can form coalitions, which can act as input processes to the global workspace. Since globally broadcast messages can evoke actions in receiving processes throughout the brain, the global workspace may be used to exercise executive control to perform voluntary actions. Individual as well as allied processes compete for access to the global workspace, striving to disseminate their messages to all other processes in an effort to recruit more cohorts and thereby increase the likelihood of achieving their goals. It postulates a cortical structure that involves workspace neurons with long-range connections linking systems: perceptual, mnemonic, attentional, evaluational and motoric. What is the global workspace in neural terms? Long-range workspace neurons within different systems can constitute the workspace, but they should not necessarily be identified with *the* workspace. A subset of workspace neurons becomes the workspace when they exemplify certain neural properties. What determines which workspace neurons constitute the workspace at a given time is the activity of those neurons given the subject’s current state. The workspace then is not a rigid neural structure but a rapidly changing neural network, typically only a proper subset of all workspace neurons.

**Integrated information Theory** (IIT) attempts to explain what consciousness is and why it might be associated with certain physical systems. Given any such system, the theory predicts whether that system is conscious, to what degree it is conscious, and what particular experience it is having (see Central identity). According to IIT, a system's consciousness is determined by its causal properties and is therefore an intrinsic, fundamental property of any physical system. IIT was proposed by neuroscientist Giulio Tononi.

Dr. David Chalmers has argued that any attempt to explain consciousness in purely physical terms (i.e. to start with the laws of physics as they are currently formulated and derive the necessary and inevitable existence of consciousness) eventually runs into the so-called "hard problem". Rather than try to start from physical principles and arrive at consciousness, IIT "starts with consciousness" (accepts the existence of consciousness as certain) and reasons about the properties that a postulated physical substrate would need to have in order to account for it. The ability to perform this jump from phenomenology to mechanism rests on IIT's assumption that if the formal properties of a conscious experience can be fully accounted for by an underlying physical system, then the properties of the physical system must be constrained by the properties of the experience. Specifically, IIT moves from phenomenology to mechanism by attempting to identify the essential properties of conscious experience (dubbed "axioms") and, from there, the essential properties of conscious physical systems (dubbed "postulates").

IIT draws on the notion of integrated information, symbolized by Φ, as a way to explain generic consciousness. IIT defines integrated information in terms of the effective information carried by the parts of the system in light of its causal profile. For example, we can focus on a part of the whole circuit, say two connected nodes, and compute the effective information that can be carried by this microcircuit. The system carries integrated information if the effective informational content of the whole is greater than the sum of the informational content of the parts. If there is no partitioning where the summed informational content of the parts equals the whole, then the system as a whole carries integrated information and it has a positive value for Φ. Intuitively, the interaction of the parts adds more to the system than the parts do alone. On IIT, what matters is the presence of appropriate connections and not the number of neurons.

More from question 1 above.

\* From https://www.alpfmedical.info/remote-memory/the-standard-model-of-memory-consolidation-versus-the-multiple-trace-theory-two-divergent-views-of-the-same-process.html

“In the standard model of memory consolidation, the hippocampus is believed to rapidly integrate and bind together information transmitted from distributed cortical networks that support the various features of a whole experience in order to form a coherent memory trace. Consolidation of this new memory trace at the cortical level would then occur slowly via repeated reactivation of hippocampal-cortical networks to progressively increase the strength and stability of cortical-cortical connections. Over time, as memories mature, the role of the hippocampus would gradually diminish, leaving extrahippocampal regions, presumably cortical areas, to become independently capable of sustaining permanent memories and mediate their retrieval.

An alternative and challenging view is offered by [multiple trace theory](https://en.wikipedia.org/wiki/Multiple_trace_theory), which posits that the hippocampus retains a permanent role in memory storage and retrieval as long as memories exist. This view is supported by three main lines of clinical and experimental observations that cannot be accounted for by the standard model of memory consolidation. First, retrograde amnesia can, in some cases, be ungraded (i.e., 'flat'), wherein both recent and remote memories have been reported to be similarly impaired. Second, certain retrograde amnesia gradients have been reported to last for decades or up to almost the entire human life span in some amnesic patients, thus raising the question of the ethological value of such an extended period of consolidation. Third, the observation of a retrograde amnesia gradient and its temporal extent may depend on the type of declarative memory to be consolidated (episodic, semantic or spatial). The main features of the multiple trace theory are as follows. Each consciously experienced event would consist of a cohesive hippocampal-cortical ensemble. Each time that this particular event is recalled, it would be recreated and recoded in the form of multiple and stronger related memory traces dispersed over larger areas of hippocampal-cortical networks. Therefore, the relative sparing of remote memories in amnesic patients would be a function of the extent of hippocampal damage, with limited damage producing temporally graded retrograde amnesia and extensive lesions, resulting in a flat gradient for retrograde amnesia. It has been proposed that the recurrent creation of multiple hippocampal-cortical traces would predominantly favor the integration of information with preexisting knowledge to form old semantic memories (memory for general knowledge of facts) whose retrieval could possibly occur without the contribution of the medial temporal lobe memory system (this could be why patient HM could recall previously stored semantic information). However, in the case of remotely acquired episodic memories, which are autobiographical and richly detailed in nature, these authors postulated that retrieval would always require the contribution of hippocampal-cortical networks.” “It must be noted however, that the results of some case studies, for instance, patient E.P., who suffered large lesions of the medial temporal lobe following an episode of viral encephalitis, do not support the multiple trace theory. Despite extensive hippocampal damage, this patient had excellent autobiographical memories from his youth and could accurately recall the spatial layout of the area where he grew up more than 50 years earlier.”

Neurobiological theories of episodic (i.e., event) memory differ in the proposed duration of hippocampal support for episodic retrieval. In standard systems consolidation and computational-based theories of episodic memory, new hippocampal-dependent episodic memories become reorganized into a distributed neocortical network, such that remote memories are no longer dependent on the hippocampus. By contrast, according to multiple trace theory, the transformation hypothesis, contextual binding theory, and scene construction theory, episodic memory is hypothesized to be continuously dependent on the hippocampus for as long as the memory retains spatial detail and context-specific episodic content.

Has multiple trace theory been refuted? Robert J. Sutherland Justin Q. Lee Robert J. McDonald Hugo Lehmann First published: 04 October 2019 https://doi.org/10.1002/hipo.23162 “Multiple trace theory (Nadel & Moscovitch, *Current Opinion in Neurobiology*, 1997, 7, 217–227) has proven to be one of the most novel and influential recent memory theories, and played an essential role in shifting perspective on systems‐level memory consolidation. Here, we briefly review its impact and testable predictions and focus our discussion primarily on nonhuman animal experiments. Perhaps, the most often supported claim is that episodic memory tasks should exhibit comparable severity of retrograde amnesia (RA) for recent and remote memories after extensive damage to the hippocampus (HPC). By contrast, there appears to be little or no experimental support for other core predictions, such as temporally limited RA after extensive HPC damage in semantic memory tasks, temporally limited RA for episodic memories after partial HPC damage, or the existence of storage of multiple HPC traces with repeated reactivations. Despite these shortcomings, it continues to be a highly cited HPC memory theory.”