Intuition: Role, Biases, Cognitive Basis, and a Hypothetical Synergistic Explanation of Intuitive Brain Operations

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Abstract

This paper explores the characteristics of the intuitive responses that are generated by our brain continuously in an automatic and effortless manner. However, while intuition is a very powerful mechanism, it is also subject to many biasing influences. The author discusses the role of intuition, examines representative examples of biasing influences, compares cognitive theories of intuition advanced by Simon (2002), Klein (2003 and 1999), and Kahneman (2011), and then advances a hypothetical explanation of the neurological operations underlying intuition based on Hebbian rules (Hebb 1949) of plasticity in combination with synergetic principles.

Keywords

Anticipation, bias, brain, cognition, Hebbian rules, intuition, neuron, prediction, reasoning, Recognition-Primed Decision (RPD) model, synapse, synaptic chain, synergistic effect, synergetics, synergy, System 1, System 2.

Synergetics is the study of systems in which the behavior of the system is unpredictable from the behavior of its individual component parts taken separately. Typically, the output of such systems is far greater than the sum of the individual outputs of their components. Buckminster Fuller (1975) expanded synergetics to its broadest terms, as the study of identifying and understanding the methods that nature uses to coordinate the physical and metaphysical universe. He argued that synergetics has applications in all areas of human endeavor by providing a method and philosophy for the solution of problems and the design of artifacts.

Throughout nature there are countless examples of synergistic effects ranging from the chemical combination of compounds such as hydrogen and oxygen to form water, to the cooperative interaction of genes in genomes, and socially organized groups such as bee colonies, wolf packs and human societies. Corning (2005) has suggested that synergy of various kinds is the basis of the progressive evolution of complexity in living things over time. According to this hypothesis synergistic effects have provided advantages in respect to survival and reproduction that have favorably influenced natural selection.

In this paper the author advances the hypothesis that the synergistic interactions[1] within the 84 billion neurons and 1000 trillion synapses of the human brain (i.e., connectome) may be sufficient to account for the essential qualities of human intelligence; namely experience and knowledge, beliefs, reasoning, ability to learn, creativity, and intuition (Figure 1).

[1] Synergistic is defined here to include not only the excitatory neurons but also the inhibitory neurons that will reduce the action potential of synapses, because the later play an essential role in neuronal operations.

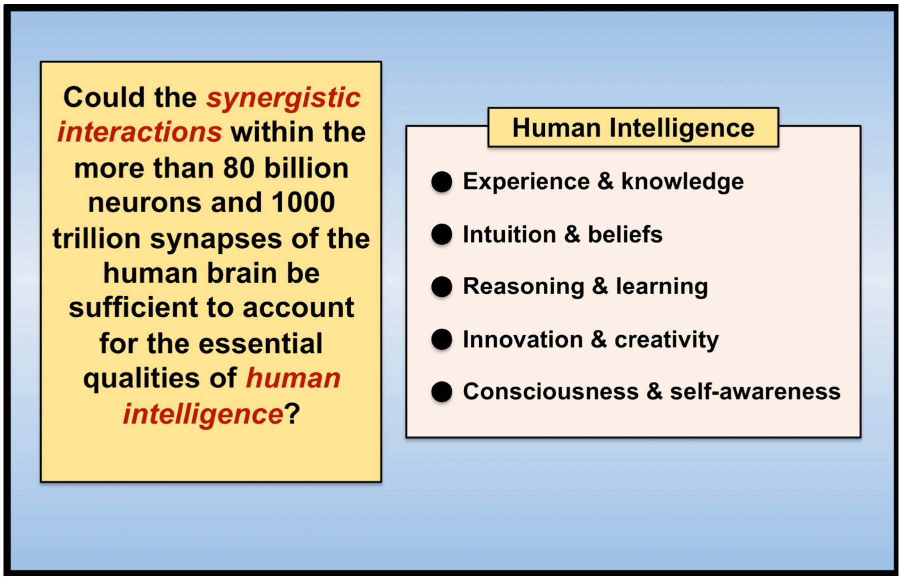

Figure 1: A hypothetical question?

The most mysterious of these qualities is intuition, which allows us to reach conclusions without any conscious reasoning. An examination of the characteristics of intuition is followed by a discussion of cognitive theories that have been advanced by Simon (2002), Kahneman (2011), Klein (1999) and a hypothetical neuroscience explanation that is based on synergistic concepts.

Distinction Between Prediction and Anticipation

The biological basis of our brain suggests that we largely operate on autopilot. For every step we take our brain projects the muscular contractions that are necessary and the expected intermediate results. As we descend a staircase our brain anticipates the sensation of our foot touching the lower step and the impact on our balance as we automatically transfer the weight of our body from the upper leg to the lower leg. If for some reason the brain's predictions are not met, such as if we missed the lower step because we were momentarily distracted, then we are immediately placed on alert. Similarly, when we listen to a familiar tune our brain anticipates the next note before it occurs. When we drive home at the end of a workday along our normal route we anticipate each set of traffic lights and automatically slow down or speed up as our brain judges the best speed to avoid having to stop at a red signal.

It would appear that the manner in which our brain anticipates the next step in a sequence of steps is closely aligned with our current understanding of how intuitive judgments are made. The ability of the brain to cause the appropriate muscles to contract as we walk or run, or reach for our car keys on the table, or peddle a bicycle, or dry our body with a towel after taking a shower, and the automatic manner in which the brain performs these actions requires the same neurological mechanisms that are used by intuition. In other words, neural activation sequences that have been primed by repetitive stimuli that allow our brain to judge what is normal and what deviates from normality are essentially no less predictive than the sequence of muscular contractions that allow us to perform a wide range of movements without mental effort. In this same way our automatic recall of the remainder of a melody after hearing only the first few bars is simply the continuation of the sequence of neural activations that represent this set of sound stimuli in our brain.

Memory and prediction are closely allied functions in brain operations. Both are predicated on the fundamental notion that neural activations are strengthened by repetition. If certain stimuli are repeated, then the responding sequence of neural activations are primed by those stimuli to execute more easily. This increased sensitivity to a particular stimulation is akin to a primitive form of memory. Since the same (or similar) stimulation will through repetition increase the responsiveness of a particular pattern of neural activations, it can be argued that the memory of the stimulation is embedded in the neural response pattern. Eventually even only a partial stimulation will be sufficient to activate the neural response pattern because the level of sensitivity of the brain's activation pattern to the particular stimulation has increased in sensitivity. In this way the brain becomes predictive through primed activation patterns.

It must be pointed out that in this sense the word *predictive* is used to describe the ability of the brain to anticipate a likely need rather than forecast a future event or outcome. The key factor that distinguishes between prediction and anticipation is the time element. Our brain's anticipation of the muscular contractions that are required for physical movement and our ability to automatically recall the next several steps in a sequence (e.g., a melody) after experiencing only a very limited number of preceding steps (i.e., bars of the melody) are short term forecasts with time measured in fractions of a second. This kind of next step anticipation is far removed from what we commonly associate with the ability to predict future events.

Multiple studies have shown that our world is largely unpredictable for any but the most immediate changes/predictions. For example, while investment advisors are typically convinced of their success rate they typically perform no better than rolling dice (Nisbett and Wilson 1977, Lewis 2003, Taleb 2007). Kahneman (2011, 215) cites an analysis of the financial performance data pertaining to 25 investment advisors over a period of eight years in which the average correlation coefficient was 0.01 (i.e., essentially zero). Our ability to construct the cause and effect explanations of the past gives us the false impression that we can also forecast the future (Taleb 2007). Thus we suffer from the illusion that what we see in hindsight was predictable before it occurred.

Throughout this paper the notion of the word *prediction* is associated with short term anticipation rather than longer term forecasting of future events, trends or outcomes.

Intuition and Reasoning

Most thoughts and impressions arise in our minds without us knowing how they came to our conscious experience. We cannot trace how we came to the belief that a steering wheel is used to change the direction in which a car is traveling beyond the general explanation that this belief like many others is based on our past experience. The mental work that produces impressions, opinions, and intuitions occurs in an automatic mode subconsciously in our mind. While the majority of these intuitive judgments might lead to correct conclusions, many of them will be biased by a variety of factors that range from our current emotional state to our expectations[2].

Research suggests that the human brain functions in two distinct modes (Figure 2). The initial response to any stimulus such as an image or situation is an automatic reaction or judgment that is based on experience and emotional state. We cannot trace the origin of this intuitive judgment beyond a general understanding that it is related to our knowledge and past experience of the situation. Kahneman (2011, 20) refers to intuition as *System 1* that "*... operates automatically*

[2] In his excellent book entitled *Thinking Fast and Slow* Kahneman (2011) identifies at least two dozen of these biasing factors with detailed descriptions and illustrative examples.

and quickly, with little or no effort and no sense of voluntary control". Typical levels of complexity that can be handled by intuition (i.e., System 1) include: determination of the relative location of objects in three-dimensional space; direction of a sound source if the listener has adequate hearing in both ears; detection of happiness, sadness, hostility, or surprise in the image of a face; detection of hostility and other moods in a voice; words and simple sentences; and, elementary arithmetic (e.g., 1+1=2).

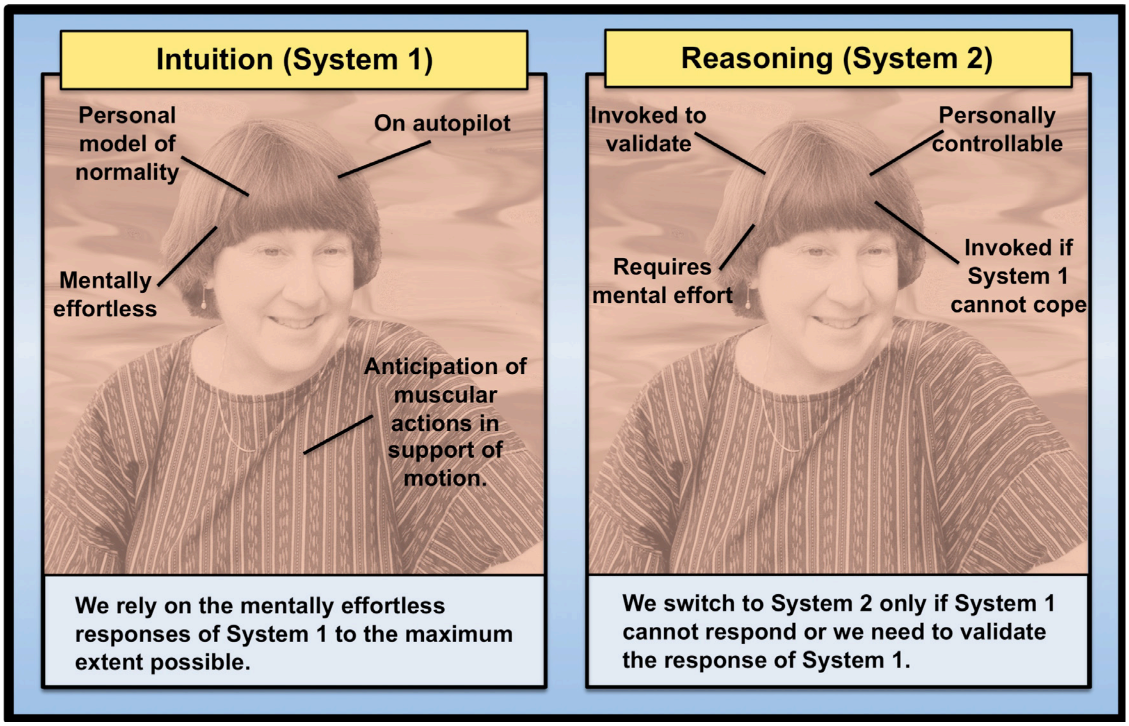

Figure 2: Distinction between intuition (System 1) and reasoning (System 2)

We tend to rely on our intuition to the maximum extent and only switch to deliberate reasoning (i.e., System 2) when we either see a need to question and validate our intuitive response or we are unable to adequately deal intuitively with the situation at hand. An example of the latter would be if we are trying to multiply together two larger numbers like 34 and 27. In other words, our System 1 is continuously active while System 2 is invoked on demand only. Also, while System 1 operates effortless, System 2 requires effort in the form of attention and concentration. This means that System 2 is vulnerable to disruption. Not only do disruptions tend to break concentration but once concentration has been broken it requires considerable willpower to reengage in the logical reasoning and thought processes that are the essential elements of System 2 operations. As Kahneman (2011, 31-5) points out System 2 requires exertion. This has been amply demonstrated by experiments. In particular, the pupils in our eyes are sensitive indicators of effort. Hess (1965) found that they dilated visibly when test persons were asked to multiply two-digit numbers and even more with more difficult problems. Based on such findings Kahneman suggests that the law of least effort applies not only to physical exertion but also to cognitive tasks. If there are several ways of achieving a goal then people will inevitably eventually gravitate to the least demanding process of reaching that goal (Kool et al. 2010, McGuire and Botvinick 2010). In other words, consideration of economy is an intrinsic part of human nature. We balance the cost associated with effort with the benefit derived from the effort.

While System 2 monitors System 1, it will allow considerable leeway to System 1 and will take over only when either System 1 cannot cope (e.g., when complex calculations, deliberate memory searches, comparisons, planning, or choices are required) or when the conclusions reached by System 1 are sufficiently unacceptable to System 2. System 2 is of course ultimately in charge with the ability to change the conclusions reached by System 1. However, once System 2 has been invoked its deliberations are greatly influenced by existing beliefs and emotional attitudes (Kahneman 2011, 103). Therefore, System 2 is more likely to acquiesce to System 1 than disagree. For example, if we do not like something then the conclusions reached by System 1 in response to questions such as how useful, how risky, how beneficial, or how successful, are likely to be negatively influenced. Conversely, if we like something then such answers will be more favorable to a positive response. In this respect our emotional demeanor has a strong influence on System 1 and System 2 may not correct this bias in any but the more extreme cases.

Due to our tendency to avoid mental effort it is not unreasonable to characterize System 2 as being somewhat lazy. This is particularly apparent in our willingness to avoid a difficult question by substituting an easier question that System can deal with. For example: How satisfied are you with your life? is a difficult question that requires deeper thought and consideration of multiple aspects of our life. This is the province of System 2. However, rather than invoke System 2 we will try to remain in the domain of System 1 by substituting an easier question such as: How satisfied am I right now? In other words, as much as possible we will try to maintain an effortless state under the control of System 1.

This tendency is also reflected in our innately human aversion to change. Coping with changes in our environment requires the deliberate reasoning, analysis, and planning capabilities of System 2. Since System 1 is based entirely on experience it cannot deal with any significant changes from status quo. Accordingly, our reluctance to change is in close alignment with our intrinsic desire to effortlessly submit to the control of System 1. Innovation and introspection as characterized by the common phrase *looking out of the box* are very effortful endeavors that require the capabilities of System 2.

The Role of Intuition

The principal function of System 1 is to maintain a model of our personal world that represents what is normal to us. Whether or not System 1 has a role in updating this model beyond *priming* in *associative activation* is not entirely clear. Certainly the deliberative processes of System 2 will update this model. So what is normal to us? Based on our experience it is what we reasonably expect to occur. However, our expectations can be easily altered by our experience of events that occur purely by chance. If we experience an unexpected event the first time it is likely to surprise us. If by chance we experience it a second time we will be much less surprised because it has now become part of our model of what is normal, although it may be barely inside the boundary of that model. Kahneman (2011, 72) cites the example of meeting a colleague during a holiday on a remote island in Australia that caters for only 40 guests and then meeting the same colleague by chance a few weeks later during a theater performance in London. The second meeting was less surprising than the first meeting because in Kahneman's model of what is normal this colleague has now become the person that one meets in unexpected places.

In maintaining this model of normality System 1 is of course an early warning system of impending threats ranging from extreme dangers to mild discomfort or embarrassment. However, System 1 is more than an early warning system. Also included in our model of normality are the actions that we have taken in the past to react to such threats or for that matter to any situations that are in our model of normality. In this regard the role of System 1 is as much predictive as it is attentive to threats. Our brain does not compute achievable solutions from first principles, but utilizes learned action sequences. These achievable solution sequences are an integral part of our model of normality, serving as prototypes that can be modified, combined and reused in either their original form or modified form or assembled form (Hawkins and Blakeslee 2004).

Cognitive Basis of Intuition

Simon (2002, 56) defined intuition in terms of triggering the memory that is formed by experience: "*... the situation has provided a cue, which has given the expert access to information stored in memory and this information provides the answer. Intuition is nothing more and nothing less than recognition.*" Therefore, according to Simon the mystery of knowing something without being able to trace the origin of that knowledge (i.e., intuition or System 1) is an integral component of consciousness (Figure 3).

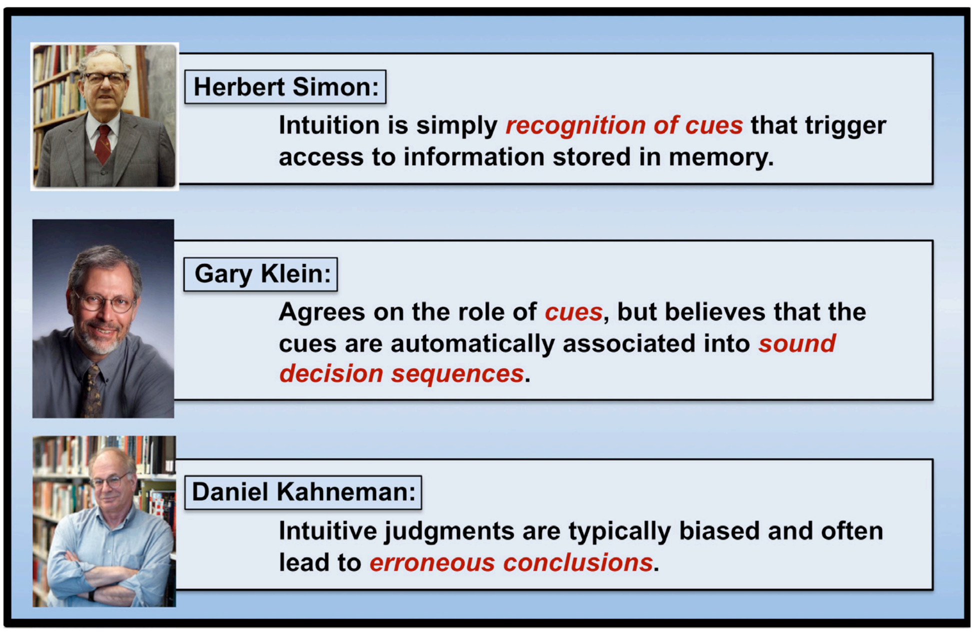

Figure 3: Theories of the cognitive basis of intuition

Like Simon, Klein (1999) and the Naturalistic Decision Making (NDM) group also believe that experts make intuitive judgments based on the cues in the situations that they are confronted with. However, their explanation goes further in suggesting that System 1 then automatically associates these cues into sound decision sequences. This is contrary to Kahneman's thesis that intuitive judgments are typically biased and often lead to erroneous conclusions (Kahneman 2011, 235). Klein and Kahneman (2009) agreed to collaborate in a joint study to determine the boundary between reliable and biased intuitive judgments.

The NDM theory is based on the hypothesis that experienced commanders such as fire captains and military commanders usually generate a single option drawn from the repertoire of patterns that they have compiled during their extensive experience. They mentally simulate the option to see if it fits the situation and modify it if necessary. Only if it still cannot be made to fit will they consider an alternative option and repeat the process. Klein formalized this hypothesis into a theory referred to as the Recognition-Primed Decision (RPD) model. All of Klein's examples are drawn from studies under time-critical conditions involving professionals with decades of experience such as seasoned fire captains, military commanders, and chess masters. Kahneman's examples, on the other hand, were based on less critical studies involving assessments and forecasts that were less focused and made by less experienced persons.

The conclusion that Kahneman and Klein drew from their joint study is that the level of experience-based expertise of the decision maker, the nature of the decisions to be made, the required degree of focus, and the urgency of the situation, are factors that will influence the quality of the intuitive decision making process. More specifically they agreed on the following principle: The confidence that persons have in their intuitive judgments is not a reliable guide to the validity of those judgments (Kahneman 2011, 240). They then formulated the following two requirements that must be satisfied for an intuitive judgment to be trusted:

a) A domain that is sufficiently regular to be predictable. For example, the fire fighting and chess domains. However, neither stock market predictions nor entrepreneurial business projections would fall into this category.

b) Extensive experience or practice that has allowed the person making the judgment to gain an understanding of the regularities of the domain.

They argued that the examples of successful intuitive decisions that Klein found in fire captains and military commanders were due to the cues that were automatically associated by System 1, even though they had not been consciously categorized by System 2. On the other hand, Kahneman's examples of decisions made by investment consultants were largely erroneous because of the unpredictability of the forecast environment.

What appears to be of particular significance is that Klein's studies involved situations in which the results of the decisions made by these highly experienced decision makers were in almost all cases promptly shown to be good or bad. This timely validation added to their experience an important rating of success. In other words, the consequences of their decision represented a metric that became an integral part of their experience base. On the other hand, Kahneman's examples involved responses to questions that were less focused, not time critical, and did not involve the solution of a problem that needed to be urgently implemented and would therefore be immediately proven to be successful, partially successful, or unsuccessful. The feedback was either indirect or in the distant future or not at all. If it was indirect such as the accuracy of an investment decision then the outcome was subject to interpretation, with the opportunity of the decision maker to excuse even a totally unsuccessful decision on the grounds of a unique set of unusual circumstances that were unlikely to be repeated. Under these circumstances the negative outcome may only slightly or not at all influence the intuitive judgment of the decision maker in a similar future situation.

Biasing Influences on Intuition

All persons perform feats of intuitive expertise each day. These range from determining the trustworthiness of a stranger from a casual interaction to reducing the speed in our car as we observe changes in traffic patterns due to car density or weather conditions on a highway. In all of these cases our intuitive judgments are based not only on cues that our senses pick up automatically from our physical surroundings but also on other factors that may bias or judgment in many ways. For example, the recent car accident of a friend may influence us to reduce our speed more drastically, while having watched a Formula 1 car race on television several days ago where rain did not appear to slow down the competitors may cause us to slow down less or not at all.

In the 1970s social scientists commonly believed that people are generally rational and that fear, affection and hatred explain most of the occasions when people depart from rationality. Tversky and Kahneman (1974) disputed this notion. They showed that many intuitive responses are found to be biased when subjected to deeper analysis. Certainly, the ease with which the factors that are available for an intuitive judgment come to mind is likely to impact the judgment itself. For example, asked if aircraft crashes or automobile accidents are the more frequent cause of fatalities a respondent may be swayed by recent media coverage of a major air crash with several hundred fatalities to side with air transport fatalities when in fact ground transport fatalities are much more frequent.

As shown in the following examples, there are many ways in which the automatic responses of our System 1 produce biased judgments.

Substituting an Easier Question: When faced with a difficult question for which the responder has no immediate intuitive answer there is a tendency for the responder to substitute an easier related question. Kahneman (2011, 12) uses the example of the chief investment officer of a large financial firm who decided to make a substantial investment in an automobile company. When asked why he had made that investment decision he replied that he had been impressed by the cars manufactured by that company at a recent automobile show. In this case "Do I like this car?" replaced the more difficult and prudent question "Is this stock underpriced?".

Ego-Depletion: Research has shown that self-control is governed by System 2 and is depleting. Any effort of self-control is tiring and will impact the willingness to exert self-control in the next challenge. Baumeister's research team (1998) found that mental effort reduces the glucose level in the blood and there is some evidence that the effects of ego-depletion can be countered by the ingestion of glucose. In this context Kahneman (2011, 43) describes a somewhat disconcerting finding of a study involving eight parole judges in Israel that spent entire days reviewing parole cases. With on average only 35% of parole requests being approved the default is denial of parole requests. In plotting the parole approvals over time the study found that the approval rate increased to 65% for a limited period after each of the three daily food breaks.

Laziness: It appears that System 2 requires significant cause to be invoked. Logical errors allowed by System 1 do not necessarily invoke System 2. In other words, an intuitive response that is logically incorrect may not be checked by System 2. Frederick (2005) used the following puzzle to study a central aspect of decision making:

If a bat and ball cost $1.10 and the ball costs $1.00 more than the ball,
then what is the cost of the ball.

The intuitive answer is 10 cents, however, on further examination this would lead to a total cost of $1.20 for the bat and ball set. The correct answer is 5 cents. The intuitive response could have been rejected with a relatively small effort by invoking System 2.

Associative Activation: A particular word such as *headache* or a particular graphic image such as a car accident fatality will immediately invoke an emotional reaction through an automatic association in our brain with some past experience. This is System

1 at work by a mechanism referred to as *associative activation*. The word *headache* may invoke memories, which invoke emotions, which in turn invoke other physical responses (e.g., facial expression, tensing of muscles, activation of sweat glands, increased heart rate, and so on); - reinforcing each other in a pattern of cognitive, emotional and physical involuntary responses.

In a second or two System 1 accomplished a remarkable feat. Starting from a completely unexpected event it automatically linked the word (or image) in a causal scenario that included evaluation as a possible threat, creation of a context, and preparation for the threat that has now become more likely. System 1 treated the word (or image) as a representation of reality, with our body reacting to the word (or image) as reality. In other words, we think not only with our brain but also with our body. This combination of body and brain thinking is not a sequential but a parallel mechanism of mental associations and physical responses.

Associative activation is greatly influenced by *priming* due to recent experiences such as a recent migraine headache or a recent car accident. The influence of priming can vary from very strong to very weak depending on the recency and intensity of the associated experience, with an extreme condition such as post-traumatic stress spontaneously serving as the cause rather than the result of *associative activation*. Priming can significantly influence the action of persons through the intuitive operations of System 1. For example, studies have shown that the location of a voting station can influence the voting results of a proposition (Kahneman 2011, 55). In the same way priming is used commercially to influence the likelihood of purchasing an article.[3]

Cognitive Ease: Past exposure to a word, sentence, or image creates a condition of *cognitive ease*; - i.e., the reappearance of that word, sentence or image makes it easier for System 1 to process. It creates the illusion of a level of familiarity that is not necessarily warranted. The phenomenon of *cognitive ease* will occur even if only a portion of the sentence is repeated. For example:

> Tests have shown that people who were frequently exposed to the phrase "... *the body temperature of chicken* ..." were more likely to accept as truth the statement "*... the body temperature of a chicken is 144°F ...* " (Kahneman 2011, 62).

System 1 does not necessarily distinguish truth from familiarity. In other words, anything that makes it easier for System 1 to make associations may also bias beliefs (Morewedge and Kahneman 2010). Advertisers have known and taken advantage of this fact for many years.

By reducing cognitive strain, we can invoke the illusion of truth when we are teaching, communicating or trying to persuade people to accept a particular course of action. The following are typical examples:

- Highlighting a key word or phrase in a sentence or one item in a list of items on a PowerPoint slide with color and/or bold font.

[3] There are probably multiple examples of priming that influenced the election results of the Trump-Clinton US presidential election campaign in 2016; - e.g., dress and demeanor (body language) of the candidates, the selection of election rally venues, the WikiLeaks disclosures relating to Clinton, economic circumstances of the voters, recent terrorist attacks, and so on.

- Using simple language with words that are commonly part of the vocabulary of most persons.
- Formatting text so that it can be understood at a glance (e.g., bullets instead of paragraphs).

On the other hand, cognitive strain can be used to advantage to force persons to invoke System 2. For example, lack of contrast may invoke System 2 to interpret the meaning of a paragraph or the relevant items in a list of items.

Anchoring Effect: System 1 is heavily influenced by a priming effect based on prior information that may be unrelated to the particular issue that System 1 is responding to. Tversky and Kahneman (1981) conducted an experiment in which they rigged a wheel of fortune that included numbers from 0 to 100 to stop only at 10 or 65. They spun the wheel and asked persons an unrelated question such as: What is your best guess of the percentage of African nations that are members of the United Nations? Invariably the answer would be closer to the number at which the wheel stopped (i.e., 25% if the wheel stopped at 10 and 45% if the wheel stopped at 65).

Availability Heuristic: According to Kahneman (2011, 129) "… *this is the process of judging frequency by the ease with which instances come to mind*" in which both System 1 and System 2 are involved. A series of studies undertaken by a group of German researchers led by Norbert Schwartz (1991) in the 1990s showed how an estimate of the frequency of a category will be impacted by a requirement to list a specified number of instances. They asked people to list a sizeable number of instances of a certain kind of behavior (e.g., list eight instances in which you behaved compassionately). While the first few instances are likely to be readily identified the remaining ones will require increasing effort. They found that the people who had struggled to list a larger number of instances rated themselves less strongly in the category than those that had been asked to list only a small number of instances. In other words, people feel that if they have difficulty coming up with a larger number of instances then the intuitive judgment (i.e., based on the operation of System 1) is that this category of instances is not strongly represented. It is interesting to note that while System 2 was invoked most strongly to search for the last few instances, the relative rating was made automatically by System 1 based mostly on the increasing effort toward the end of the search phase that was required to be exerted by System 2. It suggests that the priming influence is greatly impacted by recency.

Outside View: When undertaking a sizable project such as the construction of a new home we tend to be over optimistic in our estimates of how long the project will take and what the final cost will be. This is our *inside view*, which is based more on our intent, objectives and enthusiasm than on reality. If we were to compare our estimates of completion time and final cost with the statistical data of such projects, we would find that the average duration and final cost could be 50% to 100% greater than our estimate. This is the *outside view*. We typically do not go to the trouble of seeking an 'outside view' and if we do or are forced to by others then we tend to ignore it. Why is this the case?

a) The *inside view* is adopted spontaneously based on our circumstances and our experience which is likely to be scarce.

b) At the beginning of the project we typically have only a vague notion of a plan.
c) We extrapolate from that incomplete information to forecast the future. The early circumstances of the project are likely to be more positive and not representative of the middle and end stages of the project.
d) We do not allow for the "… unknown unknowns".

According to Flyvbjerg (2005, 2006) non-consideration of the *outside view* is the single most critical mistake that we make. In technical terms consideration of the *outside view* is referred to as *reference class forecasting* and involves the following steps:

a) Identifying an appropriate reference class (e.g., constructing a new home).
b) Obtaining the statistics of the reference class (e.g., duration, cost).
c) Using specific information about the circumstances of the project to adjust the reference class predictions.

Optimism: Optimism is widespread, stubborn and costly. Positive people tend to work harder and are generally more cheerful than the majority of people. They include inventors, entrepreneurs, military leaders, and other talented people that have considerable influence on others through their confidence, optimism and motivation. From a positive point of view optimism encourages persistence to overcome obstacles and resilience in the face of setbacks. However, optimistic people also take more risks than they realize and due to their overconfidence underestimate the odds that they face. They typically underestimate or ignore statistical data, such as:

- Chances that a small business in the US will survive for more than five years is only 35%.
- 60% of new restaurants are out of business after three years. Typically, the owners do not believe that this *outside view* applies to them.
- Continued persistence when obstacles arise can be expensive.
- 90% of car drivers believe that they are better than average drivers.

The reasons for these self-serving opinions are manifold:

a) We focus on the *internal view* (i.e., our objectives) and ignore statistics.
b) We neglect the role of luck and assume the illusion of control.
c) We focus on our own capabilities and ignore the plans/skills of others.
d) We focus on what we know and neglect what we don't know.

The remedy to mitigate this bias suggested by Klein (Kahneman 2011, 264) is referred to as *pre-mortem*. Klein suggests that before an important decision is made it is useful to gather the people that are knowledgeable about the decision and ask them to write a brief history of failure if the plan was implemented and turned out to be a disaster a year in the future.

Statistical Intuition: People and even statistical experts are not good intuitive statisticians (Kahneman 2011, 5). In other words, even experts are likely to overestimate the reliability of statistical results obtained from small samples, or congruently the size of a sample required to produce reliable statistical results (Cohen 1969). Studies have shown that even experienced statisticians tend to underestimate the appropriate sample size for reliable statistical results. Kahneman (2011, 109) cites the following example that he credits to the statisticians Wainer and Zwerling (2006).

A study of kidney cancer in more than 3000 counties in the US indicated that the incidence of cancer was lowest in sparsely populated rural areas. At face value this might suggest that their low cancer rates are due to the healthier living style of rural farming communities; namely clean air, unpolluted water, and fresh food without additives. However, the study produced conflicting results because it also found that the incidence of cancer was highest in sparsely populated rural areas. Again we are tempted to infer that their high cancer rate is due to the poverty of the rural communities combined with a high-fat diet, too much alcohol and lack of access to good medical care. Each of these interpretations are classic System 1 conclusions, where System 1 will jump to conclusions as soon as it is able to weave an apparently plausible story. It automatically makes connections between distinguishing factors on the assumption that these factors are the cause of the differences. In this case System 1 assumes that rural counties are different from suburban counties and that there must be a reason for this difference. The fact that the statistical results are simply a probability and not the cause of the results is beyond the capabilities of System 1.

Hypothetical Neuroscience Explanation of Intuition

The question of what is the neural basis of the operations that are responsible for storing the information that supports intuition in memory is particularly intriguing. It appears that some situations are more effective in creating the necessary memory associations in support of intuition than others. For example, a situation that invokes fear may after a single occurrence have a lasting effect on a pattern of neural activations, while it may take hundreds of repetitions to obtain a similar level of primed activation when we are learning a skill such as a backhanded table tennis smash. A hypothetical explanation of the underlying neurological operations based on synergistic principles may be constructed along the following lines.

Every time our brain performs any operation hundreds of thousands of its microscopic components (i.e., neurons) are activated through the electrical and biochemical processes of their networked connections (i.e., synapses). A key aspect of these neural interactions is that some memory of these activations remains so that the next time a similar operation is required to be performed the same activations are more easily executed. This phenomenon was first formalized by Donald Hebb (1949) in two rules:

Rule 1: *If neuron A and neuron B are repeatedly simultaneously activated, then the connections between them are strengthened in both directions.*

Rule 2: *If neuron A and neuron B are repeatedly activated sequentially, then the connection from neuron A to neuron B is strengthened.*

Both of these rules have become known as the Hebbian rules of plasticity. In his 1949 book, *The Organization of Behavior*, Hebb also proposed that neurons are connected in cell assemblies. It follows that neurons whose synaptic strengths have increased through some particular kind of sensory stimulation will through their connectivity form an assembly of neurons that have now become sensitive to this type of sensory stimulus. We can call this a synaptic chain based on a pattern of strong connections. Any stimulus that activates the first group of lower level neurons will activate the higher level neurons in this chain. Of course each neuron in a synaptic chain simply reacts to the electrical stimulations that it receives through its synapses.

There is a great deal of synergy involved since a single neuron may have hundreds or even thousands of connections. Whenever some of these connections receive inhibitory signals in addition to the more common excitatory signals both the strength and the timing of the signal that is passed on by that neuron[4] are impacted. While each neuron contributes to the actions of the synaptic chain or multiple chains that it is connected to and each synaptic chain contributes to the outcome of such connectome operations, the nature of the outcome cannot be predicted from the actions of an individual neuron (Figure 4).

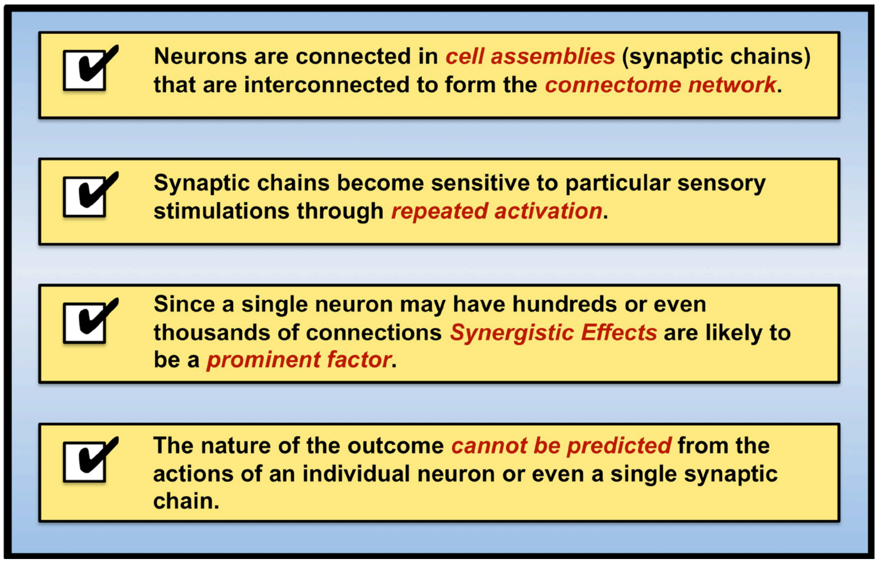

Figure 4: Synaptic chains and synergy

Applied on a larger scale to the operation of the more than 80 billion neurons and 1000 trillion synapses that constitute the human brain these two simple rules could form the basis of the predictive nature of our intuitive capabilities (i.e., System 1). System 1 is continuously monitoring our senses and interpreting any stimuli that are received within the context of our experience. Every movement we make with our limbs and every action we take is subject to the predictive nature of brain operations. We could think of System 1 as an automatic analysis capability that receives feeds from a vast array of sensors. Whenever the data received from the sensors is within the realm of expectations System 1 will perform its analysis in an automatic manner. In this sense memory may be a much more basic function than our common human association with information, knowledge, and intelligence. It simply means that some sequential neural activation is more easily performed due to repetition. While the mechanism is quite different, an analogy may be found in shape-memory materials that will return to their original shape[5] due to a solid-state phase change that is usually induced by a change in temperature.

[4] Under certain circumstances when the sum total of the inhibitory signals received by the neuron are strong enough no signal may be passed on, or if it is an inhibitor neuron an inhibitor signal may be passed on. A neuron is either excitatory or inhibitory but not both.

[5] For example, NiTiNOL, which is a nickel (Ni) and titanium (Ti) alloy. The shape-memory characteristics of NiTiNOL were discovered at the Naval Ordnance Laboratory (NOL) in White Oak, Maryland in 1961 (Buehler et al. 1963). Other shape-memory alloys are copper-aluminum-nickel, copper-zinc-aluminum, and iron-manganese-silicon.

Perhaps a closer analogy to the neural concept of memory is the sand on an ocean beach. The sand is made up of millions of silicon grains that in their dry state are readily blown into undulating sand dunes by the wind and immediately rearranged with every step as we walk across the dry sand toward the ocean. As we near the water's edge we see the waves shaping the wet sand as they wash onto the shore. During high tide the waves carve out inlets of various sizes that allow the water to penetrate beyond the water's edge with the distance depending on local sand levels and previous wave actions. Where waves have formed deeper channels in the sand the water will flow more easily and each repetition will slightly increase the depth of the channel allowing the water to penetrate further onto the shore. In this respect the waves have imposed forces on the sand that have induced the sand to react in certain ways. In a similar manner environmental stimuli trigger a large number on neurons in our brain to activate each other with electrical impulses that are channeled through networks of neurons. Each time similar stimuli are received the assemblies of neurons are more easily activated through the priming of the previous activation. In this respect it may be argued that the source of memory is nothing more than repetition and synergy.

However, the intuitive responses of System 1 are at a much higher level of cognition, involving the interactions of many neural assemblies (i.e., sub-networks). How can the necessary neural associations take place? The explanation may be as follows. Once a particular cell assembly (chain A) has been repeatedly activated it would be reasonable to expect that a stimulation coming from another cell assembly (chain B) through one or more synapses anywhere in chain A could activate the neurons in chain A. If the connections are sufficiently strong then the spiking will propagate through the entire chain without the need for the particular sensory stimulus that was originally responsible for the formation of chain A.

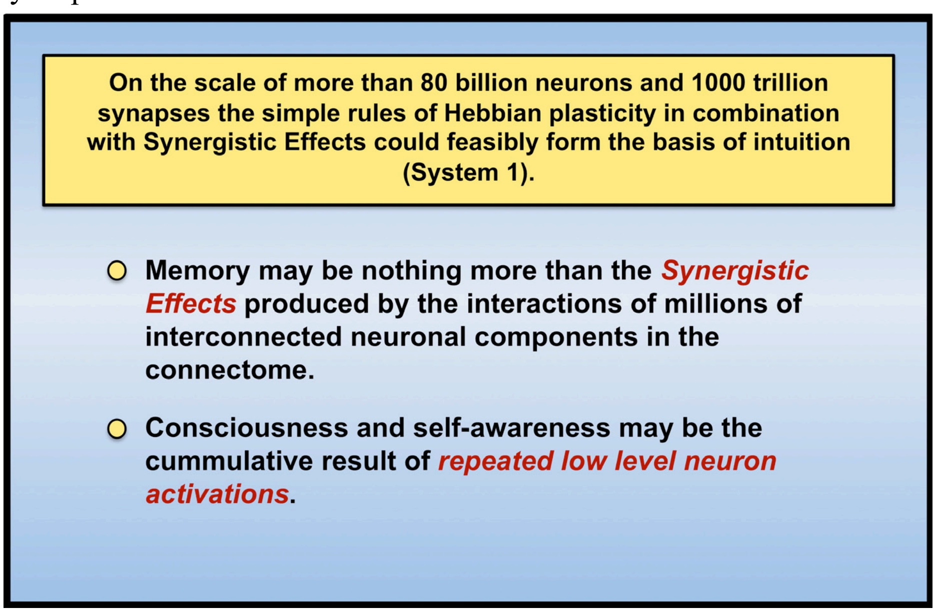

Figure 5: A hypothetical conclusion

This would provide an explanation of how the brain operates in support of associative memory; - i.e., any stimulus that activates chain A will trigger the recollection of the sequence of ideas (memories) that are associated with chain A and every successive recollection of these memories will further strengthen the connections of chain A based on the two Hebbian rules. It would therefore appear plausible that the cumulative result of this low level automatic neural memorization process is the primary neurological basis of the operation of System 1 (i.e., intuition). The hypothetical question then becomes: Is it conceivable that the synergistic effect that is produced by the repetition of impulses that are triggered by stimuli within a network of billions of neurons and trillions of connections may result in a human level of consciousness and intelligence (Figure 5)?

Conclusion: Limitations of Intuition

System 1 has an impressive range of capabilities that are always available. What these capabilities have in common is that they are automatic and do not require the selection of a single course of action among alternative interpretations. Typical examples include:

1. Judges near distances and the relative location of objects.
2. Recognizes voices over remote communication devices.
3. Detects hostility in a voice.
4. Orients to the source of an unexpected sound (unless the person is hearing impaired).
5. Understands simple sentences (i.e., that are unambiguous and comprised of only a few words).
6. Makes very simple calculations (e.g., 2 + 2 = 4).
7. Averages a small set of quantities (i.e., up to around seven quantities).
8. Drives a car on an empty road.

While these capabilities are dependable in as much as that they are always available, they are not necessarily reliable because they can be easily influenced by a wide variety of biasing factors that were discussed in a previous section. In this respect the following characteristics of System 1 are of particular concern:

1. Jumps to conclusions based on scarce evidence (e.g., *reference dependence*).
2. Accepts erroneous conclusions rather than invoke System 2 for verification purposes (e.g., *statistical intuition*).
3. Is unduly influenced by recency and repetition (e.g., *priming*).
4. Accepts weak reference points (e.g., *anchoring effect*) or ignores reference points altogether.
5. Substitutes an easier question for a difficult question.
6. Underestimates the difficulties involved in achieving an objective by focusing on the desired outcome rather than the path to the outcome (e.g., *outside view* and *optimism*).
7. Allows the emotional influence of a past event or experience to unduly influence the spontaneous judgment of a current situation (e.g., *associative activation*).
8. Allows the desire of achieving a certain state or outcome to dismiss contrary evidence (e.g., *wishful thinking*).

System 1 does not make choices because it does not recognize alternatives. It will automatically accept a version of the situation that fits into the context that is currently most strongly represented by the particular activation pattern that has been triggered in our brain. In this regard activation pattern refers to the repeated sequence of neural activations that are automatically triggered by System 1 in response to the particular situation. By context is meant the story that is associated with the activation pattern, which is the sequence of stimuli that caused our brain to respond with this particular activation pattern. Clearly both the nature of those stimuli and the recency of the last occurrence of those stimuli have a major bearing on the version of the situation story that System 1 jumps to (Kahneman 2011, 79-80).

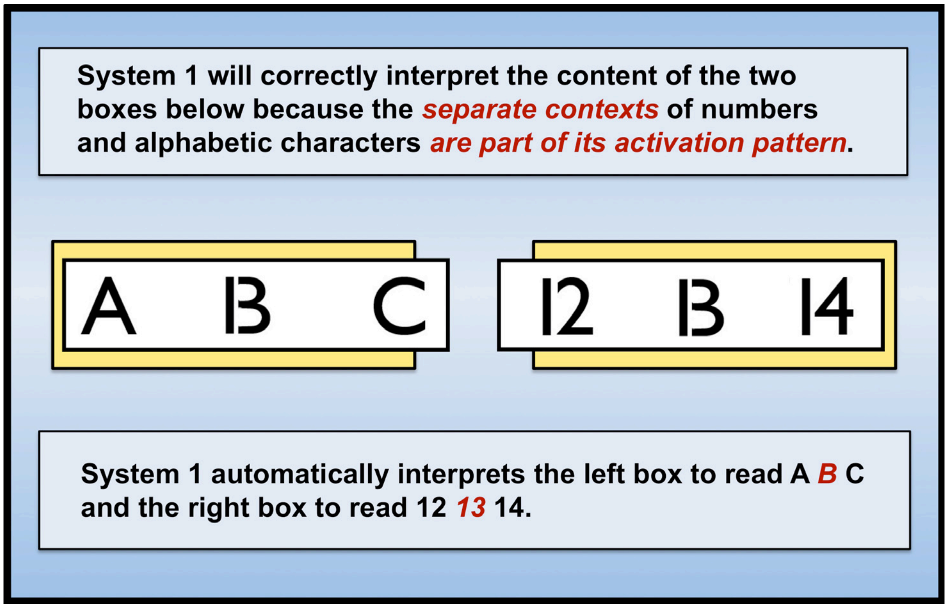

Figure 6: Context is part of the activation pattern of System 1

An example of the role of context is provided by the two boxes shown in Figure 6. Box 1 and 2 are automatically assumed by System 1 to represent "A B C" and "12 13 14", respectively. On closer examination we see that Box 1 could also be read as "A 13 C" and Box 2 could also be read as "12 B 14". However, System 1 will automatically read Box 1 in the context of alphabetic characters as "A B C" and Box 2 in the context of numbers as "12 13 14". The separate contexts of numbers and alphabetic characters are part of the activation pattern.

It is the nature of System 1 to jump to conclusions based on the available evidence without regard to either the quality of the evidence or the size of the leap. Coherence in System 1 is based on automatic associations that appear plausible without further examination. In this regard System 1 weaves a story in the form of a sequence of associations that makes sense in a superficial manner. The difference between these intuitive associations and the associations created by dreams during sleep is perhaps no more than the greater degree of consciousness when we are awake. This would suggest that System 1 is active at all times, whether we are asleep or awake and that System 2 does perform a subtle monitoring function that is governed by our state of alertness. During sleep the influence of System 2 is minimal allowing the associations formed by System 1 to create stories that would not be tolerated by System 2 while we are awake and in a heightened state of alert. The proposition that System 2 is at least minimally active during sleep is evidenced by the fact that we abruptly wake up if our dreams become too extreme (e.g., nightmares).

System 1 can deal well with averages because it operates on the basis of prototypes or typical exemplars (Kahneman 2011, 93), but has difficulty in computing sums (i.e., totals or quantity). For example, in Figure 7 System 1 has no difficulty estimating the average length of the seven lines but cannot without invoking System 2 estimate the total length of the seven lines if they are placed end-to-end.

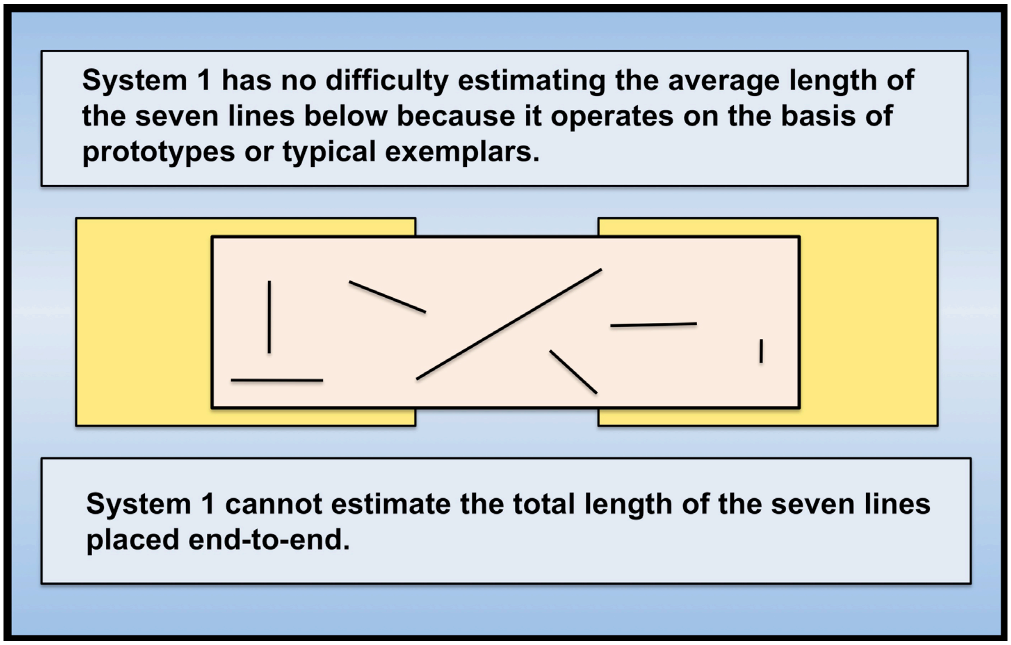

Figure 7: System 1 can estimate the average length of lines but not the summated length

During our wakeful state the degree to which System 2 is active is governed by the stimulations that we receive. The stimulations range from tasks that require the reasoning capabilities of System 2 because they cannot be accomplished effortlessly by System 1 to the extreme state of alertness produced by a threat detected by System 1, which requires immediate avoidance or planning actions. In other words, we are on autopilot with System 1 until circumstances arise that require effortful reasoning and/or planning tasks that cannot be accomplished without System 2. During sleep our level of alertness (i.e., consciousness) is greatly reduced so that only very extreme autopilot conditions will invoke System 2 and then wake us up because only in a wakeful state can we achieve the necessary level of alertness.

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