CONCEPTUAL FOUNDATIONS OF PSYCHOLOGY

Philosophical Foundations
Neuroscience: Mind and Brain
Experimental Methods
Biology
Measurement
Psychoanalysis
Development
Computation

DANIEL N BUB
A very fast modern supercomputer can execute more than a quadrillion calculations per second. To give you some idea of what a quadrillion means as a number, if you took just one second to view a single page of this textbook, and I was able to write a quadrillion pages, you would need more than thirty-one years of reading to finish the book. By contrast, human neurons transmit information at a snail’s pace. Using an ingenious methodology, Helmholtz was the first to demonstrate that a nerve impulse travels at about 57 miles per hour. At this speed, it will take a few milliseconds for an electrical impulse to move between neurons. Despite our relatively sluggish neural speeds, we can accomplish many tasks requiring very complex information processing (for example, identifying a familiar face or spoken word) in under a second. In comparison, supercomputers carrying out the same tasks are painfully slow. How do we do it? Equally remarkable is the fact that the brain has to often cope with sensory information that is seriously underspecified.
We have already seen that the image on the retina is two-dimensional. So in effect, our visual system always has to compute a solid object given definite limitations in the evidence that the eye is able to obtain from the world, by inferring a third dimension.

The problem is this: Different objects at varying orientations and distances from the eye -- say, lines A, B, C, D and E -- can all produce exactly the same image on the retina. Donald Hoffman in his book entitled *Visual Intelligence* states the fundamental problem of seeing objects in depth as follows:

Because the image on the retina has just two dimensions, a retinal image allows countless interpretations of a visual object in three dimensions.

The fact that we have two eyes doesn’t overcome this constraint. The flatness of an image on the retina applies to the input of either eye. We can say that vision has to cope with information from the eye that is underspecified; there is not enough information in the physical stimulus itself (the light falling on the eye) to compute the shape of an object. This *poverty of the stimulus* implies that the visual system has to add information by constructing depth based on certain rules.

Helmholtz was one of the first vision scientists to recognize this problem. He argued that perception requires a kind of “unconscious inferencing” by which the visual system actively constructs an interpretation of the retinal image. The unconscious knowledge that the visual cortex uses is, of course, domain-specific. Our brain solves the problem of seeing in depth by making certain assumptions about the relationship between the retinal image and objects in the world.

Here is an example of a simple rule that the visual system must incorporate.

Assume that the view of the physical object producing a retinal image is a generic view.

A generic view is one that is typical in the sense that you are not looking at the object from an unusual angle to produce the image on the retina. Of course you might be doing just that, but statistically speaking this is a very low probability event. The blue object on the right is interpreted by us as a straight line even though the image on the retina, as we have noted, is consistent with countless other possible objects, including a side view of a bicycle wheel, but such a view would be unusual. A simple movement of your head would reveal that the wheel is curved rather than straight, and that the view yielding the impression of a vertical line was accidental. Almost every view of a wheel will appear curved except for the accidental view suggesting a straight edge. By contrast,
a straight line looks that way from nearly every viewpoint except when you look at the line ends-on, in which case this accidental view will yield a single point on the retina.

The visual system will therefore always interpret a straight line on the retina as corresponding to a straight line in three dimensions, based on the rule that the image matches the stable (generic) view of an object. You can see the rule in operation by comparing your visual system’s construction of the three objects above. On the left is the well known Necker cube which everyone will readily interpret as a three-dimensional object. The shape in the middle -- known as a Kopfermann figure after the psychologist who analyzed its visual properties -- is harder to see as a cube. You will often perceive it simply as a flat hexagon with three lines through the middle joining the vertices. Interestingly, a very small change to this figure yields the object on the right which you again see as a cube.

This pattern of effects can be explained by combining the rule of stable views with another two rules:

(i) Always assume that a straight line in a two-dimensional image is a straight line in three dimensions.

(ii) If two lines end at a point in the two-dimensional retinal image, then assume that they also end at a point in three dimensions.

The Kopfermann figure has three lines that intersect in the middle. The first rule requires that these lines are straight in three as well as two dimensions, making it difficult for the visual system to represent the edges of a cube. Of course, there are accidental views of the cube that will yield exactly this image on the retina but the visual system prefers the assumption that it is decoding a stable, non-accidental view.

The third figure no longer has three straight lines spanning its vertices. Instead, we always have three lines meeting at a point. The configuration of lines forms \(Y\)-junctions as well as arrow-junctions (an example of a \(Y\)-junction is indexed in red, and an arrow-junction in blue). Boxes have \(Y\)- and arrow-junctions whenever two surfaces meet, so the visual system quickly infers that the object has corners and is therefore solid. \(Y\)-junctions are harder to extract in the central image given the presence of straight lines, which trigger rule (i) above.

**Helmholtz’s Sign Theory**

The rules of our visual system are complex and sophisticated. We realize they must exist through carefully designed experiments that make use of objects to capture the rules in action. For example, the Kanisza Triangle in the figure on the left, appears against a slightly darker background, but is
not physically there. It is inferred by your visual system. What I mean by ‘not physically there’ is that a photometer measuring the amount of light coming from locations A and B will show that there is no difference at all in the intensity of light coming from these two locations, even though any observer experiences a completely different reality; location A appears noticeably brighter than B. On the basis of these perceived changes in brightness (which are not physically there!) we construct the silhouette of an object.

The fact that we are using quite specific rules to construct figures can be established by finding the conditions that trigger them. For example, compare the two figures below. On the left we see four brackets that enclose a square space. On the right we clearly see what appears to be the silhouette of a square sitting on top of four circles, parts of which are occluded (hidden) by the object we have constructed. The middle of this square appears brighter than the center of the image on the left. Again, a photometer would disclose no such objective difference in brightness. What rules, though, triggered your visual system to construct the occluding square on the right but not on the left? We can discover the content of these principles by learning about the conditions that trigger them.

Notice that both language and vision demand unconscious rules of inferencing, though of course the rules and the kind of inferences are quite different in the two domains. The brain needs some way of computing the form of an object given sensory input that is inherently ambiguous. An inherent stimulus poverty applies equally to the child’s task of determining the abstract linguistic structures or forms that underly the relationship between sentences and their meaning. For example, the sentence Gabriel is easy to please means that it is easy for someone to please Gabriel, so the form of the sentence has Gabriel as the object of an action. Yet simply change the word easy to eager -- Gabriel is eager to please -- and the sentence now communicates the idea that Gabriel wishes to carry out the action of pleasing another. The surface word order (Gabriel comes first in both sentences, even though he is the subject in one and the object in another) is not enough to determine the meaning of each sentence, just as the image on the retina is insufficient to determine the three dimensional structure of an object. Language comprehension requires that the child has unconscious rules that enable him or her to derive (i.e. actively construct) the meaning of a sentence from its underlying form. Likewise, other unconscious rules -- specific to the visual domain -- enable us to identify objects using their spatial form.

Helmholtz referred to his influential theory of perception as a ‘sign-theory’, because his general assumption was that there is no simple resemblance between the neural events that give rise to sensations and physical objects in the world. Just as the label for an object is a sign that does not resemble the object itself, the correspondence between physical objects and the neural signals they evoke is symbolic.
In this respect, there is a remarkable similarity between Helmholtz’s theory and Descartes’ attempt to analyze the relationship between neural events and the physical objects that give rise to them. Recall that Descartes wrote:

Now, if words, which signify nothing except by human convention, suffice to cause us to conceive of things to which they bear no resemblance, why could not nature also have established a certain sign that would cause us to have the sensation of light, even though that sign in itself bore no similarity to that sensation?

A crucial difference between Descartes and Helmholtz, though, is that Helmholtz argued that our construction of objects from neural signals is learned through experience; we neither have an innately specified representation of space, nor of objects. According to Helmholtz’s sign theory, we develop an understanding of the correspondence between physical objects and neural signals by learning about the contingencies between the actions we carry out and their perceptual consequences.

To understand what this means (remember to avoid just trying to memorize the above section in italics) consider the following passage from Helmholtz:

It is easy to see that by moving our fingers over an object, we can learn the sequences in which impressions of it present themselves and that these sequences are unchanging, regardless which finger we use. It is thus that our knowledge of the spatial arrangement of objects is attained. Judgments concerning their size result from observations of the congruence of our hand with parts or points of an object’s surface, or from the congruence of the retina with parts or points of the retinal image. A strange consequence, characteristic of the ideas in the minds of individuals with at least some experience, follows from the fact that the perceived spatial ordering of things originates in the sequences in which the qualities of sensations are presented by our moving sense organs.

Helmholtz was arguing that you learn to represent the position of objects in space by tagging the spatial ordering of events you experience through movement of your sense organs. Such movements include very rapid changes in eye fixation (these take place about once every 1/5 of a second) or slower movements of the head, wrist or fingers. The sequence of events that occurs as a result of our movements usually remains the same regardless of the sense organ responsible. This common experience of the contingencies between actions and their perceptual consequences in different sensory systems provides the foundations that allow us to acquire the unconscious principles that generate three dimensional representations of objects.

We note that space is conceptualized by Helmholtz as an abstract domain that integrates a number of different modalities. This idea should alert you to the distinction between the terms domain-specific and modality-specific. Space as a domain is common to action, touch, vision, and even audition (you can localize sounds in space, though not very well in comparison to visual localization). The different senses that produce the same ordering of spatial events are referred to as input modalities. So we can say that the representation of space is domain-specific but modality-independent; it is the same location of an object that I can touch and perceive, but the input modalities that provide the details of the object’s spatial posi-
tion (relative to the midpoint of my body, say, as a reference) are different.

In a classic experiment on the role of motor experience in the construction of space, Helmholtz fitted observers with lenses that systematically altered the visual field by shifting the perceived location of objects several degrees to the right. Participants were asked to visually attend to an object, then closing their eyes, to reach and touch it. The task entailed representing the location of the target object in short term memory, and integrating the movement of the hand with the eye. Not surprisingly, observers initially erred by moving their hands too far to the right of the object. After a short time of practice, however, during which participants were allowed to handle objects while looking through the distorting lenses, their reaching performance improved dramatically. This benefit was termed perceptual adaptation by Helmholtz. Initially, the feeling that participants reported was one of conscious effort; they had to direct their hands to the left of the object to avoid the rightward bias induced by the artificial lenses they were wearing. With time, though, pointing movements became effortless and no longer required conscious attention. What do you think would happen to the reaching performance if the glasses were now removed after extensive training? The answer is that spatial errors were again apparent: participants reached too far to the left of the target object. The representation of space itself had been temporarily altered through perceptual adaptation. Presumably, much lengthier experience during infancy must play a role in the calibration of space.

Helmholtz’s emphasis on movement as being fundamental to establishing visual representations of space and objects is noteworthy. Like many other thinkers since then, he considered that the function of perception was to enable adaptive goal directed action. According to this view, our brains are not designed to establish veridical or objectively accurate representations of the world but only to ensure that our perceptual inferences or constructions generally allow for successful actions.
Human reaction time can be impressively fast under optimal conditions. For example, world class sprinters at the 2008 Beijing Olympics sometimes had reaction times (RTs) to the starter’s pistol that were as quick as 110 milliseconds (110 ms is just a bit more than 1/10th of a second). A false start is defined by the International Association of Athletics Federations (IAAF) as a reaction time (in this context, a leg movement detected by electronic sensors time-locked to the starter’s signal) that is shorter than or equal to 100 ms. This value was decided on because objective tests have shown that no one, however much he or she practices, can produce a voluntary RT that is equal to or faster than 100 ms from the onset (the beginning) of a sensory event like a tone or a flash of light.

Any task, even one that simply demands a prepared action to a cue (for example, an athlete beginning to move as quickly as possible on the starter’s signal), takes a certain duration that reflects the time course of underlying mental events. From a methodological standpoint, the average RT will tell us nothing about the processing steps involved in a particular task. The athlete is in some preparatory state that will rapidly trigger a particular...
course of action as soon as the brain decodes a go signal but beyond this very general description, we do not have more to say, other than that the whole process from the onset of the auditory signal to the beginning of the motor response can be as fast as (but not much faster than) 110 ms.

We need some way of using RT (the time interval in milliseconds from the onset of a particular sensory event to a response) to identify the structure and organization of mental events. This enterprise, which began under Wundt’s influence, is referred to as mental chronometry. Nowadays one can read articles or books with titles like *Timing the Brain: Mental Chronometry as a Tool in Neuroscience*, or *Chronometric Explorations of Mind*. The use of RT to test claims about cognitive processing systems is a crucial part of modern experimental psychology.

**Donders’ Subtractive Method**

The original attempts by Wundt and his students were, perhaps not surprisingly, limited in important ways. It is by understanding and going beyond these limitations that mental chronometry has become so fundamental to modern psychology. F.C. Donders, a medical scientist and ophthalmologist working with Wundt, developed an approach in 1868 which is referred to as the *subtractive method*. The idea is to design a number of tasks in such a way that each task adds a different processing stage which can then by isolated by subtracting the average RT of one task from another.

Consider the example with which we began this section. Preparing a response to a stimulus or go signal (if you are a sprinter in a race, you prepare to leap forward when you hear the starter’s signal) is pretty much the simplest voluntary task it is possible to devise. You know exactly what you have to do before the event that triggers the action, and the event itself is just a stimulus to which you must react; the task does not require that you distinguish between different sensory events (say, a loud versus a softer start signal) before reaching a decision to move.

Donders termed this kind of reaction, a *simple* reaction; there is only one response to a single stimulus. For example, a light goes on and the instruction is to press a key or a button as soon as possible after the onset of the stimulus. For Donders, this simple RT task (we will call it Task A) could be used as a *baseline*. Task A (requiring only simple reactions) captures the overall speed of responding to a predetermined
event. Included in the task is the translation of a motor intention into an overt physical action, so we will refer to this component as \textit{response execution}. Donders assumed that the task was sensitive to factors like the average speed of nerve conduction in each individual. We can compare the RT we obtain in this task with another more complex task (call this Task B) that requires additional processing steps. Subtracting the average RT's obtained for the two tasks (Task B - Task A) should give you an RT difference which, according to Donders’ subtractive methodology, would then provide a pure measure of the time required to complete these additional processing steps.

Suppose in Task B there is more than just one stimulus and a single response. Instead, let us require the following of our participants: If the stimulus is a triangle, press one button or response key as quickly as possible (say, a button beneath the forefinger of your right hand). If the stimulus is a circle, press another button (a button beneath the forefinger of your left hand).

Task B involves a \textit{choice reaction}. You must \textit{identify} which shape (triangle or circle) has been presented, and you must \textit{select} which key (left or right) to depress. A choice reaction task therefore requires the mental operations of \textit{stimulus identification} and \textit{response selection} as well as \textit{response execution}.

Consider now Task C designed by Donders. The task requires only one response linked to a stimulus (say, respond to the triangle, and ignore the circle). Like Task B, you must identify which of two stimuli has been presented (triangle versus circle). There is no requirement however to \textit{choose between two alternative responses} once you have detected the target event. Task C is referred to in the modern literature as a \textit{go/nogo} task. The \textit{C} reaction involves \textit{stimulus identification, and response execution}, according to Donders, but no \textit{response selection}.

We can subtract Tasks A, B and C as follows:

The average RT for Task C \textit{minus} the average RT for Task A (\(C-A\)) will provide us with a measure of how long stimulus identification takes.

Task B minus Task C (\(B-C\)) should indicate the time for \textit{response selection}.

Despite its intuitive appeal, the logic of Donder’s subtraction methodology is not at all straightforward. It rests on three assumptions:

(i) The mental processes of stimulus detection, stimulus identification, response selection and response execution are arranged sequentially in the sense that the output of one serves as the input to the next.
Only one process can be active at a given instant between stimulus input and response output. Each process or processing stage takes a certain amount of time, referred to as the stage duration. RT is equal to the sum of all the stage durations (the serial processing assumption).

A stage can be added or omitted to a sequence of processes without altering the duration of the other processing stages. This is termed the assumption of pure insertion.

The first two assumptions may be valid under certain task conditions but are unlikely to be true of cognitive processes in general. For example, in cascade models, later stages of information processing can begin to operate before previous stages reach completion. Each stage begins working on partial information that rapidly becomes more detailed over time, until enough information has accumulated in the system to trigger a response.

The most contentious assumption, however, is the assumption of pure insertion, that a stage of processing can be added to a sequence without changing the operation of previous processing stages. Students of Wundt relied on introspection to argue that performing Task C (go/nogo) did not feel like carrying out Task A with just the added component of stimulus identification. The task itself felt like something qualitatively different. Likewise, it was argued on the basis of introspection that Task B did not feel like Task C with the addition of an extra component. All the tasks felt quite different in ways that did not support the assumption of pure insertion.

You should raise your eyebrows, of course, at this kind of argument. The emphasis on introspection as an analytic tool to uncover the organization of basic cognitive processes, is no longer a fundamental part of modern psychology. There are good reasons for this; much of the processing that underlies speeded reaction time tasks is unconscious, so no amount of training in introspective techniques can grant us reliable access to mental events that unfold within a few hundred milliseconds.

How would we develop an adequate test of the validity of the assumption of pure insertion, at least in regard to Donders’ A, B and C tasks? Donders himself expressed some concern about this assumption. He wrote:

Some people give the response (in Task C) when they should have remained silent. And if this happens once, the whole series must be rejected: for, how can we be sure that when they had to make the response and did make it, they had properly waited until they should have discriminated?

Take some time to think about the concern that Donders’ expressed (it’s a good idea to read the segment above more than once). Suppose participants on the go/nogo task incorrectly respond to the nogo stimulus (in our example the circle) on a certain percentage of trials, which they have been instructed to ignore. These errors (a rapid anticipatory response triggered incorrectly by the wrong stimulus) might also have occurred for the target object (the square or the go signal), only the experimenter would have to count these as correct and has no way of distinguishing between these responses.
and other RT’s that involved more detailed processing of the target square. In other words, the participant may have changed the amount of time he or she allows before responding to the target in the go/nogo task, triggering on some trials very fast anticipatory responses before the stage of identification has been completed. If this were true, the components involved in Task C are not just those which determine performance in Task B minus the added stage of response selection. The go/nogo task may differ from the choice task in other respects as well, either at the level of stimulus identification or at the stage of response execution (indexed by the component labelled ‘baseline’).

Interactive Activation

In the late 19th century, James McKeen Cattell -- a student of Wundt who went on to hold a professorship at Cornell University -- invented equipment that allowed him to measure the speed with which an observer could identify a visual word, letter or other object. The stimulus on each trial (a printed card) was hidden behind a black screen at the beginning of each trial. An electronic device quickly removed the screen and at the same instant a clock (termed a chronoscope) would begin timing in steps of 1 ms. The response of the participant would then close a switch that stopped the clock. Cattell built a device that enabled the vibrations of the participant’s spoken response to act as the signal that stopped the chronoscope so that he could measure the speed of verbal responding to a stimulus.

Cattell found that when participants were asked to identify (by naming) short words (say, between four and six letters in length), RT was no different than RT to name individual letters. He concluded that ‘we do not therefore perceive separately the letters of which a word is composed but the word as a whole’.

It turns out that a large number of experiments since Cattell’s initial research on the identification of words and letters have demonstrated that words are actually perceived better than individual letters. Cattell’s equipment was too crude to show the perceptual advantage for words. The effect (superior identification of a visual word relative to a letter) has been so widely replicated in hundreds of studies that it has been given a name and an acronym: the word superiority effect or WSE. Does this result mean, as Cattell inferred, that a word is seen by a skilled reader as a perceptual whole rather than as a string of individual letters?

There is an important mistake in Cattell’s thinking about this evidence that we should unpack. In the diagram on the left, two stages are depicted, one for letters and the other for word identification. They operate strictly in sequence; the stage of letter perception runs to completion before word perception can begin. According to this little diagram, it is not possible for word identification to be better than letter identifi-
cation because the stage of word processing depends on completing the earlier stage of letter perception.

We call this arrangement of processing components *feed-forward* -- information flows in just one direction, from letter processing to words. Given this arrangement it is indeed the case -- as Cattell inferred -- that better perception of words than letters must imply that reading a word cannot depend on prior identification of its constituent letters. Instead, there must be another route from squiggles on the page to the identity of a word that bypasses letters, as depicted in the next diagram. We will assume this route involves a holistic perception of word shape. However, there is an interesting alternative that was not well understood during the early days of mental chronometry.

Consider the third diagram: There is a *feed-forward* connection from letter to word processing but in addition, the activation at the level of the word module *feeds back* onto letter perception. This type of functional architecture (we have used the term *functional architecture* before; if you are not sure of the meaning, check out the section on Lichtheim) is known as a *feed-forward/feedback* model of information processing. We will consider in general terms how this arrangement can produce better perception of letters in words than a letter on its own. A more detailed analysis is presented in the case study entitled "An Interactive Activation Model of Reading". Let us make a number of basic assumptions about the flow of information to and from letter and word processing mechanisms *(to and from because the model has feedforward as well as feedback connections)*. First, we will assume that letters in a short word (say four letters in length) can all be processed at the same time rather than sequentially. The term for this type of processing is *spatially parallel processing*. Second, we further assume that information processing occurs in the two components of the diagram (Letter Perception and Word Perception) at the same time. Thus, it is *not* the case, that the word-level component of the system must wait to begin processing until letter perception is complete. Rather, as soon as *some* information begins to accumulate over the four spatial locations occupied by letters, words become activated,
though at first there may be no single word that is activated strongly enough to produce a conscious percept.

We can say that words are processed in parallel with letters, but be careful to note that the term parallel processing in this sense means that several processing modules (in this case, the letter and word-level component) operate at the same time rather than in sequence to produce a response. The other sense of the term parallel refers to the fact that a particular processing component (in this example, the letter processing module) can operate on many spatial locations at the same time. Be sure to distinguish between these two different ways in which the term parallel processing is being used.

Consider how the model reacts to the visual word TAKE. As letter perception begins, not only will the letters T-A-K-E become active but so will other letter detectors that are similar in shape to these letters. For example, the letter F, will be partially activated by T, and so will E, because all three letters have some features in common (e.g. an upright ‘post’ - l - is a feature that is the same for all of them), R will be activated by K (both share the upright post and a diagonal ‘foot’) and so on. At the same time (because the processing levels in the model work in parallel), words become somewhat active, though none of them strongly enough to produce a definite response. The letters T-A-K-E will activate the words LAKE, FAKE, TALE, TAME, TART, and many others.

Now comes the interesting part. These partially excited words feed their activation back onto letter detectors. That means the letter sequence A-K-E will receive very strong feedback support from the words TAKE, FAKE, MAKE, RAKE, and so on, all of which have been activated to a lesser or greater extent by the array T-A-K-E. The letter T will receive feedback from the activated words TAKE, TALK, TAME, TALE, TALL etc. This feedback from word units back to letter units enhances the activation within the letter processing module. These strongly activated letter units will in turn combine to enhance the strength of the activation of the word unit TAKE, which then feeds more activation back onto letters. The feedforward/feedback cycle continues until the system rapidly settles on to the correct target. An isolated letter as a stimulus or a random string of letters has no such feedback from word-level representations to enhance the strength of activation over time, and the net result is the well known WSE.

Additive Factors

The previous section describes two processing components which interact, in the sense that word-level activation influences the prior stage of letter recognition. This type of feedforward/feedback processing loop is an important part of the brain’s speed and efficiency, despite the rather sluggish neural transmission time first documented by Helmholtz. Because multiple stages of processing work interactively and at the same time, the brain rapidly settles on a response to a perceptual event.

Not all stages of processing interact in this way, of course; there are definite bottlenecks where one stage cannot
begin to operate before a previous stage has run to completion. Recall that the logic of subtraction methodology requires us to assume that: (i) processes are sequential so that the output of one stage acts as input to the next and (ii) only one process is active at a time. Assuming these conditions are met, how should we proceed to obtain further insight into the organization of different processing stages that occur between stimulus input and response output?

It has been established that Donders’ subtractive method has some fundamental problems. The main one, as we have seen, concerns the argument of pure insertion: that adding (or removing) a processing stage from a sequence will leave other processes unaltered. The figure below depicts that this is often not the case; removing Stage 3 in this example, alters the nature of processing at the level of Stage 2. It follows that subtracting the average RT’s of two different tasks will generally not tell us much about underlying mental processes.

Donders had no statistical methods available to go beyond subtraction methodology. The development of additional analytic tools provide the modern foundations of mental chronometry. A discussion of these techniques is presented in the case study entitled “Additive Factors Logic”. They are based on the general idea that it is possible to systematically vary an experimental factor so as to affect a particular processing stage. For example, consider again Donders’ choice reaction time task. Recall that participants must produce one response to a stimulus event (say, a triangle) and another response to a different event (e.g. a square). Hypothetical stages involved are: Stimulus Identification, Response Selection and Response Execution.

One factor that could be varied concerns the quality of the image affecting the stage marked Identification. The triangle and square could be presented clearly on some trials or rendered harder to see (obscured) on other trials. We can call this factor Stimulus Clarity and it has two levels (Clear ver-
The participant’s response is to press one key to signal the identity of the triangle and another key for the square. Obviously it will harder to identify an obscured object than the same object that is clearly visible.

An experimental factor that will affect Response Selection is to make the choice of response easy or hard for the participant to decide on. Suppose we assigned the triangle to a Left Response key and the square to a Right Response key. On some trials we presented the target object on the left of the display, other trials on the right. A spatially compatible mapping between the stimulus and response would occur when the target is on the left and a left-sided response is required, or when it is on the right and a right-sided response is required. A spatially incompatible mapping occurs when the target is on the right but a left-sided response is the correct choice, or the target is on the left and a right-sided choice of responding is needed. A compatible stimulus-response (SR) mapping is easier than an incompatible SR mapping.

We have two factors then: Stimulus Clarity and Response Compatibility, each with two levels, and each of which is designed to affect a particular processing stage. The logic of additive factors, discussed in the case study entitled Additive Factors Logic, can be used to test whether two stages function independently of each other or whether they do not in fact operate as distinct components of a functional architecture.

Notice the wording of the previous sentence. Two processing stages linked together in a feedforward/feedback cycle will not operate independently of each other. Yet they may certainly exist as distinct components of a functional architecture, at least in the sense that each component relies on different kinds of information. The identification of individual letters requires the visual system to extract distinctive features that are common to different shapes. For example, A, A, A, A, A, A
are easily recognized as the same item despite their differences in appearance. The identification of a word includes a stored representation of the order of a sequence of letters: EAT, TEA, ATE, all have the same letters but are quite different at the word level. We can certainly infer, then, that the processing of a word requires the brain to access a qualitatively different kind of information than the visual features needed to perceptually identify letter shapes. In that sense, letter-level processes must be modularly distinct from word-level processes even though the two levels operate interactively. While mental chronometry may not easily disentangle processes that work interactively, the methodology is just one amongst many techniques that can be used to understand the architecture of complex information processing systems.

Word Superiority Effect Demo