What *do* Psychologists do?

Two Examples from Research in Cognitive Psychology

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A few issues earlier (*Resonance*, November,1997) I had written an article titled 'Is Psychology a Science?' In it, I described some aspects of psychological research that I felt were related to the question of what constitutes scientific enquiry. In this article, I'd like to give you a feel for the kinds of questions psychologists ask, and how they attempt to answer them. I've chosen the broad area of *cognitive psychology* – the study of how people acquire, organise, remember and use knowledge to guide their behaviour.

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The goal of a cognitive psychologist is to understand mental processes through inferences based on observable behaviour, and conversely, to explain observable behaviour with reference to hypothesised mental processes. Within the field, some psychologists study the acquisition of information (sensation and perception), while others study memory, reasoning and the 'higher' mental processes. Our first example comes from the study of visual sensation and perception.

Sensation and Perception

When stimulus information reaches the senses, it is processed to some extent in the sense organs themselves, and then sent on in some form, via neural pathways, to the brain. The word *sensation* is used to describe this initial processing, as also the immediate experience with the stimulus. *Perception* refers to the organisation and integration of this sensory input in the brain, allowing the human being to extract rudimentary meaning from the stimulus (for example, 'This object is a book', or 'That sound is a train whistle'). Perceptual processes are much less accessible to physiological study than are sensory processes. This means that

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cognitive psychologists must devise ingenious experiments that will enable them to study perception from *outside* the brain! Here is a nice example, from the work of a psychologist named Anne Treisman, in the field of visual sensation and perception.

This morning, you probably had the following perception – ‘This is a bar of soap.’ The complexity behind this ‘simple’ perception becomes easier to appreciate when you start at the beginning. The initial information about the scene in front of you (called the stimulus array) is received by the rods and cones in your retina, and is nothing more than a pattern of light and dark patches. Each cell in the retina records only the amount of light it has received. This information is subsequently integrated in stages. A single cell combines the information from a group of adjacent retinal cells, a single cell at the next level combines the information from several of those cells, and so on. Some of this integration takes place in the eye itself, but the bulk of the work is done in the visual cortex of the brain. The integration of stimulus information is done in such a way that, fairly early on, there are cells in the cortex which can indicate the presence of certain *features* in the stimulus (for example, a line slanted at a particular angle). In the case of your bar of soap, these *feature-detector cells*, as they are called, will ‘detect’ two pairs of parallel lines (assuming that your soap is rectangular). What we have been describing so far are called *bottom-up processes*, since they start with the raw material of individual cell processes and attempt to build a perception of the whole in stages. A computer could be programmed to go through the steps I’ve described so far! What remains is the integration of the individual features, the parallel lines, to form a perception of a single rectangle – and the recognition of this as a bar of soap. It turns out that bottom-up processes cannot accomplish this without the help of some prior knowledge in the system; knowledge about distinguishing objects from their background, and about what soap bars look like (*top-down processes)*. This knowledge, in the form of expectations and tentative hypotheses, is needed to steer the integration process in the right direction – if it were not available,

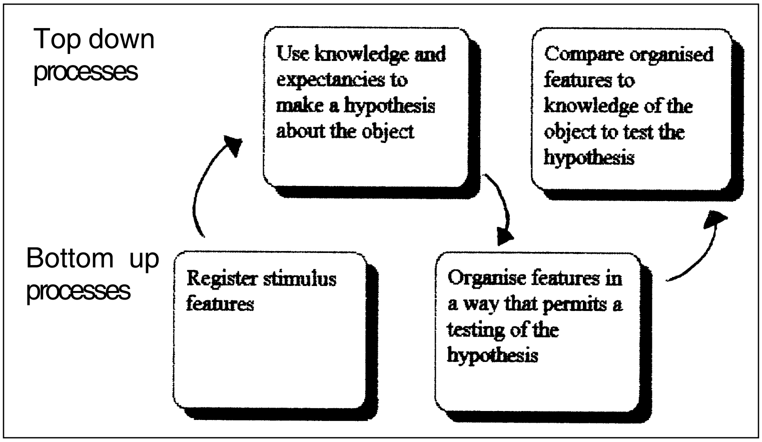

Figure 1. Perception as the interplay between bottom-up and top-down processes.

what would stop us from associating the edges of the soap with the soap dish, instead of with each other? Thus perception is currently understood as being an interplay between bottom-up and top-down processes (see *Figure 1*) – and this intricate interplay has proved impossible to simulate on a computer!

Anne Treisman's work has focussed on these two tasks of *feature-detection* and *feature-integration* in the very early stages of processing. She hypothesised that feature-detection operates on the whole stimulus array simultaneously, involving parallel processing; and that feature-integration operates in a serial fashion, on one part of the stimulus array location at a time. To set up an experiment to test this hypothesis, the reasoning she used was as follows. In a stimulus array consisting of identical simple elements (see *Figure 2*), it will be easy to spot an element that contains a different primitive feature[1] than the surrounding ones (parallel processing involved). However, if the single element differs from the others only in its *combination* of the *same primitive features*, it will be more difficult to spot (feature-integration is needed which involves serial processing). What do we mean by 'easy' or 'difficult' to spot? Obviously, if one looks for it, the different element is detectable in both stimulus arrays. But it 'pops out' in *Figure 2a*, whereas a slightly more effortful search is needed to find it in *Figure 2b*. This amounts to a difference in detection time of only milliseconds, but there are sophisticated machines that can measure reaction times in

[1] Examples of primitive features, in the context of psychological perception, are the slant, curvature or colour of individual lines.

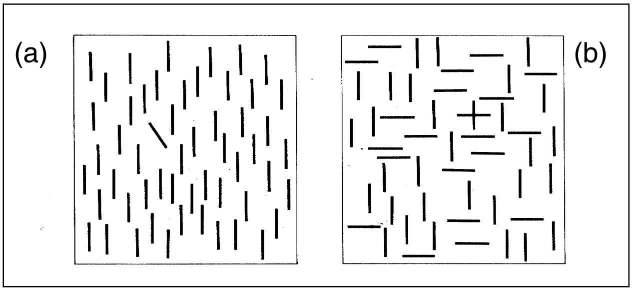

Figure 2. Two stimulus arrays of identical, simple elements.

milliseconds. So it would have been possible for Treisman to generate several such stimuli, measure the time it takes for people[2] to detect the different feature in each stimulus array, apply the necessary statistical analyses to the data, and determine whether there was significant detection speed difference in the two array types. Would this have supported her hypothesis?

[2] Who are the subjects of study in psychological research? It varies depending on the research questions, of course, but in the two examples presented here, the subjects are usually university students in the West. There are a few instances of this kind of research with other populations (children, lay people etc.) but these are less common.

Not completely, since a significant speed difference would indicate merely that one array was easier to search than the other, without telling us *why* it was easier. Maybe *Figure 2a* is easier because it has fewer total features to detect. Even if both feature-detection and feature-integration were serial processes, *Figure 2a* would be faster because there are less features to detect! What would you add to this experiment to pinpoint the reason for the speed difference? Here's what Treisman did – she varied the *number of distractors* (identical elements, i.e., the '|' in the first array or the '|' and '_' in the second) in the stimulus array for both types. If a stimulus array has to be processed serially, one spatial location at a time, response time will increase as the number of distractors increases. If, on the other hand, the array is being processed in parallel fashion, the number of distractors will have no effect on response time. Thus Treisman created arrays similar to those shown in *Figure 2*, but with varying numbers of distractors, instructing individuals to locate, as fast as possible, the one element that differed from the others in the array. Results indeed showed that the time to detect the element in arrays of the type in *Figure 2b* increased in direct proportion to the number of distractors, whereas for arrays of the type in *Figure 2a*, response time was constant *regardless* of the number of distractors present! The

Box 1

What kind of evidence might 'falsify' Treisman's theory of parallel and serial processes in early vision? The idea that one process is parallel and the other serial, implies some sort of structural difference in the ways feature detection and integration are accomplished in the brain. Here is a finding that places this idea on very shaky ground – research has shown that *extensive* practice on detecting the dissimilar item in arrays like *Figure 2b*, can flatten the relationship between number-of-distractors and time-to-detect! That is, the time to detect the item becomes a constant regardless of the number of distractors, just as in arrays like *Figure 2a*. How can practise or experience 'convert' a serial process to a parallel process? With as yet no clear explanation of how this can happen, current thinking has moved away from the position of 'parallel vs serial' process. Recent research in shape perception using experimental methods very similar to Treisman's original work, indicates that instead of a sharp dichotomy between parallel and serial processes, it is more useful to describe an 'ordering' of detectability from very quick to more effortful, trying to define a psychological continuum that corresponds to a physical dimension. This type of research brings together work in psychophysics, computer vision, and cognitive psychology.

experiment thus provided evidence in favour of her hypothesis that feature detection is a parallel process and feature integration is a serial process.

Reasoning

Much further beyond sensation and perception in the cognitive process, are the phenomena of 'higher' mental processes – memory, comprehension, reasoning, problem solving, etc. The second example of research that I have chosen is from the area of logical reasoning, or propositional reasoning. Instead of describing a single experiment, I've chosen to describe two competing theories of reasoning and just briefly outline the kind of research you will find here. I'll start with some definitions.

A common instance of *propositional reasoning* is the syllogism, which consists of three propositions: two premises and a conclusion. For example,

All p are q	(premise)
p	(premise)
Therefore q	(determinate conclusion)

Or,

All p are q	(premise)
not p	(premise)
Therefore may or may not be q	(indeterminate conclusion)

(You could also generate conclusions when the second premise is 'q', and when it is 'not q'.) We have all reasoned in this way in everyday life, as for instance when we hear,

"If it rains tomorrow, we will not go to the zoo".

If tomorrow is sunny, it does not necessarily follow that we will go to the zoo. And if we went to the zoo, it definitely was not raining! And so on (see *Box 2* for other types of syllogisms).

When presented with syllogisms, in either abstract or concrete terms, people[2] tend to make certain predictable errors in reasoning, called logical fallacies. For decades, psychologists have been interested in the question of how human beings engage in deductive reasoning, and particularly in the source of our errors in reasoning. The dominant theory for years has been that the brain is equipped with formal rules of inference, which we use to reason deductively. Piaget, a famous psychologist of this century, once said "Reasoning is nothing more than the propositional calculus itself"! Several slightly different models have been put forth within this theme –they are all called 'rule theories'. These theories assume that there are two aspects in reasoning: context–free syntactic rules (as in formal logic), and the systematic mapping of statements in natural language onto the syntactic rules. So, errors in reasoning are assumed to arise from errors in the mapping process, or perhaps the lack of a certain formal rule in one's repertoire.

"Contrariwise", continued Tweedledee, "If it was so, it might be; and if it were so, it would be; but as it isn't, it ain't. That's logic."
Lewis Carrol

Rule theories were able to explain some but not all of the empirical data. There are still some psychologists who prefer to make modifications to an existing rule theory to account for all the data! But since the 1980s, a new, non-rule-based theory of propositional reasoning has gained acceptance among many cognitive researchers. It is called the 'mental model' theory. It suggests that our deductive ability is based not on *syntactic*

Box 2. Further Examples of Syllogistic Reasoning

(It may help to use Venn diagrams to understand some syllogisms).

1. All p are q.
   Some p are r.
   Therefore, some q are r.
   Or, therefore some r are q.

2. p or q but not both.
   Not p.
   Therefore, q.

When we substitute concrete terms in place of abstract symbols like p and q, very interesting things happen! For instance:

1. All musicians are humans.
   Some musicians are men.
   Therefore, some men are humans.

2. I am at home, or I am outside, but not both.
   I am not at home.
   Therefore, I am outside.

The conclusion in the first case sounds a little strange – even though it is a perfectly logically valid statement given the premises. And in the second case, you may have felt that you could reach the conclusion without using logical reasoning, since it is just 'common sense'. In these situations, psychologists have found that reasoners use general knowledge, believability and specific experiences in addition to (or sometimes instead of) logical reasoning. These phenomena have been studied to some depth, especially over the last 10 years, with interesting results (see Suggested Reading for references).

procedures and *formal rules*, but on *semantic* procedures and *mental models*. To give you a bare-bones description of the theory – reasoning involves the construction of internal representations[3] , which are mental analogues of the situation described in the premises. Next, we search for a conclusion that is consistent with the representations. Finally, we search for counterexamples, i.e., alternative models of the premises which would make this conclusion invalid. If none are found, we judge the conclusion to be logically valid.

How do we construct this mental model? We use our understanding of the *meanings* of such terms as *and, if, or, not*. It is

[3] The nature of internal representations is itself a huge area of research! How is information represented in the brain – as analogues of visual images, or propositions, or both? There is some evidence that verbal, visual-spatial and conceptual information may be represented in different ways and even in different areas of the brain. We are a long way from knowing the exact nature of mental representations! If you are interested in reading about landmark research in the area, see the first two references in the list of suggested readings.

in these crucial terms that the meaning of the entire proposition lies, and according to the theory, a semantic analysis of these terms is sufficient to build the necessary representations. What do these models look like? For the purpose of explaining logical reasoning, the mental model theory is not concerned with the *subjective experience* of the model in the brain. It may be in the form of a visual analogue, or propositional, it doesn't matter. In formulating their theory, the researchers have used symbols such as follows:

If p then q. This can be represented by the following models

p q (represents p and q)
~p q (represents not-p and q)
~p ~q (respresents not-p and not-q)

Thus if the second premise is 'not p', we conclude 'may or may not be q'; if the second premise is 'not q' we conclude 'not p', and so on.

In the mental model theory, errors may be made when a person does not completely understand the meaning of the term *if* in the proposition, so that some models are left out or incorrect ones built. Errors also occur when the propositions are complicated enough to require several models to be built. This puts a strain on short term memory resources, making errors more likely. Experiments have been designed that predict different patterns of errors under the rule theory and the mental model theory – so far, these experiments have yielded results supporting the latter.

The beauty of the mental model theory is that it is essentially a description of normal comprehension processes. The mental model construct had been introduced in the 1970s, to explain general comprehension phenomena, problem solving, spatial reasoning and quantitative reasoning in cognitive psychology. If the same theory can explain the data in deductive reasoning, there is no need to assume the separate existence of inferential rules in our brains!

So, how well has the mental model theory done in explaining data? It accounts for all the phenomena so far explained by rule theories. But, as mentioned earlier, it accounts for several empirical facts about normal human reasoning that rule theories *cannot* explain. For instance, it has been shown that we use the *meanings* of premises to make deductions, such that we rarely make conclusions that contain less semantic information than the premises; we seek conclusions that are more parsimonious than the premises; we draw conclusions that make explicit some information merely implied in the premises. Here are some examples:

When asked what follows *logically* from: "Pig A went to market and Pig B stayed at home", we do not conclude: "Pig A went to market". And when asked what follows logically from: "Pig C had roast beef. Pig D had none", we do not conclude "Pig C had roast beef and Pig D had none". Note that the conclusions do follow logically, but we don't spontaneously draw them. Instead, we conclude things like "Pig B did not go to market", or "Pig A and Pig B are not in the same place".

One of the more interesting phenomena in this field is the effect of believability on logical reasoning. We know that people perform better on syllogisms when they are placed in a familiar context. It is a common error to conclude "not q", following the premises "If p then q; not p". But when asked what follows logically from "If it is a human being then it is a mammal; it is not a human being", people rarely conclude, "It is not a mammal". The fact that there is this difference between syllogisms in abstract and concrete forms is difficult to explain from a rule theory. But does it constitute evidence for a mental model theory? One can argue that in this case, people completely side-step logic and use only specific experience or general knowledge. New ideas have come up to help explain this kind of phenomenon, including the possibility that different people tend to use different strategies at different times (aargh!)... in which case the task ahead consists of figuring out the conditions under which people use various strategies to reason. I hope these two forays into cognitive psychology have been interesting to you, and that I have been able to convey a sense of the research process through them. Here's a quote I found recently – you can look at it as being optimistic *or* pessimistic about the future of psychology, whatever you wish!

"*If the human mind was simple enough to understand, we'd be too simple to understand it*" – Emerson Pugh.

Suggested Reading

[1] L A Cooper and R N Shepard. Turning something over in the mind. *Scientific American*, December, 1984.

[2] R A Finke. *Principles of Mental Imagery*. Cambridge. MA. MIT Press, 1989.

[3] P N Johnson-Laird. *Mental Models: Towards a Cognitive Science of Language, Inference and Consciousness*. Cambridge. MA. Harvard University Press, 1983.

[4] P N Johnson-Laird and R Byrne. *Deduction*. Hove. UK. Lawrence Erlbaum, 1991.

[5] A Treisman. Features and objects in visual processing. *Scientific American*. November, 1996.

[6] A Treisman and S Gormican. Feature analysis in early vision: Evidence from search asymmetries. *Psychological Review*. 95.15–48, 1988.

[7] In addition, you may be interested in reading articles from the following American Psychological Association journals:
Journal of Experimental Psychology. Human Perception and Performance
Journal of Experimental Psychology. Learning, Memory and Cognition.

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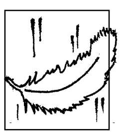

Physical science and philosophy stand side by side, and one upholds the other. Without something of the strength of physics philosophy would be weak; and without something of philosophy's wealth physical science would be poor.

D'Arcy Wentworth Thompson