Information and Information Processing

Nick Chater

PhD

University of Edinburgh

1989

Declaration

I declare that this thesis has been composed by myself and that the research reported therein has been conducted by myself unless otherwise indicated.

Nick Chater

Edinburgh, 1 July 198

Acknowledgments

First, I must thank my supervisors Terry Myers, Robin Cooper and David Willshaw, who have allowed me the freedom to pursue all sorts of diverse paths, without losing faith that something coherent would come out in the end. I thank them also for the willingness with which they have given me their time and help throughout the last three years. I should also like to thank my examiners Greg Jones and Chris Thornton.

This research has been influenced profoundly by discussion and collaboration with my collegues and friends Jerry Seligman, Mike Oaksford & Mike Malloch. Discussion of situation semantics and Dretske with Jerry, and the joint writing of two extended papers on related issues has been of inestimable benefit to me. Jerry's penetrating insight and clarity of thought has been a wonder and an inspiration. Mike Oaksford realised long before I did the relationship between information-based semantics and non-symbolic computation, and has been a constant sources of ideas, discussion and enthusiasm. Mike Malloch has also had a profound influence on my thinking - especially in demolishing my naive intuitions that easy answers are available to difficult questions.

I owe a great debt to Karen Lyon for her friendship, encouragement and support. Without her I doubt if the thesis would have been completed on time. I should also like to thank James Tresilian, whose sharp ideas and deep knowledge have benefitted me inestimably, and whose enthusiasm has done much to keep me working. I also owe a lot to Mark Hepple, who has taught me all sorts of things without even trying (such as how to be skeptical and enthusiastic at the same time) and whose crisp thinking has been has set me an example to which I can only aspire.

I have also benefited from discussing my ideas in the StaGr workshop, the Mental Lexicon workshop and the PDP workshop at the Centre for Cognitive Science. The environment in Edinburgh has been ideal for pursuing this research - I thank everyone at the Centre for making this such a happy and fruitful place to work.

Finally, I should like to thank my parents, for always trusting that things would work out in the end, despite all kinds of uncertainty and changes of direction, and for their constant support, encouragement and love.

This research was supported by an ESRC Postgraduate Studentship (no. C00428622023).

Abstract

Despite its name, "information processing" psychology has become gradually divorced from the mathematical theory of information. However, Dretske (1981) has proposed that information theoretic ideas can be extended to generate notions of information content and semantic content which may be applied to the analysis of perceptual and cognitive activity, and which found a theory of propositional attitudes. In this thesis, I shall argue Dretske's account is only tenuously related to its supposed information-theoretic basis, and that a misunderstanding of the relationship between the two has generated a number of crucial flaws in Dretske's analysis. A revised account, formalised in terms of propositional logic, is presented. The revised analysis embodies the claim that informational properties cannot be ascribed absolutely, but are necessarily relative to the informational idealisation chosen. I argue that Dretske's failure to recognise "idealisation relativity" has serious ramifications for the application of informational ideas to information processing in general, and mental activity in particular. For example, by varying the informational idealisation adopted, the distinction between perception and cognition can be manipulated almost arbitrarily. Building on Dretske's analog-digital distinction, I propose that information processing may quite generally be seen as a matter of transforming information from unusable (inexplicit) form, to usable (explicit) form. Two important difficulties with applying informational ideas to the analysis of propositional attitudes - Misrepresentation and Detectability - are addressed.

Contents

Chapter 0: Introduction

0.1 Information and Psychology

It is perhaps ironic that the rise of information processing psychology since the 1960's has been concurrent with a decline in the interest in the use of methods from information theory in psychology. The pioneering work of Shannon and Weaver (1949), which promised to be a major theoretical tool of the cognitive approach (e.g. Attneave, 1959), has fallen out of fashion in the "information processing school". The application of information-theoretic measures to human performance spawned a wide variety of experimental investigations. In a typical experiments, subjects were asked to identify the position of a marker which might appear at one of a number of locations on a continuous scale. As expected, the greater the number of possible positions of the marker the harder identification became. Interestingly, according to Shannon and Weaver's measure, the amount of *information* carried by the subject's judgement was roughly constant at around 3.0 - 3.2 bits, however many positions the marker might take (Hake & Garner, 1951). In similar experiments, subjects were asked to identify each of a number of pure tones. Almost independently of the range of frequencies of the tones, or their relative spacing, it was found that subjects were able reliably identify each tone if the number of possible tones was 5 or below. This corresponds to a limit of about 2.2 bits of information (Pollack, 1952).

Information theory was also used to explain differences in the way in which meaningful and nonsense stimuli are processed and remembered. The crucial difference was identified not as meaningfulness *per se*, but as the amount of *redundancy* in the stimulus, again measured in bits of information. In a famous study of the effects of redundancy on memory for more or less sentence-like lists of words, Miller & Selfridge (1950) conclude that "The significant distinction is not to be drawn between meaning and nonsense but between materials that utilize previous learning and permit positive transfer and materials that do not. If the nonsense preserves the short range associations of the English language that are so familiar to us, the nonsense is easy to learn". Further work (Merlis & Jacks, 1952), using a slightly different recall procedure showed that meaningfulness of stimulus material, over and above redundancy does seem to be important. Nonetheless, it seemed impressive that the information-theoretic approach seemed able to make *any* contribution to the study of linguistic meaning. However, the way Miller & Selfridge describe their results highlights what came to be seen as the downfall of the application of information theory in psychology (Haber, 1974). Miller & Selfridge point out that what is crucial is not the redundancy of the signal *per se*, but the degree to which that redundancy fits with "previous learning" allowing "positive transfer". Processing appears not to be dependent purely on the informational properties of the stimulus, but on the degree to which the subject is familiar with, and has an understanding of, the relevant domain. For example, the processing of visually presented letters is very different for subjects familiar with the relevant script, rather than subjects who are not (and who appear to process the stimulus as a complex arrangement of lines are curves). These differences have been consistently demonstrated in the perception and reproduction of letter strings (Haber, 1974). Similarly, letter strings which constitute words of a language are processed very differently from strings which do not, provided that subjects are familiar with that language. It was considerations such as this that lead Miller (1956) to postulate the cognitively defined notion of a "chunk" (which might correspond to a letter, to a word, to a phrase), as an appropriate measure for the study of human information processing, rather than the information-theoretic "bit". The process of "chunking" came to be seen as a matter of the internal symbolic description that a subject imposed on the input. How the input is symbolically encoded is dependent on how the subject *understands* that input, on what is *known* about the relevant domain. Information-theoretic measures came to seem inappropriate since they did not seem to be able to take into account the role of such knowledge (Laming, 1973; Haber, 1974). Haber puts the point succinctly.

> "In retrospect, we can now see that the failure [of information theory in psychology] was due to a specific problem in the definition of information... the [inability to capture the] relativization of the amount of information in a signal to what the recipient of that signal already knows about the signal and about the circumstances of its reception." (Haber, 1983:71)

Hence,

> "...while it was generally easy to calculate the amount of information in a stimulus or in a response, such calculations did not correlate with any interesting or relevant behaviour of real perceivers, rememberers or thinkers." (Haber, 1983:71)

Rational reconstruction of the science is invariably speculative, but it is tempting to draw out two additional theoretical reasons for the waning of enthusiasm among psychologists for talk of information channels, bits per second, equivocal signals and so on.

Firstly, information theory provides a quantitative rather than a qualitative analysis of information bearing signals. It can measure *how much* information is carried by, for example, the thermostat being on (given some idealisation of the states and associated probabilities involved), but gives no account of *what* information it conveys - perhaps that the room temperature is below 20 °. Yet modern psychological theorizing is paradigmatically concerned with mental *representation.* The theorist is primarily interested in *content*, and this is just what appears to be beyond the scope of information theoretic tools. Only in ecological psychology has informal talk of information in something like an information theoretic sense remained (and even here the relationship between the Gibsonian and information theoretic notions is a matter of debate (Neisser, 1977; Hamlyn, 1977)). Yet ecological psychologists have vociferously *opposed* the information processing approach and questioned the necessity of postulating mental representations (Gibson, 1979). For the mainstream cognitive psychologist, theorizing in terms of contentful mental representations and computational processes operating over them, information theoretic tools have little to offer.

A second reason for the downturn in psychological interest in information theoretic notions is surely that there appeared to be an alternative and more powerful notion of content which *does* provide an account of the content of informational signals. In logic, computer science, and even in natural language semantics the tools of model theoretic denotational semantics appeared to provide an admirably rigorous and precise account of the meaning of complex symbolic structures. More generally, it seemed that appeal to content of mental representations need no longer be considered unscientific. If talk of meaning is legitimate in computer science, then surely it is legitimate in psychology. Such reasoning is particularly persuasive since digital computers are often taken to be the paradigm example of information processing. After all, the age of information processing psychology is also the age of the computer metaphor. If computer science is able to ignore information theory, then it is natural to suppose that psychology may be able to do the same.

With the advent of the 1980's the notion of information has, however, had something of a renaissance. There has been a growing dissatisfaction with the dominant paradigm in the study of cognition. Firstly, standard semantic methods are only applicable to symbolic computation, whereas cognitive modeling has shifted focus to non-symbolic, and particularly Connectionist, styles of computation. It may be that a very large part of human mental activity should be viewed as non-symbolic rather than symbolic computation. Hence a semantics which applies only to the latter may be unexpectedly limited in scope, from the point of view of psychology. Secondly, traditional model theoretic semantics is not readily taken to wholly license talk of the content of mental representations. Advocates of the standard paradigm have pointed out that although model theoretic semantics may give an account of the compositional structure of a system representation, it is silent about the interpretation of the non-logical base terms of that system. It has been proposed that a standard semantical account might be supplemented with an information based account of meaning of such terms (Stampe 1977, Fodor, 1984,1989). More radically, the standard model theoretic account has itself been criticized as an appropriate tool for studying the meaning of natural language utterances (or, equally, any postulated system of internal representation) (Barwise & Perry, 1983). The proposed alternative is to develop an information based account of semantics. It may be hoped that a sufficiently broad semantical account, which is not tied to symbolic structures, might be appropriate for the analysis of non-symbolic computation.

Dretske (1981) provides a thorough and detailed account of the theoretical underpinnings of information based theory of content, and applies it to a wide range of psychological issues - from the distinction between perception and cognition, to concepts, knowledge and belief. Yet the account of content that he provides is inspired by the quantitative, content-independent notions of Shannon and Weaver's information theory. Dretske is thus proposing that the ideas of information theory may, after all, prove central to the development of psychological theory.

In this thesis I shall examine both Dretske's account and some of the key applications to which it is put, in detail. The informational notions that Dretske introduces are found to require significant modification, and the resulting account is cast formally in terms of propositional logic. Also Dretske's specific applications are found to be problematic, and an alternative conception of how informational notions relate to psychology is proposed. Nonetheless, I shall argue that Dretske's ideas may indeed be relevant to the project of developing a notion of meaning appropriate to psychological theory. Unfortunately, when the essence of Dretske's account is uncovered, the notions of Shannon and Weaver's information theory have little role to play.

0.2 Information and Representation

Information Theory gives a measure of the amount of information associated with a state of affairs, and the amount of information that may be transmitted between states of affairs. It gives no account of information *content.* That is, although the theory gives a measure of how much information is generated by some state of affairs, or carried between states of affairs, it gives no account of *what* that information is.

Oversimplifying a little, the amount of information generated by the occurence of some state of affairs is a measure of the number of possibilities reduced in virtue of the occurence of that state of affairs. For example, under natural informational idealisations, the casting of a die generates more information than the toss of a coin. A throw of a die reduces six possible states of affairs (that the die shows 1, 2, 3, 4, 5 or 6 uppermost) to one. A toss of a coin merely reduces two possible states of affairs (heads or tails) to one. Suppose that an observer shouts "Hurrah!" just when the coin lands heads, and "Oh no!" just when the coin lands tails. Then some particular shout (say, of "Hurrah!") also reduces two possible states of affairs (two possible shouts) to one. Hence it generates the same amount of information as the tossing of the coin. However, the information generated is not *new* information, since the way that the coin falls determines the particular shout the observer makes That is, once the possible states of the coin are reduced the possible shouts are too. The shout may be treated not as generating new information but as *carrying* information generated by the coin This is an instance of information *flow* between the state of affairs at the coin and the state of affairs at the shout (we might equally well trace the flow of information between the state of the coin and the precise forces exerted as the coin is thrown, or the instaneous dynamics of the arm of the thrower, and so on). The direction of information flow need not follow the direction of causality. Just as the way that the coin falls determines the shout made, the shout that is made determines the way that the coin falls. Information can be viewed as flowing in either direction, depending on what is viewed as known and what is viewed as unknown.

Although there is no notion of information content within Information Theory itself, many theorists in psychology, both within the mainstream cognitive tradition (Marr, 1982) and ecological psychology (Gibson, 1979), have informally used a notion of information content. In the psychology of vision, it is important to characterize the particular information that is carried about the structure of the visual scene by the structure of the optic array. If an organism is approaching an object, the time to contact is specified by the rate of expansion of the optic array. A theory of perception must capture not only that the value of expansion of the optic array carries some *amount* of information about the time-to-contact, but that an expansion of such and such carries the information that time-to-contact is so and so. Similarly, information about the relative distances of objects is carried by the magnitudes of disparities between the images on each retina, the speed of optic flow as the eye moves through space, and so on. Taking an example from the psychology of hearing, the relative timing of auditory input at each ear carries information about the direction from which the sound originates. Psychology is concerned primarily with the *content* of information signals, and not with measuring *how much* information they carried. Dretske (1981) quotes Gibson on the use of information in ecological psychology:

> "Let us begin by noting that *information about* something means only *specificity to* something. Hence, when we say that information is conveyed by light, or by sound, odor, or mechanical energy, we do not mean that the source is literally conveyed as a copy or replica. The sound of a bell is not the bell and the odor of cheese is not the cheese. Similarly the perspective projection of the faces of an object (by the reverberating flux of reflected light in a medium) is not the object itself. Nevertheless, in all these cases a property of the stimulus is univocally related to a property of the object by virtue of physical laws. This is what I mean by the conveying of environmental information." (Gibson, 1966)

Putting the matter in rather unecological terms, the basic intuition that underlies the informal notion of information used in psychology is that a signal carries the information that P just when it is possible to *learn* that P from that signal. The hat on the hatstand carries the information that Fred is at home because it is possible to learn that Fred is at home from the hat's being on the hatstand. A footprint in the flowerbed carries the information that the murderer escaped through the window, because it is possible to learn that the murderer escaped through the window from the presence of the footprint. No one may realize that the murderer's escape must have been through the window, even though they notice the footprint. The detective may pay little attention to the footprint since the gardener often walks in that flowerbed. Yet if the gardener has actually been concentrating on the rhododendrons for the last two weeks, then the presence of the footprint may carry the information that the murderer left through the window nonetheless. From the point of view of what information is carried, what is important is that it is *possible* to learn how the murderer escaped, even if no one *actually* learned this.

On this informal notion of information, the optic expansion's being such and such carries the information that time-to-contact is so and so because it is possible to learn that time to contact is so and so second from the fact that the optic expansion is such and such. Similarly, given that the disparities in the two retinal images are such and such, it may be possible to learn that object A must be twice as far away as object B. Or again, if the sound of the clap arrived simultaneously at each ear, it is possible to learn that it must have originated from a point on the plane normal to the axis of the two ears.

An important aspect of this informal notion of information is that it is *factive*. That is, if a state of affairs carries the information that P, then P must be the case. On this construal of information, misinformation is not a species of information. The factive character of our informal notion of information is derivative on the factive character of learning. That the hat is on the hatstand carries the information that Fred is at home if it is possible to *learn* that Fred is at home from the fact that the hat is on the hatstand. Yet a proposition can only be learned if it is the case. For example, I cannot *learn* that it is midnight by looking at my stopped watch if it is actually early afternoon. If it is possible to *learn* that Fred is at home, Fred must *be* at home. So, in general, for a proposition P to be carried by a signal (for P to be learnable), P must be true. However, while the truth of P is a necessary condition for information to be carried, it is not, of course, sufficient.

Suppose that Fred lost his hat yesterday, but that his cousin Eric is visiting, and has left *his* hat on the hatstand. Then the hat's being on the hatstand does not carry the information that Fred is at home, even if it happens that Fred *is* in. The fact that Fred is at home cannot be *learned* from the hat's being on the hatstand, there is no lawful relation between Fred's hat being on the hatstand and his being at home. Similarly, I cannot *learn* that it is midnight from looking at my stopped watch, even if, by coincidence, it *is* midnight. There must be some lawful dependency between the information carrier and the information carried. Since this is an informal, intuitive notion of information, an elucidation of the nature of this dependency is absent.

How does this informal notion of information content relate to the quantitative account given by Information Theory? Dretske (1981) reconstructs the intuitive notion using Information Theoretic tools. A large part of the discussion in the first part of this thesis focuses on the adequacy of his account. Certain modifications to and simplifications of the Dretskian approach are suggested.

What is the relationship between the notion of information content and the traditional notion of representation? There appear to be a number of significant differences: 1. there may be information without representation; 2. there may be representation without information; 3. a state of affairs may carry many pieces of information, whereas a representational content is unique.

1. The fact that a lake is covered with ice may carry the information that the temperature is below freezing. *Prima facie*, the state of the lake does not *represent* the temperature as being -20 °. A sneeze may carry the information that Eric has a cold, but it does not represent Eric as having a cold. Information can be carried without being represented.

2. By the facticity of information, an utterance of "The earth is at the centre of the universe" cannot carry the information that the earth is at the centre of the universe given the facticity of information, since the earth is not at the centre of the universe. Yet the utterance does *mean* that the earth is at the centre of the universe, nonetheless; the earth is *represented* as being at the centre of the universe; the proposition that the earth is at the centre of the universe is *expressed*. The proposition that an utterance expresses can be true

or false, whereas information is always veridical. Misinformation is not a species of information, but misrepresentation *is* a species of representation.

3. A state of affairs may carry very many different pieces of information, whereas, say, an utterance expresses only one proposition. A particular utterance of "The earth is at the centre of the universe" might carry information about the state of mental health, sex, mood, country of origin of the speaker and so on. However, it has only one content: that the earth is at the centre of the universe.

So information content and representation are *prima facie* very different. However, Dretske (1981) nonetheless attempts to provide an account of representation (within a limited domain) in informational terms. He defines what it is for a state of affairs to carry a piece of information in *digital* form, and then what it is for a state of affairs to carry a piece of information in *completely digital* form. For Dretske's analysis, a given state of affairs can carry only one piece of information in completely digital form. This piece of information is identified with semantic or representational content. Although there are many difficulties for a Dretskian account, I shall argue that, despite appearances, an informational analysis of representation may be appropriate for psychology and computer science.

0.3 An Introduction to Information Theory

Dretske (1981) attempts to explicate the notions of content, cognition, belief and concepts by extending the Communication Theory or Information Theory of Shannon and Weaver (Shannon, 1949). Let us first introduce the elements of this theory.

Information as reduction of uncertainty

Information theory treats the amount of information associated with some event with the reduction of relevant possible states of affairs, given that event. Suppose that the relevant states of affairs are the heads/tails orientation of three coins, after they are flipped. Assuming that the coins are unbiased, there are eight equally likely possible outcomes: HHH, HHT, HTH, HTT, THH, THT, TTH, TTT. If one coin is flipped and falls 'heads', then the number of possible outcomes is reduces to four - the remaining two coins may still be either heads or tails: HHH, HHT, HTH, HTT. Hence, uncertainty about the states of the coins has been reduced by the first coin's falling heads. The set of possibilities has been reduced from 8 to 4. The second coin is then flipped and falls 'tails'. Now there are only two possible outcomes remaining - HTH, HTT. After the third coin has fallen 'tails' there is only one possibility remaining: HTT. There is nolonger any uncertainty about the heads/tails states of the three coins. The amount of information that a state of affairs carries is supposed to measure the extent to which uncertainty is reduced, or the extent to which possibilities are eliminated. Since the flipping of each coin reduced the number of possible outcomes, we wish to associate some amount of information with each such event.

What is an appropriate measure to be associated with each event? The first flip reduces the number of possibilities from 8 to 4, the second flip reduced the number from 4 to 2, and the third from 2 to 1. It might seem natural to make the number of possibilities eliminated the measure of information. Yet, this makes the amount of information associated with a flip depend radically on the order in which we consider the flips. If the flipping of one coin is considered first, then it has information value 4, if it is considered last it has just 1. Further, if we increased the number of coins, then we should have further information values associated with a simple coin flip (in fact, 2 to any power would be a possible value). Yet, there is something in common between all the flips that we have considered so far. In each case, the number of possibilities is halved. So a better measure of the amount of information associated with an event would seem to be the proportion of possibilities reduced associated with an event. In accordance with this intuition, a coin flip might be assigned the value 0.5, whatever the order in which the coins are considered. This measure of the information associated with a state of affairs is independent of the order in which the coin flips are considered, and independent of the total number of coins. However, this measure is not quite what we require.

Suppose that we consider the flipping of two of the three coins. This reduces the number of possibly outcomes from 8 to 2. Hence, on our proportion measure, the amount of information associated is 0.25. Yet the flipping of the two coins is made up of two individual flips, each with information 0.5. On the present measure, two events of informational value 0.5 combine to produce a single event of informational value 0.25. The informational value assigned to *two* flips is *less* than that assigned to one. Yet intuitively, we should like our measure of information to be additive. The information associated with an event made up of two (independent) events should be the sum of the information associated with each individual event considered separately.

This condition is easy to enforce. On the present measure, the reduction of possibilities by a factor of $2 = 2^1$ (one flip) is associated $1/2^1$ units of information; reduction by a factor of $4 = 2^2$ (two flips) is associated with $1/2^2$ units; reduction by a factor of $8 = 2^3$ (3 flips) is associated with $1/2^3$ units; and so on. So let us take the *exponent* as our measure of information, rather than the fraction itself. Reduction by a factor of 2^n (n flips) is thus associated simply with n *bits* of information. So, reducing 8 equally likely possibilities to 1 requires 3 bits of information; reducing 4 equally likely possibilities to 1 requires 2 bits of information; reducing 2 equally likely possibilities to 1 requires 1 bit of information. The general rule is plain enough. Reducing n possibilities to 1 requires log n bits of information (here and henceforth all logarithms will be taken to be log base 2). This measure of information *is* additive. The information associated with n + m flips (n + m bits) is the sum of the information associated with n flips (n bits) and m flips (m bits). This measure is the essence of that proposed by Shannon and Weaver (1949). To outline the account more fully, we must introduce a definition.

A *source* is a specification of a set of mutually exclusive and exhaustive possibilities each with an associated probability. For a source S we shall denote its n possible states, $S_1,...S_i,...S_n$. Each state S_i has an associated probability $p(S_i)$.

The set of all possible head/tales states of three coins is the particular source we have been dealing with so far. The flipped coins must occupy exactly one of the states HHH, HHT, HTH, HTT, THH, THT, TTH, TTT (assuming that they cannot balance on edge). Hence, the states are indeed mutually exclusive and exhaustive. In the present case, the probability associated with each possibility is equal (0.125), since the coins are unbiased and fall independently. A particular state of the source (say that the coins are THH) is said to *generate* information (in this case 3 bits, since 8 equally likely possibilities have been reduced to 1). If we let $I(S_i)$ be the amount of information generated by a source which reduces n equally likely possible states of affairs to 1 (by being in state S_i, rather than in some other of the n states), the generalisation of the end of the last paragraph can be put as follows:

$$I(S_i) = \log n$$

(Dretske, 1981:7).

So far we have been dealing with sources in which each possible state is equally likely. Thus, if there are n states, they each have the probability 1/n. Notice that our formula above could have been written,

$$I(S_i) = \log (1/p(S_i))$$

where $p(S_i)$ is the probability of the source's being in the state S_i. This suggests how we may generalise to sources which have states which are not equally probable.

Suppose that a coin is biased, such that it falls heads 0.9 of the time. The flipping of such a coin should, in general, lead to less reduction in uncertainty, and hence to less information generated, than in the unbiased case. This is because the state of the coin is actually fairly predictable in any case - it is a pretty safe bet that it will be 'heads'. Thus there is less uncertainty to reduce, and less information generated. The formula

$$I(S_i) = \log (1/p(S_i))$$

can be applied to cases in which the states are not equally likely. $I(S_i)$ is the amount of information generated by a source's being in a particular state S_i. This is known as the *surprisal* of that state of the source S_i. If the state of a source has the probability 0.5, then the surprisal is 1 bit. If the state of the source is probable ($p > 0.5$ - heads in the present example), the surprisal is less than 1 bit; if the state is improbable ($p < 0.5$ - tails in the present example), the surprisal value is greater than 1 bit. Let us denote the average surprisal at a source S by I(S).

$$I(S) = \Sigma_i \, p(S_i).I(S_i)$$

The arithmetic works out to show that the amount of average information generated by a biased coin is less than that generated by an unbiased coin. When the biased coin comes up heads it generates less information than the unbiased coin; when it comes up tails it generates more information. Since it comes up heads much more often on average it generates less information than the unbiased coin, as expected.

We now have a fuller intuitive picture of what 'amount of information' measures. The amount of information associated with a *particular* state of affairs measures the reduction of uncertainty given the occurrence of that state; to what extent possibilities have been eliminated; the degree to which the occurrence of that state is surprising. The amount of information associated with a *source* measures the *average* amount of information associated with the states of that source; the degree to which the state of the source is unpredictable.

Information transmission

So far we have dealt merely with the generation of information at a source. Now we turn to the transmission of information. Let us consider three British gymnasts performing on the beam to a partisan British crowd. Suppose that each of them has a half chance of falling off during their routine. Suppose also that the crowd groans when and only when a gymnast crashes to the floor. For each routine there are two relevant states of the gymnast (fell off or stayed on), and two relevant states of the crowd (groaned or did not groan). Let us denote a gymnast's safely staying on the bar by S, and falling off by F. Let us denote the crowd's groaning by G, and the crowd's remaining happy by H. Both the state of the gymnast and the state of the crowd can be considered as sources of information. For the gymnasts, there are eight equally likely outcomes - SSS, SSF, SFS, SFF, FSS, FSF, FFS, FFF. Each of these outcomes has a surprisal of 3 bits. Similarly, for the crowd there are eight equally likely outcomes - HHH, HHG, HGH, HGG, GHH, GHG, GGH, GGG. Again the surprisal of each outcome is 3 bits. Hence, both *sources* generate 3 bits of information.

How much information is generated by the two sources considered together? A natural response is just to add together the information generated by each source. In this fashion we would say that the two sources considered together must carry 3 + 3 = 6 bits of information. However, the state of the crowd is precisely tied to whether or not the gymnast has come to grief. Hence, if we get SSF (safe, safe, fell), then we must get HHG (happy, happy, groan). So there are only 8, equally likely, possible states of the two sources considered together. Hence, both sources generate just 3 bits of information between them. How are we to explain the puzzle that the gymnasts generate 3 bits of information, and the crowd generates 3 bits of information, but that the two together still only generate 3 bits of information? Given the state of the gymnasts, the state of the crowd is wholly predictable. Hence, the state of the crowd carries no new information, given the state of the gymnasts. The state of the crowd can be said to *carry* information about the state of the gymnasts rather than generate any new information. An informational source which is viewed as carrying information about the state of some other informational source is called a *receiver*.

A receiver is a specification of a mutually exclusive and exhaustive set of possibilities, $R_1,...R_i,...R_n$, each associated with a probability $p(R_1),...p(R_i),...p(R_n)$. In addition, each state of the receiver is associated with a conditional probability for each state of the source. A *signal* is a particular state of the receiver R_i, which may carry more or less information about the state of the source depending on the probabilities involved.

Let us treat the state of the crowd as receiving information about the gymnasts. For each state of the crowd there must be an associated probability conditional on each state of the source. In this example, the probabilities are straightforward. Take some state of the crowd (say GGG). The conditional probability of that state given the corresponding state of the gymnasts (FFF) is 1; the conditional probability is 0 for all other states of the gymnasts. Of course, in a more realistic idealisation of the scenario, the specification of the probabilities would be more complicated since the probabilities would be between 0 and 1. For example, the crowd might groan at disasters other than falling off the bar, and might not groan if the falling off were done with such grace and aplomb as to appear to be part of the routine.

How much new information is generated by the crowd - that is, how much information is not merely transmitted from the state of the gymnasts? Or again, how uncertain is the state of the crowd given the state of the gymnasts? Suppose that the gymnasts are in the state S3 (say SFS). Then we calculate the information generated at the receiver just as before, except that instead of using the absolute probability values, we use the probabilities conditional on S3. The amount of new information generated is known as noise, and denoted N(S3).

$$N(S3) = \Sigma_i\ p(R_i/S3).I(R_i/S3), \text{ where}$$

$$I(R_i/S3) = \log 1/p(R_i/S3)$$

The average noise N is simply:

$$N = \Sigma_i \, p(S_i) \, N(S_i)$$

Noise is a measure of the amount of information generated at the receiver which is new information, relative to the source. Suppose that the crowd was characterised as having four instantaneous possible states instead of two at any time instant. These might be happy and eating popcorn (H+P); happy and not eating popcorn (H-P); groaning and eating popcorn (G+P); groaning and not eating popcorn (G-P). Suppose that whether or not the crowd is eating popcorn is dependent solely on the presence of the popcorn sellers in the aisles. The popcorn sellers are randomly present for exactly half the routines, and their presence is, of course, quite unrelated to whether or not the British gymnasts are on or off the floor. Consider a particular routine of a British gymnast. Previously, the gymnast's performance generated one bit of information, and the crowd's reaction generated one bit of information. And, given the gymnast's performance, the state of the crowd was determinate - thus there was no noise (this may be verified using the formulae above). Now, however, the crowd is viewed as having four equally likely states. So the state of the crowd generates 2 bits of information. Some of this information must, therefore, be new. In fact, exactly 1 bit is noise, and 1 bit is old information, transmitted from the source. Intuitively, this is because, given the state of the gymnast (say, on the floor), there are just two possible states of the crowd (groaning and eating popcorn, or just groaning). This reduction of four equally probable states to two equally probable states amounts to the transmission of 1 bit of information from the state of the gymnast (the source) to the state of the crowd (the receiver). A specification of the state of the crowd which resolves the issue one way or the other generates the remaining 1 bit of new information (noise). Following Dretske (1981:19) let us call the amount of information generated at the receiver, R, transmitted from the source, S, $I_s(R)$. This is the *overlap* of the information associated with the source and the receiver, and hence the amount of information that the receiver carries about the source, $I_s(R)$, is the same as the amount of information that the source carries about the receiver, $I_r(S)$. The same amount of information flows between informational sources in each direction. The total information generated at the receiver (I(R)), the amount of information carried about the source $I_s(R)$, and the noise (N(R)) may be related as follows:

$$I(R) = I_s(R) + N(R)$$

That is, the amount of information generated at the receiver is the sum of the amount transmitted from the source to the receiver (Is(R)) and the noise (N(R)).

Just as not all the information generated at the receiver need be transmitted from the source, not all the information generated at the source need be transmitted to the receiver. The quantity of information that is not transmitted is known as the *equivocation*. Just as noise is a measure of the uncertainty of the state of the receiver given the state of the source, the equivocation E(S) is a measure of the uncertainty of the state of the source given the state of the receiver. So far our examples have all been of equivocation free information transmission - the whether or not the gymnasts fell off or not was completely determinate given the state of the crowd. However, suppose that we consider the state of the gymnasts to include the colour of their strip - at random they choose red, white and blue (-L); or leopard skin (+L). There are now four equally probable states each gymnast S+L, S-L, F+L, F-L. The groaning and pop corn eating behaviour of the crowd can only determine that a gymnast has fallen off - there are still two equally likely possible cases - say F+L and F-L. (Of course, we are assuming, perhaps implausibly, that the strip worn has no effect on the likelihood of calamity). Hence, there is 1 bit of equivocation. The mathematics is completely analogous to that for noise. In particular,

$$I(S) = I_r(S) + E(S)$$

That is, the amount of information generated at the source is the sum of the amount transmitted from the source to the receiver ($I_r(S)$), and the equivocation (E(S)).

Notice that, in the examples so far, whether or not information transmission is noisy or equivocal is dependent on the way we characterise the system. In particular, it is relative to the specification of the source (the state of the gymnast). In one case, the state of the gymnast is characterised only by whether or not the routine is completed without mishap (no equivocation), in the other we take in to account the colour of the strip worn (equivocation). Further, informational properties are relative to the specification of the receiver (the state of the crowd). In one case the crowd is either happy or groans (no noise), in the other we also took in to account popcorn eating (noise). Such specifications may appear arbitrary - and indeed there is no constraint that the characterisation make intuitive sense. For a source (or a receiver) is just any set of mutually exclusive and exhaustive states.

How much information is carried by some state of affairs, whether information transmission is equivocal or noisy, and so on, is dependent on what the states of the source and receiver are taken to be, and the values of the associated absolute and conditional probabilities. Informational properties quite generally are relative to the *informational idealisation* of a situation. We shall see, however, that in a variety of applications of information theory to the problems of representation and content it is easy to lose sight of this fundamental relativity. The fact that such relativity to the specification of source and receiver is built in to information theory at its very foundation will have far reaching consequences for the development of an information-based account of content.

So far our examples have been extremely idealised. For example, the crowd is supposed to groan when and only when a British gymnast falls off the bar. However, more realistically the crowd might groan only, say, 90% of the time; perhaps their attention is sometimes distracted by the some other event; further, there might be other reasons for groaning - perhaps 20% of groans are caused by the scoreboard showing the marks of British competitors in other disciplines. In this case, the information transmission between gymnast and crowd is both equivocal and noisy. It is equivocal because the state of the crowd does not fully determine the state of the British gymnast. If the crowd groans, a British gymnast has probably come to grief - but perhaps the scoreboard has just been updated. If the crowd does not groan, then the British gymnast has probably successfully negotiated the routine - but it is possible that the Russian on the floor exercise so captured the crowd's attention that the fall passed unnoticed. The information transmission is noisy since the state of the crowd is not fully determined by the state of the gymnast. If the gymnast falls off then the crowd will probably groan, but not if their attention has been distracted; if the gymnast does not fall off then they may groan anyway, when the scoreboard is updated.

Within information theory we have no account of *what* information is carried by a signal. Dretske (1981) attempts to augment the theory with an appropriate notion of information content, which accords with our pretheoretic intuitions. As we shall see, Dretske's account is only loosely related to ideas from information theory. It is to this account that we turn in Chapter 1.

Chapter 1: Information Content

1.1 Dretske on Information Content

Dretske provides the following definition of information content:

> "*Information content*: A signal r carries the information that s is F = The conditional probability of s's being F, given r (and k), is 1 (but given k alone, less than 1)" (Dretske, 1981:65)

where k stands "for what the receiver already knows (if anything) about the possibilities that exist at the source" (Dretske, 1981:65). For the moment we shall ignore this complication.

In the case of the flipped coin, the observer shouts "Hurrah!" if the coin falls heads, and "Oh no!" if the coin falls tails. Since the fact that the coin falls heads can be *learnt* from the shout of "Hurrah!", on our intuitive account of information content, the fact that observer shouts "Hurrah!" carries the information that the coin fell heads. This intuition accords with Dretske's definition. Making the appropriate substitutions, we obtain:

> The shout's being "Hurrah!" (the signal, r) carries the information that the coin (s) fell heads (F) = The conditional probability of the coin's falling heads given the shout's being "Hurrah!" is 1.

In the example, the probability of the coin's falling heads is indeed 1, given a shout of "Hurrah!", so the information is carried.

Prima facie, the restriction that the conditional probability, p, must be precisely 1 may seem to be over restrictive. If we consider our informal notion of information content, as that which can be learned from a signal, it is perhaps unclear whether or not it is possible to learn some proposition from a signal when the relevant conditional probability is less than 1. One persuasive intuition is that learning would be impossible, if learning some proposition requires such perfect evidence. Can I not learn that the cat is outside (if the cat is outside), from your assurance, even though there is a small chance that you may be mistaken? However, Dretske persuasively argues that if p is set at any value less than 1, paradoxical consequences ensue. I shall present the essence of his arguments in a slightly different form.

Consider a lottery in which just one of the n tickets reveals the winning number when the aluminium foil is scratched. Suppose that we allow p to be less than 1. The new criterion is that p is greater than 1 - δ, for some small δ. For any such δ, there will be an n (> 1/δ) such that the probability of a given ticket not carrying the winning number is greater than 1 - δ. Hence, if I buy a losing ticket, the information that I will lose is already carried, simply by my buying a single ticket. For the conditional probability of my losing, given that I buy a single ticket, is greater than 1 - δ, and so fulfills the relaxed criterion. Yet on this analysis, actually scratching the ticket to reveal the losing number carries no new information, since this information is carried just by my buying the single ticket. Yet surely I have learnt something by scratching the ticket - after all, it would be crazy for me to buy the ticket and never check to see if I had won, on the basis that I already possessed the contrary information. Difficulties multiply if we consider the case in which I buy many (losing) tickets. If I have the information that each ticket, individually, is a losing ticket, then surely I have the information that all the tickets are losing tickets. However, if I buy enough tickets then the probability that all of the tickets are losers will be *less* than 1 - δ. So the information that all the tickets are losers is *not* carried, even thought the information that each individual ticket is a loser is carried. So, scratching each individual ticket is informationally uninformative, but scratching all of them is not! Dretske concludes that this paradoxical conclusion rules out any non-zero value of δ. (A counter to this, which Dretske does not discuss is that δ could be treated as a free parameter, which should be set for any situation so that such problems do not arise. An unappealing aspect of this line is that the setting of an appropriate d will thus require some prior analysis of the situation, and what calculations we are interested in.

Dretske argues further than allowing a probability p of less than 1 also leads to paradoxical consequences for the integrity of information *flow*. Consider the pretheoretic account of the information content of a signal as what can be *learnt* from that signal. If C can be learnt from B and B can be learnt from A, then C can be learnt from A. In terms of information content this observation generates what Dretske calls the Xerox principle.

> "If A carries the information that B , and B carries the information that C, then A carries the information that C." (Dretske, 1981:57)

This principle can only be denied on pain of undermining the possibility of chains of information flow. (In logic, such a move would be analogous to denying that if $A \vdash B$ and $B \vdash C$, then $A \vdash C$, without which inferential chains are banished.)

The Xerox principle is, however, incompatible with the concession that p may be less than 1. Consider a row of n dominoes. Suppose that each domino has a probability of greater than 1 - δ of knocking over the next domino, and that the dominoes are stable otherwise.

So, since this probability of the next domino falling is greater than p then, on our relaxed criterion, the falling of each domino carries the information that the next will fall. By the Xerox principle, the falling of the first domino will therefore carry the information that the last (the nth) domino will fall, for any n. However, as n increases, the probability that the last domino will fall tends to 0. In intuitive terms, if the links in the informational chain are not perfectly secure, then if the chain is made sufficiently long, then it will be almost bound to break. So, given a long enough row of dominoes, we seem to be forced to the conclusion that, however long the row of dominoes, the falling of the first domino carries the information that the last domino will fall (assuming that, however unlikely it may be, all the dominoes do happen to fall. This is required because since information is factive and the falling of each domino carries the information that the next will fall.) This will be true even if the conditional probability between the falling of the first and last dominoes - in other words, the probability that all the dominoes fall, if the first one does - is, say, one in a million. Yet this conclusion directly contradicts the conclusion obtained if we consider the conditional probability between the first and last dominoes directly, rather than considering the intervening informational links. In informational terms, the point is this: if a small amount of equivocation is tolerated in carrying of information, that equivocation may be increased arbitrarily in information flow. So no equivocation can be tolerated - p must be 1 and no less (again there is the possible counter that δ may be set appropriately for each situation considered).

It might be objected that since, in the above example, the contradiction is obtained only when all the dominoes fall (since only then are all the informational links in place), then the last domino will necessarily fall if the first one does - the conditional probability that the last domino falls, given that the first falls, must be 1, after all. However, this reasoning is fallacious. By making the row of dominoes as long as required the conditional probability between the first and last dominoes *can* be made arbitrarily small. The paradox that information may flow between each informational link but not along the whole chain only arises in the rare eventuality that all the dominoes do happen to fall. Given that this is the case, then the falling of the last domino is trivially determined by the falling of the first. But this does not mean that the conditional probability between the falling of the two dominoes is 1. All that follows is the trivial observation that the conditional probability of the last domino falling is 1, given that the first domino falls *and that all the dominoes fall.*

Superficially more innocuous than the restriction that p is exactly 1, is that Dretske's definition of information content applies only to contents of the form s is F. This may not appear to be a very severe limitation, since it seems to include any information content which can be rendered in subject-predicate form. However, Dretske points out that the scope of his account is intended to be rather more restricted. The account applies to contents of the form *s* is *F*

> "...where the letter *s* is understood to be an *indexical* or *demonstrative* element referring to some item at the source. What the definition gives us is an account of... a content that might... be expressed by saying that *r* carries the information *of* or *about* *s* that it is *F*." (Dretske, 1981: 66)

> "...it is *only* the descriptive or conceptual elements embodied in the *predicate* expression ("...is *F*") that reflect the informational content of the signal. The subject term merely attaches that content to a particular individual." (Dretske, 1981: 67)

So Dretske takes his theory to give an account of what it is for a signal to carry the information, of some object, that it has a certain property. The specification of the object to which the property is attached is not part of the information content. All that is important is *what* object is specified, not *how* it is specified:

> "What the definition gives us is an account of what philosophers might call the signal's *de re* informational content... A signal's *de re* informational content is determined by two things: (1) the individual *s* about which the signal carries information, and (2) the information (determined by the open sentence "...is F") it carries about that individual. What descriptive phrase we happen to use (in the verbal expression of a signal's information content) to refer to the individual about which information is carried is irrelevant." (Dretske, 1981:66-67)

> "Signals can therefore differ in the information they carry in two ways. If r_1 carries the information that *s* is *F* and r_2 carries the information that *s* is *G*, then (assuming *F* and *G* give expression to independent features or characteristics) they carry different pieces of information. In addition, however, r_1 may carry the information that *s* is *F* while r_2 carries the information that *t*, a different individual, is *F*... Throughout this work attention will be restricted to propositional contents of the *de re* variety [that is, to differences of the former kind]." (Dretske, 1981: 67)

That is, Dretske's account can distinguish the former contents which have different *de re* contents and but does not deal with the latter, which have different *de dicto* contents. The point may be rephrased as follows. If the information carried is that *s* is *F* rather than that *s* is *G* or *H*, then the information content of some signal falls within the scope of Dretske's definition. In this case, the information content is that the specified object has this property rather than that property. However, Dretske's definition does not include the case in which the information carried is that *s* is *F*, rather than that *t* is *F* or *u* is *F*, since the specification of an object can not be part of the information content of the signal. In more concrete terms, the Dretskian definition is appropriate for explicating what it is for a signal to carry the information that an apple is red rather than green or brown, but not for explicating what it is for a signal to carry the information that *this* apple is green, rather than that apple or this pear. For in the latter case, the information carried is about *which* object has a certain property.

1.2 Breaking the Restriction to Contents of the form *s* is *F*

Dretske's account of the information content of a signal is limited to contents of the form *s* is *F*, where the singular term which picks out the object *s* is not part of the content. A signal can have the information content that Fido is asleep rather than awake, but not that *Fido* is asleep, rather than Rover. There does not appear to be a correlate of this restriction in our informal notion of information. It seems equally possible to *learn* either piece of information from a signal.

Suppose that I hear snoring from next door, and wonder which of the dogs is sleeping. If you look next door, and whisper "Fido", this signal carries the information that Fido is asleep rather than awake. On the intuitive notion of information, the signal carries the information that Fido is asleep rather than awake, since it is possible to learn that Fido is asleep rather than awake from the whisper. Since the snoring has already told me that one of the dogs is asleep, the whisper seems to carry the specific information that it is *Fido* rather than Rover who is asleep. Yet this is just the kind of information that Dretske's account rules out. For although the proposition that Fido is asleep is of the form *s* is *F*, the signal carries information which picks out the individual *s* (that it is Fido rather than Rover), rather than attaching a property (being asleep) to a specific individual.

The cleavage between the Dretskian notion of information content and our intuitive notion is far greater than is suggested by the previous example. On our intuitive account, not only is it possible for a signal to carry information about the identity of *s* in propositions of the form *s* is *F*. Rather, a signal may carry any proposition *at all*.

Suppose that an undercover policeman is visiting the leader of a gang of bank robbers ostensibly to finalise the details of their next robbery. He arranges a code with a confederate who is watching the bank robber's house. The crucial signal is whether or not he puts his coat on before he leaves the house. The confederate then decides if the police should move in. The agreed code could be such that policeman puts on his coat before he leaves the house just when:

All the robbers in the gang are present in the house

It is possible that the policeman's cover has been blown

None of the robbers is armed

None of the robbers believes that the police are after them

and so on. None of these sentences is of the form *s* is *F*. Their logical form, under standard semantic analysis, involves quantification or modal operators. Yet the confederate can perfectly well learn the truth of each of these propositions from the way in which the policeman leaves the house, given the adoption of the appropriate code. In each case, the conditional probability of the truth of each proposition, given that the policeman leaves the house with his coat already on, is 1.

These examples suggest that Dretske's definition of information content may be generalised to apply to an arbitrary proposition P, rather than applying just to propositions of the form *s* is *F*:

> *Information content* 2: A signal *r* carries the information that P, where P is any proposition = The conditional probability of *P*, given *r*, is 1.

[Dretske's parenthetical *k* is left out for simplicity]

Before discussing the application of this revised definition, let us tidy up the notation. Sources and receivers are both species of informational source. Hence, a uniform notation should apply to states of source and receiver alike. In Dretske's original formulation, the lowercase *r* stands for a *particular state of the receiver*, whereas the lowercase *s* stands not for a particular state of the source, but for the *object* at the source. The particular state of the source (the information carried by the signal) is denoted by the complex formula *s* is *F*. In the revised formulation we also have a terminological inconsistency. As before the state of the signal is denoted by a lowercase *r* but the state of the source is now denoted by a capitalised *P*. This appears to build in a spurious asymmetry between the the information carrier (state of the receiver) and the information carried (state of the source).

It might be countered that there *is* a distinction between *r* and *P*. For *r* stands for the state of the receiver *simpliciter*, whereas P stands for the *proposition* that the source is in such and such a state. So perhaps the difference in notation marks an important conceptual distinction: that between a state and a proposition. However, since there is a one to one correspondence between the states of an informational source, and the set of propositions that the source is in each of those states, this is not a substantive constraint. Thus, we may equally speak of the information carrier as *being* the state of the receiver or as being the *proposition* that the receiver is in that state. Similarly we may equally speak of the information carried as being the state of the source or the proposition that the source is in that state. Either line may be taken, but the same line should be taken for both sources and receivers. Throughout the present account we shall employ proposition talk rather than state talk. Let us now render our revised treatment of information content. The information carried (the state of the source) and the information carrier (the state of the receiver) are both rendered as propositions:

> *Information content 3*: A signal *Q* carries the information that P, where P is any proposition = The conditional probability of *P* given *Q* is 1.

Now that the constraint on the form of the proposition has been dropped, the appropriate signal may carry the information that all the robbers in the gang are present in the house; that it is possible that the policeman's cover has been blown; that none of the robbers is armed and so on.

Rather than laboriously illustrate how our revised definition of information content is appropriate in each of our previous cases, let us take a fresh example. Suppose that the army lay a minefield in training only when it is impossible that anyone will wander into it by accident in the next few days. Perhaps they surround the area with barbed wire, and post up large warning signs, until the mines are defused. Clearly the proposition that it is impossible that anyone will wander into the field by accident in the next few days may be *learned* from the fact that the field is mined. So this information is carried by the fact that the field is mined, on our intuitive account (indeed, this information typically *would* be learned by anyone who knew how rigourous the precautions are). However, such a complex, modal information content is beyond the scope of Dretske's definitions. It is, however, captured by our revised, more general, formulation. Consider the state of the field. It can be mined or unmined. These alternatives are, of course, mutually exclusive and exhaustive. Since the army will only mine a field given that certain conditions hold, the state of the field can be viewed as a receiver carrying the information about whether those conditions hold. Applying our definition, we have, in particular, that:

> The signal *Q* (that the field is mined) carries the information that P (that it is impossible that anyone will wander into the field in the next few days) since the conditional probability of *P* given *Q* is 1.

It seems that the revised definition better captures our intuitive notion of information. This has been done simply from abstracting away from a constraint that Dretske imposes on the structure of propositions that can be carried by a signal. It is natural to wonder why Dretske imposes this restriction. In the following sections, the reason for the restriction is examined. I shall argue that it stems from the identification of information theoretic talk about sources and their states with everyday talk of objects and their properties. .

1.3 Sources and Objects; States and Properties

An informational signal carries the information that a source is in some state. If a coin is tossed, it must fall either heads or tails. Thus, these states constitute an informational source. A shout of "Heads" might carry the information that the source is in the "Heads" state (assuming that the speaker is reliable), rather than the "Tails" state. Informally, the information content of the shout is that the coin fell heads. Yet this description suggests that the information content of the signal is that some object, the coin, has a certain property, falling heads. There is a natural mapping between these the descriptions in terms of states and sources, and the description in terms of objects and properties. Information that a source is in some state seems *ipso facto* to be information that an object has some property. Hence it is tempting to identify the everyday notion of an object with informational notion of a source and the everyday notion of a property with the informational notion of a state.

The information carried by an informational signal reduces the possibilities at the source. That is, the signal carries the information that the source is in some particular state or restricted set of states. If we identify sources with objects and states with properties, then an informational signal carries the information that an object has some (possibly disjunctive) property. So, according to the identification, the information content of a signal must be of the form *s* is *F*. Further, in an informational system, the signal can carry information only about what state the source is in, and no information about *what* the source is. For there can be only one source, and it is part of the specification of the informational system. According to the identification, this observation becomes the constraint that no informational signal can carry information about the identity of the object *s*. The information carried cannot pick out that object, but merely say *of* it that it has the property *F*.

Thus the restrictions that Dretske puts on the scope of his account seem to follow from his identification of sources with objects and states and properties. Further, these identifications are implicit throughout Dretske's text. For example, Dretske outlines the following scenario:

> "There are four possibilities (*P*, *Y*, *B*, and *G*) at the source. They are equally likely. A signal *r* arrives, altering the configuration of probabilities as follows:

$P(P/r) = .9$
$P(Y/r) = .03$
$P(B/r) = .03$
$P(G/r) = .04$

> The signal raises the probability that *s* is *P* and simultaneously lowers the probability of all competing alternatives." (Dretske, 1981: 94)

The identification of properties and states of the source is embodied in the use of the same letters (*P*, *Y*, *B*, and *G*) for both. The state of the source, *P*, is just *taken to be* that some object at the source, *s*, has the property *P*.

In this example, the symbol *s* is used, as it is throughout Dretske's exposition, to refer to both the source itself, and the object at the source. A similar identification of the receiver and some object is evident in the following passage. In explaining the definition of information content, Dretske comments that

> "The parenthetical *k* will be explained in a moment. It is meant to stand for what the receiver already knows (if anything) about the source." (Dretske, 1981:65)

The receiver is both a set of mutually exclusive and exhaustive states and an *individual* who may know about the possibilities at the source. Hence, an informational source is treated as an object. Indeed, it is treated as an object capable of having propositional attitudes.

Unfortunately, this tidy exegetical picture is complicated by a passage which appears to suggest a rather different identification:

> "Suppose a signal *r* carries the information that *s* is *F* and carries this information in virtue of having the property *F*'. That is, *r's being F*' (not, say, its being *G*) that is responsible for *r* carrying this specific piece of information. Not just any knock on the door tells the spy that the courier has arrived. The signal is three quick knocks followed by a pause and another three quick knocks. It is this particular *sequence* that carries the vital piece of information..." (Dretske, 1981:87)

Here the signal is both a *state of affairs* (that is, a state of the receiver) and an *object* capable of having properties such as *F* and *G* (here, and throughout, the notion of an object is purely the logical notion of anything that can have properties. So shouts, sequences of knocks at the door, people, tables and chairs are all objects. In particular, *events* are treated as a species of object). So in this instance, Dretske appears to be identify *states* with objects rather than identifying *sources* with objects. This inconsistency probably stems from a conflation of the non-technical and technical uses of the term "signal". Technically, a signal is just the state of an informational receiver. Each particular *sequence* of knocks corresponds to a distinct state of the receiver. That is, *r*'s being *F'* and *r*'s being *G'* correspond to distinct informational signals, rather than to different instances of the same signal *r*. So, in information theory signals may correspond to *states* of an object (e.g. that *r* is *F*') but not to objects themselves. This contrasts with the non-technical use of "signal", on which a signal corresponds to an object (in this case, a sequence of knocks at the door) which may have a variety of properties. Only if this object has the right properties will it carry the specified information. It is on the non-technical reading that we can point out that not just *any* signal (that is, any sequence of knocks at the door) conveys the information that the courier has arrived since the information is only conveyed by a particular sequence of knocks.

Are the identifications legitimate?

The above passage notwithstanding, the restrictions that Dretske imposes on the structure of information contents appear to arise out of his identification of objects with sources, and properties with states. We have yet to show, however, that these identifications are mistaken.

According to Information Theory, the fact that a source is in some state generates information. Yet throughout Dretske's discussion, there is talk of the fact that an *object* has some *property* generating information. For instance, in illustrating a point Dretske introduces a simple example:

> "Suppose *s* is a red square. Its being red generates 3 bits of information and its being square generates 3 bits of independent information..." (Dretske, 1981:64)

Yet if we frame this example in terms of sources and their states, it seems that we have two sources to one object, and so that sources and objects cannot be identified. First, consider states corresponding to the colours that the square can have - perhaps red, blue, green, and so on. Assuming that the square must be uniformly coloured, the set of states is mutually exclusive and exhaustive, since the square can have one and only one colour. So the set of colour states constitutes an informational source. If the probability of the square's being red is 1/8, then the information generated by the source being in that state is 3 bits.

How are we now to deal with shape in terms of sources and states? We can proceed in just the same way as for colour. Let the states be the shapes that the object can have - perhaps square, circle, triangle and so on. Since the object has precisely one shape, the set of states is mutually exclusive and exhaustive, and hence constitutes an informational source. If the probability of the shape's being square is also 1/8, then the information generated by the source being in that state is 3 bits.

We have defined two different informational sources, one based on the shape that an object has, and one based on the colour of that object. Within an information theoretic treatment there appears to be no way of expressing the fact that the states of the two sources are somehow about the same real world object. In any case, it is surely a mistake to *identify* some particular source defined on the properties of some real world object with the object itself, since any number of sources may be associated with a single object. In the present case, we could define sources based on the physical location of the red square (in the lounge, in the kitchen, in the garden), or based on orientation, brightness, size, etc. The states of a source may be more or less fine grained: (red, blue, green) versus (red, cobalt blue, navy blue, turquoise, light green, dark green). The states of a source may classify across more than one dimension of variation (red and square, red and triangular, red and circular, blue and square, blue and triangular, blue and circular, green and square, green and triangular, green and circular). An informational source is specified by *any* set of mutually exclusive and exhaustive states.

A further argument against the identification is that there are sources whose states do not correspond to the states of a particular object at all. We have already considered such cases. For example, the heads/tails orientations of a set of three coins defines a source with eight equally likely states. The fact that the source is in, say, state HHT does not correspond to some object having a certain property (at least, unless the collection of three coins is considered as a single object). Rather the states of three objects (the coins) are mapped onto a single source.

Suppose that a gambler bets all his money on a horse so that he can buy his wife a new lounge suite for her birthday. Then the states {{wife receives birthday present, gambler gets thrown out of the house}} may be mutually exclusive and exhaustive, and thus constitute an informational source (henceforth, I shall use double brackets to denote sets of states which constitute informational sources). However, the states do not correspond to properties of any single object.

So not only can a single object correspond to many sources, but a single source may correspond to many objects. Finally, the identification implies that just as a source is a set of mutually exclusive and exhaustive set of states, so an object is a mutually exclusive and exhaustive set of properties! Whatever objects are, they are surely not such exclusive and exhaustive sets. So objects cannot be identified with informational sources.

There are also difficulties with the identification of informational states and properties. Consider the flipping of three coins. Each may fall heads or tails. The states of each coin may be taken to constitute an informational source. Let us call the states of the first coin S1 and S2, the states of the second coin T1 and T2, and the third U1 and U2. In the information theoretic description there is nothing to say that the apparently unrelated states correspond to the same properties (S1, T1 and U1 correspond to the property of falling heads; S2, T2 and U2 correspond to the property of falling tails). So, just as many sources may be associated with a single object, many *states* may be associated with a single property. In particular, states cannot be independent of their sources in the same way that properties are independent of the objects which instantiate them. Independent objects may have the same property, but there is no account of how independent sources can have the same state. Further, just as a source need not be associated with an object at all, so a state need be associated with no particular property. After all, if a source does not correspond to an object, then the states of source cannot correspond to the properties of that object.

Consider the three coins. Each coin has either the property of falling heads or tails. The eight informational states may be mnemonically labelled: HHH, HHT, HTH, HTT, THH, THT, TTH, TTT. These states do not correspond to the properties of any object (unless the three coins are viewed as a single object with such *ad hoc* properties as falling head-head-head, head-tail-tail, tail-head-head...).

Notice that there are important differences in the expressive power of object-property talk and source-state talk. Viewing the example in terms of objects of properties, we may note that, say, HHT, HTH, and HHT have something in common. That is, one of the coins fell heads, and the other two fell tails. While, on our mnemonic labelling, it is apparent that the states do have something in common (since the labels contain one "H" and two "T"s), if we relabel the states non-mnemonically {{S1, S2, S3, S4, S5, S6, S7, S8}}, the set of states in which one coin falls heads is {S4, S6, S7}. In terms of objects and properties, the states in which just one coin falls heads can be straightforwardly delimited. Yet there is no way to pick out this set in terms of sources and states, except by enumeration.

The intuitive notion of information content applies to any proposition, whereas Drestke's notion is more restricted. In particular, an information signal is viewed as carrying information of the form *s* is *F*. Yet it seems that Dretske's definition can easily be extended to deal with arbitrary propositions. The source of Drestke's restrictions appears to be the identification of objects with sources, and properties with states. In the present section we have seen that these identifications are unworkable.

Let us now turn to Dretske's restriction that an information signal may not carry information which picks out the object *s*, but only *about* some object *s* that is *F*.

1.4 *De Re* and *De Dicto*

Dretske says that his definition of information content gives us an "account of what philosopher might call the signal's *de re* informational content, a content that might, (more revealingly) be expressed by saying that *r* carries the information *of* or *about s* that it is *F*. This content is called a *de re* (versus a *de dicto*) content because what is being described when we describe a signal's informational content is a relation between what is expressed by an open sentence ("...is *F*") and some individual *s*." Given that Dretske identifies objects with sources and properties with states, this restriction follows directly from the trivial observation that an informational signal can carry no information about the nature of the source. Information reduces possibilities *at* a given source, rather than specifying one source rather than another.

If objects are identified with sources, and properties are identified with states, then the observation that a signal carries information about the *state S* of the *source s* becomes the constraint that a signal carries information that the *object s* has the *property S*. The observation that a signal cannot carry information about the nature of the source *s* becomes the constraint that a signal cannot carry information picking out the object *s*.

It is this constraint on informational content that a signal can carry that Dretske expresses by saying that his definition of information content gives us an "account of what philosophers might call the signal's *de re* informational content". I have argued that this constraint flows naturally from the conflation of objects with sources, and properties of objects with states of sources. In introducing the apparently natural extension of Dretske's ideas to arbitrary propositions, it was argued that such a restriction is unnecessary. Further, it is unable to handle some of Dretske's own examples. For instance, having introduced the definition of information content, and having argued that it applies only to *de re* rather than *de dicto* propositional contents, Dretske applies the definition to the following scenario.

A group of eight employees must decide who is to perform some unpleasant task. Since they must choose one and only one employee, the set of possible choices constitutes a source. Having made their decision, the employees write the name of the hapless individual on a piece of paper and have it sent to the manager. There must be one and only one name on the piece of paper that the manager receives, and which name is present carries information about the state of the source. Hence, the set of eight possible names may be viewed as a receiver. In one scenario, the employees agree to name Herman if either Herman or Shirley are selected, since Shirley has delicate health. As it happens, Herman is selected directly, and so the memo arrives on the manager's desk with "Herman" printed on it. The note having "Herman" on it is consistent with 2 out of the 8 employees having been initially selected. Since this involves reducing 8 equally likely possibilities to 2...

> "...communication theory told us that the note carried only 2 bits of information about which employee had been selected... But although this theory tells us *how much* information the note carries, it does not tell us *what* information it carries. As far as this quantitative theory is concerned, the memo could carry a variety of different messages as long as these messages have a measure of 2 bits. So, for example, the memo might carry the information *that either Herman or Shirley was selected* (2 bits) or it might carry the information *that either Herman or Donald was selected* (2 bits). Both these possible messages are *true* (since Herman was selected)... Our definition of a signal's propositional content neatly distinguishes between these two possible messages. It fixes on *Herman* or *Shirley* as the content rather than *Herman* or *Donald* because the former possibility (given the name appearing on the memo) has a probability of 1 while the latter possibility has a probability of only .5." (Dretske, 1981:68)

The information content that *Herman or Shirley* are selected is of the the form *s* is *F*, so this content might superficially appear to be compatible with Dretske's account. However, the information content of the signal does not specify what property the object *s* has, but rather to pick out which which object or objects have that property. The information content of the signal is that *Herman or Shirley* rather than *Herman or Donald* or *Eric* is selected. The content is not that Herman or Shirley are *selected* rather than *left out*. Making the appropriate substitutions in Dretske's text we have:

> "The informational content of a signal is being expressed in the form "*s* is *F*" [*Herman or Shirley* are *selected*] where the letter *s* [*Herman or Shirley*] is understood to be an *indexical* or *demonstrative* element referring to some item at the source. What the definition gives us is an account of... a content that might... be expressed by saying *of* or *about s* [*Herman or Shirley*] that it is *F* [... *is selected*]." (Dretske, 1981: 66)

> "...it is *only* the descriptive or conceptual elements embodied in the *predicate* expression ("...is *F*") [...*is selected*] that reflect the informational content of the signal." (Dretske, 1981: 67) (My additions in square brackets)

In the present case, the information carried by the signal is not *of Herman or Shirley*, that one of them was selected. Rather, it is *of* the *selection* that Herman or Shirley was picked. Perhaps Dretkse's account can be saved by recasting "Herman or Shirley (*s*) are selected (*F*)" as "the selection (*s*) was Herman_or_Shirlied (*F*)", say. However, the need to resort to such convolutions in order to make simple examples fit the required form is unnecessary, if we merely lift the restrictions on the propositional content of an informational signal.

According to the revised definition of information content, an information signal may carry an arbitrary proposition. A signal *Q* carries the information that P, where P is any proposition if and only if the conditional probability of *P* given *Q* is 1. The probability that Herman or Shirley is selected, given that the name "Herman" is on the memo (the signal) is 1. The probability that Herman or Donald is selected, given that the name "Herman" is on the memo is less than 1. Hence according to the revised definition the signal carries the information that *Herman or Shirley* rather than that *Herman or Donald* is selected, as required. The propositional account does not differentiate between *de re* and *de dicto*.

1.5 Multiple Information Contents and Nested Information

Consider again the case of the flipped coin and the shout. The observer shouts "Hurrah!" for heads, and "Oh no!" for tails. According to our current definition of information content, the shout of "Hurrah!" carries the information that the coin fell heads, since the conditional probability of the proposition that the coin falls heads given the proposition that the observer shouted "Hurrah!" is 1.

Perhaps we allow in to the idealisation the possibility that the coin may occasionally balance on edge. This elicits a cry of "Good grief!". Such an idealisation contains a source and receiver each with three rather than two possible states. The cry of "Heads!" carries the information that the coin fell heads, and also carries the information that the coin did not fall tails, that the coin did not balance on edge, and, for that matter, that the coin neither fell tails nor balanced on edge.

Dretske makes the point as follows:

> "... it makes little sense to speak of *the* informational content of a signal. For if a signal carries the information that *s* is *F*, and *s*'s being *F* carries, in turn, the information that *s* is G (or *t* is *H*), then this same signal also carries the information that *s* is *G* (or *t* is *H*). For example, if *r* carries the information that *s* is a square, then it also carries the information that *s* is a rectangle. This is so because if the conditional probability (given *r*) of *s*'s being a square is 1, then the conditional probability (given *r*) of *s*'s being a rectangle is also 1. Furthermore such a signal will also carry the information that *s* is a quadralateral, a parallelogram, *not* a circle, *not* a pentagon, a square *or* a circle, and so on. Similarly, if the mercury's expansion carries the information that the temperature is rising, then any signal carrying the information that the mercury is expanding also carries the information that the temperature is rising... This point may be expressed by saying that if a signal carries the information that *s* is *F*, it also carries all the information *nested in* *s*'s being *F*. This follows immediately from our definition of a signal's informational content and the following definition of the nesting relation:
>
> The information that *t* is *G* is nested in *s*'s being *F* = *s*'s being *F* carries the information

that t is G."

(Dretske, 1981:70-71)

Since on our revised definition of the notion of information content, informational signals are specified by atomic propositions (P, Q), rather than propositions of the form s is F, the definition of nestedness becomes simply:

> The proposition that Q is nested in the proposition that P = P carries the information that Q.

The definition applies straightforwardly to our initial example. Consider the proposition that the coin fell heads; that the information that the coin did not fall tails; that the coin did not balance on edge; that the coin neither fell tails or balanced on edge; that the coin is in stable (rather than unstable) equilibrium; that the Queen's head is uppermost; that the bet has been won; that the observer is 5 pounds richer. All these propositions are nested in the proposition that the observer cries "Hurrah!" (if the idealisation is sufficiently rich, as will be stressed below).

Notice that the nestedness relation is not antisymmetric. That is, Q's being nested in P does not preclude the possibility that P is nested in Q. According to our definitions, P and Q will be mutually nested just in case the conditional probability of P given Q is 1, and the conditional probability of Q given P is 1. This will be true if there is some lawlike relation between P and Q which ensures that if either is true then both are true. Let us say that propositions P and Q *track* each other if they are mutually nested. If P and Q track each other, they have identical informational properties: that is, P carries the information that R just when Q carries the information that R; and a signal S carries the information that P just when it also carries the information that Q. For example, the proposition that the Queen's head faces up tracks the proposition that the coin falls heads, since neither proposition can be true without the other being true. All and only signals that carry the information that the Queen's head faces up also carry the information that the coin fell heads; and all and only pieces of information carried by the proposition that the Queen's head faces up are also carried by the proposition that the coin fell heads.

We have seen that a signal may carry many pieces of information. Information content is thus crucially different from semantic or representational content. Whereas the observer's utterance of "You owe me five pounds" carries the information that he is happy, that he is from Scotland, that he has a cold, that he is owed five pounds, and so on, it *means* just that his friend owes him five pounds, and no more. To account for representation in terms of informational content we must have some way of specifying some unique content from the mass of information that a signal carries. To this end Dretske introduces the notions of a signal's carrying information in *digital* and *completely digital* form. In later sections we shall be extensively concerned with these ideas and their application.

1.6 Relativity to Knowledge: the Parenthetical *k*

Informational Properties and Informational Idealisation

Informational properties are relative to the specification of an informational system. In the example of the British gymnasts and the partisan crowd (of section I.2), what information the state of the crowd carries and whether information transmission is noisy or equivocal were found to depend on the particular informational idealisation chosen.

Consider the informational idealisation of the receiver: Is the crowd viewed as a two state source (happy, or groaning); or is it viewed as a four state source (happy and eating popcorn; happy and not eating popcorn; groaning and eating popcorn; groaning and not eating popcorn)? Since there is no dependency between popcorn eating and the performance of the gymnast, if we employ the latter idealisation, some of the information generated by the crowd being in a particular state is not information carried about the state of the gymnast. Hence information transmission is noisy. If the two state idealisation of the state of the crowd is employed, there is no such additional information, and hence information transmission is noiseless.

Or consider the idealisation of the source. Is the state of gymnast treated as a two state source (either on the beam or on the floor) or a four state source (either on the beam or on the floor wearing either red, white and blue or leopard skin strip)? Since the colour of the strip is not determined by the state of the crowd (assuming that the idealisation of the crowd is not sensitive to the giggling of the spectators), there is information generated at the source which is not carried by the state of the receiver. That is, information transmission is equivocal. If the two state idealisation of the state of the gymnasts is employed, all the information generated at the source (whether or not the gymnast falls off) is carried by the state of the crowd (whether the crowd is happy or groaning). Hence information transmission is not equivocal. So, if two state sources are used in both cases, transmission is noiseless and unequivocal. If four state sources are used, information transmission is *both* noisy and equivocal - informational properties are dependent on the way in which the states are individuated.

Informational properties are also sensitive to the absolute probabilities of each state of the source and receiver and the conditional probabilities of each state of the receiver given each state of the source. In the present example, we have assumed that the crowd will certainly groan, if the gymnast falls off the bar. Despite the partisan attitude of the crowd, there are imaginable circumstances in which the gymnast falls off the bar and the crowd does not react. For example, the entire crowd could simultaneously be doing up their shoelaces at the time of the fall, and so fail to notice it; the crowd could be under mass hypnosis; the stadium might be rocked by an earthquake, thus distracting the crowd from the event, and so on. If these are treated as genuine possibilities, then the conditional probability of the crowd groaning, given the gymnast's mishap is less than 1. It is always possible to *imagine* ways in which information flow might break down. The voltmeter might be faulty, the informant might be lying, my senses might be deceiving me. The probabilities we assign to the absolute and conditional probabilities will depend on which imaginable possibilities we take into account, and which we idealise away from.

Since informational properties depend on the specification of the states of the source and receiver and the associated absolute and conditional probabilities we have considerable freedom in assigning informational properties to real world situations. Dretske notes that, pretheoretically, information transmission appears to be relative to the knowledge of an observer, and builds this directly in to the definition of information content by adding the parenthetical *k*. I shall argue that this move is unnecessary. What is relative to the knowledge of the observer is *the informational idealisation appropriate for modeling the situation.* The different idealisations appropriate for different observers will automatically generate the differences in the informational properties that our intuitions require. In short, I argue that the importance of the knowledge of the observer is that it constrains the way in which the theory is appropriately applied, and should not be part of the theory itself. This is more than a terminological variation. Firstly, many different knowledge states of the observer may correspond to the same informational idealisation - much of the observers knowledge may be irrelevant, for example. Secondly, idealisation relativity applies even when there *is* no observer. Thirdly, putting considerations of observer knowledge outside the domain of the theory of information allows a tractable formalisation of Dretske's ideas to be provided (as we shall see below).

Knowledge Relativity

Dretske explains the role of the parenthetical *k* in the definition of information content as follows:

> "Our definition of informational content makes reference to what the receiver *already knows* (*k*) about the possibilities existing at the source. To illustrate, suppose that there are four shells and a peanut is located under one of them. In attempting to find under which shell the peanut is located, I turn over shells 1 and 2 and discover them to be empty. At this point you arrive on the scene and join the investigation. You are *not* told about my previous discoveries. We turn over shell 3 and find it empty. How much information do you receive from this observation? How much do I receive? Do I receive information that you do not receive?" (Dretske, 1981:78)

> "Having already examined shells 1 and 2, I know they are empty. The peanut is under either shell 3 or 4. When we turn over shell 3 and find it empty, the two possibilities are reduced to one. Hence, the third observation provides me with 1 bit of information as to the whereabouts of the peanut. You, however, undertake the examination of shell 3 in ignorance of the results of the first two observations. For *you* there are four possibilities and the examination of shell 3 reduces these four possibilities to three. Hence, you receive only .42 bits of information as to the whereabouts of the peanut. Since there are 2 bits of information associated with the peanut's being under shell 4, you receive *too little* information to locate the peanut... On the other hand, the third observation supplies me with the information that shell 3 is empty (1 bit) *and* the information that the peanut is under shell 4 (1 bit). The latter piece of information is (for me) nested in the former piece of information. For you it is not." (Dretske, 1981:79)

Dretske's calculations are based on the following reasoning. Since I know that the peanut is not under shell 1 or shell 2, and have no further information about the location of the peanut, the source has two equally probable states (peanut under shell 3 or 4). When shell 3 is uncovered, only one possible state remains (peanut under shell 4). 2 equally probable alternatives have been reduced to 1. Hence 1 bit of information is generated at the source. Since you initially know nothing other than that the peanut is under on of the four cups, the lifting of cup 3 reduces 4 equally probable state to 3. This generates just .42 bits of information.

A source consists of a set of mutually exclusive and exhaustive states, each with an associated probability. In the calculations above, in considering the amount of information that I gain from the lifting of shell 3, a source with two equally likely states is employed (peanut under shell 3 or peanut under shell 4). In considering the amount of information that you gain from the lifting of shell 3, a source with four equally likely states is employed (peanut under shell 1, 2, 3, or 4). These are distinct sources. That is, on Dretske's own account, the appropriate informational idealisation of the situation is relative to the knowledge of the observer under consideration. Since information content is defined like all other informational properties relative to an informational idealisation, there is no need to build knowledge in to the definition of information content. The intuition that information content is relative to knowledge is captured by the fact that knowledge constrains the appropriate informational idealisation and that information content is relative to informational idealisation.

Dretske takes his example to elucidate the significance of "what the receiver *already knows* (*k*) about the possibilities existing at the source" (Dretske, 1981:78). However, the calculations above have concerned only information generated at the source. In the example, as outlined, no receiver has been specified. There has been no mention of a set of mutually exclusive and exhaustive set of states with associated absolute probabilities, and probabilities conditional on the states of the source. We have been concerned with information generation, and not information flow. While there are no receivers, in the information theoretic sense, there are observers: you and me.

Some mutually exclusive and exhaustive set of states of an observer can, of course, be viewed as a receiver. However, as noted above, Dretske seems rather to *identify* observers with receivers. *k* "is meant to stand for what the *receiver* already knows" (Dretske, 1981:65). But receivers cannot *know* anything. They are merely sets of states with associated probabilities. We argued above that informational sources cannot be identified with objects; still less can they be identified with *people*. So we cannot accept at face value Dretske's conclusion that what is required is

> "... a *relativisation* of the information contained in a signal because *how much* information a signal contains, and hence *what* information it carries, depends on what the potential receiver already knows about the various possibilities that exist at the source." (Dretske, 1981:79)

The substance of Dretske's analysis of the example, however, is unobjectionable. According to the definition of information content, Dretske might be expected to take a single informational system (with one source and one receiver) and somehow apply to it a knowledge relative notion of information content. That is, the notion of information content would assign a different information content to the same signal of the same receiver, about the state of the same source, depending of the knowledge of the observer. In practice, however, Dretske adopts distinct idealisations of the situation (two distinct sources, one with two states and one with four states), according to the knowledge of the observer that he is considering, and applies the same notion of information content in each case. Dretske's conclusion that the information carried by a signal is knowledge dependent might be recast. What is required is

> A relativisation of the information generated by an occurrence because how much information an occurrence contains, and hence what information it carries, depends on what idealisation of the information system we adopt.

The degree to which an idealisation captures our intuitions about what information some occurrence carries for an individual, depends, at least in part, on what that individual takes the possibilities to be. That is, what that individual already knows about the various possibilities (such as whether or not the peanut can be under shells 1 and 2) constrains the way the information theoretic apparatus should be applied. The parenthetical *k* need play no role in the account of information content itself.

Information Content and Propositions with Probability 1

It may be argued that Dretske's parenthetical *k* cannot be dispensed with so easily. Consider a variant of the previous example. As the peanut and the cups are being set up I sneakily look through the keyhole, and see that the peanut is under shell 4. I then come in and begin the procedure as usual. Shell 1 is lifted and found to be empty. On the revised definition of information content, we arrive at the very counterintuitive conclusion that the proposition that shell 1 is empty carries the information that the peanut is under shell 4. Applying our new definition of informational content, we have:

> The proposition that the peanut is not under shell 1 carries the information that the peanut is under shell 4 = The conditional probability that the peanut is under shell 4, given that the peanut is not under shell 1, is 1.

Since I saw the peanut being put under shell 4, the probability that the peanut is under shell 4 is 1, on any informational set up which appropriately idealises my knowledge of the situation. Hence, trivially, the probability of the peanut's being under shell 4 *given that the peanut is not under shell 1* is also 1. So, according to the revised definition, the information that the peanut is under shell 4 is carried. More generally, if any state of a source has probability 1, then it must have probability 1 conditional on any other state. If the probability that the sun will rise is 1, then the probability that the sun will rise, given that the Johnny forget to do his homework is also 1. Hence, Johnny forgetting to do his homework carries the information that the sun will rise.

Dretske avoids this problem in his definition:

> "*Information content*: A signal *r* carries the information that *s* is *F* = The conditional probability of *s*'s being *F*, given *r* (and *k*), is 1 (but given *k* alone, less than 1)" (Dretske, 1981:65)

The clause "(but given *k* alone, less than 1)" corresponds to the informal intuition that you can't learn something that you already know. So according to an appropriate idealisation, the probability that the coin is under shell 4 is 1, *given k alone*, and hence no signal *r* can carry this piece of information. Similarly, neither Johnny's forgetting to do his homework, nor any other signal can carry the information that the sun will rise, if we idealise the *absolute* probability that the sun will rise as 1.

One natural way to avoid the consequence that any signal carries all propositions with probability 1, according to the revised definition, is to borrow Dretske's approach. That is, we could stipulate that a proposition at a source may be carried by signal if its absolute probability is not 1:

> A signal *Q* carries the information that P, where P is any proposition = The conditional probability of *P* given *Q* is 1, *and the absolute probability of P is less than 1.*

However, this option is a provisional solution only. As we modify and generalise our theory of information content, we must ensure that the new account also avoids this consequence. In the formal treatment below (2.5), we shall see that this may be straightforwardly avoided.

1.7 Information and the Real World

In Chapter 2 we turn to the modification and simplification of Dretske's notion of information content. We have found two crucial presuppositions of Dretske's work to be unsound. Firstly, that objects can be identified with sources, and properties with states; and secondly, that the informational properties of a situation can be specified independently from any particular informational idealisation. I shall now argue that these assumptions are closely related.

Information theory idealises situations into informational sources and states (I use *situation* as loosely and atheoretically as possible). Informational properties are defined within an informational idealisation. Hence, the informational idealisation that we choose influences the informational properties that we ascribe in a particular situation. The number of bits that the falling of a coin generates is dependent on the idealisation that we employ. If we are concerned only with heads/tails orientation, then only 1 bit is generated; if our idealisation includes the position on the ground on which the coin falls, then considerably more information is generated. Since Dretske bases his theory of informational and semantic content on (some of) the ideas of information theory, this *idealisation dependence* applies equally to both accounts. Whether or not a shout of "Heads" carries the information that the coin actually fell heads is dependent on the idealisation of the situation that we choose. For example, suppose that the speaker tells the truth half the time and lies the other half of the time. On this particular occasion, he decided to tell the truth. On one idealisation, the utterance does not carry the information, since there is only a 75% chance that the coin is in fact heads, given the shout. On another idealisation, the utterance *does* carry the information, since, given that he had decided to tell the truth, the probability that the coin was heads, given the shout was 1. We can idealise a voltmeter as giving the correct reading with probability 1 (if it is working); on the other hand, we can idealise the same voltmeter as giving the correct reading with probability .95 (because it doesn't work properly 5% of the time. In general, we may either *presuppose* that certain conditions hold as prerequisites for the idealisation, or include the possibility that they do not as part of the idealisation.

The idealisation dependence of informational properties appears to contrast with the apparent idealisation *in*dependence of physical properties. For example, the mass or temperature of the coin are the same under any idealisation. Whether the coin is idealised as a point mass, or as a thin disc, or as a cylindrical volume, it still is assigned the same mass and temperature. If we wish to be realists about information and information flow, the idealisation dependence of informational properties may be worrying.

The idealisation dependence of informational properties may be rendered unthreatening if *there is only one appropriate idealisation of the real world.* Of course, in analysing particular situations with particular informational idealisations we may only capture incomplete fragments of the whole. Indeed, the incompleteness of these fragments may mislead us as to the informational properties that should be ascribed. If our idealisation is too impoverished, for example, we might not account for the information that the temperature of the coin carries about the temperature of the room. However, on what I shall call the *one true informational idealisation* hypothesis, there is a determinate fact about whether such information is carried or not. This view is analogous to the naive view (with no derogatory overtones intended) of idealisation in the physical sciences. To idealise the coin as a point mass is appropriate for predicting the trajectory that it takes when flipped; an idealisation as a thin disc may be appropriate for accounting for the fact that it cannot be passed through the cheese grater; an idealisation under a description of its conductivity may be appropriate for accounting for the degree to which its temperature mirrors the temperature of the room. But, on the naive view, if we knew everything about the coin, we could frame a single idealisation (perhaps such an idealisation would be expressed in terms of atoms and molecules) capturing all the physical properties of the coin. This would be a basic physical idealisation. Less general idealisations are only useful insofar as they are special cases of the larger idealisation. The basic physical idealisation might be said to ground physical properties. Similarly, on a naive realist view towards information, then there should be a basic informational idealisation which grounds informational properties.

Hence although informational properties are relative to idealisation, according to the "one true" informational idealisation hypothesis, informational properties need not be seen as intrinsically relative to a particular idealisation. There is, on such a view, a fact of the matter as to whether the shout carries the information that the coin fell heads or not. The fact of the matter is determined by whether or not the information was carried on the one true informational idealisation.

I argue that i) it is inescapable that informational properties *are* idealisation relative; ii) the "one true" informational idealisation hypothesis is untenable. Hence it is impossible to make informational ascriptions about the world *tout court* without specifying an informational idealisation to which the informational properties ascribed are relative. That is, unless a particular idealisation is understood, it cannot be asserted that the flipping of the coin carries 1 bit of information; or that the shout carries or does not carry the information that the coin fell heads.

Since Dretske does not explicitly discuss the issue of idealisation relativity, it would be misleading to ascribe to Dretske the view that either i) or ii) are mistaken (although it is possible that he may hold this position). However, Dretske does implicitly go against i) and ii) in that he consistently *does* ascribe informational properties as if these are bare properties of the world.

How is it that Dretske does not notice that he has adopted this strong and controversial position? I argue that it is the result of a running identification of informational sources with real world objects, and of informational states with properties of those objects. There is an easy slippage between talk of an informational source consisting of two mutually exclusive and exhaustive states of the coin as generating 1 bit of information, and the coin itself generating 1 bit of information. Indeed, such confusion is latent when we say, for example, "consider the coin as a two state source". Yet it is a category mistake to identify sources with objects. A source is just a set of states, not an object. The coin has mass, temperature and orientation. A set of states can have none of these properties.

The identification of objects with sources and properties with states appears to give a trivial translation from "informational talk" into "real world" talk. The content of a shout is not just that some source is in such and such a state, but that the coin has the property of falling heads. If we are realists about the ontology of the real world (about objects and properties), then, given the identification, we can be realists about the informational world. In so far as there are real world facts about what objects and properties there are, and what laws hold between them there will be corresponding informational facts about what sources and states there are and what information flows between them. That is, informational properties turn out to be idealisation *in*dependent after all. For there is, if we make the identification between informational and real objects, one true idealisation - the one that corresponds to the objects and properties and laws that make up the world. Of course, such a line is less than persuasive for those who find notions of object, property and law problematic. Still, surely to show that an account of content is naturalistically respectable there is no need to explicate notions which underlie the physical sciences also.

So the identification of real and informational objects leads to a "one true idealisation" view of information. The informational properties of a system may be specified without specifying a particular way in which that system is being idealised by the theorist, but *tout court*. Hence, Dretske's conflation of informational and real objects leads him to the view that informational properties can be specified without reference to idealisation.

Although I have extensively argued against the identification of sources with objects and states with properties, I have not argued against the "one true" idealisation hypothesis. Rather than addressing the hypothesis head on, the subsequent discussion will attempt to show the inappropriateness the hypothesis by tracing the consequences that it has for the development of the theory. I claim that Dretske's account is strongly influenced by the constraint imposed by the hypothesis.

Consider the "knowledge relativity of information (1.8, above). In the present account, this was explained as a consequence of the fact that appropriate informational idealisation of a situation is *inter alia* a function of the knowledge of the participants. I know that the peanut is not under shell's 1 and 2, and so a two state source is an appropriate idealisation of the position of the peanut. For you, on the other hand, the peanut could be under any of the shells, and so a four state source is appropriate. Dretske, however, does not appeal to the relativity of informational properties to idealisations; rather, he adds the "parenthetical *k*" to his definition of information content.

I shall argue below that the "aboutness" condition in the analog-digital distinction, and the account of the communication channel are also products of Dretske's unwillingness to accept idealisation relativity. The "one true idealisation hypothesis" creates a variety of difficulties for the analog-digital distinction. The "aboutness" condition on digitalisation amounts to an attempt to circumvent some of these difficulties; it is an attempt that I claim is ultimately unworkable.

In considering these issues in detail below, I aim to show that the relativity of informational properties to informational idealisation is fundamental to the proper treatment of information and information processing.

1.8 Propositions and States

According to the revised treatment of informational content, an informational source is taken to consist of a set of mutually exclusive and exhaustive *propositions*:

> A signal *Q* carries the information that P, where P is any proposition = The conditional probability of *P* given *Q* is 1.

The state of the receiver (the signal, *Q*) and the state of the source (the information carried, *P*) are propositions. On this approach, every proposition that can be carried by an informational signal must belong to some informational source in that idealisation. So if a signal carries information about a source {{*P1, P2,....PN*}}, then the only propositions that it can carry are *P1, P2, ...PN* (and, perhaps, Boolean functions of these). Let us return to the case of the flipped coin, which may fall heads or tails. The most natural informational idealisation is {{coin falls heads, coin falls tails}}. The observer's shouting "Hurrah!" carries the information that the coin fell heads, since the probability of that state of the source, given such a shout, (the proposition that the coin falls heads) is 1. Informally it seems that the observer's shouting "Hurrah!" also carries further, distinct propositions: that the Queen's head is facing up, that the monarch's head is facing up, that the Queen's head is visible, and so on. Similarly, it seems that a cry of "Oh no!" carries the further information that the Queen's head is facing down, that the monarch's head is facing down, that the Queen's head is not visible and so on.

If states are identified with propositions, then each of these propositions corresponds to a different informational state. An informational source is a set of mutually *exclusive* and exhaustive propositions. Hence if two states can be true together they must belong to *distinct* informational sources. Any propositions that are carried by the same signal *will* be true together, given that signal. Hence, the propositions that the coin fell heads, that the Queen's head is facing up, that the monarch's head is facing up, that the Queen's head is visible, must belong to different informational sources. The number of informational sources required in our informational idealisation is in danger of getting very large indeed. It appears necessary to postulate distinct informational sources: {{coin falls heads, coin falls tails}}; {{Queen's head faces up, Queen's head faces down}}; {{monarch's head faces up, monarch's head faces down}}; {{Queen's head is visible, Queen's head is not visible}}.

In the formal account of information theory, on which Dretske's notion of information content based, an informational system consists of a Source, a Receiver and the absolute and conditional probabilities associated with their states. To formalise the intuition that a signal can carry more than one piece of information, the account must simply be extended to allow informational systems to have more than two informational sources. To capture the richness of our previous example, we shall need a lot more than two.

Such informational inflation may make one wonder if distinct informational sources are really necessary. Should the propositions that the coin fell heads, that the Queen's head faces up, that the monarch's head faces up, that the Queen's head is visible really be treated as corresponding to distinct informational states? Perhaps these propositions should be viewed as different ways of describing the same informational state. Perhaps the grain of informational states should be coarser than the grain of propositions. There is an intuition that, in the situation described in the example, the coins falling heads, a monarch's facing upward, the Queen's head being visible and so on, *all amount to the same thing*. However, there are two considerations which mitigate against using some coarse grained notion of state rather than a finer grained notion of proposition.

Firstly, the information content of a signal is typically construed as propositional. The shout of "Hurrah!" is said to carry the information *that* the coin fell heads. The object of "that" clauses are typically taken to be propositions rather than states. If the "states" of informational sources are taken to be propositions, then the propositional nature of information content does not stand in need of explanation. On the other hand, if the informational notion of a state is considered to be distinct from (perhaps more coarse grained than) the proposition which is the content of the signal, then an additional account of how to get from state-talk (in the which the informational set-up is described) to proposition-talk (in which content ascriptions are made) is required. That is, since the information theoretic apparatus only licenses talk of states, there is need for an account of how a signal's determining that a source is in a particular state amounts that signal's carrying a particular proposition. The advantage of the identification of states of a source with propositions is that there is no need to provide such an account - for a signal to determine that the source is in state S6 is *ipso facto* for it to carry the proposition that *S6*. It seems parsimonious to argue that informational sources are collections of propositions, and that a signal (some proposition *Q*) carries a proposition (*P*) just if the probability of *P* given *Q* is 1. It seems distinctly less parsimonious to argue that states are somehow different from, but closely related to, propositions, such that a signal may carry a proposition just when it determines that the source is in an appropriate state. If the states of an informational source are not identified with propositions, then a rigourous account must be provided of the relationship that *does* connect the two. For it is this relationship which licenses talk of a *proposition* being carried by a signal, rather than merely talk of the state of the source being determined by a signal. A theory that does not spell out the nature of the relationship between states of an informational source and propositions is not properly described as a theory of informational *content* at all. The present approach does provide an account of this relationship, albeit the simplest possible relationship, identity.

This argument for a propositional treatment is hardly overwhelming. Perhaps some natural and appropriate mapping between state-talk and proposition-talk can be provided, or perhaps our naive ascription of *propositional* content is misguided, and should be replaced with a coarser grained state-based notion. However, I take the second consideration to be more compelling - that what licenses our intuitions about *which* propositions amount to the same thing in a given informational set-up are best captured within the information idealisation itself. To perform this task, the idealisation must be able to represent the distinct propositions separately, before demonstrating that they are, in the relevant sense, equivalent. The point is best made with reference to specific examples.

In the case of the coin which may fall heads or tails, it seems plausible that the proposition that the coin fell heads, and the proposition that the Queen's head faces up, amount to the same thing. However, consider an example in which the coin is picked at random from a collection of old British coins. There might be a half chance that the coin picked has a queen on it, and a half chance that it has a king on it. In an appropriate informational idealisation of *this* example, the proposition that the Queen's head faces up may be more specific than the proposition that the coin fell heads. Even in this case, the proposition that the coin falls heads still seems to amount to the same thing as the proposition that a *monarch* faces up since a monarch faces up when and only when the coin falls heads. Suppose, however, that the coin is drawn from a collection of coins of the world. Then the proposition that a monarch is facing up is more specific than (and hence carries) the proposition that the coin falls heads, for it may be that, say, a president is depicted on the coin rather than a monarch. Similarly, the proposition that the coin falls heads and the proposition that the Queen is visible do not amount to the same thing if the coin may balance on edge. If the coin balances on edge and is oriented appropriately, the Queen may be visible, but the coin has not fallen heads. So the proposition that the coin falls heads is more specific than (and hence carries) the proposition that the Queen is visible.

We noted above that our intuitions that distinct propositions can amount to the same thing is best treated *within* the informational framework. Specifically, I propose that two propositions amount to the same thing, relative to a particular informational idealisation, just in case they track each other.

Propositions *P* and *Q* track just when *P* carries the information that *Q* and *Q* carries the information that *P*. The relation of tracking is an equivalence relation. It is symmetric (if *P* tracks *Q* then *Q* tracks *P*), transitive (if *P* tracks *Q* and *Q* tracks *R*, then *P* tracks *R*), and reflexive (*P* tracks *P*). Hence, given an informational idealisation, we may partition the set of propositions into equivalence classes. This partition is informationally well motivated since if *P* and *Q* track they have identical informational properties (see section I.7 above). That is, *P* carries the information that *R* just when *Q* carries the information that *R*; and a signal *S* carries the information that *P* just when it also carries the information that *Q*. So if *P* and *Q* track each other, from an informational point of view, they *do* amount to the same thing (the present informal discussion will be made precise in the Chapter II). On this line the informational equivalence of distinct propositions can only be ascertained from *within* the informational idealisation. Distinct propositions must receive distinct representations within the informational system. Hence, in our initial example, the propositions that the coin falls heads, that the Queen's head faces up, that a monarch faces up, and that the Queen is visible, should be assigned to different informational states in the informational idealisation. For only by examining the information flow within this particular informational idealisation can we discover that the these propositions are informationally equivalent. If these distinct propositions are assigned the same informational state in the idealisation (on the basis that the grain of states is coarser than the grain of propositions), then the informational relation between the coin's falling heads and the Queen's head facing up cannot even be *expressed*, since there are not two informational states but one.

1.9 The Problem of Probabilistic Contents

Dretske discusses the restriction that a signal only has a certain proposition as its information content if the conditional probability that the proposition is true given that signal is precisely 1.

> "Up to this point examples have been carefully chosen so as to always yield an identifiable content. Not all signals, however, have an informational content that lends itself so neatly and economically to propositional expression. Suppose that *s* can be in any of four different states, each of which is equally likely: *A*, *B*, *C*, and *D*. Suppose, furthermore, that *s* occupies state *B* and a signal *r* carries 1 bit of information about the situation at *s*. There are a variety of ways a signal can carry 1 bit of information about the condition of *s*. It might, for example, reduce the probability of *A* and *D* to 0, leaving *B* and *C* equally likely. In this event the signal carries 1 bit of information and (according to our definition) carries the information that *s* is in either state *B* or *C*. But the signal might also shift the configuration of probabilities in such a way as to yield 1 bit of information. If, for example, the conditional probabilities are:
>
> $P(A/r) = .07$
> $P(B/r) = .80$
> $P(C/r) = .07$
> $P(D/r) = .06$
>
> then... the equivocation is 1 bit. Hence, *r* carries 1 bit of information about the condition of *s*. What is the *content* of this signal? What is the message? We obviously cannot suppose that the signal carries the information that *s* is in state *B* because, even though *s is* in state *B*, this condition generates 2 bits of information and our signal carries only 1 bit. Neither can we suppose that the signal carries the information (say) that *s* is in either state *B* or state *C*. For although *s is* in either state *B* or state *C* and although this condition has a measure of only 1 bit, our definition tells us that this is *not* the 1 bit of information that the signal carries (since the probability of this state is less than 1). There is not, in fact, any unqualified way of expressing the information carried by this signal. The best we can do in such cases is to say that the signal carries the information that *s* is *probably* in state *B*. This comes closest to satisfying our definition of informational content, since (we may suppose) the conditional probability of *s*'s probably being *B*, given *r*, is unity. I am not sure that it makes sense to talk this way. It is silly, of course, to think of *s*'s probably being *B* as itself a condition of *s* that we could receive information about, as something that could have a conditional probability of 1 and therefore qualify as the informational content of a signal. But this is not the point. When there is no sentence describing the situation that does exist at the source which satisfies our definition of informational content, and we nonetheless wish to give propositional expression to the quantity of information that is transmitted, we are forced to adopt the expedient of talking about the fact that *something is probably so* as the informational content of a signal." (Dretske, 1981:68-70)

Dretske's discussion points out a dilemma for an account of information content. On the one hand, there is good reason to maintain that a signal *Q* cannot carry the information that *P* (in Dretske's terms that *s* is *F*) unless the probability of *P*, given *Q* is 1, and no less (see 1.1). On the other, there is an intuition that slightly equivocal signals (where the conditional probability is just less than 1) can be given a propositional content. Namely, the signal *Q* may intuitively seems to carry the information that *probably P*. Yet *probably P* is not a state of the informational source at all, and hence the signal cannot carry the information that the source is in that state. I shall term this dilemma the problem of probabilistic contents.

This dilemma appears problematic for Dretske, since informational contents of the form *s* is *probably F* appear to fall outside the scope of the definition content. The source has states *F*, and *G*, but it appears that cannot have additional states *probably F* and *probably G*. The states of a source must be mutually exclusive, whereas the states *s* is *probably F* and *s* is *F* can co-occur. Dretske believes that "We are forced to adopt the expedient of talking about the fact that *something is probably so* as the informational content of a signal" (Dretske, 1981:70). Yet there is no attempt to integrate the intuition that equivocal messages can have probabilistic contents with the definition of informational content. Probabilistic contents are *sui generis*.

Yet the dilemma appears problematic for the revised account also. The revised account was intended to apply to informational contents which correspond to arbitrary propositions, rather than only those which have the form *s* is *F*. However, it seems that one class of proposition does not yield to such a treatment - namely probabilistic propositions. That is, the revised account appears to be unable to handle probabilistic propositions of the form *probably P*. For a source consists of a set of mutually exclusive and exhaustive propositions, *P1*, *P2*... *PN*. It does not have additional states *probably P1*, *probably P2* and so on.

However, the difficulties for these accounts are only apparent. The discussion will proceed in terms of the revised account of informational content, but the resolution of the problem of probabilistic contents applies equally well to the original Dretskian definition.

Let us consider two dice, one blue and one red. The blue die has 1 spot printed on all sides except one, which has six spots. The red die has 6 spots on all sides except one, which has a single spot. Suppose that we are playing a game in which you roll one of the die, I have to guess whether or not it will fall "1" or "6". The procedure is as follows. I close my eyes, while you choose one of the dice. Before opening my eyes, I must make my guess. Then you throw the die. Suppose that I sneakily watch you choosing the die, and see that it is blue. I cannot learn from this whether the die will fall "1" or "6", but I *can* learn that it will fall "1" with probability 5/6. There are two possible choices of die: blue, (the die probability 5/6 of falling 1), or red (the die has probability 1/6 of falling 1). Hence the {{there is probability 5/6 that the die will fall "1", there is probability 1/6 that the die will fall "1"}} is a set of mutually exclusive and exhaustive states, and so constitutes an informational source. Given that I see that the coin is blue (the signal), the conditional probability that *the die has probability 5/6 of falling 1* given that signal, is (exactly!) 1. So, the definition of informational content captures the probabilistic information content of the signal directly, *relative to a source whose propositions are themselves probabilistic in character.*

Informational properties are relative to the specification of the informational system. If the informational source has states P, Q and R, then the only propositions that a signal can carry about that source (as the theory stands) are P, Q and R. Hence, no signal can carry the propositions *probably* P, *probably* Q and *probably* R, just as no signal can carry any other propositions S, T, U. In Dretske's example, no state of the source $\{\{A, B, C, D\}\}$ has probability 1 given the signal. However, the source $\{\{B$ has probability .80, B has probability not equal to .80$\}\}$ *has* a state which has conditional probability 1, given the signal. Relative to this informational source, the signal has the informational content that B has the probability .80.

It might be objected that no account has been offered of how the propositions that *probably* P and P are related. We have merely postulated distinct sources $\{\{A, B, C, D\}\}$ and $\{\{B$ has probability .80, B has probability not equal to .80$\}\}$. Since we are treating states as unstructured propositions, the latter source might just as well be denoted by $\{\{E, F\}\}$. The fact that the state B has a conditional probability of .80 given state E is accidental, as far as the theory is concerned. Yet, from our perspective, this fact is far from accidental, since E just *is* the proposition that B has a conditional probability of .80.

An informational theory of content which deals only with unstructured propositions will, however, fail to pick up *all* regularities based on the internal structure of propositions. Just as the informational relationship between *probably* P and P is arbitrary, from the point of view of the theory, so is the informational relationship between the propositions that *John loves Mary* and *John loves someone*, or that *Eric owns a dog* and *Eric owns an animal.* Since the theory is defined at the level of unstructured propositions, informational relationships which are predictable from the internal structure of the propositions cannot be captured within the theory.

Returning to our original dilemma, the intuition that informational signals can carry probabilistic information has been reconciled with the restriction that a signal can only carry a proposition if the conditional probability of that proposition, given that signal, is exactly 1. There is no need to treat probabilistic information contents any differently from non-probabilistic information contents. There *is* a need to define distinct informational sources for each.

In Chapter 1, Dretske's account of information content was introduced and it was proposed that it be recast in propositional terms. In Chapter 2, this propositional account leads naturally to a more fundamental reworking of Dretske's account.

Chapter 2: A Propositional Account of Information Content

2.1 Introduction

Dretske's account of informational content is intended to apply only to propositions of the form *s* is *F*. The revised account applies to any proposition *P*, and the conflation of objects with sources and properties with states has been expunged. However, the account of information content is still based on Dretske's probabilistic formulation. In this section, some rather more radical revisions are proposed. These are intended to both generalise and simplify the existing account. Our final formulation excises the notion of probability and models informational systems using the propositional calculus. The information content of a proposition *P* becomes simply the set of all propositions derivable in the system after the assertion of *P*, that were not derivable before the assertion of *P*. The path from information theory to the propositional calculus turns out to be surprising direct.

Dretske motivates his account of information content as a natural extension of Shannon and Weaver's quantitative account of information. However, neither Dretske's account of information content, or the revised account, appear to presuppose the full apparatus of the theory. The definitions are as follows:

> "*Informational content*: A signal *r* carries the information that *s* is *F* = The condition probability of *s*'s being *F*, given **r* (and *k*), is 1 (but given *k* alone, less than 1)" (Dretske, 1981:65)
>
> *Informational content 3*: A signal *Q* carries the information that P, where P is any proposition = The conditional probability of *P* given *Q* is 1.

There are two relevant points to note about these definitions. Firstly, they make no reference to probabilities other than 1; secondly, they make no reference to the notion of an informational source. I shall examine the role of probability in a Dretskian approach to information content in the remainder of this section. In the next section, I shall suggest that informational sources should be taken as secondary to information states (propositions), and that the theory of information content should be framed purely in terms of the latter notion.

2.2 Does Information Content Need Information Theory? I: Probability and Information Content

A signal *Q* carries a proposition *P* just when the probability of *P*, given *Q*, is 1. Hence, to derive the information content of the states of an informational system, all that is required is a specification of the conditional probabilities between states which are exactly 1. What about the specification of absolute probabilities? If we want to capture the intuition that a proposition cannot be learned from a signal if it has probability 1, then we must specify which informational states have absolute probability 1. From the point of view of the theory of information content, the values of all the other conditional and absolute probabilities (those less than 1) are irrelevant.

This suggests that, from the point of view of specifying information content, informational systems may be economically specified. Below a formal account of informational systems will be proposed, in terms of propositional logic. I shall argue that this simple apparatus allows us to capture the intuitions underlying Dretske's approach. Although we are not quite yet in a position to introduce the formal approach, the kind of simplified specification of an information system that might suffice may nonetheless be illustrated (using somewhat suggestive notation). Suppose that our informational system consists of four informational sources. Source $\{\{A, B, C, D\}\}$ corresponds to the choice of one of four knobs on the cooker; $\{\{E, F, G, H\}\}$ corresponds to a jet of gas emerging from one of four gas rings. Each knob turns on a single gas jet, and no two knobs turn on the same gas jet. $\{\{I, J, K, L\}\}$ corresponds to the cooker's being in the kitchen (which it invariably is), the bathroom, the bedroom, and in the garden shed. $\{\{M, N\}\}$ corresponds to the cooker's being an electric cooker (which it is not) or a gas cooker (which it is).

$\{\{A, B, C, D\}\}$
A, *B*, *C*, *D* form an informational source

$\{\{E, F, G, H\}\}$
E, *F*, *G*, *H* form an informational source

$\{\{I, J, K, L\}\}$
I, *J*, *K*, *L* form an informational source

$\{\{M, N\}\}$
M, *N* form an informational source

I

state *I* has absolute probability 1

N

state *N* has absolute probability 1

E -> *A*

the conditional probability of *A*, given *E* is 1

F -> *B*

the conditional probability of *B*, given *F* is 1

G -> *C*

the conditional probability of *C*, given *G* is 1

H -> *D*

the conditional probability of *D*, given *H* is 1

Such a specification captures what is required to map out the information flow within the informational system. Of course, since we have presented only a flavour of what the formalisation of an informational system might look like, rather than a formalisation proper, there are variety of unresolved technical questions. For example, is it legitimate to write *X* -> *I*, for any proposition *X*, since given that the absolute probability of *I* is 1, the probability of *I* conditional on *X* must be 1? Indeed, should informational sources in which one state has probability 1 be treated as legitimate? Should there also be a preclusion relation, -|, such that *X* -| *Y* if the conditional probability of *Y*, given *X*, is 0? How can we specify the information contents of signals which specify that a source is in either of, say two, states? Suppose that a state *X* has a probability 1, given that one source is in state *Y*, *and* another source is in state *Z*. How is this to be expressed in our notation? These issues will be resolved when the formalisation is introduced.

The discussion so far may be summarised as follows. Intuitions about informational content, even when that content is probabilistic (in the sense used above), may be captured with reference to absolute and conditional probabilities of exactly 1 (and, perhaps 0, if we countenance the -| relation). Hence, from the point of view of informational content, an informational system may be specified by listing the states (propositions) with probability 1 (if we countenance such states at all), and specifying the probabilistic dependencies between states of different sources of value 1 (and perhaps 0), by some relation "->" (and perhaps "|-"). That is, we need specify only the *determinate* dependencies between informational states. All reference to probabilities may be excised without affecting the scope and explanatory power of our notion of informational content. This excision constitutes a considerable departure from the spirit of the probabilistic treatment of information due to Shannon and Weaver. It is not that a Dretskian account of informational content is in any way at odds with information theory. It is rather that Dretske's treatment of informational content and the probabilistic apparatus of information theory seem to have little to say to one another. Rather than providing the basis for Dretske's treatment, the probabilistic aspect of information theory appears to have little relevance to it.

Despite the fact that the treatment of information content does not use the concept of real valued probability, which is central to an information theoretic approach, the two approaches *do* appear to have significant commonalities. In particular, the basic objects of both are informational sources: sets of mutually exclusive and exhaustive states. In the next section I shall argue that this commonality is more apparent than real.

2.3 Does Information Content Need Information Theory? II: Sources and States

Both Dretske's definition of informational content and the present, revised definition are concerned only with the signal, Q, and the proposition carried P. There is no mention of the other states of the receiver (of which Q is the actual state), or other states of the source (of which P is the actual state). All that matters is that the conditional probability of P, given Q, is 1. In information theory, the specification of an informational system involves the specification of informational sources, and informational sources are specified by listing their states (and the probabilities associated with each state). There are no other states than these. That is, states have no existence independent of the informational sources to which they belong.

Yet it seems that the informational link between Q and P may be recognised by the account of informational content regardless of the nature of the informational sources to which Q and P belong.

There is an analogous direct link between some state of the source and some state of the receiver in information theory. A quantity of information, $I(S_i)$, *is* associated with a single state, S_i, dependent only on its probability, $p(S_i)$, and hence independent of the source to which it belongs:

$$I(S_i) = \log (1/p(S_i))$$

$I(S_i)$ is the amount of information generated by a source's being in a particular state S_i. This is termed the *surprisal* of that state of the source S_i (1.2 above). Information theory is not primarily concerned with the amount of information generated by any particular state, but rather with the *average* amount of information generated or transmitted in an informational setup. The notion of an informational source (a set of mutually exclusive and exhaustive states) is introduced to allow the quantification of this average value. The average amount of information at a source is just the sum of the surprisals of each state of that source, weighted according to the probability of that state.

$$I(S) = \Sigma_i \, p(S_i) \, I(S_i)$$

I(S) is the average amount of information generated by the source S. Since information theory is, in practice, concerned with this average quantity, rather than the information generated by specific events, it is natural to specify an informational system by specifying the informational sources (source and receiver). States need not have existence independent of the propositions to which they belong, since it is only in the context of an informational source that a state can play a role in determining average quantities of information.

The study of informational content is concerned with specific information flow between propositions (states), *P* and *Q*. In the present reformulation, propositions, rather than informational sources, will be elementary. Any mutually exclusive and exhaustive set of sources constitutes an informational source. Hence, a proposition may belong to several sources, or to no sources at all.

2.4 Informational Systems - A Propositional Approach

So far, the account of informational content treated only unstructured propositions. However, if all propositions are treated as atomic, then the theory will be unable to capture certain important informational generalisations. For example, suppose that the fact that there is a frantic scratching sound at the door carries the information that the cat is at the door *and* that the cat is being chased by the dog. Then the scratching must carry the information that the cat is outside. Suppose that the cat running up the tree carries the information that *either* it is being chased by the dog, *or* that it is chasing a squirrel. Then the cat running up the tree *and* the dog being in his kennel carries the information that the cat is chasing a squirrel. Suppose that the fact that there is food on the table carries the information that the dog comes indoors, then the fact that the dog does *not* come indoors carries the information that there is *not* food on the table. If we treat conjunctive, disjunctive and negative propositions as atomic, then the informational relations above will be purely accidental. In order to capture these informational generalisations, we shall represent complex propositions as Boolean functions of their constituents: P & Q, P v Q, -P and so on. Notice that informational relations between propositions which are below the level of atomic propositions are accidental on this formulation: for example, if a signal carries the information that all men are mortal it carries the information that Socrates is a man. This generalisation can only be captured if we analyse propositions at the level of the objects and properties. (The propositional treatment given here may be naturally extended to cover such cases, by employing a richer logic).

The atomic propositions of an informational system might be: that the coin falls heads; that the coin falls tails; that the coin falls on edge; that there is a shout of "Hurrah!"; that there is a shout of "Oh no!"; that there is a shout of "Good grief!". Then the system will also have the propositions: that the coin falls heads *and* there is a shout of "Hurrah!"; that the coin does *not* fall tails; that there is a shout of "Oh no!" *or* (there is a shout of "Good grief!" *and* the coin does *not* fall tails); and so on. The atomic propositions may be arbitrarily Booleanly conjoined to produce the unbounded set of all propositions in the idealisation. These may be characterised by a simple inductive definition.

Let the language L be defined as follows:

Let **P** = P_1,.....P_N,.... be the propositional letters. These correspond to the atomic propositions of the information system.

Let the propositional connectives be -, v, &, ->, <-> (the additional connectives " ->" and "<->", may be freely added, since they can be defined in terms of the other connectives, and will later prove useful).

Each wff of L corresponds to a possible proposition of the informational idealisation.

Formation Rules

1) Any propositional letter is a wff

2) i) if A is a wff, so is -A

ii) if A, B are wffs, so are

$$A \vee B,$$
$$A \,\&\, B,$$
$$A \text{ -> } B,$$
$$A \text{ <-> } B$$

3) Nothing else is a wff.

This definition omits parentheses for simplicity. Strictly speaking, they are required to specify complex syntactic forms unambiguously. For example, (A & B) v C must be distinguished from A & (B v C).

An informational source is a set of mutually exclusive and exhaustive propositions. The set $\{A_1, A_2,... A_i, ... A_n\}$ is a source if either A_1 is holds and the rest do not, or A_2 holds and the rest do not... or A_n holds and the rest do not. Expressing this in propositional logic:

$\{A_1, A_2,... A_i, ...A_n\}$ is a source iff

$$[\ A_1 \ \& \ \text{-}(A_2 \vee A_3 \ ... \ A_n)\ ] \vee$$
$$[\ A_2 \ \& \ \text{-}(A_1 \vee A_3 \ ... \ A_n)\ ] \vee ...$$

$$[\ A_i \ \& \ \text{-}(A_1 \ ... \ A_{i-1} \vee A_{i+1} \ ... \ A_n)\ ] \vee ...$$

$$[\ A_n \ \& \ \text{-}(A_1 \ ... \vee A_{n-1})\ ]$$

If a set $\{A_1, A_2,... A_i, ...A_n\}$ is source we enclose it is double parentheses: $\{\{A_1, A_2,... A_i, ...A_n\}\}$.

2.5 Specifying an Informational Idealisation

Having specified the propositions that are part of an informational system, we now turn to specifying the informational properties which characterise a particular idealisation. First we introduce the basic idea via some examples. Then I shall present a more formal account.

Suppose that the tossed coin may fall heads, tails or balance on edge $\{\{H, T, B\}\}$ and that the shout may be "Hurrah!", (if the coin is heads) or "Oh No!" otherwise {{*Hurrah*, *Oh_no*}}. We assert

{{*H*, *T*, *B*}}
{{*Hurrah*, *Oh_no*}}

as axioms of the system (strictly speaking, we assert the lengthy formulae of propositional logic to which these are equivalent). Further, we wish to capture the dependencies between the states of these sources:

Hurrah <-> *H*
Oh_no <-> (*T* v *B*)

A set of formulae closed under deduction is called a theory. The theory induced by these axioms, that is, their deductive consequences, characterises the informational system. Some of these consequences are:

Hurrah -> *-T*
Hurrah -> (*-T* & *-B*)
Hurrah <-> *-Oh_no*
{{*Hurrah*, *T*, *B*}}
{{*Oh_no*, *H*}}
{{(*Hurrah* & *H*), *T* v *B*}}...

There are unboundedly many sets of axioms which induce the same theory. Thus there are unboundedly many sets of axioms with which the informational system may be specified. The choice of which subset of the formulae of the theory are taken as the axioms, and which are consequences of these axioms, is arbitrary. Let us now give a more formal exposition.

Assume some Gentzen type formulation of the rules of proof of the classical propositional calculus. In a Gentzen type formulation the proof rules are of the form $\Delta \vdash \alpha$. That is, the basic relation is is that of syntactic implication between sets of sentences Δ and a single sentence α. This is important in defining a theory, below. (By contrast, in a Hilbert formulation, the rules are of the form $\vdash \alpha \rightarrow \beta$. That is, the basic relation is that of material implication between *single* sentences of L.)

If Δ is a set of wffs,

$[\Delta] = \{\alpha | \Delta \vdash \alpha\}$ is the theory generated by the set of sentences Δ.

A theory is a set of sentences closed under implication: if some set of sentences of the theory imply some further sentence, then that too must be in the theory. The notion of a theory will prove important below.

So an informational setup is captured by specifying axioms of propositional logic which describe the informational structure of the setup. Let us reconsider the example of the coin and the shout. Suppose that a coin may fall heads, tails or may balance on edge (*H*, *T*, *B*). An observer shouts "Hurrah!" (*Hurrah*) just if the coin falls heads, and "Oh no!" (*Oh_no*) otherwise. In this case, there are two natural informational sources. Since the coin must fall heads, tails or on edge, but can only fall one way, {{*H*, *T*, *B*}} may be taken as an axiom. Similarly, the shout must be exactly one of "Hurrah!" and "Oh No!" and so {{*Hurrah*, *Oh_no*}} may be taken as an axiom. Now let us capture the information dependencies between the way the coin falls and the shout emitted. There is a shout of "Hurrah!" if and only if the coin falls heads: *Hurrah* <-> *H*. There is a shout of "Oh no!" just when the coin falls tails or on edge: *Oh_no* <-> (*T* v *B*). There are indefinitely many additional informational properties that we might add as axioms. For example, if the coin falls tails, there is a shout of "Oh no!": *T* -> *Oh_no*. However, this follows from the other axioms (it is a trivial consequence of *Oh_no* <-> (*T* v *B*)), and so it need not be added. The informational properties of the system may be captured the axioms and their consequences - the theory that the axioms induce. We shall sometimes refer to this theory as the *information state*. If the set of axioms is Δ, the information state is the theory generated by those axioms, [Δ]. In this case,

$$[\Delta] = [\{\{H, T, B\}\}, \{\{Hurrah, Oh\_no\}\}, Hurrah \leftrightarrow H, Oh\_no \leftrightarrow (T \vee B)]$$

Tracking

If two propositions track, then if one holds then the other must hold and vice versa. In the above example, *Hurrah* and *H* track, and this is captured by the axiom *Hurrah* <-> *H*. In general, we shall say that propositions *P* tracks proposition *Q*, given some set of axioms Δ, just in case,

$$\Delta \vdash P \leftrightarrow Q$$

Clearly, this definition is symmetrical - *P* tracks *Q* just when *Q* tracks *P*.

2.6 Change and Information Flow

So far, we have assumed that the axioms of an informational system are fixed. Yet in the study of the generation and flow of information it must be possible to express change. Suppose that there is a yell of "Oh no!". This may be added to the axioms Δ to produce a new set of axioms, Δ'. The yell of "Oh no!" will have considerable informational ramifications. For example, if the yell was "Oh no!", the coin must either have fallen tails or balanced on edge *T* v *B*, and cannot have fallen heads -*H*. These ramifications are consequences of the theory, [Δ'] generated by the new set of axioms, Δ, *Oh_no*.

[Δ', *Oh_no*] = [{{*H*, *T*, *B*}}, {{*Hurrah*, *Oh_no*}}, *Hurrah* <-> *H*, *Oh_no* <-> (*T* v *B*), *Oh_no*]

It is easy to show that, for example, *T* v *B* and -*H* are consequences of Δ, *Oh_no* and hence members of [Δ, *Oh_no*].

1. Δ, *Oh_no* |- *Oh_no*	(axiom)
2. Δ, *Oh_no* |- *Oh_no* <-> (*T* v *B*)	(axiom)
3. Δ, *Oh_no* |- *T* v *B*	(from 1, 2)

Q.E.D

1. Δ, *Oh_no* |- *Oh_no*	(axiom)
2. Δ, *Oh_no* |- {{*Hurrah*, *Oh_no*}}	(axiom)
3. Δ, *Oh_no* |- -*Hurrah*	(1, 2)
4. Δ, *Oh_no* |- *Hurrah* <-> *H*	(axiom)
5. Δ, *Oh_no* |- -*H*	(3, 4)

Q.E.D.

Fresh Consequences and Informational Content

These are all *fresh* consequences of the system. That is, they are consequences of Δ, *Oh_no*, but not Δ alone. They all seem to be propositions that can be *learned* from the presence of the new premise *Oh_no*. Surely it is just these new consequences which are the information that is carried by the signal. Indeed, the notion of fresh consequence seems to capture, in our propositional theory, Dretske's notion of informational content.

Dretske's account of information content is as follows:

"*Informational content*: A signal r carries the information that s is F = The condition probability of s's being F, given r (and k), is 1 (but given k alone, less than 1)" (Dretske, 1981:65)

So, according to Dretske, the proposition that the coin fell tails or balanced on edge is *carried by* the shout's being "Oh no!". For the probability that the coin fell tails or balanced on edge is 1, given that the shout is "Oh no!" (and k), but is less than 1, given k alone. On the propositional account, the proposition that the coin fell tails or balanced on edge is a *fresh consequence* of the shout's being "Oh no!". For T v B is a consequence of *Oh_no* (and Δ), but is not a consequence of Δ alone. Dretske's condition that the conditional probability is precisely 1 is replaced by the constraint that the proposition carried is a *consequence* of the signal (and the axioms of the current informational state). Dretske's stricture that this information cannot already be known, which was our remaining motivation for the presence the parenthetical k in the definition of informational content, corresponds to the restriction that the proposition carried is a *fresh* consequence. So, as promised in I.6, k may be eliminated without loss.

The notion of fresh consequence may be formalised straightforwardly. Firstly, we define the *full* informational content of a signal to be just the set of consequences of the signal (and the current axioms of the system) which are not consequences of the current axioms alone. Formally,

The *full* informational content, $S(\alpha)$, of α

$$= \{[\Delta, \alpha]\} - \{[\Delta]\}$$

The full content of a signal (proposition) is the set of all *fresh* consequences. Since, for any formula P, there are unboundedly many logically equivalent formulae (for example, P v P, P v P, P v P v P, and so on), if $S(\alpha)$ is non-empty, it will be unbounded.

Full content is, of course, a function of both the current axioms of the system (Δ) and the axiom added (α). Hence, it does not make sense to ask what the full content of a signal is, without specifying the state of the system at which this is to be evaluated.

α carries the information that A iff A is an element of $S(\alpha)$.

More generally, we say that

α carries the information that P where P is a subset of $S(\alpha)$.

So, a signal carries all and only propositions which are members of the full informational content and all and only sets of propositions that are subsets of the full informational content. Of course, what information a signal α carries is dependent on the current axioms of the system, Δ.

Does the propositional reformulation really capture Dretske's informational content? Let us consider how the revised account treats two examples that Dretske considers to be particularly important. The first requires that the account handle disjunctive contents; the second involves the apparent "knowledge relativity" of informational properties.

Recall Dretske's example of a group of 8 workers who must choose which of them is to perform some unpleasant task, and write the name of the unlucky worker on a memo to the manager. In one scenario, they decide that they will write Herman's name on the memo if Herman is selected or if Shirley is selected (in deference to Shirley's delicate health). As it happens Herman is selected, and so his name is written on the memo. Dretske remarks as follows:

> "...communication theory told us that the note carried only 2 bits of information about which employee had been selected... As far as this quantitative theory is concerned, the memo could carry a variety of different messages as long as these messages have a measure of 2 bits. So, for example, the memo might carry the information *that either Herman or Shirley was selected* (2 bits) or it might carry the information *that either Herman or Donald was selected* (2 bits). Both of these possible messages are *true* (since Herman was selected)... Our definition of a signal's propositional content neatly distinguishes between these two possible messages. It fixes on *Herman* or *Shirley* as the content rather than *Herman* or *Donald* because the former possibility has a probability of only .5." (Dretske, 1981: 68)

It was argued that this example is beyond the scope of Dretske's account and requires a propositional treatment. The formal propositional definition assigns the appropriate informational content to Herman's name being on the memo.

There are two sources: the employees must choose precisely one of eight possibilities, A, B, C, D (Donald), E, F, S (Shirley), or H (Herman); the memo has exactly one of seven possible messages: A', B', C', D', E', F', H' (Herman's name on the memo). So we have the following two axioms:

1. {{A, B, C, D, E, F, S, H}}
2. {{A', B', C', D', E', F', H'}}

The states of the two sources are linked such that each state of the memo corresponds to just one employee, except if Herman's name is on the memo (H'), when either Herman (H) or Shirley (S) may be chosen. Formally, this may be rendered:

3. A' <-> A
4. B' <-> B
5. C' <-> C
6. D' <-> D
7. E' <-> E
8. F' <-> F
9. H' <-> S v H

So, before the name on the memo is decided, the information state is [Δ], where,

> Δ = { {{A, B, C, D, E, F, S, H}}, {{A', B', C', D', E', F', H'}}, A' <-> A, B' <-> B, C' <-> C, D' <-> D, E' <-> E, F' <-> F, H' <-> S v H }

If Herman's name appears on the memo, then the axiom

10. H'

is asserted. The new information state is [Δ, H']. By our definition, a proposition P is carried by Herman's name being on the memo (H'), if P is in the set [Δ, H'] - [Δ].

Let us consider whether Herman's name appearing on the message carries the information that H (Herman was selected), H v S (Herman or Shirley was selected) or H v D (Herman or Donald was selected). Plainly, none of these are consequences of Δ, since any of the employees might have been selected. S v H *is* a consequence of Δ, H':

1. Δ, H' |- (H' <-> S v H)	(axiom)
2. Δ, H' |- H'	(axiom)
3. Δ, H' |- S v H	(1, 2)

By hypothesis, Δ, H' is consistent with Shirley being selected. If Shirley is selected, then H (Herman is selected), and H v D (Herman or Donald is selected) do not hold. So Δ, H' can not have H or H v D as consequences. Hence, while S v H is carried by Herman's name being on the memo, H and H v D are not. So the propositional account gives just the result that Dretske recommends.

Now let us turn to Dretske's shells and peanut example. This is intended to illustrate that the information carried by an event (e.g. the lifting of shell 3) is relative to the knowledge of the observer. Dretske attempts to capture this by introducing the parenthetical *k*. We argued above (section I.6) that the knowledge of the observer should not be treated as part of the theory. Rather the informational idealisation appropriate for modeling the situation is sensitive to the knowledge of the observer. Since informational properties are idealisation relative, the information that an event carries is derivatively sensitive to the observer's knowledge. Does our formalism actually generate intuitively appropriate predictions?

Let us call the basic propositions are S1, S2, S3, S4 (where S_i is the proposition that the peanut is under shell i). Since the peanut must be under some shell but cannot be under more than one, exactly one of S1, S2, S3, S4 must hold. So {{S1, S2, S3, S4}} is an axiom. When I come in to the room for the first time, I know only that the peanut is under one the four shells. Hence, an idealisation appropriate for modeling my point of view need have no further axioms. If I am shown that shell i is empty, then my idealisation must be revised by adding the axiom $-S_i$ to the current informational state. Hence, after I have been shown that both S1 and S2 are empty, the current informational state is Δ, where:

$$\Delta = \{ \{\{S1, S2, S3, S4\}\}, -S1, -S2\}$$

Recall that I see that shells 1 and 2 are empty *before* you come in to the room. Hence, we should distinguish the idealisation appropriate for me, Δ_{me}, and the idealisation appropriate for you, Δ_{you}. Both idealisations include {{S1, S2, S3, S4}}, but only my idealisation includes the additional axioms -S1 and -S2.

$$\Delta_{me} = [\{\{S1, S2, S3, S4\}\}, -S1, -S2]$$

$$\Delta_{you} = [\{\{S1, S2, S3, S4\}\}]$$

Suppose that we are both shown that shell 3 is empty. This carries different information for you and me. Hence, the full informational content under the two idealisations are, respectively, for me,

$$[\{\{S1, S2, S3, S4\}\}, -S1, -S2, -S3] - [\{\{S1, S2, S3, S4\}\}, -S1, -S2]$$

and, for you,

$$[\{\{S1, S2, S3, S4\}\}, -S3] - [\{\{S1, S2, S3, S4\}\}]$$

Under my idealisation, S4 is part of the full information content. Intuitively, before I see that shell 3 is empty, I do not know that the peanut is under shell 4 (S1 does not follow from the axioms); afterwards, the peanut can *only* be under shell 4 (S4 *does* follow from the axioms *and* -S3). So S4 is part of the informational content of -S3, under my idealisation. By contrast, on the idealisation appropriate to you, S4 does not follow from the addition of -S3 as an axiom. The peanut could still be under shell's 1, 2 or 4. So, while S1 v S2 v S4 *is* part of the informational content of -S3, S4 is not. Hence, the "relativity to knowledge" is captured by the relativity of the information carried by a signal to the current informational state of the system. Thus Dretske's parenthetical *k* may be dispensed with.

Dretske notes that on the idealisation appropriate for me the signal -S3 carries 1 bit of information, and whereas on your idealisation it carries just 0.42 bits of information. Intuitively, since I have more information than you have, I can exploit the new axiom more fully. This suggests that the information that the signal carries for me includes all the information that it carries for you.

However, the signal also carries information under your idealisation that it does not carry under mine. For you, -S2 carries the information that -S2 v -S3. However, since my idealisation has -S3 as an axiom, -S2 v -S3 is a derivable *before* the signal -S2 is added. So -S2 v -S3 is not part of the informational content of the signal. Informally, since I know more than you, the signal may carry propositions that are news to you, but that are not news to me (and so do not count as part of the information content under the my idealisation).

2.7 Summary

In this section, a simple propositional formalisation of some of Dretske's ideas about information generation and information flow has been presented. A signal, α, carries a proposition P, if P is a *fresh consequence* of α. That is, if P does not follow from the current set of axioms Δ, but *is* a consequence of Δ, α. This definition within our propositional account of information appears to capture the essence of Dretske's informal, probabilistic formulation of information content. When applied to two key examples, the propositional approach is shown to give the same results as Dretske's informal analysis, as predicted. Indeed, the propositional definition is more parsimonious. For there is no need to build "knowledge relativity" in to the definition, using some device analogous to Dretske's parenthetical *k*. Rather, knowledge relativity is a *consequence* of i) that considerations of what the observer knows affect the choice of an appropriate informational idealisation; ii) whether or not a proposition is carried by a signal is dependent on the informational idealisation chosen.

Since the full content of a signal (if non-empty) is an unbounded *set* of propositions, an informational signal has (very) many information contents. In contrast, according to the intuitive notion of the *semantic* content, the semantic content of, say, an utterance, is typically taken to be unique. So a reconstruction of semantic content requires a more restricted notion than information content. To this end, Dretske introduces an important distinction between information carried in *analog* and *digital* form. The more restricted notion of information carried in digital form is the basis for the reconstruction of semantic content. It is to the analog-digital distinction we turn in Chapter 3.

Chapter 3: The Analog-Digital Distinction

3.1 Traditional Accounts of the Analog-Digital Distinction

In Chapter 2, we analysed Dretske's notion of informational content and gave an alternative account to his probabilistic formulation in terms of the propositional calculus. In this chapter, we turn to Dretske's analog digital distinction. This distinction is fundamental to Dretske's account of how semantic content can be derived from informational dependency. Further, it is the basis for Dretske's approach to perception, belief and knowledge. In particular, Dretske takes the distinction between information carried in analog and digital form to provide a foundation for a sharp distinction between sensory or perceptual processes on the one hand, and cognitive processes on the other. In Chapter 4 we shall examine this claim in detail, and discuss the way in which the notion of information content can be applied to elucidate the nature of information processing. In the present chapter, the discussion will primarily focus on various difficulties with, and adjustments to, Dretske's analog-digital distinction. In the previous section we rendered Dretske's account of information in terms of the propositional calculus. In the present section, I show how the analog-digital distinction may be straightforwardly cast in these terms.

Before outlining Dretske's analog-digital distinction, let us survey various ways in which the distinction has been characterised. There are almost as many variants of the analog-digital distinction as there are authors discussing the topic. Although, there are certain core intuitions about what is analog and what is digital, making these intuitions precise has proved extremely difficult. For example, the display on a digital watch is paradigmatically a digital representation of the time. The position of the hands on Big Ben are a paradigmatically analog representation of the time. A linguistic formula carries information in digital form; a photograph carries information in analog form. A VAX is a digital computer; a set of resistors and capacitors used to directly model the differential equations of some system is an analog computer. Chess is digital, shove ha'penny is analog. The analog-digital distinction has been taken to apply to the way in which some information is conveyed, to systems of representation, to styles of computation and so on. In the rest of this section, I shall try to draw out some of the main threads in recent discussions of the distinction.

1) Minsky (1967) gives a characterisation from the point of view of computer science:

> "Computer scientists often talk of a distinction between "digital" and "analog" quantities, where a digital quantity is one that takes on only one of a fixed, finite set of values while

an analog quantity has values from a continuum, e.g., the voltage measured across a resistor or capacitor. The term "analog" comes from the era in which most "computers" were electrical or mechanical devices designed to approximate the differential equations of continuous physical systems, in such a way that one could think of an analogy between the physical behaviour of the computer and the other system. In this sense, [in automata theory] we are deciding to develop our theory around ideas of finite mathematics rather than infinite, continuous, differential mathematics." (Minsky, 1967:29)

From the above passage, distinctions on four dimensions may be drawn:

i) continuous versus discrete quantities

ii) computation by analogy versus non-analogical computation

iii) dynamical systems (of electrical or mechanical components) versus formal systems

iv) discrete (finite) mathematics versus continuous mathematics

All of these aspects have been elaborated by other authors, as we shall see.

2) Banks (1977) draws out two readings of the distinction (senses i) and ii) above) which he takes to be relevant to the concerns of psychology:

"The term "analog" has two different meanings when applied to models of mental activity. The first meaning comes directly from the idea of analogy. It indicates that the mental processes themselves model in some way the events or objects being thought about, and perceptual mechanisms may even be used internally. Analog models of this type are generally called image processing models.

The other sense of "analog" implies only that mental processing operates on a continuous representation of some kind. This sense derives from the first, since a complete mental representation of perceptual events that map, one for one, every possible sensory level would have to be a continuous representation. A continuous representation is generally considered to be one in which any two points, arbitrarily close together, still have a third point placed between them. However, a weaker notion that retains the idea of a mapping could preserve the interval scale (or ratio scale) properties of the perceptual continuum but not have the accuracy that would be required to represent separately every possible level of it." (Banks, 1977:118-119)

Strictly, the definition that Banks gives corresponds to the mathematical notion of denseness rather than continuity. The rationals are dense (there is a rational which lies between any two rationals), but not continuous (since there are also irrationals between any two rationals). It is the notion of denseness which is used by Goodman (1968) in his definition of analog versus digital symbolic schemes.

3) The notion analog mental processes as processes of *analogy* is developed in the work of Roger Shepard.

Shepard and his associates (e.g. Shepard, 1978; Shepard & Cooper, 1982) conducted an important series of experiments in which subjects are presented with a pair of 2 dimensional plane figures, or 2 dimensional projections of 3 dimensional figures. The pair consists either of identical figures, at different angles of orientation (in 2 or 3 dimensions), or of mirror image figures, also at various angles of orientation. The task is to distinguish the identical pairs from the mirror image pairs as rapidly as possible. If the pairs were identical, rather than mirror images, Shepard found a linear relationship between the angle between the orientation of two shapes and the time taken to classify them as the same. If the shapes could be manually manipulated, a natural way to solve the problem would be to physically rotate the shapes until they are aligned. Although the shapes cannot be physically rotated, it seems that subjects instead perform a continuous "mental rotation". This hypothesis is supported by the finding that if a shape in an intermediate orientation is presented while the subject is in the middle of "mentally rotating" a shape, there is a very fast same/different judgement for the interposed shape. It is argued that the rotated shape really does pass through the intermediate orientations and so can be immediately compared with the interposed shape.

The conjecture that subjects mentally rotate is that the temporal evolution of an actual physical rotation of one of the shapes is mentally simulated. Shepard argues that mental imagery in general typically involves the simulation of temporal evolution of processes in the world. The interpretation of these results and related results on the timing of the mental scanning of images (Kosslyn, 1980) and their relevance to the analog-digital distinction has been controversial (Kosslyn, Pinker, Smith & Schwartz, 1979; Pylyshyn, 1981).

Shepard (Shepard & Chipman, 1970; Shepard, 1975) argues that the crucial question surrounding the debate on the nature of mental imagery is whether or not there is a "second-order isomorphism" between the structure of the world and the structure of the mental processes mediating computation about the world. Consider how the positions of the planets in two weeks time might be predicted. If the initial conditions of the solar system and the laws of Newtonian gravitation are applied, then a solution may be calculated analytically. An alternative approach is to use an iterative numerical algorithm, which updates the state of the planetary system by small increments. Such an iterative model passes through the intermediate state corresponding to the intermediate state of positions of the planets. In both cases, the correct output is obtained (there is a "first-order isomorphism" between the modeled system, and the modeling system). Only in the latter case is there an isomorphism between the intermediate states of the modeled system, and the modeling system. This is what Shepard calls a second-order isomorphism between the modeled system and modeling system. Processes which preserves a second order isomorphism are termed *analog* processes.

Pylyshyn (1981, 1984) has argued against Shepard's characterisation of analog .processes. For Pylyshyn, what it is crucial is not *that* a second order isomorphism is maintained with the modeled system, but *how* such an isomorphism is generated. In an iterative computer simulation on a conventional computer of the movement of the planets. The isomorphism is the result of the application of rules to items in propositional database. The modeling process (the processing of the computer) is a product of a stored symbolic program running on a conventional digital computer. Nonetheless, for Shepard, such a computation is analog. Pylyshyn, on the other hand, claims the computation should be seen as digital. He claims that the substantive issue concerns the principles that underlie the computational process (such as transforming a mental image). For Pylyshyn the substantive issue is whether the process is governed by rules and representations or determined by the properties of the implementational substrate? Before we turn to Pylyshyn's own characterisation of the analog-digital distinction, let us consider David Lewis's treatment of analog.

4) Lewis (1971) takes the paradigm case of analog representation to be representation of numbers by physical magnitudes such as voltage, angle or length:

> "...*analog* representation of numbers is representation of numbers by physical magnitudes that are either primitive or almost primitive..." (Lewis, 1971:325)

where

> "We define a *primitive magnitude* as any physical magnitude that is expressed by a primitive term in some *good* reconstruction of the language of physics - good according to our ordinary standards of economy, elegance, convenience, familiarity." (Lewis, 1971:324)

and,

> "...physical magnitudes... are *almost primitive* [if] definable in some simple way, with little use of arithmetical operations, in terms of one or a few primitive magnitudes." (Lewis, 1971:324)

Lewis also gives a rather elaborate characterisation of digital. On Lewis's account the notions of analog and digital, while mutually exclusive are certainly not exhaustive.

If an analog representation of a number is directly tied to a physical magnitude, then the causal role of that representation may be mediated directly by the physical laws which apply to that magnitude, rather than indirectly via rules and representations. It is this difference in causal role that is the essence of Pylyshyn's characterisation of the analog-digital distinction.

5) Pylyshyn (1981) takes a digital computation to be based on rules and representations, which encode "tacit knowledge" about the domain of computation in propositional form. Pylyshyn (1980, 1984) argues claim that a substantial part of human mental activity has this character. For Pylyshyn, this is the force of treating cognitive processes as a species of cognition. On the other hand:

> "...an analog process... is one in whose behavior must be characterised in terms of intrinsic lawful relations among properties of a particular physical instantiation of a process, rather than in terms of rules and representations (or algorithms). Whenever people appeal to an "analog representational medium"... they take it for granted that this medium incorporates a whole system of lawfully connected properties or intrinsic constraints and that is precisely this set of properties and relations that determines how objects represented in that medium will behave." (Pylyshyn 1981: 157)

While Lewis stresses that analog *representations* must be encoded by physical magnitudes (the magnitudes over which physical laws are defined) Pylyshyn stresses that analog *processes* must operate in virtue of the "lawfully connected properties or intrinsic constraints" of the representational medium.

Pylyshyn (1979) has shown experimentally that there is an influence of the content of the image on the speed at which images are rotated. For example, subjects mentally rotate light objects faster than they can mentally rotate heavy objects. Pylyshyn argues that such effects undermine the view that mental rotation is mediated by the underlying physical properties of the medium of representation, since the properties of this medium should be independent of *what* is represented. In the terms of Pylyshyn (1984), the processes operating on mental images appear to be *cognitively penetrable* - that is, sensitive to the *content* of what is represented. Pylyshyn argues that cognitively penetrable processes must be governed by underlying rules and representations; their behaviour cannot be understood as a function of the implementational medium.

On Pylyshyn's reading of the analog-digital distinction, the very fact that the second order isomorphism between image and world is so close (that it is sensitive to the relevant physical properties of the particular objects being transformed) implies that mental imagery is based on tacit knowledge, and is hence digital.

6) For Pylyshyn, a digital process is one that is governed by rules and representations. Haugeland (1981) attempts to spell out what it is for a system to be rule governed. The characterisation of such *formal systems* is the basis of Haugeland's notion of "digital". The

account focuses on the syntactic, and not the semantic aspect of rules and representations. There need be no meaning attached to the syntactic tokens in a formal system.

> "A *formal system* is like a game in which tokens are manipulated according to rules, in order to see what configurations can be obtained. Basically, to define such a game, three things have to be specified:
> (1) what the tokens are;
> (2) what the starting position is; and,
> (3) what moves are allowed in any given position.
> [A formal system is]... entirely *self contained.* Only its own tokens, positions, and moves make any difference to it... the "outside world"... makes no difference whatsoever in the game. Second, every relevant feature of the game is *perfectly definite*; that is... there are no ambiguities, approximations or "judgement calls" in determining what the position is, or whether a certain move is legal... Third, the moves are *finitely checkable*, in the sense that for each position and each candidate move, only a finite number of things have to be checked to see whether the move would be legal in that position...we will say that a game or system that has all three properties is *digital.* All formal systems are digital in this sense." (Haugeland, 1981:6-7)

> "An analog device, on the other hand, doesn't even have clearly defined moves, rules and positions - though it may have states (which may change) and there is usually some way that it is supposed to work. The crucial difference is that in analog systems the relevant factors have not been defined and segregated to the point where it is always *perfectly definite* what the current state is, and whether it is doing what it is supposed to do. That is, there will often be slight inaccuracies, and marginal judgement calls, even when the device in working normally" (Haugeland, 1981:19)

7) Another characterisation of the analog-digital distinction focuses on the difference between idealisations which employ discrete versus continuous mathematics. Viewed as a symbol processing device, the conventional computer is a paradigm example of a discrete mechanised formal system. So it counts as a digital system in Haugeland's terms. However, from the point of view of the electrical engineer, a computer is an array of continuously varying electrical components. The behaviour of these components is appropriately described by a system of differential equations, rather than a set of formal rules. So it seems that whether a system is seen as digital or analog depends upon the kind of analysis adopted. This brings us to points iii) and iv) in Minsky's text: the distinction between formal and dynamical systems, and the concomitant application of discrete or continuous mathematics . The suggestion is that whether a system is analog or digital is determined by the kind of mathematical idealisation with which it is described. The centrality of this distinction between modes of mathematical analysis had been stressed by a number of authors (Rosen, 1985; Padulo & Arbib, 1974; Smolensky, 1988).

There is a deep cleavage between the methods of discrete mathematics (automata theory, category theory, logic, algebra and so on) and continuous mathematics (dynamical systems theory, field theory, analysis, differential calculus and so on). Despite the many analogies between the two branches of mathematics, discrete and continuous mathematical methods appear to analyse systems in fundamentally different ways. If a system (device, process) is analysed using discrete mathematics, then it is treated as having discrete states, and the temporal evolution of the system is described by a system of rules specifying the allowable transitions between states. That is, it is viewed as some kind of *automaton.* To adopt such an analysis is to model the system as a *digital* system. By contrast, if a system is analysed as a continuous system, it is modeled by specifying a vector field over a manifold (or equivalent) (Hirsch & Smail, 1974). Each point in the manifold is a state of the system, and the vector at that point specifies the change in the state of the system at that point. On this version of the analog-digital distinction, to adopt a dynamical analysis is to model the system as an *analog* system.

According to this view, the analog-digital distinction is, in the first instance, a distinction between species of idealisation, rather than kinds of system. However, the distinction may derivatively be applied to systems themselves. A system which is most appropriately idealised using discrete mathematics may be labelled *digital* and a system best modeled with continuous mathematics labelled *analog*. This derivative analog-digital distinction does not rigidly divide systems into disjoint classes - for, as we noted above, a computer may be viewed under a continuous idealisation (analog) by the electrical engineer, and a discrete idealisation (digital) by the computer scientist. Nonetheless, we may loosely categorise hourglasses and sliderules, on the one hand, as analog and quartz watches and pocket calculators, on the other, as digital.

In this section we have surveyed some of ways in which the analog-digital distinction has been drawn. In the next, we turn to Dretske's treatment.

3.2 The Analog-Digital Distinction: From General Laws to Specific Instances

Dretske notes that he uses the terms analog and digital in a slightly non-standard way:

> "The analog-digital distinction is usually used to mark a difference in the way information is carried about a variable property, magnitude, or quantity: time, speed, temperature, pressure, height, volume, weight, distance, and so on. Ordinary household thermometers are analog devices: the variable height of the mercury represents the variable temperature. The hands on a clock carry information about the time in analog form, but alarm clocks convert a preselected part of this into digital form.
>
> I am interested, however, not in information about properties and magnitudes and the various ways this might be encoded, but in information about the instantiation of these properties and magnitudes by particular items at the source. I am interested, in other words, not in how we might encode information about temperature, but in how we might represent

> the *fact* that the temperature is too high, over 100°, or exactly 153°. What we want is a distinction, similar to the analog-digital distinction as it relates to the representation of properties, to mark the different way *facts* can be represented. Can we say, for example, that one structure carries the information that *s* is *F* in digital form, and that another carries it in analog form?" (Dretske, 1981:136)

In the section 3.1 we outlined some of the many ways in which the terms "analog" and "digital" have been characterised. The analog-digital distinction has been taken to classify styles of computation, to distinguish continuous versus discrete phenomena, to distinguish between systems idealised by discrete mathematics from systems idealised by continuous mathematics and so on. In his account of the standard accounts of the analog-digital distinction, Dretske focuses on the reading which distinguishes continuous versus discrete methods of encoding the value of a property. The height of the mercury (continuous) encodes temperature in analog form; the on-off value of the thermostat (discrete) encodes the temperature in digital form; the position of the hands of a clock (continuous) encode the temperature in analog form; the on-off state of an alarm clock, or the reading on a digital watch encode the temperature in digital form. It is this set of intuitions which Lewis's account, described briefly in the previous section, attempts to capture (Lewis, 1971).

Dretske notes that he is "interested... not in how we might encode information about temperature, but in how we might represent the *fact* that the temperature is too high, over 100°, or exactly 153°". What Lewis gives is an account of what it means to say that, *in general*, the height of the mercury is a digital representation of temperature or that the state of the thermostat is an analog representation. Dretske notes that this account has nothing to say about informational content of *particular states*. What is it for a particular height of the mercury (say, 50 mm) to carry the particular information that it is 25°? What is it for a particular state of the thermostat (say, "off") to carry the information that the temperature is above 20°?

Yet there is a very natural way to introduce an analog-digital distinction for the way in which particular pieces of information are carried. The distinction in the particular case is inherited from the distinction in the general case. The *particular* information that it is 25° is carried in analog form if the magnitude concerned is encoded *in general* in analog form (according to a Lewis style definition). *Mutatis mutandis* for information carried in digital form. So the thermometer carries the information that it is 25° in analog form because thermometers encode temperature in analog form. The particular state of the thermostat on some occasion carries the information that it is over 20° in digital form, since, in general, the thermostat encodes temperature in digital form. The analog-digital distinction for particular pieces of information is precisely tied to an analog-digital distinction for the encoding properties and magnitudes. Notice that, on this account, there is no *informational* asymmetry between the way in which the thermometer and the thermostat carry information. The difference is simply inherited from a putative distinction between the character of their physical embodiments (roughly, continuous versus discrete, where the precise sense is fixed by an account such as Lewis's).

Rather than using Lewis's analysis of analog and digital, we might prefer to use the distinction between idealisations using discrete mathematics versus idealisations using continuous mathematics. The thermometer is naturally modeled as having a continuum of informationally relevant states (the height of the mercury is naturally modeled as a real number); the thermostat is naturally viewed as having just two informationally relevant states (on and off), and thus may be better modeled as a simple automaton. On this account, some particular state of a thermometer - say, with the top of the mercury column precisely at the 20° mark - would be said to carry the information that the temperature is 20° in *analog* form, since the state of the thermometer is one of continuously many states (under a natural idealisation). Similarly, some particular state of a thermostat - for example being *on* - would carry the information that it is below 20° in *digital* form, since the state of the thermostat is defined with respect to a discrete idealisation. Again, the analog-digital distinction for particular instances is simply inherited directly from the account of general analog-digital distinction.

So we have at least two natural ways of distinguishing information carried in analog and digital form. In both cases, the distinction between analog and digital information content is inherited from a distinction *extrinsic* to the account of information itself - where this account is provided by some analysis of the difference between analog and digital *systems*, such as we have discussed above. However, Dretske pursues neither of the approaches outlined above. Rather, he proposes a distinction *internal* to the theory of information content, based on none of the accounts of the analog-digital distinction that we have discussed. Dretske's distinction turns out to be very interesting and important, and much of the rest of his theory is founded upon it. The use of terms "analog" and "digital" is suggestive, but, I shall argue, misleadingly so.

3.3 Digitalisation, complete digitalisation and semantic content

Let us turn at last to Dretske's distinction between information carried in analog and digital form. First we must introduce the auxiliary notion of *nestedness*, which is simply the reverse of the *information carries* relation:

"The information that t is G is nested in s's being F = s's being F carries the information that t is G." (Dretske, 1981:71)

In propositional terms, this becomes,

B is nested in *A* when and only when *B* carries the information that *A*.

We are now in a position to draw the analog-digital distinction.

"...a signal (structure, event, state) carries the information that *s* is *F* in *digital* form if and only if the signal carries no additional information about *s*, no information that is not already nested in *s*'s being *F*. If the signal *does* carry additional information about *s*, information that is *not* already nested is *s*'s being *F*, then I shall say that the signal carries this information in analog form... Every signal carries information in both analog and digital form..." (Dretske, 1981:137)

How does this definition relate to our pretheoretic notions of analog and digital? Dretske explains how the definition distinguishes information carried in paradigmatically analog and paradigmatically digital form:

"To illustrate the way this distinction applies, consider the difference between a picture and a statement. Suppose a cup has coffee in it, and we want to communicate this piece of information. If I simply *tell* you, "The cup has coffee in it," this (acoustic) signal carries the information that the cup has coffee in it in digital form. No more specific information is supplied about the cup (or the coffee) than that there is some coffee in the cup. You are not told *how much* coffee there is in the cup, how large the cup is, *how dark* the coffee is, what the shape and orientation of the cup are, and so on. If, on the other hand, I photograph the scene and show you the picture, the information that the cup has coffee in it is conveyed in analog form. The picture tells you that there is some coffee is in the cup, the shape, size, and color of the cup, and so on."

I can say that *A* and *B* are of different size without saying how much they differ in size or which is larger, but I cannot picture *A* and *B* as being of different size without picturing one of them as larger and indicating, roughly, how much larger it is. Similarly, if a yellow ball is situated between a red and a blue ball, I can *state* that this is so without revealing where (on the left or on the right) the blue ball is. But if this information is to be communicated pictorially, the signal is necessarily more specific... For such facts as these a picture is, of necessity, an analog representation. The corresponding statements... are digital representations of the same facts." (Dretske, 1981: 137-8)

We shall consider the analog-digital distinction in some detail below. First, however, we shall compare the notion of digitalisation with a related notion that Dretske introduces in order to provide an account of belief - *complete* digitalisation.

Dretske introduces *complete* digitalisation as a refinement of digitalisation *tout court*:

"Structure *S* has the fact that t is F as its semantic content = (a) *S* carries the information that t is F and (b) *S* carries no other piece of information, r is G, which is such that the information that t is F is nested... in r's being G." (Dretske, 1981: 185)

A piece of information that is the semantic content of a signal is said to be carried in completely digital form. Let us say that all information carried by a signal which is not carried in completely digital form is carried in *fairly* analog form.

Roughly, for a piece of information to be carried by a signal in completely digital form, there must be no additional information carried by that signal. I shall argue that digitalisation *tout court* is an extension of this notion, in which only additional information *about* the source *s* is excluded. So, despite Dretske, I shall claim that digitalisation is an elaboration of the more basic notion of complete digitalisation, rather than *vice versa*. However, immediate comparison of the notion is not easy since Dretske's formulations of the two look rather different. Indeed, as the definitions stand, they do indeed behave differently. However, I argue the main source of difference is due to a flaw in the characterisation of semantic content. This flaw has the consequence that *no* information that a signal carries about a source can be the semantic content of that signal. Once it is eliminated, and definitions are cast in the same terms, the straightforward relation between them becomes apparent.

Let us re-examine Dretske's definition of *digital*:

> "...a signal (structure, event, state) carries the information that *s* is *F* in *digital* form if and only if the signal carries no additional information about *s*, no information that is not already nested in *s*'s being *F*." (Dretske, 1981:137)

How does digitalisation *tout court* relate to the notion of complete digitalisation? Superficially, the definitions are very different. The information that a signal carries in completely digital form is the *semantic content* of that signal, where:

> "Structure *S* has the fact that *t* is *F* as its semantic content =
>
> (a) *S* carries the information that *s* is *F* and
>
> (b) *S* carries no other piece of information, *r* is *G*, which is such that the information that *s* is *F* is nested... in *r*'s being *G*." (Dretske, 1981: 185)

(I have substituted an "*s*" for each "*t*", to ease the comparison with digitalisation)

As it stands, the definition of semantic content will not do. The signal *S* is that the receiver is in some state (for Dretske this is the same as saying that some object at the receiver, *a*, has some property, *Z*). Let us suppose that this signal (*a* is *Z*) carries the information that *b* is *Y*. The present definition has the consequence that this arbitrary piece of information about an arbitrary object *b* (where *b* is not equal to *a*) cannot be the semantic content of the signal. That is, the definition of semantic content is sufficiently restrictive to rule out *every* piece of information carried about *any* source. The unexpected consequence is easily derived.

By hypothesis, that *a* is *Z* carries the information that *b* is *Y*, and so *b* is *Y* is *nested* within the information that *a* is *Z*. So there *is* a piece of information, namely *a* is *Z* in which the information that *b* is *Y* is nested. So, according to the definition of semantic content, the information that *b* is *Y* is not the semantic content of the signal - the information is not carried in completely digital form. Since *s* is *F* is an arbitrary piece of information, this observation means that *no* information that a receiver carries about a source can be carried in completely digital form. For all such information is carried by (is nested within) the state of the receiver - i.e. the signal itself.

On the present definition, the only information that a signal *a* is *Z* can carry in completely digital form is simply that *a* is *Z*. Even this information is not necessarily carried in completely digital form. Notice that any two states which track are *ipso facto* nested within each other. Thus, according to the present definition, neither of them can be carried in completely digital form. So, if the signal (say, a shout of "Heads!") tracks a state of the source (that the coin falls heads) even the signal *a* is *Z* is not carried in completely digital form. In such a case, the signal has not even the trivial semantic content. It has no semantic content at all.

One approach to avoiding these difficulties is to amend the definition such that i) additional information *at the receiver* does not count as genuine additional information - so, in particular, that *a* is *Z* does not count as genuine additional information. ii) the semantic content itself may not be the state of the receiver. The first change blocks the unpalatable inference that no information that a signal carries about a source can be the semantic content of that signal, simply because all information carried about the source is nested in the state of the receiver. The second change disallows the state of the receiver (*a* is *Z*) from being its own semantic content.

However, it is not sufficient merely to disallow states of the receiver. Suppose that two cards are balanced in an inverted "V". Consider two informational sources {{left card up, left card down}}, {{right card up, right card down}}. Since the left card will fall when and only when the right card falls, the states of these sources track each other. We noted above that if two states track each other, then neither can be the semantic content of a signal. Suppose that an observer shouts "Left card up" just when the left card is up, and "Left card down" just when the left card is down. What is the semantic content of these cries? Since the states of the receiver {shout of "Left card up", shout of "Left card down"} tracks the state of, say, the left card {left card up, left card down}, all information that is carried by (is nested in) the cry will *ipso facto* be carried by the state of the left card. Hence, no such information can be the semantic content of the cry, since a semantic content cannot be nested within any other piece of information (such as the state of the left card) carried by the cry. Yet neither can the state of the left card itself be the semantic content of the cry, since it tracks, and hence is nested within, the state of the right card. Hence, the cry has no semantic content. So the definition of semantic content is problematic even if we disallow states of the receiver.

The semantic content of a signal is intended to be the maximal piece of information that a signal carries. That is, all other information that the signal carries is nested within the semantic content. Since informational states may track each other, there is the possibility that more that one informational state may "tie" as the maximal piece of information carried. On the present definition, if there is a tie, then both states are excluded. In such cases, the signal has no semantic content.

These difficulties can be at least partially obviated by changing the definition so that, rather than excluding tied maximal pieces of information, we take each of them to be equally valid semantic contents. According to this modification, the cry of "Left card up" carries both the information that the left card is up and the information that the right card is up in completely digital form. Semantic content is then unique only up to the equivalence classes induced by the tracking relation.

Let us make this point more precisely, drawing an analogy with a simple arithmetical example. According to Dretske's original definition:

> *s* is *F* is the semantic content of a signal iff no other piece of information, *t* is *G*, carried by the signal, nests *s* is *F*.

This entails that there is a unique semantic content or no semantic content at all. Consider an analogous putative definition of what it is for an element of a set of numbers to be *big*. Given a set X $\{x_1, x_2, ...x_n\}$, x_k is big iff there is no element of X, x_i, such that $x_i \geq x_k$. If, say, x_3 and x_7 are joint highest numbers, then neither element is big, since $x_3 \geq x_7$, and $x_7 \geq x_3$ and $x_3 \geq x_7$.

According to the revised definition of semantic content:

> *s* is *F* is the semantic content of a signal iff there is no additional information, *t* is *G*, carried by the signal, that is not nested in *s*'s being *F*

This definition has the consequence that semantic content is not necessarily unique. The relevant arithmetical analog of *this* definition is that x_k is big iff there is no element of X, x_i, such that it is not the case that $x_k \geq x_i$. If there is a tie between x_3 and x_7 then they are both big, since for both there is no element of the set which they are not greater than or equal to.

This revised definition of semantic content is equivalent to Dretske's original definition of what it is to carry information is digital form, with the "aboutness" condition removed:

> "...a signal (structure, event, state) carries the information that *s* is *F* in *digital* form if and only if the signal carries no additional information... that is not already nested in *s*'s being *F*." (Dretske, 1981: 137)

So, under the revised definition, semantic content, or the completely analog-digital distinction is more basic than Dretske's analog-digital distinction.

3.4 Pictures and Utterances

Why does Dretske add the "aboutness" condition to semantic content, to produce his analog-digital distinction? I argue that this move is an attempt to capture various intuitions about the application of the analog-digital distinction, while maintaining the "one true idealisation" hypothesis. These intuitions and two attempts to account for them are the subject of this section. Recall that Dretske uses his analog-digital distinction to differentiate the way in which information is carried by a statement and a photograph:

> "Suppose a cup has coffee in it, and we want to communicate this piece of information. If I simply *tell* you, "The cup has coffee in it," this (acoustic) signal carries the information that the cup has coffee in it in digital form. No more specific information is supplied about the cup (or the coffee) than that there is some coffee in the cup. You are not told *how much* coffee there is in the cup, how large the cup is, *how dark* the coffee is, what the shape and orientation of the cup are, and so on. If, on the other hand, I photograph the scene and show you the picture, the information that the cup has coffee in it is conveyed in analog form. The picture tells you that there is some coffee is in the cup, the shape, size, and color of the cup, and so on." (Dretske, 1981: 137)

Prima facie, however, there is all sorts of additional information carried by my telling you that the cup has coffee in it - that I've noticed that the cup has coffee in it, that I speak English, where I am from, that I have a cold, and so on. So how can we defend the intuition that there really is a difference between the two cases? I shall examine two accounts. Firstly that *utterances* do indeed carry just as much unwanted additional information as photographs do, but that *statements* construed abstractly, do not. Secondly, that the "aboutness" condition in the definition of *digital* may be invoked to rule out unwanted. additional information. On this account, the "aboutness" condition is used to rule out the unwanted additional information since it is not genuinely *about* the cup (or the coffee).

i) Level of Abstraction

Given some appropriately rich informational idealisation (perhaps the signal is described in terms of the detailed structure of its acoustic waveform) an *utterance* of "The cup has coffee in it" carries a wealth of information over and above the information that the cup has coffee in it - about the speaker's mood, state of health, nationality and so on. However, consider a more abstract description of the utterance - simply that it is a tokening of that particular sentence of English. The fact that the utterance is a token of the sentence "The cup has coffee in it" no longer carries (at least much of) the unwanted additional information. In our informal terms, that the speaker, say, has a cold can only be learnt from the utterance in virtue of the quality of the speech signal - not in virtue of the words uttered. Yet even on this more abstract description, *some* unwanted additional information is carried - for example that the first word of the utterance was "The", that the speaker knows English and so on. So let us consider a still more abstract description of the utterance. The fact that the utterance *expressed the proposition* that the cup has coffee in it carries still less information. This fact carries no information about the words or even the language used. In general, the more general the description of an event (from a low-level acoustic specification, to a specification of sentence type, to a specification of the proposition expressed) the less unwanted additional information is carried.

The amount of information that a state of the world (event, occurrence) carries, like all informational properties, is relative to an informational idealisation. If some event (state of the world, occurrence) is idealised under a very specific description (perhaps each acoustic description corresponds to a distinct informational state), then the relevant state of the informational system may carry a lot of additional information. If, under a more coarse grained idealisation, the same event (state of the world, occurrence) is idealised under a more general, abstract description (perhaps acoustical objects are only distinguished if they are tokens of different sentences of English, or if they express of the same proposition), then the relevant informational state will carry rather less information. The coarser the grain of the informational idealisation under which a state of the world is idealised, the less information that will be carried.

This observation suggests that the apparent asymmetry between the way in which linguistic utterances and photographs carry the information that the cup contains coffee is due to the fact that our natural, intuitive idealisation of the photograph is under some specific, physical description, whereas our natural, intuitive idealisation of linguistic utterances is under a much more abstract description (sentence type, proposition). Thus the specific properties of the utterance are idealised away, and hence can play no informational role. On the other hand, the specific (e.g. physical) properties of the photograph are part of the idealisation, and carry all sorts of additional information about the photographed scene. Hence, according to our natural idealisation, the photograph is considered to carry the information that the cup has coffee in it in analog form, whereas the linguistic expression is considered to carry this information in digital form.

On this account, under an appropriately general description of the photograph it too carries the information that the cup has coffee in it in digital form. For example, suppose that photographs are classified *according to whether or not they depict a cup which contains coffee.* Thus we may define a two state source {{photo depicts cup containing coffee, photo contains cup not containing coffee}}. Under *this* informational idealisation, the photograph carries *only* the information that the cup contains coffee and so carries this information in digital form. So *perhaps* the crucial difference between the two cases is not the difference between pictorial and linguistic description, but between the level of abstraction that seems most appropriate in the two cases.

From Dretske's specification of the example it is unclear whether this is the interpretation that he intends. Rather than using the terms 'utterance' (physical) or 'proposition' (abstract), be uses the term 'statement', which is notoriously ambiguous between the two. Grayling notes that:

> "Often philosophers make a three-way distinction, between sentences, statements and propositions. A statement, on the received interpretation, is an actual use of an uttered or inscribed sentence on a particular occasion [i.e. an utterance]. Often, however, 'statement' is used as a synonym for 'proposition'..." (Grayling, 1982:41)

If the difference between the information carried by a photograph and a statement is based on the level of abstraction at which they are typically idealised, then the cleavage is dependent on the propositional reading of 'statement'. There need be no difference between the way a photograph or an *utterance* carries the information that the cup has coffee in it. However, rather than appeal to levels of abstraction, Dretske takes a rather different line.

ii) A Real Difference Between Linguistic and Pictorial Representation: The Appeal to "Aboutness"

The preceding analysis relies on the observation that whether a piece of information is carried in analog or digital form to be a function of the level of abstraction used to idealise the situation. Thus, the difference between pictures and statements relies crucially on the fact that statements are interpreted as being less concrete than pictures. However, Dretske's account is not consonant with such an interpretation. Rather, Dretske seems to use 'statement' as synonymous with 'utterance'. While he grants that an utterance carries all sorts of additional information, over and above that the cup has coffee in it, he attempts to rule out this additional information as being of the *wrong* kind. I take Dretske to hold that the analog-digital distinction captures a genuine difference between the way in which information is carried by utterances and photographs.

A presupposition of this reading is that it is possible to make sense of the notion of information flow, independent of any particular 'level of abstraction' or informational idealisation. We noted above that whether or not some piece of information is carried in digital form may depend on the level of abstraction that is used to describe the situation. Indeed, more generally, we have stressed throughout that informational properties are relative to the informational idealisation of the scenario under study. As I read Dretske, the analog-digital distinction is intended to mark a real difference in the way in which utterances and pictures carry information. That is, on a sufficiently detailed idealisation, perhaps detailed enough to capture the entire structure of information flow within the situation (if this is possible!), or perhaps as the description tends towards this limit (if it is not), the utterances may carry the information that the cup has coffee in it in digital form and picture can carry this information only in analog form. To some it may seem unlikely that sense can be made of "idealisation independent" information flow. I shall not deal with this larger question directly, but rather assume that this approach can somehow be made coherent, and show how it does not allow us to capture our intuitions about what information is carried in analog or digital form, despite Dretske's ingenious technical manoeuveres.

If it *is* possible to make sense of the notion of "idealisation independent" information, then we should be able to take any real, lawlike dependency as conveying information. The height of the river carries information about the recent rainfall, the curve of the river carries information about the underlying topography and geology of the area, the bubbles on the surface carry information about the locations of resident fish, the temperature carries information about time of year, and so on. It seems that information flow is ubiquitous; the world is "teeming with information" (Devlin, 1988); and not just teeming with information in the sense of Shannon & Weaver (1949), but it appears to be teeming with *information content.*

Let us assume that information flow is not dependent on the particular idealisation that we choose, but part of the world order. According to this view, the claim that a piece of information carries information in digital form is extremely strong. For a signal to carry the information that *s* is *F* and *no additional information* comes to the claim that there are no additional lawlike dependencies whatever between the signal and the source which carry additional information about any informational source. Indeed, if we consider how the distinction applies in practice, we find that the condition is too stringent to be met, even by linguistic utterances, which, for Dretske, are paradigm cases of structures which carry information in digital form.

Both a picture of a cup with coffee in it and an utterance of "The cup has coffee in it" carry more information than that the cup has coffee in it. At a minimum, the picture carries additional information about the layout of the scene, and the utterance carries additional information about the voice of the speaker. Indeed, every utterance will carry some additional information over and above its semantic content, and hence will not carry that semantic content in digital form. So it seems that there are no relevant distinctions between pictorial and linguistic representation - they both carry information in analog form. What is required is a criterion to eliminate this unwanted additional information.

So far we have ignored an important aspect of Dretske's characterisation of the analog-digital distinction. "A signal... carries the information that *s* is *F* is *digital* form if and only if the signal carries no additional information *about s*..." (my italicisation of "about"). A signal may carry a piece of information in digital form despite the fact that it carries any amount of additional information as long as none of that information is *about the object at the source*. It is this "aboutness" condition that lets the analog-digital distinction differentiate between the utterance and the photograph. The utterance carries information about the voice, country of origin, mood of the speaker. Yet the information that the cup has coffee in it is carried in digital form as long of none of this information is about the cup. Indeed, it seems *prima facie* plausible that the only information that the utterance carries about the cup is that it has coffee in it. The utterance does not carry information about the colour, size, orientation of the cup, or about how much coffee is in it. By contrast the photograph of necessity carries such additional information about the cup.

There are two problems with the invocation of "aboutness". Firstly whether or not the "aboutness" condition can be made to eliminate unwanted additional information and so make sense of the analog-digital distinction, Dretske's later analysis is still problematic. From the point of view of providing an account of meaning, the notion of digitalisation *tout* *court* has a very undesirable property - that a signal can carry many distinct pieces of information in digital form about different objects. Suppose that there is a cry of dismay as a bridge collapses in the river. This cry might carry the information, of the bridge, that it had collapsed, in digital form, since the cry might carry no additional information *about the bridge*. However, the cry might also carry the information, of the car on the bridge, that it had plunged into the river, in digital form, since the cry might carry no additional information about the car. Yet intuitively we want the semantic content to be unique. In the case of an utterance of "The cup has coffee in it", the semantic content should be just that the cup has coffee in it. In his later development of the theory, Dretske points out this failing, and avoids it by replacing *digitalisation* with *complete digitalisation*. For, as we saw in the quotation at the beginning of this section, the information that a signal carries in completely digital form *is*, for Dretske, its semantic content. So, the "aboutness" condition is rejected just when it might be thought that it would be needed most - in providing an account of meaning.

The secondly difficulty with appealing to "aboutness" is that it is very difficult to provide a workable account of "aboutness" such that an utterance of "The cup has coffee in it" carries no additional, unwanted information. It is to this more specific problem that we turn in the next section. In subsequent sections, I shall develop the "levels of abstraction" account of our analog-digital intuitions, and account for Dretske's cases with a formulation of the analog-digital distinction which makes no reference to the problematic notion of aboutness.

3.5 Difficulties with "Aboutness"

For Dretske, the content of an informational signal is of the form *s* is *F*, where *s* is an indexically specified object at the source. The content of the signal is that the designated object *s* has the property *F*. It seems natural to say that this piece of information is *about* *s*, and not, say, about some other object *r*. Hence, on a Dretskian notion of information content, there is no need to build in a separate account of "aboutness"; for it is built into the structure of the information carried. The object that a proposition is *about* is simply the "indexically" or "demonstratively" specified object *s* at the source.

It has been argued that information content should, rather, be treated as unstructured. The notions of object and property, as they are used in Dretske's theory are conflated with the notions of source and state. Once these notions are unconfounded, it was concluded that the latter, but not the former, have a legitimate place in the theory.

If we are to maintain the propositional approach, we should aim to i) demonstrate that Dretske's use of the notion of "aboutness" does not save Dretske's use of the analog-digital distinction, in distinguishing, e.g., utterances from pictures; ii) that a proper treatment of the distinction can capture the intuitions that "aboutness" is intended to account for in some other way. In particular, as outlined above, I shall appeal to the relativity of informational properties to informational idealisation. I shall deal with the first point in the rest of this section, and take up the second in the next.

Given an arbitrary proposition, how do we specify what object or objects it is about? Let us assume that, at minimum, a proposition is about any of its constituents. So, the proposition that John loves Mary is at least about John and Mary. Applying this criterion to the example of the utterance about the coffee cup, we get rather unexpected results.

An utterance of "The cup has coffee in it" is supposed to carry the information that the cup has coffee in it in digital form, despite the additional information that it carries, since that information is not about the cup. Unfortunately however, the utterance appears to carry a host of propositions which (on the minimal "constituency" criterion) *are* about the cup (Seligman & Chater, 1989). For example, the utterance carries the information that the cup is being talked about; that the cup has been noticed by the speaker; that the speaker has realised that the cup has coffee in it; that the cup is being talked about loudly, that the cup is being talked about in a low pitched voice. Indeed, in general, for any property *G* of the utterance, the utterance carries the information that the cup is being talked about *G*ly. The property *G* is perhaps most naturally thought of as an acoustical property, but it need not be. *G* may be a wholly arbitrary property of the utterance such as being made on a Tuesday, or being made by the seventh son of a seventh son. So, if the utterance occurs 40 miles from Glasgow, then the utterance carries the information that the cup is being talked about 40 miles from Glasgow.

If we accept that such additional information is indeed about the cup, then it seems that, according to Dretske's definition, the utterance does not carry the information that the cup has coffee in it in digital form after all. To block such counterexamples we need some restriction on which propositions containing the cup as a constituent are genuinely about the cup and which are not. Suppose that some such restriction picks out some subset, *S*, of propositions that are about the cup. If *S* fulfills the role that we have assigned it, it will include the proposition that the cup has coffee in it, but exclude the counterexamples. The proposition that the cup is being talked about loudly would fall outside *S*.

Only propositions in the set *S*, which are genuinely *about* the cup are relevant to determining whether or not a given piece of information is carried in digital or analog form. That is, all propositions which are part of the information content of a signal (in this case, the utterance) may be ignored in determining whether some piece of information is carried in digital or analog form. Yet by excluding all such propositions, we ensure that none of them can be carried in digital form by *any* signal. Propositions outside *S* are simply not digitalisable. In particular, for example, an utterance of "The cup is being talked about loudly" can not carry the information, about the cup, that it is being talked about loudly. Yet if this utterance does not carry its semantic content in digital form, why should an utterance of "The cup has coffee in it" carry *its* semantic content in digital form?

The consequences of adopting some restrictive subset *S* are even less appealing if we turn to the implications for Dretske's account of propositional attitudes. Dretske argues that a necessary condition for an organism to believe or know that *s* is *F* is that some internal structure of the organism carries the information that *s* is *F* is digital form. It has been suggested that a proposition such as that the cup is being talked about is not digitalisable. Yet, given Dretske's account of belief, that such propositions are not only unknowable, but quite literally unbelievable.

Seligman and Chater (1989) point out that the account also has problems with propositions which fall *inside* *S*. Let us consider what propositions might be left inside *S*. Propositions involving being talked about loudly, and being noticed, may seem to be somewhat suspect. Perhaps it really *is* impossible to carry such peculiar pieces of information in digital form. Perhaps, then in these case the semantic content of an utterance is carried in analog rather than digital form.

This approach is tenable only if at least some core set of propositions does not fall outside *S*. For these at least, it might be possible to say that the semantic content of an utterance is carried in digital form. At minimum, surely propositions about the non-relational, physical properties of objects lie within *S*. For example, we want an utterance of "The cup weighs more than 100 grammes" to carry the information that the cup weighs more than 100 grammes in digital form. Presumably propositions about physical properties such as height, weight shape and so on must be included within *S*. If *these* propositions are problematic, then which propositions are not? If there is to be any principled criterion for membership of *S*, then surely it must at least include ascriptions of such non-relational, physical properties. Nevertheless, it turns out that any subset *S* which does include such propositions is still not sufficiently restrictive to maintain our intuitions about what information an utterance carries in digital form.

Seligman and Chater (1989) present the following case. Imagine a black box lying on a table in Robin's office. Robin says "The black box is a tape recorder". Intuitively, this utterance carries the information that the black box is a tape recorder in digital form, in the same way that "The cup weighs more than 100 grammes" carries the information that the cup weighs more than 100 grammes in digital form. But suppose that the tape recorder was recording Fred's utterance. The state of the magnetic tape can be specified in purely physical terms. Suppose that the tape is in state T having recorded Fred's utterance. Then the black box has a non-relational physical property P, of its tape being in state T. Moreover, Fred's utterance carries the information that the black box is P. By our minimal assumption, the proposition that the tape recorder is P is in the subset S (since P is a non-relational, physical property). So we must conclude that the utterance of "The black box is a tape recorder" carries the information that the black box is a tape recorder in analog form. In fact, whether or not the information is analog or digital depends on whether or not the tape recorder is on!

These arguments appear to undermine the attempt to analyse the difference between the way in which utterances and pictures can carry information, in terms of the analog-digital distinction.

The underlying problem in the tape recorder example is that utterances have the power to causally interact with the events that they are describing. The same argument will apply to any other information bearing object with such causal powers (e.g. mental states).

The only remaining option is to say that which propositions are members of S is decided for each specific informational occasion. That is, in order to get a satisfactory notion of aboutness, we must *specify* which properties of the object s are relevant to determining whether the information that s is F is carried by a signal in digital or analog form. In Dretske's account, this specification is built into the very definition of information. The source in any informational exchange is defined as a set of mutually exclusive and exhaustive states. The properties of being in each of these states are precisely those required. According to a specification in which the only source is {{the black box is a tape recorder, the black box is not a tape recorder}} the information that the black box is a tape recorder is carried by Robin's utterance in digital form. But according to a specification in which the audio signal on the tape in the black box is given the information is carried in analog form.

However, to admit this relativity to specification is just to appeal to the relativity of informational properties of a situation to the informational idealisation. The "one true informational" idealisation must be abandoned.

3.6 The Analog-Digital Distinction and Idealisation Dependence

Informational properties are relative to informational idealisation. Unless we have some way of picking out a privileged idealisation (the "one true" informational idealisation) this implies that whether or not a piece of information is carried in analog or digital form is relative to the informational idealisation of the situation. Thus, it cannot form the basis for an absolute distinction between the ways in which certain structures carry information (e.g. utterances carry information in digital form; pictures carry information in analog form).

In section 3.5, it was argued that, according to Dretske's account, an utterance of "The cup has coffee in it" does not have as its semantic content that the cup has coffee in it, and does not even carry this information in digital form. Rather, the signal carries all sorts of additional information, much of it about the cup, on any idealisation rich enough to be the "one true idealisation". Such a rich idealisation will unavoidable pick up all sorts of unwanted informational dependencies involving the utterance. Let us now relativise the treatment to particular idealisations. Under a simple idealisation the information that the cup has coffee in it *is* carried in digital form. If the idealisation is enriched, the information is carried in analog form. This point is best made by example.

Suppose that Bill is a compulsively truthful poisoner and that he has just made you a cup of coffee. Being unable to see if the cup is full or empty you are unsure whether the cup on the table is the cup Bill has just brought you or the one that he drank earlier. You also do not know whether Bill has put poison in the cup. If he has, then he speaks in a faltering voice, due to an understandable nervousness. For if there is coffee in the cup, *you* are about to collapse, and if there is not, *he* is. If the cup is not poisoned, then Bill speaks in his normal voice. You ask "Does the cup have coffee in it?" and Bill says "Yes, the cup has coffee in it" in faltering voice. Is the information that the cup has coffee carried in digital or analog form by Bill's utterance? It depends on what idealisation of the situation is chosen.

Idealisation 1: Simple source, simple receiver. The receiver has two states {{Bill utters "Yes, the cup has coffee in it", Bill utters "No, the cup does not have coffee in it"}}. The source has two states {{the cup *has* coffee in it, the cup does *not* have coffee in it}}. The states of the source and the receiver track each other, since Bill is perfectly reliable. On this idealisation, the utterance *does* carry the information that the cup has coffee in it in digital form, since it carries not additional information about the cup, or anything else (except itself).

Idealisation 2: Rich source, simple receiver. The source may be idealised as having four states {{unpoisoned coffee, poisoned coffee, unpoisoned dregs, poisoned dregs}}. The receiver is idealised as having two states as before. The utterance again carries the information that the cup has coffee in it in digital form under this idealisation. Intuitively, we might argue that the character of the utterance (faltering or normal) carries information about whether or not the cup is poisoned. That is, the utterance carries additional information, over and above that the cup has coffee in it. However, idealisation 2 is not rich enough to capture the manner of Bill's utterance, since it is too weak to distinguish a faltering from normal renderings of "Yes, the cup has coffee in it".

Idealisation 3: Simple source, rich receiver. As in idealisation 1, we idealise the source as having two states {{the cup has coffee in it, the cup does not have coffee in it}}. The receiver is idealised as having four states {{faltering utterance of "Yes, the cup has coffee in it", normal utterance of "Yes, the cup has coffee in it", faltering utterance of "No, the cup does not have coffee in it", normal utterance of "No, the cup does not have coffee in it"}}. On this idealisation also, a faltering utterance, say, carries the information that the cup has coffee in it in digital form. Intuitively the fact that the utterance is faltering carries the additional information about the cup that it is poisoned. However, idealisation 3 is not sensitive to such additional information. If the source has just two states {{coffee, no coffee}} then the tenor of Bill's voice carries *no information at all.* That Bill said that the cup had coffee in it *completely determines* the state of the source; the is no further information that can be carried about it.

Idealisation 4: rich source, rich receiver. Suppose that both the source and the receiver are described as four state sources. The states of these sources track each other in the natural way: faltering "Yes" tracks poisoned coffee; faltering "No" tracks poisoned dregs; normal "Yes" tracks unpoisoned coffee; normal "No" tracks unpoisoned dregs. In this case, a faltering utterance of "Yes, the cup has coffee in it" carries the information that the cup has coffee in it in *analog* form. For it carries the more specific information: that the cup contains *poisoned* coffee. This piece of the information *is* carried in digital form.

Under a weak idealisation, the faltering utterance carries the information in digital form.

Under a richer idealisation the utterance carries the information in analog form. If we aim to capture the entire informational structure of the world our idealisation will be very rich indeed. Hence, it is not surprising that, according to the "one true idealisation" hypothesis, it turns out that the content of an utterance is carried in analog form.

Note that the example does not depend on the fact that we are dealing with linguistic utterances rather than, say, pictures. For example, suppose that Bill has a Kodak Instamatic camera. Somewhat bizarrely, rather than responding verbally to your question, he takes a quick snap of the coffee cup, and hands you the photograph, a thirty seconds later. If he is nervous his hands shake as he takes the picture, and so the photo is blurred. The photograph may be idealised as having two or four states, just as the utterance is above: two states {{picture shows a full cup of coffee, picture shows an empty cup of coffee}}, four states {{blurred picture of a full cup, clear picture of a full cup, blurred picture of an empty cup, clear picture of an empty cup}}. In the verbal example, the sentence uttered carries information whether the cup contains coffee and the tenor of voice carries information about whether it contains poison. We could construct a precisely analogous example in which the content of the picture (coffee versus dregs) carries information about whether the cup contains coffee, and the clarity or otherwise of the picture carries information about whether the cup contains poison. The informational properties of the two examples are precisely the same, irrespective of whether the information is carried verbally or pictorially. The crucial factor, in determining whether the information that the cup contains coffee is, in both the pictorial and linguistic cases, the level of abstraction at which the situation is described. This is perhaps hardly surprising in the light of our observation that, quite generally, informational properties of a situation are relative to the information idealisation chosen.

3.7 Formalising the Analog-Digital Distinction

In section 2.5, we formalised Dretske's notion of information content in propositional logic. In the current section, an extension of this formalisation is given, in which the complete analog-digital distinction and Dretske's analog-digital distinction are defined. The semantic content of a signal (the information that it carries in completely digital form) is closely related to what we called the full content, in section 2.5. To capture Dretske's analog-digital distinction, it is necessary to capture the notion of "aboutness", at least in a rudimentary form. That is, there must be some way of specifying which propositions are about the object at the source, and thus which propositions are relevant to the analog-digital distinction. In the present formulation, this is done simply by specifying an arbitrary subset, *X*, of relevant atomic propositions. Only propositions constructed entirely out of these atomic propositions are deemed to be relevant. This amounts to allowing the recursive definition to range over only a restricted set of propositional letters. The language so generated is the *relevant* subset of L.

As before, let the language L be defined as follows:

Let **P** = $P_1, \ldots\ldots P_N \ldots$ be the propositional letters

Let the propositional connectives be -, ->, V, &, <->.

Formation Rules

1) Any propositional letter is a wff

2) i) if *A* is a wff, so is -*A*
 ii) if *A*, *B* are wffs, so are:

A -> *B*,
A v *B*,
A & *B*,
A <-> *B*.

3) Nothing else is a wff.

Suppose that it is a dark night and a lookout is on a hill overlooking the coast watching for smugglers. He waves a lamp if he sees anything suspicious on the coast. If the smugglers are about to land, then the lookout feels panicky and the waves will tend to be irregular and unsteady. Further, if it is very windy, the lamp will flicker persistently. Let the atomic propositions of the informational idealisation be: lamp on (*a*); lamp waving (*b*); lamp flickering (*c*); suspicious events on the coast (α); smugglers approaching (β); high wind (ξ). Suppose that the smugglers are indeed approaching (β holds). Does a waving, flickering light carry this information in digital form {*a*, *b*, *c*}? Certainly, the information is not carried in *completely* digital form, since the state of the light carries the additional information (ξ) that it is windy (or, for that matter, α & ξ, or β -> ξ and so on) However, suppose that we restrict the set of relevant propositions to those which are about suspicious events on the coast {α, β} rather than about the state of the wind {ξ}. The only relevant complex propositions should be only those which are composed purely of α's and β's.

Those which contain ξ are partly about the state of the wind, and are thus excluded from consideration. Given this restriction, the signal carry the information that the smugglers are approaching in digital form. For there is no additional information carried *about suspicious events on the coast.*

Now let us reconsider the problem of trivial additional information. That the light is waving (that *a* holds) carries the information that there are suspicious goings on at the coast (α). Trivially, it also carries the information that the light is waving (*a*). Yet this does not count as *additional* information, if the lookout is perfectly vigilant, since the light will be on if and only if there are suspicious events afoot (that is *a* and α track each other). So *a* carried by α, and is *a* is not *additional* information. However, if the lookout is very tired and periodically falls asleep, then there may be suspicious events, but no waving light. So the trivial content that the light is waving (*a*) is no longer nested in the desired content - that there are suspicious goings on at the coast (α). In intuitive terms, the light waving carries more information than that there are suspicious goings on; it carries the information that the lookout is awake. So α is not carried by the signal *a* in *completely* digital form. Invoking the relevance restriction, if only propositions that are relevant are constructed from α and β then propositions about the wakefulness of the lookout do not count as additional information. So the information the light's being on may carry the information that there are suspicious goings on in (but not completely) digital form, even with a dozing lookout.

The information that the smugglers are about to land need not, of course, be carried in digital form. If the lookout waved the lamp madly when and only when the smugglers had their knives between their teeth, then the state of the lamp would not carry the information that the smugglers are about to land in digital form. For it would carry additional information about suspicious activities at the cove: that the smugglers were ready for battle! On any natural criterion of relevance (at least from the point of view of customs and excise) this *highly* relevant information about the goings on at the coast.

The relevance restriction is formalised simply by restricting the recursive definition to the relevant subset of the propositional variables. Let us denote the language generated from this restricted set X, by L^X.

> Where X is a subset of **P**, Let L^X be the language in the variables X generated by the formation rules of L.

For example, suppose that **P** is [α, β, ξ] and X is [α, β]. Then α, β, α <-> -β, α v (α &

β) are in L^X; ξ, $\alpha \vee \xi$, $\alpha \rightarrow (\xi \rightarrow \beta)$ are not. L^X is, of course, itself a subset of L.

As in 2.5, we assume some Gentzen type formulation of the rules of proof of the classical propositional calculus. As before, informational state is characterised by a theory [Δ].

If Δ is a set of wffs then,

$[\Delta] = \{\alpha | \Delta \vdash \alpha\}$ is the theory generated by the set of sentences Δ.

If a signal (proposition) is added as a premise, the new information state will be a new theory. A piece of information is part of the content of the signal, if it is an element of the new theory, but not the old. The information is a *fresh consequence* of the signal. Information content was simply characterised as follows.

A signal (proposition) α carries a proposition β iff β is a *fresh consequence*, when α is added to the current informational state.

In formalising the analog/digital distinction, we are interested only in the *relevant* fresh consequences of the signal (consequence about the events on the coast). So we may introduce the more restricted notion of *relevant* information content, as follows:

> A signal (proposition) α *relevantly* carries a proposition β if β is a *relevant* fresh consequence, when α is added to the current informational state.

The *relevant* fresh consequences are simply those fresh consequences $[\Delta, \alpha]$ - $[\Delta]$ whose formulae are wffs of L^X. Notice that there is no restriction that the formulae of Δ themselves must be wffs of L^X. So, there is no restriction on the premises from which conclusions may be drawn. The premises need not be "relevant", but the conclusions must be. The notion of relevant information content will be characterised formally below. Now let us formulate the analog-digital distinctions.

The Complete Analog-Digital Distinction

Before we consider the restriction to relevant propositions which is necessary to capture the analog-digital distinction proper, let us consider the complete analog-digital distinction. Recall that the definition of information content says that a signal α carries the information that *A* iff:

A is a member of $[\Delta, \alpha] - [\Delta]$

If a signal *a* carries some piece of information A in completely digital for, then *all* the information carried by *a* (including *a* itself) is carried by A. Indeed if A carries *a* it *ipso facto* carries all the information that *a* carries. So, we define a signal α to carry a piece of information A in *completely digital* form just when the converse holds. That is, A also carries the information that α. So,

> α carries A in completely digital form just when A is a member of $[\Delta, \alpha] - [\Delta]$ and α is a member of $[\Delta, A] - [\Delta]$

A is carried in *fairly analog* form if this additional criterion is not met.

It is interesting to note that the definition is symmetrical, so that if α carries A in completely digital form then A carries α in completely digital form. Further, if α carries A in completely digital form, then α and A track each other. That is, given the state of the information system Δ, $\Delta \vdash \alpha \leftrightarrow A$ (see section 2.5) However, the converse does not hold. α and A may track but not carry each other in completely digital form.

The proof is straightforward.

First, we show that if α carries A in completely digital form, then α and A track each other. By hypothesis,

A is a member of $[\Delta, \alpha] - [\Delta]$, and

α is a member of $[\Delta, A] - [\Delta]$

so,

$\Delta, \alpha \vdash A$; $\Delta, A \vdash \alpha$

So, by arrow introduction,

$\Delta \vdash \alpha \rightarrow A$; $\Delta \vdash A \rightarrow \alpha$

from which, by the definition of "<->",

$\Delta \vdash \alpha \leftrightarrow A$ Q.E.D.

However, the converse only holds if the signal is a not already a consequence of the informational state (that is, it is *informative*, see below). Suppose that the signal adds no new information at all to the informational state:

$[\Delta, \alpha] - [\Delta] = [\Delta, A] - [\Delta] = \{ \}$

α does not carry the information that A at all (let alone in completely digital form), since A is not a member of $[\Delta, \alpha] - [\Delta]$, since this is the empty set. However, we now show that α and A *do* track each other. For, by assumption,

$[\Delta] = [\Delta, \alpha] = [\Delta, A]$

so,

$\Delta \vdash A; \Delta \vdash \alpha$

and by monotonicity,

$\Delta, \alpha \vdash A; \Delta, A \vdash \alpha$

and so, as before,

$\Delta \vdash \alpha \leftrightarrow A$ Q.E.D.

So two propositions may track each other, without carrying information about each other in completely digital form, if the signal α is already a consequence of the information state Δ. If, however, the signal is genuinely new, we may show that tracking *does* imply complete digitalisation. Given that

(1) $[\Delta, \alpha] - [\Delta]$ is non-empty and that

(2) $\Delta \vdash \alpha \leftrightarrow \beta$

we need to show that α carries β in digital form. That is,

α is a member of $[\Delta, \alpha] - [\Delta]$; β is a member of $[\Delta, \beta] - [\Delta]$

By the arrow elimination (*modus ponens*) it follows from (2) that

$\Delta, \alpha \vdash \beta$ and $\Delta, \beta \vdash \alpha$

So, $[\Delta, \alpha] = [\Delta, \alpha, \beta] = [\Delta, \beta]$ Let us call this theory S.

It follows that , $[\Delta, \alpha] - [\Delta] = [\Delta, \beta] - [\Delta] = S - [\Delta]$

To show that α carries β in completely digital form, that is, that α is a member of $[\Delta, \alpha] - [\Delta]$ ($= S - [\Delta]$) and that β is a member of $[\Delta, \beta] - [\Delta]$ ($= S - [\Delta]$)

So we must show that α and β are both in S and not in $[\Delta]$. Since $S = [\Delta, \alpha, \beta]$, trivially α and β are in S. By hypothesis, the signal α is not a member of $[\Delta]$ (it is not a consequence of the current information state, but is genuinely new information). If $[\Delta]$ does not contain α, then $[\Delta]$ does not contain β, by (2). So both α and β lie in $S - [\Delta]$ as required.

So α carries β is completely digital form (and, of course, *vice versa*) if α and β track and are not already part of the information state Δ.

Notice that a signal may carry more than one piece of information in completely digital form. For example, the cry of "Heads!" may carry the information that the coin fell heads *and* the information that Fred lost the bet in completely digital form, and the conjunction of the two propositions... and so on. Quite generally, if α is a semantic content of some signal, and if α tracks β, then β is a semantic content of that signal. That is, semantic content is only unique up to equivalence under the tracking relation.

The Analog-Digital Distinction

A signal P carries a proposition Q in *completely* digital form just when P carries Q *and* Q carries P. This ensures that all information that is carried by P is carried by Q and vice versa - the signal P carries no additional information, over and above that information carried by Q. However, Dretske's definition of the analog-digital distinction *tout court* specifies only that:

> "a signal... carries the information that s is F in *digital* form if and only if the signal carries no additional information about s..."

The signal *may* carry all sorts of additional information, but not information about *s*. In our discussion of the analog-digital distinction we concluded that a general aboutness condition was unworkable on a propositional account, but that its function might be served if we allowed arbitrary stipulations about which propositions are relevant and which are not. Above, we defined the language L^X, which is the set of formulae generated by a subset X of the propositional variables P. Then we defined $[\Delta]^X$, which is the set of consequences of a set of formulae Δ, which are in the language L^X. That is, it is the set of *relevant* consequences, relative to X.

Applying this relevance restriction, the definition of the analog-digital distinction should stipulate not that the signal P carries *no* additional information that is not carried by Q, but that P carries no additional *relevant* information not carried by Q. (A small additional point: in Dretske's account, the putative *digital content*, that s is F, must itself satisfy the aboutness condition, since it is about s. Similarly, the putative propositional digital content Q must satisfy the relevance condition. That is, Q must be in the language L^X).

Expressing these ideas more formally, we say that a proposition P carries a proposition Q in digital form, relative to X (where X is a subset of P the set of relevant propositional variables) if and only if:

1. P carries the information that Q.
2. Q is in L^X
3. $[\Delta, P]^X - [\Delta]^X = [\Delta, Q]^X - [\Delta]^X$

Condition 3 states that the relevant fresh consequences of the axioms Δ and P are the same as the relevant fresh consequences of the axioms Δ and Q. So, in particular, the signal P carries no relevant information that is not carried by Q. Can the condition be simplified by removing the term which is subtracted from both sides? In general, it is not, of course, legitimate to conclude that set A = set B from A - C = B - C. However, in the case that the subtracted set C is a subset of both A and B, the move is allowed. So, in the present case, the simplification may be made:

3'. $[\Delta, P]^X = [\Delta, Q]^X$

If a signal P carries a proposition Q, but not in digital form (relative to X), the proposition is carried in *analog* form.

There seems to be rather little in common between the definitions of the complete analog-digital distinction and the analog-digital distinction *tout court*. However, we shall see below that, when these are appropriately reformulated, a common underlying structure emerges.

Semantic Content and Relevant Semantic Content

Just as there are two analog-digital distinctions: the complete analog-digital distinction, and Dretske's analog-digital distinction *tout court*, there are two corresponding notions of semantic content: Dretske's semantic content, which I shall call "full" semantic content; and the more constrained "relevant" semantic content. The first of these is simply "full" informational content, as introduced in section II:

The full semantic content, $S(\alpha)$, of α

$$= \{[\Delta, \alpha]\} - \{[\Delta]\}$$

A formula *A* is part of the information content of α iff *A* is a member of S(a). A set of formulae, Ξ, is part of the information content of α iff Ξ is a subset of S(a)

Thus we defined the The *relevant* semantic content, $S^X(\alpha)$, of α

$$= \{[\Delta, \alpha]^X\} - \{[\Delta]^X\}$$

Not every signal will have a non-empty semantic content. If the signal is added as a fresh axiom is already a consequence of the theory (in epistemological terms, the proposition added is merely a reiteration of something that is already known), then there will *be* no fresh consequences - the semantic content will be the empty set.

A proposition is *informative* iff it has an non-empty semantic content, $S(\alpha)$.

A proposition added may have some fresh consequences, but no *relevant* consequences. In the example of the smugglers and the lookout, that the pub has just closed may carry all sorts of information (if the informational idealisation is broad enough), but none which is relevant to the goings on at the coast.

A proposition is *relevantly informative* iff it has an non-empty relevant semantic content, $S^X(\alpha)$.

Notice that we have defined semantic content using *sets* of propositions. In Dretske's treatment, semantic content is identified with a single proposition:

"...that piece of information that it carries in *completely digitalized form*..." (Dretske, 1981: 184)

However, a signal may carry a variety of propositions in completely digital form. Yet the notion of semantic content is intended to "...secure the desired uniqueness of a struture's semantic content..." (Dretske, 1981:184). The present definition secures the intended uniqueness.

Relevant Information Content

By analogy with the above, we may introduce "relevant" information content. This is defined in just the same way as standard information content, except that it is based on relevant rather than full semantic content:

A formula A is part of the relevant information content of α iff A is a member of $S^X(a)$.

A set of formulae, Ξ, is part of the relevant information content of α iff Ξ is a subset of $S^X(a)$.

Let us make the analogy rather more concrete. A proposition P carries a proposition *tout court* Q if and only if Q is a fresh consequence of the information system, when P is added as an axiom. Similarly, a proposition P *relevantly* carries a proposition if and only if Q is a *relevant* consequence of the informational system, when P is added as an axiom. Relevant information content can be used to reformulate the analog-digital distinction in a rather redundant but illuminating form.

P relevantly carries the information that Q iff

1. for any proposition R, if Q relevantly carries R, so does P.
2. for any proposition R, if P relevantly carries R, so does Q.
3. Q is relevant (in L^X) (Since the content must *itself* be relevant)

The analogous reformulation of the complete analog-digital distinction gives:

1. for any proposition R, if Q carries R, so does P.

2. for any proposition R, if P carries R, so does Q.

Thus, we see that the two distinctions are formally very closely related. The key difference is that the analog-digital distinction has the asymmetrical condition that Q must itself be relevant. Since Q relevantly carries the information that Q, and P relevantly carries all the information that Q relevantly carries, this entails that P relevantly carries the information that Q. However, Q need not relevantly carry the information that P, since P may not *be* relevant. If P is not relevant, it cannot be relevantly carried by any signal at all.

There are two ways in which we might attempt to restore symmetry to definition of the analog-digital distinction. Firstly, the stipulation that Q is relevant could be deleted. However, this has the consequence that P may *relevantly* carry the information that Q without carrying (*tout court*) the information that Q at all. For example, consider the information state defined by the following propositions: P -> R and Q -> R. If R is stipulated to be the only relevant proposition, then P and Q have the same relevant consequences, if added to the informational idealisation. But surely this should not imply that P relevantly carries Q (and, for that matter, *vice versa*), since the whether Q holds is wholly independent of whether P holds. In particular, P may hold, and relevantly carry the information that Q, even though Q does not itself hold. This violation of facticity is surely unacceptable. (If we retain the additional condition that Q is itself relevant, then that P carries all the relevant information that Q carries implies that P carries the information that Q. So, if P holds then so does Q, and hence information is factive, as required).

Secondly, we could impose symmetry by stipulating that Q is relevant *and* that P is relevant. However, we noted above that since Q relevantly carries the information that Q and P relevantly carries all information that Q relevantly carries (by hypothesis), P relevantly carries Q. If we stipulate that P is relevant then by a precisely similar argument we have that Q relevantly carries that P. A signal carries all the information that it relevantly carries. Hence, P carries the information that Q and vice versa. So, by the definition above, P carries the information that Q in *completely* digital form. So, on this revised definition, the notion of digitalisation turns out to be *more* stringent that the complete digitalisation. Yet the reason for introducing digitalisation *tout court* was to provide a *less* stringent definition. So the asymmetry of the definition appears to be unavoidable.

The Ubiquity of Digitalisation

Let us finally turn to the question of the ubiquity of digitalisation - an issue which will be important in our discussion of the application of the analog-digital distinction to perception and cognition in the next chapter. Specifically, does every informative proposition digitalise some piece of information?

Dretske says that:

> "... a signal carrying information in analog form will always carry some information in digital form. A sentence expressing *all* the information a signal carries will be a sentence expressing the information a signal carries in digital form (since this will be the most specific, most determinate, piece of information the signal carries)." (Dretske, 1981: 138)

If we consider both digitalisation *tout court* and complete digitalisation there are two questions - one in which we consider the relevance restriction and one in which we do not. First, does every *relevantly informative* proposition (one which has a non-empty set of *relevant* fresh consequences) carry some *relevant* proposition in digital form? Second, does every informative proposition (one which has a non-empty set of fresh consequences) carry some proposition in digital form? We need consider only the first question, since the second is a special case, in which the set of *relevant* basic propositions is the set of *all* basic propositions. Let us frame the question more formally.

Given a language, L, current information state Δ, and set X of relevant atomic propositions, let P be a *relevantly informative* proposition. That is, P is such that:

$$[\Delta, P]^X - [\Delta]^X \neq \{\ \}$$

Is there a proposition Q, which P carries in digital form? That is, such that:

1. P carries the information that Q.
2. Q is in L^X
3. $[\Delta, P]^X = [\Delta, Q]^X$

First, I shall prove what I call the Finite Relevant Axiomatization Lemma:

Consider the theory $[\Gamma]^X$, generated by an arbitrary finite set of formulae Γ of L. There is a finite set of formulae Γ' of *relevant* formulae (that is, formulae in L^X) which finitely axiomatize the theory:

$$[\Gamma]^X = [\Gamma']^X$$

The lemma is easy to prove X is finite - that is there are only a finite number of the relevant propositional variables. Even if this is not the case, given that Γ is itself finite, the problem can be reduced to the finite case:

Since Γ is a finite set of sentences of L, it can only contain reference to finitely many relevant atomic propositions K. Since Γ does not constrain the truth value of relevant atomic propositions outside K, the only consequences of Γ in L^X are those constructed entirely out of atomic propositions in K - those formulae in L^K. Since there is no constraint on the truth values of any atomic propositions outside K, any consequences of Γ which are *not* in L^K will follow from consequences which *are* in L^K. So if we are able to finitely axiomatize those consequences in L^K, then we have *ipso facto* axiomatized *all* the relevant consequences in L^X. Formally, this means that if $[\Gamma]^K = [\Gamma']^K$, (where K is finite) then $[\Gamma]^X = [\Gamma']^X$ (where X need not be finite).

So whether or not there are finitely many relevant atomic propositions, only the finite set which are mentioned in Γ need be considered. So, without loss of generality, we treat only the case in which the number of relevant atomic propositions X is finite.

Now the proof is straightforward. Suppose there are M relevant atomic propositions. There will be 2^M permutations of truth values for these propositions - corresponding to 2^M rows in a truth table. The Boolean function corresponding to an arbitrary formula of L^X will pick out some subset of these permutations of truth values (the rows in the truth table in which the proposition is true). Since any of the 2^M permutations may be present or absent, there will be $2^{(2^M)}$ such subsets. Two formulae are logically equivalent iff they correspond to the same subset (set of rows in the truth table). So, we generate $2^{(2^M)}$ equivalence classes. Pick a single member from *each* of these equivalence classes to form a set Z, and consider the set of these which are in the subset $[\Gamma]^X$, that we are attempting to axiomatize. Let us consider the set Y of all such propositions.

Claim: the set Y axiomatizes $[\Gamma]^X$ as required. That is,

$[\Gamma]^X = [Y]^X$

We need to show that $[Y]^X$ is a subset of $[\Gamma]^X$, and that $[\Gamma]^X$ is a subset of $[Y]^X$.

There are finitely many elements of Y, all of which are in L^X. Since the members of Y were chosen from $[\Gamma]^X$, clearly:

$[Y]^X$ is a subset of $[\Gamma]^X$

Suppose that there is some formula α in $[\Gamma]^X$ which is not in $[Y]^X$. Consider β the member of Z chosen from the same equivalence class as α. β is logically equivalent to α; and so is also in $[\Gamma]^X$. So, since Y is the subset of Z which is in $[\Gamma]^X$, β is in Y. So β is in $[Y]^X$. Hence, since α is logically equivalent to β, α is also in $[Y]^Y$, *contra* our hypothesis. So, there are no members of $[\Gamma]^X$ which are not also in $[Y]^X$.

$[\Gamma]^X$ is a subset of $[Y]^X$

Therefore, $[Y]^X = [\Gamma]^X$, and so Y does axiomatize using only relevant propositions.

Having established this lemma, we can now establish that every relevantly informative proposition carries some relevant proposition in digital form. Consider the information state after P is added, $[\Delta, P]^X$. By the Finite Relevant Axiomatization Lemma, there is a finite set of relevant formulae (that is, formulae in L^X) Ξ such that:

$$[\Delta, P]^X = [\Xi]^X$$

Let us simply conjoin the formulae of Ξ into a single proposition, R. Since this conjunct both is a consequence of its constituents, and has those constituents as consequences, then,

$$[R]^X = [\Xi]^X = [\Delta, P]^X$$

The single proposition R axiomatizes the set of relevant consequences in the new informational state $[\Delta, P]^X$.

Claim: P carries R in digital form.

To show this, we must satisfy the three conditions:

1. P carries the information that R.
2. R is in L^X
3. $[\Delta, P]^X = [\Delta, R]^X$

The second condition is satisfied trivially. R is in L^X, since it is a conjunction of formulae which are in L^X.

Showing that the first condition holds is rather more involved. To show that P carries R, we need to show that R is part of the semantic content of P. That is, that

R is a member of $[\Delta, P] - [\Delta]$

So we must show i) that R is a member of $[\Delta, P]$, and ii) that R is *not* a member of $[\Delta]$. Let us consider these in turn.

i) Since R is a relevant consequence of itself, R is a member of $[R]^X$. Since, by definition,

$[R]^X = [\Delta, P]^X$

and since, $[\Delta, P]^X \quad [\Delta, P]$

R is an element of $[\Delta, P]$

ii) Suppose that R *is* a member of $[\Delta]$ and hence of $[\Delta]^X$ (since R is in L^X). Then the addition of R to the set Δ will add no new relevant consequences:

$[\Delta]^X = [\Delta, R]^X \supseteq [R]^X$

Since $[R]^X = [\Delta, P]^X$, we have that,

$[\Delta]^X \supseteq [\Delta, P]^X$

which implies that $[\Delta]^X = [\Delta, P]^X$. Yet this is just the condition for P to be relevantly *un*informative, contra our initial assumption. So R cannot be a member of $[\Delta]^X$.

Turning to the third condition, we need to show that $[\Delta, P]^X = [\Delta, R]^X$

Since R has all the relevant consequences that Δ, P does, it automatically has all the relevant consequences that Δ does. So adding Δ to R will add no fresh relevant consequences. That is,

$[\Delta, R]^X = [R]^X$,

which is $[\Delta, P]^X$, our specification of R.

Having shown 1-3, we have shown that P carries R in digital form. So, every relatively informative proposition carries some relevant proposition in digital form.

(For clarity, R was specified so that it has the whole of $[\Delta, P]^X$ as consequences. Actually, this is a stronger condition than is necessary. For example, any proposition which has as consequences the *relevant semantic content* of P is carried in digital form. That is, if $[\Delta, P]^X - [\Delta]^X$ is a subset of $[S]$, then P carries S in digital form.)

3.8 Summary

In this section, a formalisation of Dretske's analog-digital distinction and the complete analog-digital distinction has been presented using the apparatus of propositional logic. Dretske views the complete analog-digital distinction as an elaboration of the analog-digital distinction *tout court.* However, in our formalisation, the analog-digital distinction is derived and the complete analog-digital distinction is basic. The problematic "aboutness" condition is finessed by allowing stipulation of which propositions are considered to be relevant. Which propositions *are* deemed to be relevant will depend on the aims and interests for which the informational idealisation is intended. In our example of the lookout and smuggler, from the point of view of the Customs Officer, it is natural to take the relevant propositions to be those about suspicious goings on at the coast. Information about the weather or about whether the lookout is asleep or frightened, is irrelevant. From the point of view of the lookout's wife, information about the welfare of the lookout will not be irrelevant. The information carried by a signal in digital form is relative not only to the propositions which compose the information system, and the axioms which specify the current information state, but also to which propositions are taken to be relevant.

In view of the relativity of the analog-digital distinction, it may seem surprising that Dretske directly applies the distinction to the analysis of the presumably absolute distinction between perception and cognition. In Chapter 4, I shall argue that Dretske's analysis is inappropriate, but that the analog-digital distinction may provide an important tool in describing the informational character of mental processes.

Chapter 4: Information Processing and Psychology

4.1 Introduction

In Chapters 1-3 we have introduced, modified and elaborated upon Dretske's account of information content and the analog-digital distinction. In the rest of the thesis, the emphasis will shift from the development of informational ideas *per se* to their application to mental processes. Dretske suggests that a number of psychological issues may be illuminated by informational notions. In particular, he suggests an account of the distinction between perception and cognition, and attempts to provide an informational treatment of belief, knowledge, and the nature of and acquisition of concepts. I shall argue that these specific applications are inappropriate and suggest a more general role for the information account, in providing an account of the the content of symbolic and non-symbolic states alike, and hence a general account of what information processing amounts to. The simple conception of content and information processing that I shall propose provides no direct classification of mental processes and gives no account of folk psychological categories such as knowledge and belief. Rather, it provides an informational account of what it is for an organism to *attune* its mental state and consequent behaviour to some piece of information, over and above simply carrying that information, (in, say, the state of the sensory periphery). The purpose of mental processes is seen as effecting such attunement. On this view, "information processing" psychology may be properly viewed, after all, as studying the processing of *information.*

In this chapter we shall introduce a naive account of attunement as digitalisation, and discuss Dretske's application of the analog-digital distinction to differentiate perceptual from cognitive processes. We shall consider various specific objections which cast doubt on the claim that the analog-digital distinction can appropriately be identified with a perception-cognition distinction. Further, we shall find that the accounts of the perception-cognition distinction and the naive account of attunement are undermined by the essential relativity of informational properties (including being carried in analog or digital form) to the idealisation chosen. In the light of this consideration, Chapter 5 augments the naive account of attunement as digitalisation with an explication of what it is for a piece of information to be digitalised in *explicit* form, relative to some process. Only explicit digitalisation is taken to be sufficient for attunement. In Chapter 6, we conclude by discussing a variety of arguments which purport to show, in principle, that information is an inappropriate notion with which to characterise mental states and mental processes. For example, it may be objected that if the representation *and misrepresentation* of the world is the heart of cognitive activity, how can a *factive* notion such as information be appropriate? In this chapter we shall simply assume that informational ideas may appropriately be applied to psychology, and discuss the way in which the tools that we have developed may or may not elucidate the nature of mental activity.

Throughout much of the rest of this thesis, we shall be concerned to provide an informational analysis of information processing. In particular, we shall focus on the information processing required to *recognise*, say, some animal, given a projection of a scene containing that animal on the retina. According to "information processing" psychology, such recognition tasks involve information processing of staggering intricacy and complexity. Yet not all psychologists are in agreement that this is an appropriate way to conceive of the problem. According to the ecological tradition (Gibson, 1979), the perception of the visual world is *direct* - information processing is taken to be *unnecessary*. If this is so, then any attempt to provide an informational analysis of information processing may turn out to be irrelevant to the concerns of psychology.

4.2 Is Information Processing Necessary?

According to the dominant "information processing" tradition, perception involves the detection of a rich variety of "cues" from the sensory input (the pattern of excitation at the sensory surfaces, or a neural transduction of that pattern). On the basis of these cues, the organism must generate the most plausible hypothesis about the nature of the object or event gave rise to them. Perception is seen as a matter of inference to the best explanation (Gregory, 1977; Fodor, 1983). Much of perceptual psychology is concerned with the elucidation of the nature of the cues which underlie various perceptual abilities - the perception of depth, colour, motion, and so on. A common way of demonstrating that some cue is being used in some perceptual process is by inducing illusions, in which perceptions of depth, colour, motion and so on are spuriously generated by presenting the organism with misleading cues. For example, the use of information about the retinal disparity between the image may be demonstrated by inducing the illusion of depth in a flat random dot stereogram (Julesz, 1971).

The very possibility of illusion suggests the conditional probability that the environment is in this particular state, given these particular cues, must be less that 1. So, according to this view, information about depth, colour, motion is *not* carried by the presence of the cues to which the organism is sensitive. Further, any internal state of the organism that is responsive to these cues (some internal state that corresponds to *detecting* depth, colour or motion) will *ipso facto* also not carry the such information. How then, given the possibility of error, can it be appropriate to utilise informational notions to analyse of perceptual analysis?

However, the fact that cues can be misleading *in the laboratory* does not mean that they can be misleading *in the organism's natural environment.* It may be that binocular depth cues invariably indicate the (relative) distance of surfaces, in that environment - there are no random dot stereograms in nature. If so, then *in that environment* the conditional probability that the (relative) depths are such and such, given such and such binocular disparities, will be 1. So surely depth information may be carried after all. Quite generally, the mere possibility that information flow *might be* disrupted in *some* circumstances (e.g. in the laboratory) need not imply that information flow *is* disrupted, in these circumstances (e.g. in the natural environment). (Ecological psychologists will often dismiss laboratory illusions as "ecologically" invalid). Hence, we have at least the possibility that an informational account of perception is possible. Ecological psychology may be seen as the attempt to explore this possibility. It has been concerned to describe putative "ecological" laws which govern the relationship between the structure of *real environments* to the structure of the perceptual input (for example, the optic array). These ecological laws underwrite the information that the perceptual input carries about the environment - in more ecological terminology, these laws determine what information about the environment is *specified* by the structure of the perceptual input. Candidate ecological laws relate depth to the pattern of optic flow (Gibson, 1966,1979), the time-to-contact of an approaching object to optic expansion (Lee, 1980) and so on.

However, clearly there is more to perception than merely carrying information about the properties of the environment. If an organism is to generate appropriate behaviour it must be able to *utilise* this information. Using Gibsonian terminology in a slightly non-standard way, the organism must *attune* its behaviour to the relevant information. For example, consider a bug-eating frog. Perhaps a small round dark moving patch in the visual field carries information about the presence and location of a bug. If the frog is to stay fed, it is not enough for some (perhaps retinal) state of the frog to carry the information that a bug is at such and such a location. The frog must be able to *use* this information to generate an appropriate leap - to *attune* its behaviour to the relevant information in the environment.

Of course, the psychologist will be able to trick such a frog into inappropriate jumping behaviour by presenting all manner of decoy stimuli which cast a small round dark moving patches on the frog's retina. So, in the laboratory, the firing of the bug detector, and the jumping of the frog, do not carry the information that a bug is near. Yet this does not show that the frog is not *really* attuned to bugs after all. For it may be that in the natural environment bugs are the *only* small, round, dark, moving objects. In that environment the frog's behaviour may never be inappropriate - it may be perfectly attuned. (Actually, of course, even in the natural environment the frog will no doubt jump at specks of dirt, and fragments of falling leaf - for survival, all that is required is that jumping is appropriate often enough to keep the frog well fed. The relation between small round dark moving patches and flies is not a very plausible ecological law. More realistically, there might be an ecological law to the effect that the presence of a small round dark moving patch is caused by a fly perhaps 50% of the time. Since our propositional account is able to deal with probabilistic contents (1.9), such an informational dependency, such laws are compatible with the present account. However, for simplicity, we shall leave such probabilistic cases until Chapter 6).

The goal of ecological psychology is to uncover the ecological laws which underlie the attunement of the organism's behaviour to their environment. How is depth of a nearby apple specified by binocular disparity or optic flow, so that an appropriate reach may be effected. How is the trajectory of an approaching ball specified from the visual array, so that it may be caught? What cues are used to classify an object as edible or inedible, to control feeding? So ecological psychology is concerned with characterising the informational dependencies which are exploited by the organism - by demonstrating how the relevant information about the character of the environment is specified in the optic array, the auditory input, by proprioception etc., or by some combination of sensory modalities. This amounts to providing a characterisation of the informational basis of attunement.

Suppose that we wish to design a fly catching robot, to simulate the performance of the jumping frog. The robot is intended to emulate the frog in jumping towards and catching flies - the jumping of the robot should be *attuned* to the presence and location of flies. To construct a robot which is so attuned, we must know two things. Firstly, what is it about the structure of the visual input that allows the frog to recognise the presence and location of flies. That is, what is the ecological law which relates the relevant property of the environment and the character of the optic array. In this case, the putative ecological law is simply that the presence and location of small round dark moving patches in the optic array covaries with the presence and location of flies in the environment. However, as Ullman (1980) and Braddick (1980) have pointed out, there is also the need for an account of the *mechanism* by which the information in the optic array is used. Building a fly-catching robot involves designing a machine whose behaviour is appropriately sensitive to the information in the optic array. In "information processing" terminology, this involves designing a mechanism which is able to detect and integrate the optical cues so that the presence and direction of the fly is "recognised", and which is consequently able to control jumping appropriately. Ecological laws characterise *what* information the organism must be sensitive to; to build the robot simulation of the frog, we also need to have a mechanistic account of *how* it is possible to be sensitive to such information.

To put the matter another way, the goal of ecological psychology is, on this reconstruction, to characterise the information processing *task* that the organism faces in order to attune its behaviour appropriately. In the case of fly catching, the task is to jump in some direction when and only when there is a small round dark moving patch at the corresponding location in the visual array. In the case of controlling feeding such that only edible things are eaten, the specification of the structure of the optic array to which the organism must be sensitive is presumably of staggering complexity - far more complex than current accounts can handle. A characterisation of the task that the organism must perform amounts to what Marr (1982) called a computational level (level 1) theory.

A complete understanding of how behaviour can be attuned to some aspect of the environment requires that an elucidation of not only *what the task is* but also of how it is performed. In Marr's terms this amounts to providing algorithmic (level 2) and implementational (level 3) theories. According to this characterisation, ecological psychology is concerned purely with specifying *what* the task is - in Gibsonian terminology, what "higher order invariants" in the perceptual input specify the relevant state of the environment. It is mute on the nature of the mechanisms which mediate the attunement - these might involve symbolic or analog computation, inferential or non-inferential processes. So rather than providing an *alternative* to standard symbolic, inferential, theories of perceptual processing, ecological approach may be seen as providing a characterisation of the competence that such processes must exhibit.

Gibson took his position to be radically at variance with the "information processing" orthodoxy in perceptual psychology. Yet there has been considerable debate about the real nature of the dispute between these positions (Fodor & Pylyshyn, 1981; Turvey, Shaw, Reed & Mace, 1981; Ullman, 1980).

One natural source of debate is whether or not the account of the task of the organism is adequate. Is an informational analysis of perception appropriate at all, given the possibility of illusion? Perhaps information about the environment is not, in general, specified in the perceptual input, but must be supplemented by the knowledge of the organism.

However, what has made ecological psychology controversial is its claims about mechanism. If the relevant environmental information is *already* carried by the perceptual input itself, the elaborate information processing operations postulated by standard models of perception seem to be redundant. Perhaps such intricacies are simply unnecessary - perhaps the environment can be perceived *directly.* Thus Gibson suggest that perception is *direct* and not mediated by information processing of any kind. Attunement is held to simply be a matter of directly "picking up" or "differentiating" the relevant "higher order invariants" of the perceptual input.

It is this rejection of the need for information processing in general, and in the particular the standard symbolic, inferential models that has made the Gibsonian position appear so radical. However, on close analysis it is difficult to make sense of the notion of direct perception*. Let us grant the assumption that the relevant environmental information is carried by (specified by) the perceptual input. If so, it is easy to build a device whose state *carries* this information. To a first approximation, a *camera* is adequate, since the state of the film specifies the instantaneous state of the optic array. Since Gibson stresses the informational richness of the time-varying informational stimulus, a cine camera is perhaps more appropriate. Time-varying auditory information could be recorded on a tape recorder. If we ignore the rest of the senses, it seems that we already have a device whose state carries much information about the environment - the home video camera! Certainly the home video camera does not perform a wealth of intricate information processing operations on its "perceptual" input. But it does not do anything else either - its *behaviour* is not attuned to the information about the environment. Even if some piece of information *is* carried by the perceptual input, the *attunement* of behaviour to that information is far from trivial. What is hard is not *carrying* the information that a fly or a friend or some food is present, but *utilising* this information in controlling behaviour⁺. It requires considerable sophistication to selectively jump at flies, to selectively smile at friends, or to selectively eat food rather than non-food. Jumping at passing flies involves intricate visual analysis, smiling only at friends or eating only food involves mental processes of unimaginable complexity. Even if the relevant information about the environment is specified by the perceptual input,

*Ullman (1980) suggests that Gibson may be viewed as suggesting that the mechanisms underlying perception are unitary and cannot be decomposed into simpler operations. Ullman then provides extensive arguments against this position. An alternative reading, which I shall follow, is that Gibson considered the "pick-up" of information to be a trivial problem, which thus requires no mechanism at all.

⁺This corresponds to Israel and Perry's (1987) distinction between carrying information and having information, within the situation semantics tradition.

the *utilization* of perceptual information to control behaviour seems to require considerable work. Yet, for Gibson, attunement is *trivial.* It is simply a matter of "picking up" the appropriate high level perceptual patterns. Thus, rather than taking the elucidation of ecological laws to be *part* of psychological explanation (specifying the information processing task that the organism must perform) which must be supplemented by an account of the mechanism, Gibson saw the ecological approach as providing a *complete* account of perception. For Gibson there is no problem of mechanism, since there is no need for mechanism to underlie attunement. It is simply a matter of direct information pick-up. However, if attunement is so easy, why can't rats be attuned to losing chess positions, and cameras to attractive compositions?

Just *carrying* information in the raw perceptual input does not seem to be enough to guide the appropriate *utilization* of information. We termed the problem of characterising the purpose of information processing "Gibson's problem". It is not that Gibson raised this problem, or that he suggested a solution for it; it is rather that Gibson did not consider it to *be* a problem. He considered information processing to be *unnecessary*. That, one might say, was Gibson's problem!

Gibson's problem poses a challenge to the theorist who wishes to analyse mental processes in informational terms. If information about the environment is already carried by the perceptual input what is the point of further processing. What does information processing achieve. Much of the rest of this thesis will be concerned with this question. Before turning to the approach implicit in Dretske's use of the analog-digital distinction, let us consider a more obvious suggestion - that the purpose of information processing is to enrich the information carried by the perceptual input. In short, the purpose of information processing is seen as information gain. Unfortunately, however, we shall see that, on the present account, information gain is impossible.

4.3 Information Processing and Information Reduction

A natural view of the purpose of perceptual-cognitive activity is that it allows us to *learn about* the way the world is. For example, I know that there is a dog nearby because I can see, hear or smell it. In the first instance, this ability is mediated by the fact that the states of the sensory surfaces of the eyes, ears and nose covary with, and hence carry information about, the state of the environment. Our pretheoretic, intuitive test for whether or not a piece of information is carried by the state of a structure is whether or not that piece of information can, in principle, be *learnt* by learning of the state of that structure. So, some state of my retina carries the information that there is a chair present, if it is possible to learn that there is a chair present from a detailed retinal examination. Yet this view has a rather unexpected and counterintuitive consequence.

Suppose, for concreteness, that the result of perceptual and cognitive analysis is the production of a set of sentences which describe the visual scene in terms of everyday objects and their relations. Perhaps these are roughly intertranslatable with English sentences such as "There is a chair in front of the window", "The cat is on the mat" and so on. Suppose that these formulae carry the information that is their content - that is, they carry the information that there *is* a chair in front of the window, or that the cat *is* on the mat. (Of course, in general, a sentence can mean that the cat is on the mat, even though the cat is not on the mat. In such a case the sentence does not carry the information that is its content *at all*, let alone in digital form. We shall defer discussion of how misrepresentation may be treated in informational terms until Chapter 6). It seems that everything that can be learnt from the *result* of perceptual and cognitive analysis, that is, everything that can be learnt from reading the sentences describing the environment in the language of thought, can also be learnt by looking directly at the retina. After all, the information may be obtained from the state of the retina simply by performing the relevant perceptual-cognitive analysis on the retinal state, deriving the mental sentences, and obtaining the information from them, just as before. So, any information that is carried by information bearing structures which are derived from perceptual input, are already carried by that perceptual input.

It is natural to assume that the purpose of processing raw perceptual input is to increase its information content, to enrich the informational value of the perceptual input. Yet if the informational richness of a structure is equated with the amount of information carried, this is just what cannot happen. Perceptual processing and information processing in general can only *lose* information. The output of an informational process necessarily carries no more (and typically very substantially less) information than the input.

Let us make this point rather more precisely. First, consider deterministic processes - processes in which the output is determined by, or is a function of, the input. Such a process may be modeled by a function f from the set of possible inputs I to the set of possible outputs O. So, by hypothesis, that the input is such and such determines, and so carries the information that, the output is so and so. Hence, all the information carried by the output is *ipso facto* carried by the input. If the process is *not* deterministic then the output is *not* determined by the input. Relative to the input, the output generates new information. However, this new information cannot be information about the environment, since, by hypothesis, the state of the sensory surfaces is the sole mediator of covariation with the environment. So all the information that the output of the process carries about the environment is also carried by the input.

The point can be made more generally. Consider the information generated by the output of some process. This information must either be generated by the input or by some random factors in the workings of the process (for insofar as the output is a determinate function of the input, no information in generated internally at all). So, for determinate process, all the information carried by the output is carried by the input. In a non-determinate process, all the *useful* information (i.e. not information about the random behaviour of the internal working of the device) which is carried by the output is carried by the input. So, in particular, all information carried by the output of perceptual analysis is carried by the input to that analysis.

It may be objected that we have adopted an overly passive view of the way in which organisms learn about their environment. Have we not neglected that what an organism learns is not simply determined by the state of the environment, but also by the expectations and knowledge of the perceiver. Let us consider an example from Perry (Perry, 1987) A doctor looks at an X-ray and realizes that John has broken his collar bone. John looks at the X-ray and sees only a tangle of bones. Another doctor seeing the picture will be able to conclude only that *someone* has a broken collar bone, since he does not know that the X-ray is John's. Taking a more prosaic example, suppose that I know that John usually has a red mug on his desk, and owns no other red objects, and I can see a tiny patch of red peeping from between two piles of books. There is now a temptation to argue as follows. Surely the state of the retina does not itself carry the information that there is a mug present. It is impossible to learn that a mug is present, from the state of the retina, without already knowing that the mug is the only red object that may be on the desk. Otherwise, the patch of red could be generated by a red pen, or book, or clock. Yet, given my additional knowledge, I can conclude that I am looking at the mug. So it appears that the result of my perceptual and cognitive processing can, after all, carry *more* information about the environment than the state of the sensory surface. In the case of the diagnosing doctor, although the X-ray may carry the information that the collarbone is broken, it surely does *not* specify that it is *John*'s collarbone. After all, the X-ray need not have a label attached, saying whose it is. The diagnosing doctor, who happens to know that the X-ray is John's, can draw a conclusion on the basis of his sensory input (the image of the X-ray) which is only licensed by his background knowledge about the subject of the X-ray. So, again, it seems that the internal state of doctor carries information which is *not* carried by the sensory input. In both cases, perceptual/cognitive processing seems to *enrich* the information carried at the sensory surfaces, contrary to the claim that information processing is a matter of information *reduction*.

The argument trades on the knowledge relativity of information - that a signal may carry different information for observers with different background knowledge. In 1.6, we concluded that the knowledge relativity of information is derivative on the fact that informational properties are relative to the idealisation chosen. Knowledge is relative only derivatively. What the observer knows about what is possible determines what informational idealisation in appropriate, and information content is relative to this idealisation. Recall the example of the cups and the hidden peanut. On an idealisation appropriate to my knowledge, there are two possible locations for the peanut, since I have already seen that it is not under two of the cups. Since you have just come in, according to an idealisation appropriate to your knowledge, the peanut could be under any of the four. The raising of the third empty cup thus specifies the location of the peanut on my idealisation but not on yours.

It is this knowledge relativity which is being exploited in generating the apparent case of information gain. When considering the information carried by the retina, it is natural to adopt an idealisation ignoring the additional information about which red objects may be on the desk. On this "ignorant" idealisation the red patch does not specify the presence of the red mug. Yet when we consider what I *learn* from seeing the red patch, we use an idealisation which captures my knowledge that the cup is the only red object that may be present. On *this* "knowing" idealisation, the presence of the mug *is* specified. So the alleged information gain is an artifact of a covert change of idealisation, from assuming ignorance, to capturing knowledge. Similarly, the X-ray does not carry the information that *John* has a broken collarbone in an idealisation which assumes that it could be anybody's X-ray. Yet on the idealisation appropriate for the doctor, who knows that the X-ray is John's, it does specify this information. The slippage between the "ignorant" idealisation (when considering just the X-ray) and the "knowing" idealisation (when considering the doctor) is again the cause of this apparent information gain.

Let us consider the "knowing" and "ignorant" idealisations in turn. On a "knowing" idealisation, the retinal image itself carries the information that the red mug is present - since all other red objects are excluded; the X-ray carries the information that John has a broken collarbone, since the idealisation excludes situations in which it is an X-ray of somebody else. Of course, much additional information will also be carried, about the other objects on the desk or about the shape of John's shoulder blades. To utilise the information appropriately (to pick up the mug and pour some coffee, or to pronounce the correct diagnosis), the observer must strip away this additional information. So the perceptual-cognitive system seems to be effecting information *reduction* after all. In contrast, on an "ignorant" idealisation, the presence of the red patch (and the consequent generation of the internal sentence corresponding to "There is a red mug present") is perfectly compatible with a red telephone being on the desk and the mug being, say, on the draining board. Hence, *neither* the input to perceptual/cognitive processes, or the output of those processes carry the information that the mug is present. Similarly, on an "ignorant" idealisation, the X-ray image, and the doctor's consequent diagnosis are quite compatible with someone other than John having a broken collarbone, and John being wholly intact. Hence, *neither* the X-ray or the diagnosis carry the information that John has a broken collarbone. In sum, on a "knowing" idealisation the information is carried by both input and output. On an "ignorant" idealisation the information is carried by neither. If the idealisation is fixed, information processing can only *reduce* the amount of information carried.

So the point of information processing is not to produce outputs which carry information that is not carried by the raw input. The sensory surfaces carry all the information that can be obtained about the environment. So again we must face Gibson's problem: what is the function of information processing?

Inherent in the Dretske's discussion is the important idea that the point of information processing is analog-digital conversion. Only when information is converted into digital form can it be "conceptually mobilised", "cognitively utilized" or used to "modify output". It is this approach, and variants upon it, that will we shall be concerned with from now on. Let us turn, then, to the view that attunement is a matter of analog-digital conversion.

4.4 Digitalisation and Behaviour

In 4.2, we noted that there must be more to perception that carrying information about the environment - otherwise cameras and tape recorders would count as exhibiting perception. Intuitively, there is a vast gulf between such devices and genuine perceptual systems. On what is this intuition based? Let us consider a camera and a person both facing the smiling couple Janet and John. The state of the camera and the state of the observer both carry information about the pair: that John has a handlebar mustache; that Janet has a birdsnest hairstyle; that John is taller than Janet. While the states of both the camera and human observer carry this information, only in the latter case can this information be causally implicated in behaviour. The person may selectively emit a suppressed laugh when looking at Janet's head, or ask John rather than Janet to reach for the saucepan on the top shelf. The behaviour of the camera is not sensitive to such information - it does not, for example, change its aperture or focus just when presented with a handlebar mustache. In Gibson's terms, the person is attuned to this information, the camera is not. This does not mean, however, that the camera is attuned to no information about the state of the environment. For example, on a modern automatic camera, the aperture will be adjusted in response to the light reading. Or perhaps the tripod falls over when and only when there is an earthquake of over 6 on the Richter scale. In these cases, the camera *is* attuned to information about the light intensity and the strength of earthquake, respectively.

The relevance of digitalisation is perhaps already apparent. If I suppress a laugh when and only when I see a birdsnest hairstyle, then suppressed laughter *tracks* the presence of birdsnest hairstyles. So, given that the presence of such a hairstyle is *new* information, this means that whether or not I am suppressing laughter carries the information that a birdsnest hairstyle is present (or absent) in digital form. That is, the *behaviour itself* digitalises the information. So the attunement of some behaviour to a piece of information involves the digitalisation of that information.

Consider a monkey who should race up a tree when and only when a tiger is near. If the monkey is gazing in the general direction of the tiger, the state of its retina will carry the information that a tiger is present in digital form. The optimally successful monkey must attune its tree climbing behaviour to the presence of tigers. That is, whether or not the monkey races up the tree should carry the information that there is or is not a tiger nearby in digital form. Monkeys whose behaviour is not so attuned to the presence or absence of tigers spend a lot of time unnecessarily shooting up trees, getting eaten, or both. So there is a high premium on successful digitalisation.

To be attuned to some piece of information is to be able to respond selectively to it. The attuned monkey is to be able to run up a tree just when a tiger is near, the attuned frog is able to to be able to jump at all and only flies, the attuned parent is to be able to ask John to fetch the from the top shelf in the kitchen just if he is taller than Janet. However, only on a behaviouristic psychology does attunement amount to a *fixed* link between environmental stimulus and behavioural response. As we are using the term, attunement only requires that the organism is *able* to correlate behaviour with the state of the environment - not that behaviour is invariably so correlated - the monkey might be suicidal, the frog might not be hungry, a parent might ask John to fetch the saucepan just in order to have a few quiet words with Janet. Indeed, the rise of non-behaviourist representational theories of mind, has been driven by the realisation that the link between the state of the environment and the behaviour of the organism typically depends on the goals and beliefs of that organism. In representationalist terminology, what attunement requires is that, *given* the appropriate beliefs and goals, the organism is *able* to link its behaviour to the relevant state of the environment. So, given the belief that tigers are dangerous, and the goal of avoiding danger, the attuned monkey will shoot up the tree just when tigers are nearby. (More broadly, the link between environment and behaviour may be seen as dependent on the current mental state of the organism, irrespective of whether this state is appropriately characterised using the propositional attitude ascriptions of folk psychology).

The almost unlimited *plasticity* of the link between perceptual input and behavioural output is stressed by cognitivists (e.g. Pylyshyn, 1984). To take a fresh example, let us suppose that I see a man approaching in a suit covered in arrows. Using my knowledge of old films, I realise that this specifies that he is a prisoner. Typically this might induce me to clutch my wallet. However, if I am determined not to show my disquiet, or the prisoner is handcuffed to a policeman this behaviour may not ensue. If I am an undercover policeman looking for an escaped convict, I may use some arbitrary agreed signal (perhaps raising an eyebrow or standing on one leg) to pick out suspicious characters that a colleague should follow. Attunement to a piece of information requires that I *may* establish a link between that information and some behavioural response - not that such a link need necessarily already exist.

The plasticity of response suggests that the behaviour which carries the information in digital form is *derivative* on the digitalisation of some *internal* structure of the organism which carries the information in digital form. Suppose that a raised left eyebrow is the code for the approach of an escaped prisoner. I may be instructed to change the signal and instead raise my right eyebrow. How is it possible to freely control which piece of behaviour is attuned to, and hence carries in digital form, the information that an escaped prisoner is approaching? Surely we must decouple the process of recognition (prisoner detection) from action (eyebrow raising). When I change the code, the process of villain detection is unchanged, but now it is linked to a different overt response. In mechanistic terms, this amounts to the proposal that I must possess some internal structure (a "prisoner detector") which responds selectively to prisoners, and that this internal structure may be arbitrarily connected to behavioural outputs. This is no more than an example of the general cognitivist point that the structure of behaviour is derivative on the structure of thought (e.g. Fodor, 1983).

Let us call the link between behaviour and environment *behavioural* attunement, and the link between an internal structure of the organism and environment *internal* attunement. In this terminology our conclusion concerning plasticity becomes simply that *plastic* behavioural attunement is necessarily mediated by internal attunement.

So far, we have assumed that a behaviour or the state of an internal structure is only attuned to some piece of information if it *tracks* that information, and hence carries it in *completely* digital form. However, this restriction is extremely severe, since tracking requires detection is *infallible.* A less strict characterisation is simply that the behaviour carries the information in digital form *tout court* (rather than in completely digital form) relative to some relevance restriction. Suppose that I raise my eyebrow just when a villain passes, unless I have temporally fallen asleep. So (assuming that my sleeping-waking state is included in the idealisation) the raising of my eyebrow carries information over and above that there is a villain present - namely that I am awake. So the information is not carried in *completely* digital form. However, if the only relevant propositions are about criminal movements, then this is not *relevant* additional information, and so the information is, according to this idealisation, carried in *digital* form. According to this, looser, condition, a monkey can be attuned to tigers even if it does not run up the tree *every* time a tiger is near - for example, it may fail to detect tigers when it has its eyes closed, or in the dark. It seems only reasonable to loosen this condition. For we do not surely want to say that just because if a monkey fails to spot a tiger on one tragic occasion, it never *really* detected tigers at all.

Let us stress again that we are interested in an providing an informational account of *what* attunement amounts to, rather than the mental structures and processes which effect such attunement. The internal structures which carry information in digital form might be sentences of a language of thought, single "grandmother" cells, patterns of activation in a distributed memory, holographic traces, mental images, or procedures in a "machine code" of the brain. The application of an informational account to mental processes is intended to tell us *what it is* to extract, store and utilise information about the environment, not *how* these processes are realised.

4.5 Information Processing as Digitalisation

The notion of digital information content has been invoked to provide an explication of attunement. Yet, in this section, we shall see that it is sufficiently general to apply equally to any information processing, not only to the domain of mental processes. In particular, an account of information processing based on analog-digital conversion should apply equally to symbolic and non-symbolic information processing. In this section, we shall discuss a variety of device which are pretheoretically taken to effect information processing. First, let us illustrate the general point with the example of a standard symbolic example.

Consider a cash register which can take some number of inputs (strings of key presses "7 + 4 + 3 Rtn") and immediately produces a single output (in this case, it prints the symbols "14"). Let us assume that the operation of the cash register is perfect, in the sense that on the standard arithmetical interpretation of the key presses, and on the standard arithmetical interpretation of the numbers displayed, the output number is always the sum of the input numbers. Let us consider the state of the output display. This may display symbols which decimally encode any natural number value (modulo space limitations of the display). The display will, of course, change constantly throughout the day as the cash register is in use. Suppose the output display is the symbol "6". This state of the output carries the information that the answer to the current problem is 6. For the conditional probability that the answer to the current problem is 6, given that the symbol displayed is "6" is unity. However, the very same information (that the answer to the current problem is 6) is also carried by the state of the input. For the conditional probability that the answer to the current problem is 6 given that the input is, say, "1 + 3 + 2 Rtn" is also unity. Given that the information carried by the output was already carried by the input, it seems that we have no account of what computational work is done by the cash register. However, crucially, the output symbol seems to carry the information in digital form - all you know about the problem under consideration is that its answer is 6. The problem might equally have been 2 + 4, 1 + 1 + 1 + 1 + 1 + 1, 1 + 2 + 3 and so on. On the other hand, the input key presses carry the additional information that the particular problem was 1 + 2 + 3. Hence, the key presses carry the information that the answer is 6 in analog not digital form. So, the transition from input to output has *lost* all information about the problem *except* the answer. In informational terms, the information processing function of the cash register is converting the information about the sum into digital form - that is, to lose all the rest of the information carried by the input.

In IV.3 we saw that information gain is impossible *in principle.* Nonetheless, it seems rather paradoxical that the information processing role of a device is to lose information. Intuitively, we still want to say that the role of the device is to gain information - to give us information (about the answer of the problem) that we did not have before. This apparent tension may be readily resolved.

Let us change our example slightly. Suppose that I have an addition sum written on a piece of paper. I wonder what the answer is, and decide to use the cash register to do the calculation. I then write down the answer. The paper is transformed from, say, having the symbols 6 + 3 + 2 on it to having the symbols 6 + 3 + 2; 11 on it. I feel intuitively that I have made progress by making the calculation. The symbols on the paper seem to give me more information than they did before - now I can see not only what the problem is but what the solution is too. However, from an information-theoretic standpoint it might seem that I have made no progress at all. For the additional "11" only carries the information that the answer to the problem is 11. This information is also carried by the original "6 + 3 + 2". So it seems that I have made no progress at all. Suppose that I take another addition problem (say, 2 + 9) and repeat the procedure. As it turns out the answer to this problem is also 11. Thus the output of the cash register is the same as before. The addition process can be seen as a process of categorising addition problems into classes according to their solutions. "6 + 3 + 2" and "2 + 9" are categorised to be in the same class. The output has lost the information about the particular element of the class we are dealing with. Now it is easy to see why information loss may count as cognitive progress. For suppose that I wonder whether or not the two expressions 6 + 3 + 2 and 2 + 9 are equal. I need only compare the two answers on my piece of paper. If the symbols are the same ("11" and "11") then they are equal, otherwise they are not. There is no equivalent procedure which operates directly upon the expressions "6 + 3 + 2" and "2 + 9". The only way to find out is, of course, to do the addition. So using the cash register really was useful. Although the paper carries no more information after I have calculated the addition, it does carry more information in a *usable* form. To prefigure terminology that we shall introduce in Chapter 6, the answer is only implicitly coded in the input; the answer is explicitly coded in the solution. So a general principle might be: information is only usable when it is carried in digital form. Information processing is a matter of transforming from analog form in the input to digital form in the output.

Or consider the case of logical inference from some set of premises. Suppose the premises are logical formulae in a theorem prover, corresponding to "All men are mortal" and "Bert is a man". Let us assume that these formulae do not just *represent*, but *carry* the propositions that they represent in digital form (It is reasonable to doubt, in general, both that representations need carry their contents *at all*, since representation is not factive; and it is reasonable to doubt that the information is carried in digital form. These issues are addressed in chapter 6). Given these premises, the information that Bert is a man is carried in analog form (assuming some appropriate informational idealisation). The theorem prover draws the obvious inference and derives the formula corresponding to "Bert is mortal".

This formula carries no additional information, over and above that Bert is mortal. So the operation of the theorem prover has digitalised the information that Bert is mortal.

So although information processing is a matter of information *reduction*, we can do justice to the intuition that such processing makes *more* information available. For the processes involved in the calculation of the sum or the drawing of the inference may not lead to gain of information *per se*, but it does lead to an increase in the information which is coded *in digital form.*

We noted above that since the informational account merely attempts to characterise *what* information processing amounts to, it is independent of the nature of the internal mechanism which mediates such processing. So the account applies equally to non-symbolic processes.

Consider the problem of finding the length of an irregular line, such as the course of a road or a river. A simple analog "string" solution is simply to place a string such that it follows the structure of the line as closely as possible. In this state, the string carries (more or less) detailed information about the shape of the line - its topographic character, how bumpy it is, and so on. In particular, one piece of information that the string will carry, of course, is the (approximate) length of the line. However, this information is initially "buried" in the mass of additional information. The string is then straightened out and measured, to give the approximate length of the line. The operation of straightening out the string throws away all the information about the irregular line *except its length.* The straightened string carries the information about the of the line in digital form.

Or consider the problem of ordering some set of exam scores from highest to lowest. The input is of the form (John, 35; Jill, 66; James, 45...). Clearly the raw results already *carry* the information that Jill came top, James third, and John nineteenth, and so on. However, considerable additional information is carried about the particular scores that each pupil achieved, over and above the ordinal position in the class. When the ordering is obtained such additional information is thrown away. From the point of view of the informational account, it is immaterial what sort of mechanism effects this sorting process. Let us consider an analog method from "spaghetti" computing. First, we represent the score of each pupil by the length of a piece of spaghetti, which has a label with the pupil's name written on it. Then we pick up all the pieces of spaghetti and bang them down onto the table, such that the end of each piece is in contact with the surface. The tallest piece of spaghetti is then removed and its label placed in the "1" slot; then the tallest remaining piece is placed in the "2" slot; and the procedure is iterated until all the pieces of spaghetti have been assigned a slot. Each pupil is thus assigned an ordinal position within the class. In the output, there is no additional information carried about each pupil, over and above that ordinal position, since no information about actual scores is carried by the position of the labels.

Despite their apparently naive character, such simple analog computations are good illustrations of the methods of analog computation. For much analog computation, involves the direct exploitation of the natural constraints of the substrate over which it is computing (see the discussion of Pylyshyn's characterisation of analog computation in III.1) In the cases that we considered, the analog computation exploits the constraints that string may be bent freely, but has a fixed length and that spaghetti is rigid.

As our final example of non-symbolic computation, let us consider a competitive neural network. Such a network consists of a collection of non-linear summation units, fully connected by inhibitory links between them. A pattern of activation is presented to the units, and they compete until only one, highly active unit remains. In the simplest case, in which the network is fully connected with equal inhibitory connections, the unit that is initially most active will "win" the competition. So the settling of the network acts picks out this initially most active unit - all additional information about the initial values of the various units is lost*.

Rather than consider more examples, let us consider a more general characterisation of the informational treatment of computation. The analysis of information processing that I shall sketch is no more than an informational gloss on the standard construal of (deterministic) computation.

A (deterministic) computation may be considered to perform some mapping **f**:*In* -> *Out*, where *In* is the set of possible inputs, and *Out* the set of possible outputs. Since the output is determined by the input, all the information carried by the output is already carried by the input. However, the output typically does not carry all the information that the input carries. This occurs when **f** maps more than one input onto the same output. The output does not distinguish between these various inputs - they are classified together, and so information is lost. For example, the inputs 3 + 5, 4 + 4, 6 + 2 and so on, to the cash register all lead to the output 8. The operation of the cash register serves to classify these various inputs as equivalent - to throw away additional information about them.

*In general, of course, which unit ultimately wins the competition is a very much more complex function of the initial pattern. Nonetheless, the general point is unchanged.

In more formal terms, a function **f** is said to induce *equivalence classes* of elements of *In* which map onto the same elements of *Out*. The output only specifies which equivalence class the input was in. The function **f** may be viewed as mapping each element of the input onto its equivalence class under **f** - that is, as classifying the input into these equivalence classes.

In informational terms, the function of information processing is ignoring additional information in the input, to classify the input into the relevant equivalent classes. In other words, information processing is a matter not of the *generation* new information from old, but of the *abstraction* of new information from old. Only when this abstraction is has been performed - only when the information has been digitalised - can a piece of information be utilised.

4.6 Digitalisation and Behaviour (Again)

We have suggested that, quite generally, a piece of information must be coded in digital form if it is be utilized. However, as we shall see, this position is somewhat over-restrictive. Let us again suppose, for purposes of exposition, that the vehicle of internal representation is a language of thought, and that the sentences of this language carry the information that they represent in digital form. The sentence corresponding to "John is taller than Mary and has a handlebar mustache" does not carry the information that John is taller than Janet in digital form, since it carries additional information about John's mustache (assuming that this is relevant on the chosen idealisation). Further (rather trivial) information processing is required to put this information into digital form. Yet, nonetheless, this information *is* utilisable, although it is not carried in digital form. This is because it may straightforwardly be converted into digital form, as required.

This point is analogous to that which arises in the analysis of propositional attitudes as relations to mental representations (Fodor, 1978; Dennett, 1979; Stich, 1983; Field, 1978). Paradigmatically, to believe that snow is white is to have a token of the corresponding sentence of mentalese stored in the "belief box". Yet surely the belief that armadillos don't wear trousers is not stored anywhere - the possibility has simply not occurred to us. Yet it is plausibly a consequence of beliefs which are stored directly in the belief box (perhaps, *inter alia*, that only people wear clothes, that trousers are an article of clothing and so on). So the beliefs of an organism are taken to be characterised by the sentences in the belief box and their easy (in some sense of "easy") consequences. We cannot take the beliefs of an organism to be the set of *all* derivable consequences. Firstly, the stored sentences might be inconsistent, in which case the organism will believe any arbitrary proposition and its negation; secondly, any organism that has the axioms of number theory must automatically believe that, say, Fermat's theorem is true or false - depending on whether Fermat's last theorem *is* true or false. In the informational case, if we assume that a piece of information carried by some structure may be utilized as long as there is *some* way of converting it into digital form, then *any* piece of information carried, whether in analog or digital form will be utilisable. Just as we may distinguish paradigmatic beliefs from "latent" beliefs (those which may be easily derived from paradigmatic beliefs) we may distinguish paradigmatically digital information from "latently" digital information (that which may easily be digitalised from the existing information structures). In both cases, the characterisation of "easily" is obscure, and I shall say no more about it. Nonetheless, strictly speaking, latent digitalisation is enough for attunement to a piece of information, for that information to be able to influence action, and, more generally, for the utilization of information.

It has been suggested that information can only be utilized if it is coded in digital form (or may easy be transformed into digital form) and that the purpose of information processing is to convert information from analog (unusable) to digital (usable) form. Although he does not discuss the utilisation of information in the section on the analog-digital distinction, in later discussion, (see Chapter 5 below) Dretske draws out the moral that only when some piece of information has been converted into digital form can be it be used, for example, to control the behaviour of an organism. Nonetheless, the proposal that digitalisation is a precondition for the utilisation of a piece of information is largely implicit in Dretske's text. Instead he focuses on a rather more specific claim - that the analog-digital distinction allows us to classify mental processes into two sorts. On the one hand, *sensory* or *perceptual* processes merely transmit information in analog form (thus, in our terms, leaving it is unutilisable form). On the other, *cognitive* processes effect the digitalisation of information (thus turning it into a form in which it can be utilised). In the rest of this chapter, I shall consider the putative relationship between the analog-digital distinction and the perception-cognition distinction in detail. I shall present (4.8) various reasons to suppose that the analog-digital distinction does not differentiate sensory/perceptual processes from cognitive processes, on any natural reading of these terms. Having considered some specific problems with Dretske's analysis, I shall discuss a more general difficulty. In short, the relativity of the analog-digital seems to fit ill with the presumably absolute nature of a distinction between perceptual and cognitive processes. We shall see that this relativity has import for the application of informational notions quite generally.

4.7 Dretske on Perception, Cognition and the Analog-Digital Distinction

Dretske applies the analog-digital distinction to characterising the difference between sensory (or perceptual) and cognitive processes.

> "The contrast between an analog and a digital encoding of information... is useful for distinguishing between sensory and cognitive processes. Perception is a process by means of which information is delivered within a richer matrix of information (hence in *analog* form) *to* the cognitive centers for their selective use. Seeing, hearing, and smelling are different ways we have of getting information about *s* to a digital-conversion unit whose function it is to extract pertinent information from the sensory representation for purposes of modifying output. It is the successful conversion of information into (appropriate) digital form that constitutes the essence of cognitive activity. If the information that *s* is *F* is never converted from a sensory (analog) to a cognitive (digital) form, the system in question has, perhaps, seen, heard, or smelled an *s* which is *F*, but it has not *seen that* it is *F*-does not *know* that it is *F*. The traditional idea that knowledge, belief, and thought involve *concepts* while sensation (or sensory experience) does not is reflected in this coding difference. Cognitive activity is the *conceptual* mobilization of incoming information, and this conceptual treatment is fundamentally a matter of ignoring differences (as irrelevant to an underlying sameness), of going from the concrete to the abstract, of passing from the particular to the general. It is, in short, a matter of making the analog-digital transformation." (Dretske, 1981: 141-142)

In a footnote Dretske points out that "It is not merely the conversion of information from analog to digital form that qualifies a system as a perceptual-cognitive system" (Dretske, 1981: 254) and that he will discuss the additional conditions that must be met later. To give a rough idea, a digitalised piece of information will only count as a belief if it may be causally implicated in controlling the behaviour of the organism.

At first sight, the analog-digital distinction is being used in a rather unusual way. The distinction is between the way in which information is *carried*, yet it is used to distinguish sensory (or perceptual) and cognitive *processes*. From an informational point of view, such processes take the state of one information bearing structure as input, and produce another structure as output. If a piece of information is carried in analog form in the input, and in digital form in the output, then that piece of information has been converted from analog to digital form. Perhaps the state of the retina carries the information that John is in a losing position in a game of chess in analog form, and, after the appropriate analog-digital conversion by the cognitive centres, this information is carried in digital form by some internal state of the observer. By contrast, consider the photochemical processes of the retina, which transform the impinging structure of the light into a neural pattern of activity. Both the structure of the impinging light and the neural pattern carry the information that John is in a losing position in analog form. Thus, these photochemical processes mediate an analog-analog transformation with respect to this piece of information.

So, in distinguishing analog from digital processes, Dretske is distinguishing analog-analog transformations from analog-digital transformations, relative to some piece of information. In the former case, we speak of information being "picked up" or "registered". In the latter, we speak of information being "extracted", or "digitalised". Dretske takes perceptual processes to be a matter of registering or picking up information and cognitive processes to involve extracting or digitalising information. Dretske argues that this fundamental difference in kind has been missed by much modern psychological theorising:

> "Information-processing models of mental activity tend to conflate perceptual and sensory phenomena on the one hand with cognitive and conceptual phenomena on the other. Perception is concerned with the pickup and delivery of information, cognition with its utilization. But these, one is told, are merely different stages in a more or less continuous information-handling process. Recognition, identification, and classification (cognitive activities) occur at every phase of the perceptual process. Seeing and hearing are low-grade forms of knowing.
>
> I think this is a confusion. It obscures the distinctive role of *sensory experience* in the entire cognitive process." (Dretske, 1981: 135)
>
> "...our perceptual experience (what we ordinarily refer to as the look, sound, and feel of things) is being identified with an information-carrying structure--a structure in which information about a source is coded in analog form and made available to something like a digital converter... for cognitive utilization. This sensory structure or representation is said to be an analog encoding of incoming information because it is always information *embedded in* this sensory structure (embedded within a richer matrix of information) that is subjected to the digitalising processes characteristic of the cognitive mechanisms. Until information has been *extracted from* this sensory structure (digitalisation), nothing corresponding to recognition, classification, identification, or judgement has occurred-nothing, that is, of any *conceptual* or *cognitive* significance." (Dretske, 1981:143)

Sensory (perceptual) mechanisms register information; cognitive mechanisms extract it. Information registration is commonplace - photographs, retinas and mirrors can all carry the information that John is in a losing position, or that there is a chair in the room in analog form. For Dretske, information *extraction* is rarer. Only people, and perhaps some animals or AI programs can carry such information in *digital*. Indeed, Dretske raises the possibility that:

> "It may be that the acquisition of language is essential to an organism's having the capacity to convert sensory information into digital form..." (Dretske, 1981: 143)

So, it seems that for Dretske, it is conceivable that the digitalisation or extraction of information may be an exclusively human ability.

Let us summarise the variety of theses which arise from the application of the analog-digital distinction to the perception-cognition distinction. Sensation (perception) is a matter of analog-analog transformation. Cognition involves analog-digital transformation. So, deriving the look, sound and feel of things involves only analog processes. Recognition, identification, generalisation and classification and the possession of concepts involve analog-digital conversion. To be capable of analog-digital conversion is to exhibit cognition (and hence, presumably, to be at least a rudimentary cognitive agent), modulo the additional condition that the digitalised information somehow affects behaviour.

In the next section we consider whether this distinction can be appropriately applied to differentiate perceptual or sensory from cognitive processes. Dretske's claim that there are two qualitatively distinct kinds of information processing involved in mentation has considerable intuitive appeal. In Gibsonian terms, the sensory input *specifies* some proposition about the environment if the state of that input carries the information that the proposition holds. However, such information is (typically) still carried in analog rather than digital form. For the utilisation of this information, for the behaviour of the organism to be (flexibly) *attuned* to the state of the environment, this information must be converted into digital form. So perhaps there are two distinct species of information processing - those which mediate specification, and those which mediate attunement. However, I shall argue that i) the apparently absolute qualitative distinction between informational processes is an illusion; ii) that the analog-digital distinction cannot be used to provide a taxonomy of mental processes.

4.8 Perception and Cognition

For Dretske perception involves analog-analog transformation of information:

> "Perception is a process by means of which information is delivered within a richer matrix of information (hence is *analog* form)..." (Dretske, 1981:142)

By contrast, cognition is matter of analog-digital conversion:

> "It is the successful conversion of information into (appropriate) digital form that constitutes the essence of cognitive activity" (Dretske, 1981:142)

However, this characterisation does not seem to fit well with modern perceptual theory. The goal of perceptual processing is seen as transforming the input from the sensory surfaces into a form which may be directly utilized by such cognitive mechanisms as underlie memory, learning, common-sense inference and the production and comprehension of natural language (e.g. Fodor, 1983; Lindsay & Norman, 1977; Marr, 1982). For example, the goal of a visual perception might be taken to be to take a grey level image as input and generate, say, a viewer independent, predicate calculus description of the objects present in the scene and the way in which they are arranged. Information such as that there is a cat on the mat is extracted from the richer matrix of visual input and isolated in some formula ON (CAT, MAT). Such a formula can be stored in memory, used in inference and reasoning tasks and so on (at least given the standard, if controversial, assumption that higher mental processes are proof-theoretic in character). If the goal of perception is to turn information at the sensory periphery into a form which is accessible to high level cognitive process, then perception is a *paradigm case* of analog-digital conversion - and not an example of analog-analog transformation, as Dretske intended. So, far from distinguishing perception and cognition, the analog-digital distinction seems to lump them together.

Further, the perceptual process is typically considered to be mediated by the derivation of a number of perceptual representations which describe the input at a number of different levels of description (Marr, 1982; Moore, 1982). These range from low level descriptions (close to the level of physical descriptions of the input at the sensory surface), to high level descriptions (close to, or at, the level of description into which we consciously categorise, remember, reason and talk about the everyday world). In vision, the blobs and lines of the primal sketch constitute a low level description; a description of the visual scene in terms of tables and chairs constitutes a high level description. In hearing, a description in terms of simple auditory features of the the input signal may be an appropriate description of the lowest level of representation; a description in terms of which individuals are speaking, what they are saying, and where they come from might be a relevant high level description.

The derivation of each these levels is a matter of classification, or recognition. The pattern in the visual input must be *classified* as a termination, or a continuous line, or a surface at such and such orientation and so on. Recognition, classification, analog-digital conversion are held to be ubiquitous through the levels of the perceptual process. According to modern perceptual psychology, not only does the perceptual process in its entirety involve analog-digital conversion, but the internal workings of this process involve digitalisation through and through.

So perhaps Dretske's distinction is not between sensation and perception on the one hand and perception and cognition on the other. Since the analog-digital appears to categorise perception and cognition together, perhaps it should be taken to differentiate sensation from perceptual-cognitive activity. There are (at least) two ways in which the notion of sensation may be understood, and which Dretske does not distinguish. Sensation may be considered as the excitation of the sensory surfaces by environmental stimulation - that is, sensory input, prior to processing. Alternatively it may be identified with the phenomenology of perceptual experience. I shall argue that on neither interpretation does the analog-digital distinction capture the difference between sensation and cognition. As a reading of Dretske, the first notion is *prima facie* plausible in that it appears to map the sensation-cognition distinction onto the familiar cognitivist distinction between non-computational *transduction* of the environmental input, and computational processes acting on the transduced input (Pylyshyn, 1984). However, we shall see that the non-computational processes of transduction are at least as plausibly viewed as involving digitalisation as the computational processes acting on them. It is clear from Dretske's text that he (primarily) adopts the second reading that *phenomenology* is analog. However, this position is undermined by various considerations from perceptual psychology to which Dretske himself draws attention. I shall deal with the the two readings in turn:

1) Sensation as Excitation at the Sensory Surfaces

Suppose that we construe the process of sensation to involve those processes which underlie the covariation between the physical/chemical/physiological state of the sensory surface, and environment. The chemical activity of the photoreceptors in the retina in response to visual input, or the vibration of the hair along the basilar membrane in the cochlea in response to auditory input, will then be paradigmatically sensory processes. Such a division ties in quite directly with a distinction drawn by theorists interested in which biological processes of an organism are properly viewed as computational processes. Pylyshyn (1984) distinguishes *transduction* from cognition. Transducers simply covary with the simple physical properties of the environment; cognitive processes are defined over *representations* of the environment, which may (or may not) correspond to the state of the environment.

Yet even sensory processes appear to digitalise *some* information in digital form. The chemical state of the photoreceptors in the retina plausibly carry no additional information over and above the information that it carries about the local light intensity in the relevant wavelengths; the vibration of a hair on the basilar membrane plausibly carries no *additional* information other than the sound intensity in the appropriate frequency range. In general, insofar as the state X, Y,... of the sensory surface is determined by the state of the environment, it induces a classification of the environment into states X' (states which lead to the sensory state X), Y' and so on. So it seems that X *does* carry *some* information about the environment in digital form, namely X'.

In any case, the traditional distinction between transduction and cognition is precisely that between those processes which *can* be given a simple informational explanation (perfectly reliable covariation - in our terms, *tracking*) and those which cannot (representations, which do not reliably represent the world, but may be true or false)*. As traditionally conceived, the present analysis should apply *only* to transduction, rather than only to cognition. Cognitive processes trade in representations, which may be true or false, and hence do not necessarily carry information about the environment *at all*, let alone in digital form. Thus, the putative qualitative distinction is between processes of simple covariation with the environment, which may be understood informationally, and computational processes, which may not. Whether or not this distinction is valid, it certainly does not correspond to the difference between analog-analog and analog-digital processes.

2) Sensation as phenomenological experience

Dretske identifies sensation with our phenomenological experience of the environment:

> "Sensation, what the ordinary man refers to as the look (sound, smell, etc.) of things..." (Dretske, 1981:142)

> "...I merely with to develop the idea that the difference between our perceptual experience, *the experience which constitutes our seeing and hearing things*, and the knowledge (or belief) that is normally consequent upon that experience is, fundamentally, a coding difference." (Dretske, 1981:143) (my italics)

According to perceptual psychology, the look, sound and smell of things are the *result* of perceptual activity. We do not have direct conscious access to the states of our sensory surfaces. Rather, our phenomenology represents the environmental input *as it is presented to thought* by the perceptual systems. Dretske's own examples are telling. In a footnote, he quotes Rock with approval:

> "But there is a genuine perceptual change when in viewing potentially familiar figures one goes from an initial "nonsense" organisation to a subsequent "meaningful" organisation. The figure looks different when it is recognized" (Rock, 1975 An Introduction to Perception, quoted in Dretske, 1981:257)

Organisation is a paradigmatically cognitive activity. Patterns on sensory surfaces are not organised, structured descriptions of the world are. Yet, Rock points out that the organisation of the input is crucially implicated in phenomenology. Rock's point shows precisely that phenomenology is *dependent on* rather than *prior to* perceptual processing. Another class of examples of the dependence of the phenomenal quality of the environment on perceptual processing are the perceptual constancies. Dretske quotes Woodworth (1938):

> "the retinal image continually changes without much changing the appearance of objects. The apparent size of a person does not change as he moves away from you. A ring turned

*The issue of misrepresentation will be deferred until Chapter 6

> at various angles to the line of sight, and therefore projected as a varying ellipse on the retina, continues to appear circular. Part of a wall, standing in shadow, is seen as the same in color as the well-lighted portion. Still more radical are the changes in the retinal image that occur when we move about a room and examine its contents from various angles. In spite of the visual flux the objects seem to remain in the same place..." (quoted in Dretske, 1981: 164)

Dretske phrases this point revealingly:

> "The visual experience that constitutes our sensory encoding of information about ordinary physical objects can, and generally *does*, remain unchanged in response to *quite different proximal stimulation*" (Dretske, 1981: 163)

Dretske appears to claim i) that the constancy phenomena show that sensory experience is not to be identified with the state of the sensory surfaces; ii) that phenomenological experience (in which the constancies hold) is *not* mediated by cognitive processes (analog-digital conversion). Yet, the perceptual constancies and hence phenomenological experience, necessarily involve digitalisation. For to treat an object as the same, independent of viewpoint, or to assign a surface the same colour, whatever the composition of the ambient light, is just to treat different things (at the sensory surface) as the same. This just constitutes, for Dretske, recognition, abstraction, classification, stimulus generalisation. In short, the mechanisms underlying perceptual constancies, and hence phenomenology, *ipso facto* involve digitalisation. So if our taxonomy of mental processes distinguishes processes which involve digitalisation, and processes which do not, then cognition, perception, processes at the sensory surfaces, and processes underlying phenomenology are classed together.

4.9 Is Analog-Digital Conversion Ubiquitous?

The informational distinction between analog-analog and analog-digital processes informational transformations does not appear to correspond directly to the distinction between perceptual and cognitive processes, or to the distinction between cognition and sensation. All of these involve some kind of classification, organisation, generalisation - in short they all involve the digitalisation of *some* information.

The discussion so far raises the possibility that *all* information processing involves the digitalisation of *some* information. It is to this question that we now turn.

First, let us consider a simple example. We take three sets of basic propositions: propositions about the environment (these will be the *relevant* propositions, in the informational idealisation); propositions about the state of the input to the process; propositions about the state of the output of the process. For example, suppose the basic propositions about the environment include *D*, *C* and *F* (that there are dogs, cats or ferrets present, respectively), as well as information about the weather, the time of day and so on. The input might be some complex description of the retinal image - for example, let us consider a discretized description of the image, with 100,000 pixels, each of which may be active or not (to take the simplest case). The specification of the entire retinal image involves the specification of the intensity value at each of the 100,000 pixels. Suppose that the process under study is animal recognition. The organism under study is able to spot dogs and ferrets, but not cats. Suppose that the output has just two basic propositions $D_{spotted}$, and $F_{spotted}$ - these correspond to some internal state of the organism denoting that a dog or a ferret has been detected respectively. There is no output corresponding to the detection of cats, since the organism is, by hypothesis, unable to detect cats. The "perceptual processes" under consideration map combinations of the basic input propositions (i.e. information about the light intensity at each of the pixels) onto one of the four possible combinations of the basic output propositions:

$D_{spotted}$ & $F_{spotted}$
$D_{spotted}$ & $-F_{spotted}$
$-D_{spotted}$ & $F_{spotted}$
$-D_{spotted}$ & $-F_{spotted}$

Of course, we cannot enumerate the plethora of informational dependencies between states of the input, output and the environment. Let us assume that each of the possible retinal inputs (specifying the intensity value at each pixel) determines which animals are present, as well as other features of the environment. Let us also assume that the input state determines the output state.

Suppose that a cat, a dog and a ferret are all present. The specification of the input to the perceptual process involves a specification of the light intensities at each of the pixels of the retina of the viewer, as generated by the animals and the rest of the scene. This amounts to a conjunctive proposition consisting of each of the 100,000 basic input propositions or their negations - each having the content that such and such a pixel is or not active. Since the organism is able to detect dogs and ferrets, though it is oblivious to cats, the output is $D_{spotted}$ & $F_{spotted}$.

Suppose that we add the complex conjunctive proposition for the *input* state is added as an axiom of the informational system. This will carry the information that there is a cat, ferret and dog present, but, by hypothesis, it also carries additional information about the scene - the time of day, the length of the grass, that the cat is a ginger tom (assuming that these are included in the idealisation of the environment). Hence, it carries information about which animals are present in analog form. (Notice that the input will also determine the state of the output units - but propositions such as $D_{spotted}$ and $F_{spotted}$ do not count as *relevant* additional information, since they are not about the environment). By contrast, if we instead add the conjunction for the *output* state, $D_{spotted}$ & $F_{spotted}$, the information that a cat and no dog is present, D & F, is, at least plausibly, carried in digital form. For additional information, about ferrets, the time of day, the length of the grass, and the type of cat is lost. So, *prima facie* at least, the process which maps the retinal input (under the pixel idealisation), to the dog and ferret detectors, has converted the information that there is a dog and a ferret present from analog to digital form.

(We have not shown that *no* additional information about the environment is carried, by the output $D_{spotted}$ & $F_{spotted}$. Indeed it may be argued that surely there may be such additional information. For example, if the dog is visible to the viewer, then it must be in front of, rather than behind, the garden wall. More generally, that an animal is visible carries more information than simply that the animal is present in the scene - at a minimum that the animal is visible. So it may be that some information carried in analog form cannot, in principle, be converted into digital form, since additional, unwanted information cannot be eliminated. This problem, which I shall call the *Detectability* problem is treated in detail in chapter V. For the moment we shall ignore it.)

On the basis of such examples it is natural to conclude that only very particular processes convert information from analog to digital form. Such conversion appears to require that the output covaries appropriately with properties in the environment (e.g. the dog detector fires only when a dog is present).

However, this intuition is misleading. In section III we showed that every relatively informative proposition carries some relevant proposition in digital form. This means that if the output carries any information about the environment at all, then it must carry some piece of information about the environment in digital form (in fact, we noted that it will typically carry more than one such piece of information in digital form). So as long as the input carries *some* additional piece of information about the environment, and hence does not itself carry the proposition in digital form, the input-output process involves the analog-digital conversion of that information. Hence, if the distinction between analog-analog and analog-digital processes is taken to *quantify over* pieces of information, then it is of little use, since there will be almost no analog-analog processes. Rather, the distinction should surely be framed *relative to* a particular piece of information:

> A process converts a proposition *P* from analog to digital form iff the input to the process carries *P* is analog form, and the output of the process carries *P* in digital form. This is analog-digital transformation or analog-digital conversion.
>
> If both input and output carry *P* in analog form, then the process effects only analog-analog transformation, relative to *P*.

Dretske suggested that an absolute distinction may be drawn between sensory/perceptual analog-analog processes, and cognitive analog-digital processes. However, we found that sensory, perceptual *and* cognitive processes all seem to convert some information from analog to digital form. Given the above discussion, this is hardly surprising, since just about *any* process will convert *some* information into digital form.

So the difference between cognitive and non-cognitive processes cannot be that only the former digitalise information at all. However, the possibility remains that only cognitive processes digitalise the *right kind* of information.

4.10 Digitalisation and the "Right Kind" of Information

Dretske appears to claim that only rather few information bearing structures carry information in digital form, and that only rather few processes digitalise information. Only on such a view is it appropriate to wonder whether "the acquisition of language is essential to an organism's having the capacity to convert sensory information into digital form" (Dretske, 1981: 143); and to identify cognitive processes with analog-digital conversion. Yet, according to the present formalisation, and on Dretske's admission, (just about) every signal carries some proposition in digital form, and this implies that (just about) every process digitalisation *some* piece of information.

Let us consider some examples. The waving light carries information about the goings on at the coast in digital form. The monkey shooting up a tree digitally codes the information that a tiger is nearby. In both cases, digitalisation is mediated by a (plausibly) cognitive agent. So perhaps digitalisation must involve cognition. However, the north pole of a magnet being at one end may carry the information that the south pole is at the other end in digital form; that the mercury column is on the 70 degree mark carries no additional information over and above that the temperature is 70 degrees. Surely magnets and thermometers do not exhibit cognition!

To exclude such counterexamples, it is natural to claim that digitalising *any* piece of information is not enough for cognition - that information must be of the *right kind.* The examples above suggest that the information that there are suspicious goings on at the coast and that there is a tiger present count as the right kind of information, and that the information that this end of the magnet is north, or that the temperature is 70 degrees do not. Drawing the obvious moral, the wrong kind of information is directly tied to physical quantities (magnetic polarity, temperature). Simple physical devices (magnets, thermometers) can digitalise such quantities simply in virtue of the lawful correlations with these magnitudes. Such digitalisation is ubiquitous since physical magnitudes are just those over which physical laws are defined. However there are no physical laws defined over properties such as being a nearby tiger, or being a suspicious circumstance on the coast. Perhaps laws only apply to such properties if they are recognised by cognitive agents. For example, the law-like correlation between the goings on at the coast and the waving of the light are mediated by the *recognition* of the suspicious circumstances by the lookout; the lawlike correlation between the nearness of the tiger and the monkey's climbing are mediated by the monkey *noticing* that there is a tiger. So perhaps cognition is the digitalisation of *non-physical* properties.

This line is strongly reminiscent of Fodor's (1986) proposal that sensitivity to non-physical properties is a litmus test for the presence of mental representations and cognitive processes defined over them*. Rather than debate the merits of the claim that cognition is the digitalisation of *non-physical* properties, I shall merely note the following.

A consequence of adopting such an approach is that the substantive issue is making rigorous the distinction between the right and the wrong kinds of information (between physical and non-physical properties, or whatever it is). The taxonomy is *not* given directly by the analog-digital distinction. Since I am concerned only with informational notions and their application to psychological theory, I shall not discuss how or whether an appropriate distinction between the right and wrong kinds of information can plausibly be drawn. Even if a convincing account can be provided, there are still further difficulties with the Dretskian account.

Let us suppose that some plausible putative distinction between right and wrong kinds of information can be found. Thus, we may retain the hope that the analog-digital distinction may provide an absolute taxonomy of cognitive processes. Only cognitive processes may

*For Fodor, an informational analysis is appropriate *only* at the non-cognitive level. At the cognitive level, where mental states may represent or misrepresent the world, he considers a factive notion of information to be inappropriate (e.g. Fodor, carry information of the right kind (perhaps non-physical properties) in digital form. Non-cognitive processes may carry such information only in analog form, and digitally code only information of the wrong kind. However, the possibility of such a taxonomy is undermined by consideration that we have so far ignored. Informational properties, such as being carried in digital form, are relative to the choice of informational idealisation. Since the analog-digital distinction is idealisation relative, so is an psychological distinction based upon it. *Prima facie*, at least, the distinction between sensation and cognition is absolute - surely a process can not be cognitive (or perhaps sensory or perceptual) under one idealisation, and non-cognitive under another. Idealisation relativity also appears to undermine our more general account of information processing as analog-digital conversion, as we shall see.

4.11 Idealisation Relativity

If the analog-digital distinction is to classify the mental processes involved in learning about the environment, then we must surely respect certain core intuitions. If *analog* is to denote raw, unprocessed information, and *digital* to represent the result of such processing, then, for example, the state of the retina should carry a piece of high level information, such as that there is a chair in the room, in analog form. Only after considerable analysis is this information coded in a structure which carries this information in digital form. Now that the information is digitally coded, the organism's behaviour may be sensitive to it. This is why the information processing of sensory input is important. However, whether a piece of information is carried by a structure in analog or digital form is relative to the informational idealisation adopted. We shall see that, in particular, if there is an idealisation according to which some piece of information carried in analog form by the retina is digitalisable at all, then there will be some idealisation according to which that information is carried in digital form already. So, although on one idealisation considerable analysis in required to convert the information that a chair is present from analog to digital form, on another, the information is in digital form in the input, rendering further analysis unnecessary. There are two simple ways in which an idealisation according to which some piece of information is carried in analog form may be altered in order to give idealisations according to which that information is already digitally coded. We may change 1) the characterisation of the signal or 2) the set of relevant propositions about the environment.

Consider the example of the retina and cat, dog and ferret detection of 4.9. Since each of 100,000 pixels can be in either of two states, the retina can be in $2^{100,000}$ states, depending on the intensity values at each pixel. Some of these will carry the information that the ferret is present, presumably in analog form, and some will not. However, by 1) changing the specification of the signal - the idealisation of the state of the retina, or 2) changing the specification of the environment, we can generate alternative idealisations according to which information about which animals are present is already coded in digital form. We shall consider these cases in turn.

1) Relativity to the characterisation of the signal

I shall argue that if a (digitalisable) piece of information is carried in analog form according to one idealisation, then we can specify an idealisation according to which it is digitally coded already, by reducing the richness of the specification of the signal.

If it is possible to digitalise the information that a ferret is present, there will be some detector which *does* digitalise this information*. The state of this detector carries no additional information over and above that the ferret is present.

Consider the disjunction *V* of all states of the retina that trigger the ferret detector. It is easy to show that this proposition about the state of the retina must also digitally code the information that a ferret is present. The triggering of the ferret detector carries the information that the retina is in a state which is in the disjunction *V*. So, the triggering of the detector carries *V*, and, *ipso facto* it carries all information carried by *V*. So if *V* carries any information over and above that a ferret is present, so does the detector. That is, if *V* carries the information in analog form, so does the detector. Yet, by assumption, the detector digitalises this information.

Now it is easy to provide an idealisation according to which the information is carried in digital form by the retina itself. The states of the retina are as before, except that all the disjuncts of *V* (all the states which trigger the ferret detector) are lumped together as a single state. Just as the disjunction of states *V* of the old idealisation carries the information that a ferret is present in digital form, so does the corresponding single state of the new idealisation.

Consider a case in which the ferret is in front of the retina. On the old idealisation, the

135:1987).

*Recall that in 4.9, we noted that there may be some analog information that cannot digitalised, in principle. If the ferret is only visible when it is in front of the wall, then the detection of the ferret carries the additional information about its location (assuming that the idealisation is rich enough to capture this). So the information that a ferret is present is not digisignal that this induces is very specific - the light intensity at each pixel is determined. This detailed description of the retina will typically carry detailed information about the state of the environment - information over and above that a ferret is present. However, on the new idealisation, the signal is so much less specific that all this additional information is lost.

2) Relativity to the relevant states of the environment

In this section, I shall argue that if the state of some structure carries a piece of information *at all* according to some idealisation, then, by reducing the richness of the environment we can specify an idealisation according to which the state of the structure carries that information in digital form.

In the previous idealisation, the richness of the signal is very severely reduced, so that it carries no additional information about the scene. An alternative way to achieve the same result is to reduce the richness of the scene, by restricting the set of basic propositions in the idealisation, or the subset of these which are considered relevant. In this case, no additional relevant information can be carried, not because the signal is too impoverished, but simply because there *is* no relevant additional information. Clearly an idealisation according to which the *only* relevant piece of information is that the ferret is present will suffice. More liberally, we may eliminate rather fewer states than this. For each state of the retina which carries the information in digital form on the old idealisation, in analog form, there is a set of additional propositions carried. Let us eliminate from the set of relevant propositions of the new idealisation all basic propositions which occur is any such additional proposition (perhaps one is that the ferret is in front of, rather than behind, the wall). So the retina being in such and such a state (however detailed the description) carries the information that the ferret is present in digital form, since with such an impoverished idealisation of the environment, there simply *is* no more (relevant) information to carry.

Notice that 2) applies more generally than 1). There is no requirement that the information need be digitalisable, under the original idealisation.

We have shown that under an appropriate idealisation, the state of the retina (in vision), or the vibration of the basilar membrane (in audition), can carry the *right kind* of information in digital form. The relativity of informational properties of a situation to the idealisation chosen creates serious difficulties for our account so far.

---

talisable.

Firstly, it further undermines the attempt to distinguish sensory/perceptual processes from cognitive processes. We noted above that according to Dretske:

> "The contrast between an analog and a digital encoding of information... is useful for distinguishing between sensory and cognitive processes. Perception is a process by means of which information is delivered within a richer matrix of information (hence in *analog* form) *to* the cognitive centers for their selective use. Seeing, hearing, and smelling are different ways we have of getting information about *s* to a digital-conversion unit whose function it is to extract pertinent information from the sensory representation for purposes of modifying output. It is the successful conversion of information into (appropriate) digital form that constitutes the essence of cognitive activity." (Dretske, 1981: 141-142)

On this picture, the mental processes involved in learning about the environment can be divided into two successive stages: perceptual processes, which transform information coded in analog form in one structure into information coded in analog form in another structure; and cognitive processes, which take the output of the perceptual processes and perform analog-digital conversion. Let us call these stage 1 and stage 2 processes.

In 4.9, it was noted that since just about every signal codes *some* piece of information in digital form, just about every process converts some information from analog to digital form, and hence appears to count as a cognitive process. However, it was suggested that we should restrict cognitive processes to those processes which involve digitalisation of information of *the right kind* (where propositions about chairs, tables, dogs and ferrets are paradigmatically of the right kind, and propositions about brightnesses, magnetic fields and temperatures are paradigmatically of the wrong kind). However, according to Dretske's account, what counts as a cognitive rather a non-cognitive process is dependent on the idealisation that we choose. Let us briefly return to the ferret detection example of 4.9. First we shall consider an intuitively natural idealisation, according to which the retina carries the information that such and such an animal is present in analog form, and then we shall consider a bizarre idealisation according to which the state of the retina already digitally codes this information.

Consider the proposition that the ferret is present (presumably, a proposition of the *right* kind). Taking some intuitively natural idealisation of the retina (e.g. the pixel level description), the processes at the sensory periphery (stage 1 processes) map the environment onto the retina, such that the state of the retina carries all sorts of information about the scene. Since the state of the environment carries more information than that the ferret is present, this information is initially in analog form. So the information that the ferret is present is still in analog form. The ferret detector then converts this information into digital form (stage 2).

However, consider an idealisation on which the state of the retina carries the information that the ferret is present in digital form. Then the processes which map the state of the environment onto the state of the retina will convert the information that a ferret is present from analog to digital form. Hence according to this idealisation, the (stage 1) processes determining the state of the retina count as performing analog-digital conversion. By contrast the stage 2 processes do *not* digitalise the information (since it is already in digital form). So, on such an idealisation stage 1 processes are cognitive, and stage 2 processes are not! This is precisely the opposite to the pattern of results according to the "natural" idealisation.

The implications of this observation are far reaching. It was suggested that the purpose of information processing was to convert information from analog form in the input, to digital form in the output. However, we have seen that simply by recharacterising the input, such information may be seen as digitally coded already. So further processing appears to be unnecessary. So Gibson's Problem has recurred - if digitalisation is trivial, and digitalisation is supposed to be the purpose of information processing, then such processing does not seem to be necessary after all.

4.12 Strange Idealisations and Strange Consequences

By appropriately characterising the idealisation of the signal, environment or informational laws, it may be possible to derive informational idealisations of a given situation which do *not* have counterintuitive consequences for what information is carried, and what information is coded in digital form. However, although *some* idealisations may have intuitively satisfying properties, we have seen that others will have extremely bizarre consequences. In developing an informational account of perceptual-cognitive activity and information processing in general, we are concerned to delimit the appropriate idealisations from the inappropriate. An idealisation according to which the ferret detector converts the information from retinal input from analog to digital form may be acceptable. However, on an idealisation with a two state retina (ferret projected on retina, ferret not projected on retina), or with a degenerate environment, retina itself will digitally code the presence or absence of a ferret. Yet these idealisations are just crazy! It is hardly surprising that such strange idealisations of the situation generate such strange consequences. What may, perhaps, seem worrying is that such idealisations can be formulated at all within the present framework. It is tempting to suspect that a better theory of information would somehow constrain the class of allowable idealisations to rule out idealisations with such counterintuitive consequences.

Notice, however, that analogous considerations arise in the application even of the theory of numbers. Just as the informational properties of a situation are relative to the chosen idealisation, so the *numerical* properties of a situation are relative to the chosen scheme of *individuation.* Such questions as "How many things are there in the cupboard?" are only coherent relative to a scheme of individuation. Depending on the relevant scheme, a book might count as a single thing, or as a collection of 315 things (314 pages and a cover), or as an even larger collections of lines, words, or characters. A bottle of water might be counted as one object, as two (a bottle and a body of water), as three (a bottle, a body of water and a cap), and so on. Just as we can formulate bizarre informational idealisations, we can formulate bizarre schemes of individuation. For example, the bottom half of a bottle could be individuated as a separate object from the top half, or the bottle and the table on which it is standing might be individuated as a single object. Three bottles sitting on a table might count as 4 things, 7 things, or indeed as 1 thing. As in the informational case, strange idealisations will have strange consequences for the numerical properties of the situation. What scheme of individuation is appropriate depends on the purposes of the theorist. If we are interested in whether the weight of the table/bottles set up is flattening the carpet, then we consider tables and bottles as a single system. If we are interested in trying to use bottles as poker chips, then a bottle and its cap might naturally be treated as separate objects, denoting different amounts of money.

The relativity of counting to the way in which the situation is individuated in no way detracts from its utility. Indeed the flexibility to choose a scheme of individuation appropriate to the problem is a crucial determinant of the generality of numerical notions. I can talk equally of 4 atoms, 4 ideas, 4 tables, or 4 galaxies. Of course, counterintuitive conclusion may be drawn if a scheme of individuation is chosen which is inappropriate to the purposes of the theorist. For example, according to a scheme of individuation according to which dust particles count as objects, we draw the rather counterintuitive conclusion that a dusty cupboard that has not been used for years might contain hundreds of times more objects than the wardrobe. If you are wondering where there enough room to store the ironing board, or whether which cupboard is most likely to contain something for the jumble sale, this is not a very useful scheme of individuation.

Let us draw out a few morals from this analogy. Firstly, the idealisation relativity of properties need not detract from their utility. Secondly, idealisation relativity may be crucial in allowing a theory to be applied flexibly to a situation, depending on the purposes which the theorist has in mind. This flexibility will prove crucial in subsequent discussion of how informational ideas should be applied to mentation. Thirdly, the theory can, of course, be applied inappropriately. However, it is no part of the business of the theory (of information or of numbers) to delimit appropriate from inappropriate idealisations. What is an *appropriate* idealisation is an extra-theoretic question. In the case of counting, the question of what may be viewed as an object is raised in the philosophy of identity and the psychology of perception, rather than the theory of numbers. Much of the rest of this thesis may be seen as attempt to provide the beginnings of a corresponding extra-theoretic discussion of the way in which informational idealisations may be applied to perceptual-cognitive processes and information processing in general.

In this chapter we have observed that what information is carried in digital form is crucially relative to the idealisation chosen. This observation appears to undermine our account of information processing as the conversion of information from analog to digital form. However, in the final chapters, I shall argue that idealisation relativity is not merely compatible with, but essential to, the development of an account of information processing as digitalisation.

Chapter 5: Making Information Explicit

5.1 Introduction

It has been stressed throughout the present analysis that the informational properties of a situation are relative to the informational idealisation chosen. For example, in chapter IV we saw that the information carried by the state of the retina, is relative to both the way in which it is idealised, and the idealisation of the environment (which propositions are taken to be *relevant*). In IV.10 we found that if some piece of information is carried in analog form under one idealisation, then it is carried in digital form under some other idealisation. Appropriate idealisations may be obtained either by changing the characterisation of the signal, or changing the set of relevant propositions.

If some piece of information is coded in analog form on the retina on one idealisation, then it is coded in digital form according to some other idealisation. So the contention that attunement requires that information be carried in digital rather than analog form appears to be vacuous. If the mental sentence (grandmother cell, pattern of neural activity, or whatever) that is the result of perceptual-cognitive processing carries some piece of information in digital form, according to one idealisation, then that information is already carried in digital form at the sensory surfaces, on some other idealisation. If behavioural attunement simply requires that information is carried in digital form under *some* idealisation, perceptual-cognitive processing seems to be quite unnecessary.

The problem stems from the mismatch between the apparently *absolute* constraint that information must be processed before it can be used to drive behaviour and the idealisation *relativity* of informational properties (such as being coded in analog or digital form). There may be strange idealisations upon which the retina carries the information that granny is present in digital form, but surely there cannot be strange idealisations on which the retina directly *drives behaviour*, without the mediation of perceptual-cognitive processes. Perceptual-cognitive processing may be necessary for *digitalisation* on some idealisations and not on others, but it is *absolutely* necessary for producing appropriate *behaviour*. In short, perhaps I may not need need a brain to *digitalise* the information that granny has arrived (on an appropriately bizarre idealisation of my retina), but (on any idealisation) I definitely *do* need a brain to be able to generate appropriate greeting and tea-making behaviour.

It is worth noting that the problems of idealisation relativity may be overlooked, given a covert belief in the existence of "one true" informational idealisation. The various bizarre idealisations that have been discussed then appear to present no problems for the account of attunement and information processing as matters of analog-digital conversion. For example, we could simply stipulate that attunement to the information that granny is present requires digitalisation according to this "one true" idealisation. The fact that the retina carries this information in digital form according to certain rather unnatural idealisations is then quite beside the point. Restricted idealisations are, according to this view, of value only insofar as they approximate the relevant structure of the "one true" informational idealisation. So bizarre idealisations, constructed as they are by using various *ad hoc* restrictions on the specification of signal or environment, may be dismissed as just the sort of restricted idealisations which fail approximate the "one true" idealisation. (After all, it might be argued that bizarre applications of, for example, Newtonian mechanics - such as idealising a falling leaf as a point mass - also lead to bizarre consequences. The existence of such cases in no way undermines Newtonian mechanics. A bizarre application of a theory, however sensible, may have bizarre consequences).

According to any putative "one true" informational idealisation, the state of the retina must carry far more information than that if the information is successfully digitalised, the output of perceptual-cognitive processes carry this information in digital form, according to the "one true" idealisation. Although the informational properties of a situation are relative to the informational idealisation of that situation, the informational properties of a situation *given a particular idealisation* are absolute. So, informational properties of some situation relative to the putative "one true" idealisation are *absolute*. So, if idealisation relativity is not recognised, there is no mismatch between the apparent relativity of digitalisation, and the absolute need for information processing, to allow perceptual input to appropriately influence behaviour.

In this chapter and the next, I shall argue, however, that it is because rather than in spite of idealisation relativity that informational notions may be applied to perceptual-cognitive activity, and information processing in general. I shall consider three difficulties which may be taken to challenge the utility of an informational approach to the study of mentation. In each case, we shall appeal to the flexibility licensed by idealisation relativity. In the present chapter we shall attempt to resolve Gibson's problem - the problem of providing an informational account of what information processing amounts to. In Chapter 6, we shall turn to the inter-related problems of "Detectability" and Misrepresentation.

5.2 Gibson's Problem: What Does Information Processing Achieve?

It has been suggested above (4.4) that the point of perceptual-cognitive processing is the conversion of information into a form which is utilisable by the organism. Using Gibsonian terms to express somewhat un-Gibsonian sentiments, the proposal is that such processing serves to *attune* the behaviour of the organism to the information specified at the sensory periphery. However, it has proven to be less than straightforward to capture the difference what is required for attunement, over and above merely carrying the information at the retina.

It has been argued (4.4) that the utilisation of information requires that the information be coded in digital form. So it was conjectured that information processing is a matter of analog-digital conversion. However, in 4.10, we saw that even if some piece of information is encoded in analog form according to some idealisation, there will be other idealisations according to which it is carried in digital. For example, under an idealisation of the state of the retina as either having a ferret projected on it (or not) then the retina carries the information that a ferret is present (or absent) in digital form (at least if we ignore the Detectability problem).

In short, the problem may be put as follows. That the ferret detector fires carries the information that a ferret is present in digital form. However, that the retina has a ferret projected on it also carries the information that a ferret is present in digital form. Thus, according to some idealisation, this information is digitally coded even at the lowest level. So how can the information processing purpose of the hypothetical ferret detector be analog-digital conversion?

I shall argue that the crucial consideration that has been ignored is the different causal properties in the two cases. In simple terms, it is easy, at least in principle, to have a behaviour (or belief, or other mental processes) depend on the firing of a detector, simply by passing the output of the detector to the appropriate output system (or part of memory). It is less than clear how the retina's having, or not having, a ferret projected on it can be hooked up in order to appropriately shape the organisms beliefs and behaviour. The firing of the detector has a causal efficacy that the retina's having a ferret projected on it does not. Putting it crudely, brain processes may be causally sensitive to the firing of a putative ferret detecting cell. They are *not* sensitive to whether or not the retina has a ferret projected on it or not.

5.3 Dretske on the role of causality.

In Dretske's discussion of the perception-cognition distinction, he notes that while digitalisation is necessary for cognition, it is not sufficient. The additional condition that he invokes, in the discussion of belief, is that the digitalising structure be able to effect output.

> "D.M. Armstrong, following F.P. Ramsey, takes belief to be a kind of (internal) map by means of which we steer. This, of course, is nothing but a suggestive metaphor, but it does reflect two properties that are commonly taken to be essential to the idea of a belief: (1) the idea of structure with some representational powers (hence a map), and (2) the idea of a structure that has some *control* over the output of the system of which it is part (hence something by means of which *we steer*). Up to this point we have concentrated exclusively on the first aspect of belief. The idea of a semantic structure [i.e. a structure with a semantic content], I submit, captures all that is worth capturing in the metaphorical equation of a belief with a map... But we must also take note of the second property of beliefs, the fact that these structures, in order to qualify as beliefs, must shape or be capable of shaping the behavior of the system of which they are a part.
>
> Consider, for example, an ordinary home thermostat. This device has an internal bimetal strip that registers room temperature by its degree of curvature... When the bimetal strip bends enough to touch an adjustable contact (adjustable to correspond with desired room temperature), an electric circuit is closed and a signal is sent to the furnace... In information-theoretic terms the bimetal strip is temperature detector: its curvature depends on, and carries information about, the ambient temperature. The thermostat's responses (sending a signal to the furnace) are controlled by this detector...
>
> A belief is like the configuration of a bimetal strip in a properly functioning thermostat: it is an internal state that not only represents its surroundings but functions as a determinant of the system's response to those surroundings. Beliefs *are* semantic structures, but that is not *all* they are. They are semantic structures that occupy an *executive* office in a system's functional organization... Hereafter, those semantic structures that have an executive function, that help shape a system's output, shall be called *cognitive structures* for the system in which they occur." (Dretske, 1981: 197-8)

So, according to Dretske's account, a cognitive process is one which not only converts information into digital form, but allows that information to causally influence output. This additional condition is explicated further:

> When I speak of a semantic structure determining output, I mean that the information... constituting the semantic content of that structure is a causal determinant of output. I have already... explained what is meant by the information in a structure or signal causing something to happen: viz., information (in a signal or structure *S*) causes *E* insofar as the properties of *S* that carry this information are those the possession of which (by *S*) makes it the cause of *E*. So, for example, if *S* carries the information that *s* is *F*, and this information is carried by means of *S's* having the property *G*, then we may say that if *S*'s being *G* causes *E*, the information that *s* is *F* causes *E*. If a structure has the semantic content *m*, then *m* causes *E* insofar as the properties of *S* which give it this content are those which are responsible for *S*'s causing *E*." (Dretske, 1981:198-199)

So, the processes intervening between the retina and the ferret detector has made *some* progress. That the ferret detector fires meets two criteria: i) it carries the information that a ferret is present; ii) it causally affects beliefs or behaviour or mental processes. That the retina has a ferret projected on it meets only the first of these criteria. At least *prima facie* a description of the chemical state of the retina is an appropriate description at which is causally influences mental processes - namely the neural structures which mediate the transduction of information from the sensory surface. However, under such a description, the retina no longer carries the information that a ferret is present in digital form. In fulfilling the second criterion, we have sacrificed the first.

In short then, if information is to be utilised it must be carried by a state that is causally efficacious. So, although the digitalisation of a piece of information is easy, digitalisation under a causally relevant description is hard.

Let us call the requirement that information be coded so as to have causal consequences the "Requirement of Causal Efficacy" (hereafter, RCE).

I shall argue that RCE is properly construed as picking out information which is in utilisable form, from information which is not. I shall argue that RCE is too general to pick out *beliefs* from non-beliefs pieces of information in utilisable form. I take RCE to provide an important condition on providing an account of what the purpose of information processing is (to answering Gibson's problem), rather than illuminating the nature of folk psychological notions such as belief and knowledge.

The discussion will fall into three stages. Firstly, I shall argue that causal efficacy is relative to the processes that are operating over the thermostat, thermometer or whatever. Secondly, I shall introduce some examples to show how information processing may be seen as transforming information which is not utilisable by some process, into a form which *is* utilisable by that process. Finally, I shall return briefly to consider Dretske's alternative use of RCE to characterise belief.

5.4 Process relativity

We have argued that the point of information processing is the conversion of information from unusable to usable form. The encoding of the information must have appropriate causal, as well as informational properties. Dretske considers the case of a disabled thermostat:

> "If, however, we should mechanically remove the adjustable contact so that no electrical contact could be made... No signal would be sent to the furnace... We still have an internal "map", but it no longer has its hand on the steering wheel." (Dretske, 1981:198)

Why is the information no longer usable, in such a case? Since the contact has been removed and thus thermostat no longer has "on" and "off" positions, a first suggestion might be that the information that it is above or below 20 ° is no longer converted into digital form (according to Dretske's characterisation of the set-up). However, this proposal cannot handle a slightly different example. Consider the case in which the thermostat is intact, but the output wire is disconnected from the heating system. In this modified example, the on-off state carries information about ambient temperature just as it does in the properly functioning thermostat. Further, the on-off state of the thermostat has just the same immediate causal powers as before, such as allowing current to pass or not, generating consequent magnetic fields or not and so on. These causal effects could be used to control the behaviour of *some* structures. For example, a compass needle near the wire would be deflected from North (or not) depending on whether the thermostat was on or off. So the information that the temperature is above or below 20 ° would still be in utilisable form, *for the compass needle.* However, this on-off state is no longer causally linked to the heating system - hence the information about the ambient temperature, though utilisable by the compass needle, is not utilisable by the heating system.

These considerations show that whether or not a piece of information can be utilised is dependent on what that information is to be utilised by. So the Requirement of Causal Efficacy is relative to the process or structure that is being controlled or influenced (whether the state of the heating system or the position of compass needle). We shall say that information carried in a causally efficacious form is information carried in *explicit* form (relative to some process):

> If a proposition P both carries the information that Q in digital form, and the state corresponding to P holding is causally efficacious in influencing or controlling some process, then let us say that Q is carried *explicitly* relative to that process.

If the thermostat is properly connected to the heating system, then that the thermostat is on carries the information that it is below 20 ° in explicit form, relative to the heating system. If the thermometer is not connected, it may still carry this information in explicit form relative to the compass needle, or, for that matter, to the electric circuit through which current does or does not flow.

So now we can restate our answer to our most recent incarnation of Gibson's problem. To control the heating system according to whether the temperature is above or below 20 °, temperature information must not merely be carried in digital form, according to some idealisation, but carried in in *explicit* form, relative to the the heating system. Turning to the psychological case, to have my behaviour depend up features of the environment, the relevant information must be coded in *explicit* form, relative to that behaviour.

As we have framed it, the distinction between explicit and inexplicit information is relative to a particular process. Information can be explicit with respect to one process, and inexplicit with respect to another, as we have seen. This relativity makes the explicit-inexplicit distinction, like the analog-digital distinction, inappropriate for attempting to draw absolute taxonomies of psychological states and processes.

It might be countered that this definition is too restrictive. Surely, all that is necessary is that information is coded in such a way that it *potentially* affects output. For example, if I notice the cake shop on the corner, this information may directly affect my behaviour - perhaps I go in and buy a pie. On the other hand, I may simply ignore it. It seems appropriate to say the information that the cakeshop is near is explicit in both cases. Perceptual-cognitive processing puts information in a form such that it *may* be used to determine behaviour. However, the notion of potential influence is problematic. For surely the disconnected thermostat has the potential to influence the heating system and will do so, if I connect it up again. Indeed, a broken thermostat has the potential to affect the state of the heating system - it just needs to be repaired. Yet we do not want to say that disconnected and broken thermostats carry information about temperature in explicit form, relative to the heating system. If it were, then from an informational point of view, it would be unnecessary to actually reconnect or mend the thermostat, since the relevant information is explicit, and hence utilisable, already!

Fortunately, capturing the fact that behaviour is not necessarily directly determined by sensory input does not require any adjustment in the account. In our example, the information that a cakeshop is near is *not* explicit relative to my going in to buy a pie, if I decide to walk past. However, it *is* explicit relative to my *belief* that the cakeshop is present. The presence of the cakeshop need not control my behaviour, but it does control my mental state. This does not mean that the presence of the cakeshop can never be explicit relative to behaviour. If I happen to be looking for the nearest cake shop, then my believing that I have sighted a cake shop may be lawfully connected to my going in to buy a pie. In this case, the information that a cakeshop is present may be carried in *explicit* (digital and causally efficacious) form relative to both may beliefs and my actions.

5.5 Information processing as making information explicit

In this section we shall consider a variety of examples which suggest that information processing is a matter of converting information from a form which is *not* explicit relative to some process to a form in which it *is* explicit relative to that process.

Consider a tabletop on which there is a collection of two kinds of block - small green ones and large red ones. Suppose that we want to scoop up just the red ones. If the blocks are jumbled together into a heap this cannot be done directly. First, the large red blocks must be sorted into a separate pile - *then* the large block can be scooped up selectively. The information that a block is red is carried in digital form by the proposition that it is red. Relative to the shovel, however, this information is not explicit since the shovel is not selectively sensitive to large blocks, but rather to blocks in a particular region of the table. When the blocks have been sorted into piles, the proposition that a block is in, say, the left hand pile carries the information that the block is red in digital form. Now, however, the information is explicit relative to the shovel. Whether or not the shovel picks up the block or not is determined by where it is, not by how large it is. The sorting process would not have been necessary had we been picking up the blocks with a loose mesh net. The whole jumbled pile could be netted, and all but the large, red blocks would fall through the mesh. The proposition that a block is large carries the information that it is red in explicit form, relative to the net, but not to the shovel. So the process of sorting the blocks is not a matter of converting information from analog to digital form, or form inexplicit to explicit form *per se*, but rather of converting information from inexplicit to explicit form *relative to the shovel.*

In the light of our revised conception of information processing, let us briefly reconsider one of the symbolic and non-symbolic examples of information processing that we introduced in 4.5. First, let us consider the example of the cash register. In our initial description of the case, we argued that the column of numbers which the cash register takes as input carry additional information over and above the information about their sum (for example, information about what the first number is, what the second number is, how many numbers are input, and so on). Hence, we argued, it follows that the information that the sum is such and such is carried in analog form in the input. The output of the cash register, by contrast, was held to carry none of this additional information, since it consists simply of a single number. Thus, the information processing role of the device was seen as converting information about the sum from analog to digital form. From the present perspective, however, this characterisation is oversimple. If the input is idealised differently, the information that the sum is such and such may be carried in digital form in the input. In particular, if the various inputs are characterised according as "column of numbers whose sum is 132", "column of numbers whose sum is 253" and so on, the input will carry no additional information, over and above the sum of the numbers. Indeed, according to this apparently bizarre idealisation, the value of the sum *is* explicit, with respect to the functioning of the cash register. For the category into which the input falls *does* causally determine the output of the cash register since, after all, the cash register is designed precisely to calculate sums. The output of the cash register is, for example, 153 when and only when the input is a "column of numbers whose sum is 153". However, although the input is explicit *to the cash register*, it is not explicit to the person using the cash register. Presumably, it is not the case that some "output" of the user which is sensitive to the sum of an arbitrary column of figures - unless, of course, the person is a master of mental arithmetic, in which case the information *is* already explicit to them in the input, and cash register performs no useful information processing function. The output of the cash register is, by contrast, explicit relative to the user - it carries information about the sum in a digital form which may causally determine behaviour. For example, that the cash register outputs 642, might determined that the user turns to the customer and say "That's six pounds, forty-two pence, please". To respond appropriately to the *output* of the cash register require only an understanding of the decimal system. To respond appropriately to the *input* to the calculator requires considerable facility with arithmetic. Since the former ability is much more common than the latter, calculators perform a useful information processing function. They convert information that is (for most of us) coded in inexplicit form, into a form which is (for most of us) explicit.

Similarly, recall the method of estimating the length of an arbitrary curve by overlaying a piece of string. In the original discussion, the operation of straightening the string was seen as throwing away all additional information about the curve, other than its length. Thus, this operation was seen as converting the information about the length of the string from analog to digital form. However, the initial curve may be idealised purely according to its length. According to this apparently bizarre idealisation, the information that the string has such and such a length is coded in digital form - but this information is not *explicit* relative to the process of measurement with a ruler. The reading on the ruler is simply not sensitive to the length of arbitrary curves. Only when the overlayed string has been straightened is the information about the length of the curve carried in a form which is explicit relative to the ruler - since the reading on the ruler *is* sensitive to the length of straight lines. Hence, relative to the use of the ruler, the overlaying and straightening of the string converts information about the length of the curve from inexplicit to explicit form. However, relative to some device whose reading *is* directly sensitive to the length of a curve, such as a measuring wheel which may be traced along its length, the information is already explicit relative to the input. Just as the cash register has no information processing use to the "human calculator", the "string" method of finding the length of curve is redundant, if the measuring device to be applying is inherently able to handle arbitrary curves. When using a measuring wheel rather than a ruler, there is simply no point overlaying and straightening a string, since measuring wheels may be used equally to estimate the lengths of straight lines and curves.

5.6 Dretske on belief

We have applied RCE to provide an account of the nature of information processing. Given that this it is such a general condition, it seems *prima facie* unlikely that it can be used to characterise belief. However, Dretske intends that RCE play just this role.

Before discussing Dretske's approach, it is necessary to consider how his object-property account compares to the propositional account that we have been using. According to a propositional account, *that the thermostat is on* both carries the information that the temperature is below 20 °, and causes the heating system to come on. On Dretske's account, information is seen as carried *by* objects, *in virtue* of their properties. So, for Dretske, the *thermostat* carries the information that it is below 20 °, *in virtue* of being on.

So Dretske must rule out the possibilities such as the following. Suppose that the thermostat is soldered in to the "on" position. Hence, the thermostat causes the heating system to be on. The temperature of the thermostat, and the stresses on the bimetallic strip, depend directly on the ambient temperature. So the thermostat carries the information that the temperature is 20 °, as well as causing the heating system to come on. However, surely this not count as *attunement* of the thermostat's output to the ambient temperature; the thermostat is not *using* the information about the temperature. For the causal and informational powers of the thermostat are in virtue of *different* properties. Dretske introduces this constraint:

> "...if *S* carries the information that *s* is *F*, and this information is carried by means of *S's* having the property *G*, then we may say that if *S*'s being *G* causes *E*, the information that *s* is *F* causes *E*. If a structure has a semantic content *m*, then *m* causes *E* insofar as the properties of *S* which give it this content are those which are responsible for *S*'s causing *E*." (Dretske, 1981: 198-199)

If we take objects as bearers of information, then it is necessary to specify which properties are operative. If, however, we take propositions as informationally basic, then such additional conditions are unnecessary. In the case of the soldered thermostat, it is the propositions *that* the thermostat has a bimetallic strip under such and such stresses, or *that* the thermostat is itself above or below 20 °, that carries the information about the ambient temperature. Yet it is not *these* propositions which determine the state of the heating system. Thus the information about the environment is not carried in causally efficacious form. That the thermostat is in the "on" position *does* causally affect the state of the heating system, but carries no information about the ambient temperature, since the bimetallic strip has been soldered.

Now let us return to Dretske's characterisation of *cognitive* structure, and his attempt to explicate what is distinctive about belief.

> "To qualify as a cognitive structure... an internal state must not only *have* a semantic content, it must *be* this content that defines the structure's causal influence upon output. Only then can we say that the system does *A* because it occupies an internal state with the content that *s* is *F* - *because* (in other words) it believes (or knows) that *s* is *F*." (Dretske, 1981: 199)

That is, a system believes that *s* is *F* iff it has an internal state which i) carries the information *s* is *F* in digital form, and ii) causally influences the system's output. Let us put this point in terms of our propositional account of information: a system believes that *P* iff there is a proposition *Q* about its internal state such that i) *Q* carries the information that *P*, and ii) *Q* causally influences the system's output. That is, *P* must be carried in *explicit* rather than *inexplicit* form, relative to system output.

However, this account is far too lenient. Whether the bimetallic strip is in the on or off position carries the information that it is below 20 ° in explicit form, relative to the heating system. Yet surely the thermostat (or the bimetallic strip) does not *believe* that it is below 20 °. Dretske comments in a footnote that "Thermostats... have no beliefs. The reason they do not is not that they lack internal states with *informational* content, not that these states fail to affect output, but that... these internal states have no appropriate semantic content" (Dretske, 1981: 261-262). Yet the on-off state of the thermostat seems to be precisely an internal state which carries no information over and above that it is 20 °, irrespective of what this information is about - it carries this information in completely digital form, that is, as its semantic content. In any case, we saw in 3.11 that *every* (fresh) signal has *some* semantic content. So whether or not the thermostat can be ascribed the belief that it is below 20 °, it can be ascribed some belief or other.

Any causally active signal will have *some* semantic content, and be causally efficacious relative to *some* process. The position of the on-off button on a calculator presumably carries the information that the calculator is on or off in completely digital form. The position of the button plainly affects the output of the calculator. Yet when the calculator is on it surely does not *believe* that it is on - and when it is off, it certainly doesn't believe that it is off!

5.7 Conclusions

In Chapter 4, we saw that the specific applications of informational notions suggested by Dretske do not seem appropriate. Nonetheless, it was suggested that the mental processes can properly viewed as converting information from analog (unusable) to digital (usable) form. Whereas traditional accounts of semantics apply only to symbolic structures and hence only to symbolic processes, an informational account at least promises to be broad enough to cope with mental processes whatever their character. However, we have seen that whether some piece of information *is* carried in digital form is relative to the informational idealisation chosen. Unless there is some restriction on what idealisations are appropriate, whether a piece of information is carried in analog or digital form can be manipulated almost at will. In this chapter I have discussed this difficulty and propose that the appropriateness of the idealisation of some structure (whether it be a retina or a grandmother cell or a token of a mentalese) is relative to some process or processes operating over that structure. The suggestion is roughly that an idealisation is appropriate if the(se) process(es) are causally sensitive to the classification of states that the idealisation imposes. So whether or not an informational idealisation is appropriate is *process relative*. A piece of information that is carried in completely digital form under a process relative idealisation is said to be *explicit* relative to that process. Information can only be utilized if the causal processes operating over the information bearing structure are sensitive to whatever property of the structure encodes that information. That is, information can only be utilized if it is carried explicit form. The account of explicitness applies equally to linguistic and non-linguistic structures, and hence equally to symbolic and non-symbolic information processing. Such an information based account provides the prospect of a notion of semantics which treats symbolic computation as continuous with non-symbolic processing, rather than *sui generis*.

In the final chapter, we consider two related problems for the application of informational notions to mentation, which we have left outstanding - the problems of Misrepresentation and Detectability.

Chapter 6: Information and Folk Psychology

6.1 Introduction

On a Dretske/Shannon/Weaver view of information, any structure can be seen as generating or carrying information. The ripples on a pond carry information about the size and trajectory of the stone thrown into it; the icicles on the roof carry information about the weather; the positions of the stars carry information about the time of year; and so on. Of course, just *what* information is carried is relative to the informational idealisation that we choose to apply. That there are icicles on the roof can be taken to carry the information that the temperature has recently been below 0°C (assuming that we know the freezing point of water); or equally it can be taken to carry the information that water freezes when at -5°C (assuming that we know this to have been the recent temperature). Information is ubiquitous - every process may be viewed as effecting the processing of information. This may perhaps have the ring of an substantive metaphysical thesis. However, it is no more substantive than the observation that *any* very general framework can be used to describe just about anything. For example, it is *possible* to describe arbitrary phenomena using the terms of number theory. After all, just about anything can be counted - the ripples on a pond, the icicles on the roof, the visible stars. So the pond can be said to have an *odd* number of ripples, the roof may be said to have a prime number of icicles, there may be a triangular number of visible stars. Notice that just as the informational properties of a situation are relative to the way in which it is idealised, so are the *numerical* properties of a situation. How many fronds or ripples or visible stars there are depends on what we *count as* a frond or a ripple or a visible star. Informational properties depend on how we idealise a situation as a set of *propositions*; numerical properties depend on how we idealise a situation as a set of *objects*. Further, just as almost any process can be seen as processing information, arbitrary processes can be seen as processing *numbers*. As the pond settles the number of ripples changes; the falling of the snow increases the number of icicles; the progression of the seasons affects the number of visible stars. So, in the sense in which we have used the terms, the world is full of information and information processing just in the way that the world is full of numbers and numerical processing. Both informational and numerical idealisations are sufficiently broad that they can be used to describe just about anything.

The substantive issue of whether or not mental processes should be seen as processing information (on the technical rather than informal sense) is not whether an informational idealisation can be applied at all, but whether such an idealisation is useful, explanatory, predictive, parsimonious... Of course, we can *say* that a pond has a odd number of ripples but such a description is (presumably) no help in understanding, explaining, predicting the behaviour of the surface of the pond. A full discussion of this issue is beyond the scope of this thesis. In any case, the validity of the informational approach can only be established by the development of a rigorous and detailed theory of informational semantics. The project of developing Situation Theory (e.g. Barwise, 1989), though embryonic, represents an important attempt to provide such a theory. Nevertheless, in this chapter, we shall consider some general issues surrounding question of whether an informational analysis of mental activity is likely to prove to be appropriate.

6.2 Information and Psychology

A theory of information promises the possibility of providing an account of the content of non-symbolic and symbolic states and processes, independent of their realisations. In particular, we have at least the beginnings of an account of the content of mental states, and the information processing function of mental processes. It may be hoped that a fully developed theory of information might be used to explicate what specific mental structures detect, what features of the environment particular trigger particular behaviours, what is the informational function of specific mental operations, and so on. In short, an information based semantics might play an analogous role to that of standard denotational semantics for symbolic computation. Just as standard semantics provides powerful tools for understanding symbolic computation, so a putative information-based semantics might provide methods for analysing the informational processes in general, and mental processes in particular.

Ultimately, of course, the interest of informational notions for the study of the mind depends on whether or not the informational approach can be applied in detail in practice to specific psychological structures and the processes defined over them. Since a detailed understanding of the nature of these structures and processes are a very long way off, it seems plausible that it will not prove possible to properly assess the appropriateness of informational ideas to psychology for some time. Nonetheless, some theorists have suggested that we already possess sufficient insight into the nature of thought to make at least a preliminary assessment of the utility of an informational account of content. It has been argued (Fodor, 1975) that folk psychological explanation - in particular, the explanation of behaviour in terms of an organisms beliefs, desires and other propositional attitudes - is covertly assumed by current "information processing" psychology. Further, it is argued that (appropriately reconstructed) folk-psychological notions must be part of any adequate account of mentation. In short, folk psychology is part of real psychology. This position is, of course, controversial. For example, it has been argued that folk psychology is as radically false as other folk science (Churchland, P.M., 1981; Churchland, P.S., 1986); that only syntactic properties of mental states may play a role in psychological explanation (Stich, 1983); that the adoption of folk-psychological talk should be construed merely as adopting an "intentional stance" towards an organism, rather than making substantive claims about its internal workings (Dennett, 1979). According to this skeptical view, it is pointless to seek an informational, or any other, analysis of propositional attitudes, just as it is pointless to attempt to provide an analysis of phlogiston, vital humours or the terms of any false theory. So the very fact that Dretske attempts to provide an informational account of the terms of folk psychology implicitly commits him to a realist stance towards folk psychology. In this section, we shall not discuss the complex issues surrounding the status of folk psychology, but rather we shall simply *assume* that folk-psychology is a part of real psychology, and consider various considerations which purport to show that an informational account of propositional attitudes is unworkable in principle.

In the last chapter, we noted the inadequacy of an explication of belief, which requires only that beliefs be appropriately causally efficacious. This raises the wider question of providing an adequate account of the various attitudes - belief, desire, hope and so on. However, in this chapter, we shall leave such matters aside an concentrate instead on informational accounts of the *content* of propositional attitudes. In particular, I shall consider certain arguments against the possibility of reconstructing even the very simplest content - such as that the chair or a table or a ferret is present. I shall argue that these arguments are not persuasive. In defending the viability of an informational account I shall also bring out various points about the nature of informational idealisation, which should be of interest whether or not a realist attitude to folk psychology is adopted.

6.3 Information and the Reconstruction of Folk Psychology

Informational properties are relative to the idealisation chosen. Yet ascriptions of belief, concepts and other folk psychological notions appear to be absolute. *Prima facie*, then, the informational account is inappropriate for analysing such notions. Surely the (absolute) content of a propositional attitude cannot be analysed in terms of (idealisation relative) semantic content or digital content. However, the possibility remains that there will be *some* informational idealisation under which ascriptions of semantic (or digital, or whatever) content given by the informational idealisation conform with our pretheoretic intuitions. That is, perhaps there is some idealisation according to which an informational analysis is able to provide a semantics for mental states. It would not be sufficient to show that an organism could, according to one particular idealisation, be viewed as digitalising the information that a chair is present, and that, according to some other particular idealisation, that it may be viewed as digitalising the information that a table is present. What is required is a single informational idealisation of organism, environment and the relevant law-like relations between them, so that the full range of concepts, propositional attitudes, and the like can be appropriately ascribed *at once*. We have seen that by altering the informational idealisation in a variety of *ad hoc* ways, informational properties can be manipulated in very bizarre, counterintuitive ways. However, it may be that the constraint of having to account for mental life *globally* rather than piecemeal, may rule out these bizarre idealisations. While perhaps we may reject the general notion of the "one true" informational idealisation, why should we not hold that, for the purposes of explaining the contents of mental states, there is "one appropriate" informational idealisation. Of course, providing such a complete informational account is a huge and incredibly arduous task - but surely, so far, we have seen no reason to suppose that it is not possible *in principle*. In this section, we shall outline some arguments about the *a priori* feasibility of providing a global information based semantics for mental states - what I shall call the *global naturalisation* programme. Let us first quickly examine the opposing positions.

i) Global naturalisation of the contents of folk psychological mental states is possible. An information based account offers the chance of providing a physicalist account of the folk psychological content ascriptions. Perhaps the most popular account of proposition attitudes is the Representational Theory of Mind (RTM) (Fodor, 1978). According to the RTM the possession of a propositional attitude involves a relation (of believing, desiring, fearing) to some mental representation - typically a sentence of an internal "language of thought". According to RTM, the task of giving a naturalistic account of propositional attitudes, reduces to the task providing a semantics for this internal system of representation - where the meanings of sentences of the internal language correspond roughly to the propositions in the *that* clauses of natural language propositional attitudes ascriptions. That is, the semantics of this system of internal representation corresponds roughly to that of natural language.

On many accounts (Grice, 1957) the meaning of natural language is derivative on the meanings of mental states. So there is at least the possibility that an informational account of the semantics of mental states could be extended to provide an informational account of linguistic meaning.

ii) Global naturalisation of the contents of folk psychological mental states is not possible. While global naturalisation is appealing, there are a number of considerations which may be taken to show that it is unworkable. If these considerations are held to be persuasive, then an alternative view of the role of a theory of information is required. As a descriptive tool of science, it may prove appropriate to adopt a wide variety of idealisations of the organism/environment. However, it may be that *none* of these will provide a semantics of mental processes in terms of dogs, cats, tables and chairs. So informational analysis of mentation may not reconstruct our intuitive folk psychological ascriptions. This need not be particularly distressing to theorists who are not committed to folk psychology as a basis for scientific psychology. If folk psychology is viewed as a naive, false theory of psychology, then there is no reason to suppose that an informational (or any other) account of propositional attitudes should be forthcoming.

Dretske proposes that the contents of folk psychological mental states can be explicated in terms of his notion of semantic content (as long as the property encoding that content causally influences output). Yet we noted in 3.8 that if P is the semantic content of Q, then this has the consequence that P and Q *track* each other - that is, then P and Q lawfully co-occur. Consider the case of a putative ferret detector. If the firing of some cell, or the tokening of some symbol of the language of thought, has as its semantic content "ferret here", then that cell must fire, or that symbol be tokened, *if and only if* there is a ferret present. Yet, given the fallibility of our perception of the world, surely this condition is far too strong, in both directions. Firstly, surely there will ferrets that are not detected. Secondly, surely there will be false alarms, when no ferret is actually present. These possibilities correspond to the two problems with which we shall be concerned: the Detectability Problem, and the Misrepresentation Problem.

1. The Detectability Problem: If some ferrets go undetected, then the firing of the ferret detector carries additional information, over and above that a ferret is present - for example, *that a ferret is present and not behind the fence.* So the semantic content of the state of the detector is not that a ferret is present, since this information is not carried in completely digital form. In short, since it seems inevitable that some ferrets will go undetected, the constraint that the information that a ferret present cannot be the semantic content of the internal state of any organism. Yet if semantic content is the basis for propositional attitudes such as belief, this means that no organism can have beliefs about ferrets. In short, (complete) digitalisation is too hard.

2. The Misrepresentation Problem. If the ferret detector occasionally fires when no ferret is

present, then the information that a ferret is present is *not carried at all* by the firing of the detector, by the facticity of information. Hence, *ipso facto*, this information is not carried in digital form. So perhaps not only is digitalisation too hard, but carrying information *at all* is too hard.

The discussion of these issues will fall into two parts. Firstly, in 6.4 and 6.5, I outline various ways in which the problems of Detectability and Misrepresentation may be avoided. In particular, we shall see that adversion to idealisation relativity may considerably alleviate these difficulties. Nonetheless, we shall find that this strategy is ultimately unworkable - if we are to base an account of propositional attitudes, the problems of Detectability and Misrepresented must be faced head on. Hence, we shall consider how the problems of Detectability and Misrepresentation may be reconciled with an informational account of folk psychological propositional attitudes. Dretske's own proposal to account for misattunement is introduced and rejected. In the final section, a general framework for the relationship between information idealisations and folk-psychology is proposed.

6.4 The Detectability Problem: *Digitalisation* is too hard

The Detectability Problem is that certain signals appear inevitably to carry unexpected and unwanted additional information. We noted above that, if there are occasions on which a ferret is present, but that the ferret detector does not fire, then the firing of the ferret detector carries additional information over and above that there is a ferret present. For example, it carries the more specific information that the ferret has been detected and is not behind the fence. So the information that a ferret is present is not carried in digital form. Thus no internal structure will have the content that a ferret is present.

Notice that this problem may be alleviated simply by employing the notion of digitalisation *tout court*, rather following Dretske's use of complete digitalisation (semantic content), as the foundation for the explanation of propositional attitudes. For although a signal may carry lots of unwanted additional information, much of this information may be classed as *irrelevant.* Since (at least part of) the point of perceptual activity is to allow the organism to learn about the state of its environment the criterion of relevance to be determined by some (more or less intuitive judgement) of what information is about the state of the environment (rather than, for example, the state of the perceiver). So although the detector's firing may carry additional information, on a reasonable idealisation, it may not *relevant* additional information. So the information may be carried in digital form, if not in completely digital form.

In the example of the lookout and the smugglers, the waving of the lamp carries the information that the smugglers are approaching, but also the information that the lookout is awake. According to our rational reconstruction of Dretske, such examples were precisely what motivated the introduction of the notion of relevance - and hence the derivation of digitalisation *tout court* from the more basic notion of semantic content. The restriction to *relevant* propositions allows us to ignore all sorts of unwanted additional information. This move deals with Barry Loewer's criticism of Dretske's account:

> "...*r*'s being *R* cannot have as its semantic content... information that we associate with belief contents, for example, that *s* is a dog, at least not if *r* [sic. presumably *R* is intended] is a neurophysiological property. The trouble is that *r*'s being *R* will carry information about other neurophysiological states... since if *r* is *R*, then the organism must have previously been in certain other neurophysiological states." (Loewer, 1983: 76)

Loewer does not give any examples, but they are easy to find. For instance, adapting the case of the lookout and the smugglers, suppose that the observer's ferret detector only fires when the observer is awake. So the firing of the detector carries not just the information that a ferret is present, but the additional information that the observer is conscious. Yet this is information about the *organism* and not the *environment.* So, on any reasonable idealisation, it will not count as genuine additional information, but be excluded as irrelevant.

Or consider an non-deterministic detector, which fires, on average, half of the time that a ferret is present due to a "loose connection". The firing of the detector will, in this case, carry the information that the connection is closed in addition to the information that a ferret is present. The detector carries information which is not simply determined by the state of the environment but also by a source internal to the organism (the closed-open state of the loose connection). Since this additional information is about the state of the organism, rather than the state of the environment, it is precisely the kind of information that will be excluded by the relevance criterion, and hence will not count as genuine additional information. Clearly such an non-deterministic detector does not track the whether or not a ferret is present - indeed, by adjusting the probability with which the loose connection is closed, it may fail detect an arbitrarily high proportion of ferrets. Nonetheless, it may still carry the information that a ferret is present in digital form, since, although it carries additional information, over and above that a ferret is present, this information is irrelevant to the state of the environment.

However, the Detectability Problem recurs even if we replace the requirement that a putative ferret detector must have the information that a ferret is present as its semantic content, with the more lenient requirement that this information must only be carried in digital form, relative to some appropriate relevance restriction

Recall that, if we are to provide a global naturalisation of propositional attitudes in informational terms, then the idealisation of the environment must be rich enough to capture the content of any propositional attitude. Given such a rich idealisation there is the possibility that a detector may carry unexpected fine-grained additional information.

Let us consider a metal detector, the purpose of which is, of course, to detect metal. So one might conjecture that the wailing of a successful metal detector carries the information that metal is present in digital form. Yet a metal detector does not detect just *any* metal. It does not detect metal on Mars, iron filings, or metal deposits buried thousands of feet underground. So surely the wailing of the detector carries additional information - that the metal is sufficiently near and sufficiently large for the detector to register it, and so on. In the same way, surely the ferret detector of our example carries additional information about the location of the ferret, that it is not night time, that the ferret is not occluded by the fence, and so on. Such considerations appear to apply quite generally to *any* detector system.

Just what particular additional information is carried is, of course, idealisation relative. In the discussion so far we have stressed the importance of the idealisation of the signal and the environment. In this instance, however, both of these factors are fixed. The idealisation of the signal is simply taken to be the on-off state of the detector. The idealisation of the environment is some characterisation which is sufficiently rich to capture the content of any propositional attitude. This does not, however, mean that there is no room for genuine idealisation relativity. For informational properties are relative not only to the characterisation of the signal and the environment, but also to the *informational constraints* which are captured by the idealisation. What informational constraints are naturally included in the idealisation depends how specifically we intend to idealise that situation. Let us illustrate this point with an example.

Consider Eric the butterfly, who detects a mate by the presence of the distinctive two red spots (let us assume, for the moment, that pairs of red spots occur *only* on the wings of female butterflies, so that the information that a female butterfly is present is carried). What information is carried by the firing of Eric's female_butterfly detector? There are a variety of answers, depending on the specificity of the idealisation.

i) If it is 3.30 in the afternoon, Eric has settled on an oak tree, and Eric and Ethel are the only butterflies in the vicinity at that time, then the firing of Eric's detector carries the information that Ethel is near the oak tree at 3.30 (in the *de dicto* sense - that is it *Ethel* who is near). Given this background information it is possible to *learn* of Ethel's proximity to the oak tree at that time from the firing of Eric's detector. For, since Ethel is the only other butterfly in the area, and hence the only other possible source of the two red spots, then it must be *Ethel* who is present.

ii) Suppose that the population of butterflies in the vicinity is unspecified. According to this less specific idealisation, we can learn only that *some* female butterfly is near the oak tree, at 3.30.

iii) If the time is unspecified, then the firing of the detector carries only the information that some female butterfly was near the oak tree *once*.

iv) If Eric's location is not specified, then the firing specifies just that *some* female butterfly was *near* Eric once.

and so on.

Of course, it would be misleading to suggest that there is a strict order of specificity of idealisations of this situation. Rather, arbitrary combinations of background knowledge may or may not be taken into account in the informational idealisation. For present purposes, the moral is simply that as the description of the situation becomes less and less specific, the signal carries less additional information. On a very specific idealisation of the situation, the detector carries the information that it is Ethel who is present. Such an idealisation may not apply to a similar event the next day - for it may be that in that situation some other butterfly is in the area. So on a more general idealisation, the information is not carried. This suggests that if our informational idealisation is sufficiently general, perhaps *all* unwanted additional information can be eliminated. In other words, is it possible to make the idealisation so non-specific that the *only* information carried by a signal is what we intuitively take to be its content*?

The use of general rather specific idealisation is inherently appealing, given the goal of providing an account of propositional attitudes in informational terms. After all, the beliefs of

*It is perhaps worth stressing that the specificity of an idealisation, in this sense, is a function of which *informational dependencies* are included in the idealisations. It is not a matter of the coarseness of the grain at which the environment is idealised. We found, in 4.9, that by making the characterisation of the environment very impoverished, informational properties - such as whether some piece of information is carried in analog or digital form - could be radically manipulated. The present point is that informational properties are also dependent on how rich is the characterisation of the informational dependencies between states.

an organisms are stable *across* whatever the specific details of the situations in which it finds itself. So an informational idealisation which presupposed such specific details would *ipso facto* be inappropriate.

In the case of the metal detector, however, there seems to be no idealisation, of whatever generality, which does not carry some unwanted additional information, over and above that metal is present. Since the detector is only triggered by sufficiently near, sufficiently large pieces of metal, it seems that it must necessarily carries additional information about the location and amount of metal. So the state of the metal detector does not carry the information that metal is present in digital form. If digitalisation is a prerequisite for propositional attitudes such as belief, then this implies that the detector cannot believe that metal is present. This conclusion is hardly disturbing for the proponent of an information-based semantics for propositional attitudes - for, after all, no-one ever suspected that metal detectors could have such beliefs. Nonetheless, this case does present a challenge to the attempt to provide an informational account of propositional attitudes. If metal detectors necessarily carry additional information, over and above that metal is present, why do the same considerations not apply to people too? How is it that a putative mental state which responds to metal (my internal "metal detector") need not carry additional information, and hence can carry the information that metal is present in digital form?

Dretske (1983) exploits what appears to be a crucial difference between the way in which people and metal detectors respond to metal. While the state of a metal detectors is determined by a single causal mechanism, human beliefs about metal may arise from arbitrary sources. My internal "metal detector" may fire because I have seen metal, or heard a metallic clanging, or been told that metal is near, and so on.

> "There are an unlimited number of ways of getting the information that *s* is a dog. Why couldn't a variety of such different causal lines converge on a structure so that the structure itself, though carrying information about the remote source of these lines (the dog), carried no information about *which* line joins it to the source? ...such patterns for the delivery of information could representationally "skip" the more proximal causal antecedents to yield a structure whose semantic content applied directly to the more distal condition." (Dretske, 1983:88)

It might be admitted that, *in general*, my beliefs about the presence of metal may be fixated in arbitrarily many ways. However, there will be particular circumstances in which the cause of my beliefs that metal is present is just as constrained as the cause of the wailing of the metal detector. In particular, if I am *operating* the metal detector to search a field for treasure, and there is no metal to be seen above ground, then the only cause of my belief that metal is present will be the wailing of the metal detector. If the metal detector carries additional, unwanted information about the proximity and amount of metal, then so must my belief. So how can digitalisation be a prerequisite for belief, since in this case, my belief that a ferret is present does *not* digitally code the information that a ferret is present?

This objection assumes that we are adopting a specific idealisation of the situation in which I am looking for metal. In particular, this idealisation is specific to the fact that I am in in a field in which there is no visible (or audible) metal, and so that the only way that I can come to believe that metal is present is in virtue of the wailing of the metal detector. Yet, as we pointed out above, it is hardly surprising that additional, unwanted information (about the nearness and amount of metal) is carried on a *specific* idealisation. The amount of unwanted additional information carried is dependent on the specificity of the idealisation. According to a more general idealisation (which does not, for example, specify the location at which I am conducting my search for treasure), then I might believe that metal is present simply because I come across a spent shotgun cartridge, or because I see a passing car or a tractor in the next field. According to a general idealisation the additional information about the nearness and amount of metal that, though carried by the metal detector, is not carried by my belief.

In short, in general it is the case that beliefs have (almost) arbitrary origins, and so additional information which is specific to those origins is not carried. In particular cases, beliefs may be caused only by some specific causal route, and, according to an idealisation specific to such particular cases, additional information will be carried. However, in attempting to provide an account of propositional attitudes it is precisely the general case in which we are interested.

These considerations appear to show that the Detectability Problem can be diffused. Unfortunately, the Detectability Problem returns in a new form. The firing of an X-detector surely invariably carries the information that the X *has been detected*, whatever the causal route which causes the detector to fire. However I detect the presence of the ferret - by seeing it, smelling it, hearing it, or being told about it - it is trivially true that the ferret has been detected. However, unless the detector *tracks* the presence of X's, and hence fires every time an X is present, this information is not nested within the information that an X is present. Hence, the information (that an X is detected) counts as genuine additional information - and so state of the detector does not carry the information that an X is present in digital form*. So, unless every X is detected, the information that an X is present will be

*One natural response is that the property of detectability is a bizarre relational property between organism and environment, and so that X *detected* propositions tiger detected can reasonably be excluded from set of relevant propositions undigitalisable - and, according to an account on which digitalisation is a prerequisite for belief, *unbelievable*! So the problem with which we started has returned.

We noted above that if to hold the belief that a ferret is present involves possessing some internal state which has the semantic content that a ferret is present, then such an internal state must *track* the presence and absence of ferrets. That is, such an internal state, the putative "ferret detector", must "fire" when and only when a ferret is present. It was suggested that this apparently excessively rigorous condition might be relaxed, by requiring not that the information must be *completely* digitalised, but merely digitalised *tout court*. Further, it was suggested that if the informational idealisation of the situation was sufficiently non-specific, much unwanted additional information might be eliminated. The hope was that the detector might carry the information that a ferret is present in digital form even if not all ferrets are detected - and thus reconcile the informational account of belief with the fallibility of perception. Unfortunately, it seems that despite these moves, tracking may be necessary after all.

In practice, of course, tracking cannot be achieved. A ferret or tiger may be present but under a bush, behind a tree, creeping up behind me, and so on. Hence, it seems that an internal ferret or tiger detector cannot digitalise the information that a ferret or a tiger is present, but merely that *a ferret is detected* or *a tiger is noticed*. So, we seem to be forced to the unpalatable conclusion that according to an informational analysis, beliefs turn out not to be about the world, but the perceiver's knowledge.

So the Detectability Problem cannot be avoided simply by switching from complete digitalisation to digitalisation. So we shall face up to the Detectability Problem directly.

6.5 The Misrepresentation Problem: *Carrying information* is too hard.

According to the informational account, to believe that an X is present requires that this information be digitalised. In the last section we found that, however general the idealisation of the situation, there may inevitably be additional unwanted information carried by the state of an X detector, unless X are always successfully detected. So although the information may be carried, it may not be carried in digital form. The Misrepresentation Problem

about the environment. Unfortunately, although this makes it possible to believe that a ferret is present, on an informational account, it has the consequence that it is *im*possible to believe that you have detected a ferret. For, by definition, a piece of information can only be the digital content of signal if it is *relevant*. So according to any idealisation whose relevance requirement rules that the information that a ferret has been detected is irrelevant, this information cannot be coded in digital form. Given that digitalisation is here taken to be a prerequisite for belief, then, according to such an idealisation, the proposition that the ferret has been detected is quite literally unbelievable. Since, as noted above, our goal is to find a single informational is rather more basic. Since information is factive, if some state carries the information that an *X* is present, then an *X must* be present (in the terms of Dretske's original definition of information content, the conditional probability of an *X* being present, given that state, must be 1). This means that if the putative "ferret detector" can "fire" when no ferret is present, then the firing of the detector does not carry the information that a ferret is present *at all*, let alone in digital form. It seems to be inappropriate to characterise *belief* in factive terms. For surely I can mistakenly believe that a ferret is present when I hear a rabbit rustling in the bushes, or see a squirrel through the undergrowth. In short, how can *misrepresentation* of the world be captured with a factive notion of information.

As in the case of the Detectability Problem, the Misrepresentation Problem may to some extent be alleviated by exploiting the idealisation relativity of informational properties*. *Prima facie*, the possibility of error appears to immediately rule out an informational analysis of belief. For example, a hologram of granny, or a tiger or a ferret, is more than likely to lead to a spurious belief that granny, or a tiger or a ferret is present. So surely my belief that granny, or a tiger or a ferret is present cannot carry the information that granny, or a tiger or a ferret is present, even when, as it happens, I am looking at the real thing. However, although the possibility of error does entail that information is not carried, what *counts a as possibility* is dependent on the specificity of the informational idealisation adopted. We shall make this point first by reconsidering the case of the butterfly, and then return the human ability to detect grannies, tigers and ferrets.

Recall that Eric detects a mate purely in virtue of his sensitivity to pairs of nearby red spots. We noted that since the only pairs of red spots in that part of the jungle are caused by a female butterfly, the firing of Eric's female_butterfly detector carries the information that a female butterfly is present. However, just as human perception can be deceived, so can Eric's. Indeed, since Eric's perceptual system is so simple, all sorts of non-female butterflies may trigger his detector - the L.E.D. watch of a passing explorer, adjacent red mushrooms, a field of tulips, and so on. Whether or not these are considered to be genuine possibilities depends on the idealisation of the situation in which Eric's detector fires.

Consider a very specific idealisation of the situation in which Eric and Ethel meet on a tree in the jungle, and Eric's detector fires. According to such an idealisation, it is simply not possible that Eric's detector is spuriously triggered by an explorer's watch, or a pair of mushrooms or a field of tulips. For, as it happens, there are no explorers in the area at the

idealisation to account the contents of *all* propositional attitudes, this consequence is, of course, unacceptable.

*This line is plausible only if we are considering beliefs which are relatively directly generated by perception. Dretske moment, no red mushrooms grow in the jungle (or that part of the jungle), and Eric is in an equatorial rainforest where, of course, there are no fields of tulips. So, given a very specific idealisation of the situation, there is no possibility that the firing of the detector is spurious.

A less specific idealisation might not specify whether or not an explorer is nearby at the time. According to such an idealisation it *is* possible that the detector is triggered by the explorer's L.E.D. watch. Hence, the firing of Eric's detector does *not* carry the information that a female butterfly is present, since the detector cannot distinguish female butterflies from L.E.D. watches. Taking a coarser idealisation still of the situation, which makes no reference to Eric's location, then the detector might indeed be triggered by a pair of mushrooms, or a field of tulips.

The same point may be made in the case of human perception. Suppose that I go to the fruitshop and select an apple, correctly believing it to be an apple. However, given that I am unable to perceptually distinguish real apples from wax apples, I should also form this belief even if I had selected a wax apple. Does this mean that my belief does not carry the information that what I have selected is an apple? As before, whether or not the presence of a wax apple counts as a genuine possibility depends on the specificity of the idealisation of the apple choosing situation. According to a specific idealisation, since all the apples in the shop *are* real, it is not possible that the apple that I select is in fact a wax replica. According to such an idealisation, my belief does carry the information that what I have selected is an apple. On the other hand, according to a less specific idealisation, according to which I might equally be in the fruitshop or the joke shop next door (where wax apples are sold in plenty), the information that what I have selected is an apple is not necessarily carried by my belief.

Similar considerations apply in the holograms examples. If I see a tiger in the zoo, then, on a specific idealisation, it is not possible that my belief that a tiger is present is caused by a hologram - since the zoo does not have any holograms. Hence, according to such an idealisation, the information that a tiger is present is carried by my belief. According to a broader idealisation, which does not specify whether or not I am at the zoo or at Madame Tussaud's, the possibility that I am looking at a hologram may be a genuine possibility. Hence, on this more general idealisation, the information is not carried.

Information transmission is typically governed by dependencies which are reliable only within some particular context. The thermometer tells the temperature if it is not broken, if the temperature is not above 40° C and so on. Wet pavements carry the information that it has rained recently - but not near a lawn sprinkler, a car wash, or a leaking water main. The presence of smoke carries the information that there must be fire - but not at a pop-concert, or near a toaster. Gibsonian "ecological laws" - laws by which the structure of the environment is specified by the structure of the sensory input - have this context sensitive character. For example, the time-to-contact of a directly approaching object is specified by the expansion of the image of that object (Lee, 1980); the relative depths of nearby objects is specified by binocular disparity (Braddick, 1980). Such laws *may* be violated in outside the organism's natural ecological niche. For example, time-to-contact illusions may be induced in the laboratory by, for example, projecting a film of an expanding image on a static screen (Schiff & Detweiler 1979). Depth illusions can be induced by viewing random dot stereograms through coloured spectacles (Frisby, 1980). However, this does not mean that time-to-contact or relative depth information is not specified, even in the natural environment - for such cases do not occur in that environment*.

The idealisation relativity of information has allowed us to alleviate (at least to some extent) both the problems of detectability and misrepresentation. In the case of detectability, the more general the idealisation, the less unwanted additional information carried. In the case of misrepresentation, the more *specific* the idealisation the more unwanted counterexamples are eliminated as not genuine possibilities.

Given the above discussion it seems that, *prima facie* it is may seem at least conceivable that the Detectability and Misrepresentation Problems may be avoided by a judicious choice of idealisation - sufficiently general so that the signal carries no additional information, and sufficiently specific that there is no possibility of erroneous detection. However, the feasibility of this rather difficult balancing act may be a matter of purely technical interest. For, I shall argue, any account which attempts to provide an informational account of propositional attitudes must face the problems of Detectability and Misrepresentation head on.

(1981: 212) explicitly notes that his account of belief is only intended to apply to such cases.

*Ecological psychologists have stressed that the possibility of illusion in an artificial context in no way entails that environmental information is perceptually specified in the natural environment (e.g. Gibson, 1979). The same issues arise in epistemology, where the question is whether or not the possibility of illusion under some circumstances necessarily makes certainty impossible (Goldman 1979). Indeed, the line that we have adopted here is directly analogous to Dretske's (1981) anti-skeptical arguments, although Dretske does not, of course, frame his discussion in terms of idealisation relativity.

6.6 Facing Detectability and Misrepresentation

Folk psychology ascribes beliefs and desires to people (and animals) in order to explain their behaviour. A typical case folk-psychological explanation is the following rationale for my going into the next office. I have the *desire* to write some notes on a paper, and the *belief* that this requires the use of a pen. Hence I have the consequent *desire* to find a pen. However, I also *believe* that there is no pen in my office, but that I might be able to borrow one next door - I thus *want* to *know* if this is true. A natural way of finding out involves getting up and going into the next office. So I get up and go to the next office. Of course, the exact formulation of and level of detail of such an explanation may be varied. For example, perhaps the explanation should include the reason that I did not instead shout "Have you got a spare pen" to the people next door - reasons which would presumably involve my beliefs about tacit social conventions, my desire not to flout them, and so on. Whatever the precise nature and depth of folk psychological explanations, they will frequently involve explanation of behaviour in terms not just of veridical beliefs, but of false beliefs. For example, my going into the next office to look for a pen may be unnecessary, since there is one in my coat pocket. My behaviour is explained in terms of my *false* belief that there is no pen in my office. Even in a more directly perceptual case, I may see a pen on my desk but falsely believe that it is pencil. This is, of course, not just an in principle possibility, but a matter of everyday experience - it *is* difficult to tell certain kinds of pencil from certain types of pen (particularly if they are part of the same set), until you look very closely, or start writing. Our folk psychological explanations crucially involve reference to such difficulties. I go into the next office looking for a pen, even though there is one on my desk, because I *don't realise* that it is a pencil. Or I go to pick up a pencil, with which to write a cheque, because I *believe* it to be a pen. Any reconstruction of the semantics of propositional attitudes must provide an account of how it is possible to misidentify as well as correctly identify things. It must provide an understanding of *mis*attunement as well as attunement.

The hope of *avoiding* the problems of Detectability and Misrepresentation rests on the possibility that, according to some appropriate idealisation of the situation, belief and world will be properly attuned - for example, that if the object is a pen, then I believe that it is, and *vice versa.* However, a reconstruction of the terms of folk psychology requires that we account for, rather than find some way of eliminating, cases of misattunement.

Notice that the case in which I mistake a pen for a pencil, and hence set off on an unnecessary search, may be viewed as giving rise to both the Detectability Problem and the

Misrepresentation Problem. Firstly, with respect to my beliefs about pens, my miscategorisation amounts to a failure to detect a pen. Hence, in some situation in which I do correctly identify something as a pen, my belief cannot carry this information in digital form. For my belief also carries the *more specific* information that the object has been identified as a pen. This information is *more specific*, since not all pens are detected. Secondly, with respect to my beliefs about pencils, the same miscategorisation of a pen as a pencil, my error amounts to a *misrepresentation* of a non-pencil as a pencil. Since information is factive, my belief that this object is a pencil cannot carry the information that it is a pencil. In sum, a miscategorisation that is an instance of the Detectability Problem from one standpoint is equally an instance of the Misrepresentation Problem from another*. So the problems of Detectability and Misrepresentation are closely related - they are both consequences of the misattunement of belief and the environment. If misattunement cannot be reconciled with the factive character of information, an informational account of propositional attitudes is unworkable. The rest of this chapter will be concerned with various attempts to tackle this issue. In the next section, I shall discuss Dretske's own account, and a recent proposal due to Fodor (1987). I shall argue that of these approaches are inadequate, and, in the final section, outline a rather different, though related, solution.

6.7 Dretske on Misattunement

Dretske proposes that a distinction must be drawn between the informational properties of a token of some type (e.g. some internal state corresponding to some belief) and the type itself. He proposes that the informational properties of a type are determined during a prescribed learning period - during which the type acquires as "life of its own".

> "Suppose that during the period *L* a system is exposed to a variety of signals, some of which contain the information that certain things are *F*, others of which contain the information that other things not *F*. The system is capable of picking up and coding this information in analog form... but, at the onset of *L*, is incapable of digitalising this information. Suppose, furthermore, that during *L* the system develops a way of digitalising the information that something is *F*: a certain type of internal state evolves which is selectively sensitive to the information that *s* is *F*... Once this structure is developed, it acquires a life of its own, so to speak, and is capable of conferring on its subsequent tokens (particular instances of that structure type) *its* semantic content (the content it acquired during *L*) *whether or not these subsequent tokens actually have this as their informational content...* The meaning of a structure derives from the *informational* origins of that structure, but a structure *type* can have its origins in information about the *F*-ness of things without *every* (indeed without any) subsequent token of that type having this information as its origin." (Dretske, 1981:193)

Of course, adversion to the prescribed learning period only insofar as the prescribed

*Of course, there are exceptions to this - for example, in failing to detect a pen, I need not necessarily mischaracterise it *as a pencil* or anything else - I may simply fail to notice it, or it may be lying out of sight.

learning period is less problematic that the subsequent period. Dretske suggests that:

> "In the learning situation special care is taken to see that incoming signals have an intensity, a strength, sufficient unto delivering the required piece of information *to* the learning subject... Such precautions are taken in the learning situation... in order to ensure that an internal structure is developed with the appropriate semantic content, and internal structure which constitutes a (complete) digitalisation of the information that *s* is *F*...
>
> But once we have meaning, once the subject has articulated a structure that is selectively sensitive to information about the *F*-ness of things, instances of this structure, tokens of this type, can be triggered by signals that *lack* the appropriate piece of information. When this occurs, the subject *believes* that *s* is *F* but, because this token of the structure type was not produced by the information that *s* is *F*, the subject does not *know* that *s* is *F*. And if, in fact, *s* is not *F*, the subject falsely believes that *s* is *f*." (Dretske, 1981: 194-195)

Let us put Dretske's point in the terms of one of our previous examples. Suppose that I look at a wax apple, and, being unable to differentiate wax apples from real apples, believe that a real apple is before me. Hence, by the facticity of information, this particular token of my belief that a real apple is before does not carry the information that a real apple *is* before me. Dretske proposes that, nonetheless, the *type* of internal state which is associated with this belief may have the semantic content (completely digitalise) that an apple is before me - for the digital content of the type is determined purely by what that internal state responded to *during the learning period.* Assuming that the learning period occurred in an environment in which there were no wax apples, then, Dretske argues, the tokens of that belief, during the learning period, did have the semantic content that a (real) apples is before me. If the content of the type is fixed purely by the content of the belief-tokens during the learning period, then the belief type may have the semantic content that an apple is before me, even if later tokens do not. It is this cleavage between the informational properties of type and token which allows for the possibility of misattunement.

I shall consider four objections to this view, in increasing order of importance. Firstly, the distinction between learning period and subsequent use seems at best rather artificial. Secondly, the learning period itself need not be free of spurious instances - children come across wax apples as often as adults. According to Dretske's view, this seems to raise the worrying possibility that an unwitting parent might impair a child's conceptual system for life, simply by mistakenly presenting a wax apple as real! Dretske appeals to the difference between the information that is carried by tokens and types. It has been stressed in the present analysis that it is *propositions*, rather than, say, objects that carry information. According to Dretske's account, these propositions must be of the form *s* is *F*. Yet surely to say that some object *s* has the property *F* is equivalent to saying that some *token s* is of *type F*. Accordingly, it makes sense to say that the proposition that some token is of some type carries some information, but not to say that a token or a type themselves carry information. *A fortiori* it is inappropriate to attempt to contrast the information carried by token and type. More significantly, however, Jerry Fodor (1987) raises a much more fundamental objection:

> Consider a trainee who comes to produce 'A' tokens in A circumstances during the learning period. And suppose that the teacher does his job and ensures that *only* A's elicit 'A' tokenings in the course of training... At some time later... the erstwhile trainee encounters an instance of a B and produces an 'A' tokening in causal consequence thereof. The idea is, of course, that this B-elicited tokening of 'A' is ipso facto wild [it is a case of misattunement] and, since it happened after the training ended, it has the (false) content *that* A.
>
> But this won't work; it ignores counterfactuals that are clearly relevant to determining *which* symbol-to-world correlation the training has brought about. Imagine, in particular, what *would have* happened if an instance of B *had* occurred during the training period. Presumably what would have happened is this: it would have caused a tokening of 'A'. After all, B's are supposed to be sufficient to cause 'A' tokenings *after* training; that's the very supposition upon which Dretske's treatment of wild if a B had occurred *during* training, it too would have brought about an 'A'. But that means, of course, that if you take account of the relevant counterfactuals, then the correlation that training established is (not between instances of A and tokenings of 'A' but) between instances of *A v B* and tokenings of 'A'... If 'A's are correlated with (A v B)s, then the content of a tokening of 'A' is *that A v B*. So a B-caused 'A' tokening isn't false... [and so the problem of misattunement has not been addressed after all]" (Fodor, 1987:104)

Using our example of real and wax apples Fodor's point might be put as follows. Even I am shown only genuine apples during the learning period, this does not mean that my belief *during* that period is selectively responsive to apples. For although the tokening of this belief has been perfectly correlated with the presence of instances of the category REAL APPLE, it has also been perfectly correlated with instances of the more general category REAL OR WAX APPLES. How are we to decide which of these categories is really the category to which the belief is really responding to? Surely by asking with which category is the correlation *lawlike*. This question involves appeal to the relevant counterfactuals. Namely, if a wax_apple had been presented during the learning period, would the belief that an apple is before me have been tokened? If a wax apple had been presented, a belief it is surely undeniable that such a belief would have been tokened - since, after all, such tokening does occur, by hypothesis, when a wax apple is presented after the learning period is over. So *during the learning period* the belief is really in lawlike correlation with REAL OR WAX APPLE, rather than REAL APPLE - hence the later belief tokening in response to of a previously unencountered wax apple is not an instance of misrepresentation at all. The content of the belief acquired during the learning period is that there is a real_or_wax apple before me, rather than simply that there is a real apple before me.

A precisely similar difficulty arises for the analogous attempt to solve the Detectability Problem (with which Dretske does not deal). Suppose that the appropriate belief is not tokened if some rather peculiar and previously unencountered apple is presented - perhaps a

Russet. This is an instance of the Detectability Problem, since the belief is responsive only to non-Russet apples. Hence it does not carry the information that the apple before me is a apple in digital form - it also carries the additional information that it is a non-Russet apple. If the learner has never actually encountered a Russet, then the tokening of the belief during the period is perfectly correlated both with instances of the category APPLE and the more specific category APPLES EXCEPT RUSSETS. By precisely repeating the above reasoning, it is clear that the lawlike correlation is with the latter category (since *had* a russet been presented during the learning period, it would not have tokened the relevant belief). Hence the failure to token the relevant belief in response to a previously unencountered russet does not involve misattunement after all - for the content of belief acquired during the learning period is assigned the content that there is an apple_except_russet before me.

Hence, Dretske's invocation of the learning period is unable to show how either of the problems of Detectability and Misrepresentation can be consonant with an informational account of propositional attitudes. In the final section, I shall propose that an informational idealisation may be properly viewed as *prescribing*, as well as *describing* the behaviour of a system. According to this construal, misattunement is simply a matter of the failure of the behaviour of the system to match up to the prescription that the informational idealisation provides.

6.8 Prescriptive Informational Idealisation

First let us identify two distinct, although related, questions:

i) How is a (factive) informational account to be able to account for *mis*attunement? *Prima facie*, it might seem that it may be necessary to elaborate the apparatus of the present approach to account for error. However, we shall see below that nothing more than a change of attitude towards the function of the informational idealisation is required.

ii) In view of the misattunement (the problems of Detectability and Misrepresentation) how can a naturalised (i.e. purely physicalistic) account of the content of propositional attitudes be provided? I shall argue that the change of attitude that is suggested for i) is a prerequisite for providing a solution to ii) - although, as we shall see, this change of attitude merely characterises rather than solves the problem that is faced in providing an informational analysis of propositional attitudes.

In the following discussion these issues will be addressed in turn. Let us begin with an analogy. Suppose that a scientist is faced with the task of understanding the operation of some physical system - for example, the swinging of a pendulum. The scientist might conjecture that the pendulum may be idealised as a freely swinging point mass, and thus that the period of the pendulum swings is constant. However, it turns out, after careful observation, that the periodicity is actually rather erratic. Assuming that the laws of mechanics are not called into question, such recalcitrant behaviour will be taken to imply that the idealisation is inadequate - perhaps there is an unsuspected driving force or frictional component acting, which causes the behaviour of the pendulum to depart from the behaviour predicted using the mathematical idealisation. To correct for this, the idealisation will be revised by adding various additional terms and seeing whether or not these account for the behaviour of the pendulum. Various experiments may be performed using the pendulum, to test between the different idealisations which may be suggested. Various possibilities will be explored until the scientist is satisfied that the predictions of the mathematical idealisation correspond sufficiently well with the behaviour of the real pendulum (or the enterprise is abandoned!).

Crucially, in cases of scientific investigation, a mismatch between the idealisation and the world is taken to throw into question the validity *of the idealisation.* Recalcitrant experimental findings cannot be ignored on the basis that the idealisation is valid, but that the world is simply not behaving as it should! For the scientist, an idealisation or a theory can be in error but the world cannot - for the goal of science is to *describe* the structure of the world, whatever it may be.

Consider now the clock-maker, who has a rather different attitude. The clock-maker has a very specific idealisation of the behaviour of the pendulum in mind - specifically one in which the periodicity of the pendulum swings is constant, and hence the clock keeps regular time. The clock-maker too observes a mismatch between the actual, irregular behaviour of the pendulum and this idealisation. Yet in this case, the idealisation is not seen as errorful, but the clock is diagnosed as malfunctioning. That is, for the clock-maker it is the *world* rather than the *idealisation* which should be changed. The clock-maker may propose and test various explanations of this departure from the intended behaviour, and will modify the pendulum (adding oil, changing the angle of the swing, setting the clock to be closer to the vertical and so on) until it conforms to the specified idealisation - the period is regular and the clock keeps good time. Where the scientist *modifies the idealisation* to account for a mismatch, the clock-maker *modifies the world* in order to bring it into line with the idealisation.

More generally, consider the difference of attitude of a scientist and a mechanic. If the behaviour of a system departs from that predicted by its physical idealisation, the scientist changes the idealisation. The mechanic, by contrast, changes (repairs) the system so that it conforms to the idealisation. The scientist intends the idealisation to *describe* the behaviour of the system under study. The mechanic takes the idealisation to *prescibe* the way that the system should behave. The mechanic has a concept of error *for the system*; the scientist has only a concept of error *for the idealisation* - the laws of nature cannot break down. Notice that, despite these very different conceptions of error, *both mechanic and scientist use the same principles to understand the system.* The difference lies purely in their attitudes to the divergence of system and idealisation.

Similarly, different attitudes may be taken to *informational* idealisations. As "scientists", if the idealisation departs from the observed behaviour, we modify the informational idealisation so that information flow is veridical. The idealisation is treated as a flawed *description* of the system. As "mechanics" we view the idealisation as a *specification* of the informational properties that the system should respect. Rather than modify the idealisation, we modify the system - we repair a broken thermometer so that it again carries information about the temperature; we insist that deceitful children promise to tell the truth in future, so that their utterances carry information about their actions. It is the mechanic, rather than the scientist, who has a notion of breakdown of information flow, of *misinformation*, as failure of a system to live up to its informational specification. As before, no special principles are required to handle errorful systems - simply a change in attitude to the system.

Adopting the prescriptive stance finesses both the Detectability and Misrepresentation Problems. An informational idealisation according to which a metal detector (or the belief that a ferret or granny is present) is simply taken to prescribe that the state of the detector (belief) *should* track the relevant the presence of metal (or a ferret or granny), rather than the way in which it *does* behave. So failures of both detection and misrepresentation in no way undermine the validity of the idealisation. A burglar alarm is *ipso facto* intended to sound when and only when burglars enter the premises - so under an appropriate *prescriptive* informational idealisation, the sounding of the alarm should carry the information that a burglar has entered the premises in digital form. However, in practice, of course, burglars are very adept at disabling burglar alarms before they enter, and burglar alarms are notoriously prone to going off spuriously. The actual behaviour of a burglar alarm departs very severely from the prescriptive informational idealisation which describes its function.

So the answer to our first question - how do we account for error on an informational account - turns out to be remarkably easy. Rather than necessitating the enrichment of the theoretical apparatus of the theory, all that is required is a change in attitude to the relationship between the idealisation and what is idealised.

Now let us turn to our second question: given the phenomenon of misattunement, how can a naturalised informational account of propositional attitudes be provided? The problem is that the belief that granny is present, or that there is a pen in front of me seems to be only very loosely tied to granny being present or there being a pen in front of me - so the information that granny is present, or that there is a pen in front of me, will typically not be carried at all, let alone in digital form. According to a descriptive stance, this has the consequence that, according to an informational account, the relevant beliefs does not really have the content that granny is present, or that there is a pen in front of me, after all (but rather some much weaker content). If I can't tell granny from a hologram of granny then it seems that when granny walks in I have the correct belief that granny_or_hologram_of_granny (and other grannyish looking things), rather than the false belief that granny is present (this is what Fodor (1987) terms the "Disjunction Problem").

According to a prescriptive stance, by contrast, that such and such a belief should track the presence of granny, or that there is a pen in front of me, is a specification of the way that the belief *should* be tokened. Insofar as the belief is not tokened when it should be, or is tokened when it should not, then perceptual-cognitive mechanisms which mediate the fixation of belief are seen as *malfunctioning*, as *being in error*, as being *misattuned* to the state of the environment. Since, in talk about belief, we continually talk of ignorance and misrepresentation, it is clearly the prescriptive rather than the descriptive stance that is appropriate.

In attempting to provide a naturalised informational account of propositional attitudes, we must ask not what information some internal structure is responding to, but rather what informational it is *supposed to be responding to*. That is, we require a naturalised account of the *purpose* of internal states. Needless to say, this is a very hard problem indeed, and it may legitimately be doubted whether or not a single, definitive answer is possible in principle.

It is relatively easy to provide some kind of account of the purpose of the fire alarm or some other artifact, in terms of the purpose that the designer had in mind, during the process of invention (or is it the purpose for which it is reproduced by the manufacturer, or the purpose for which it is sold by the retailer, or the purpose for which it is used by the homeowner, or some combination one or more of these). Such accounts are easy to formulate (if not easy to agree upon!) precisely because the desired explanation need not be naturalistic - that is, we can freely advert to the intentions of the designer, manufacturer, retailer and homeowner. The purpose of an artifact such as a fire alarm is (at least arguably) *derivative* on the semantic properties of propositional attitudes. Here, however, we are concerned with an account of precisely the semantic properties of these attitudes - the explanation of which must, therefore, be conducted in wholly non-intentional (naturalistic) terms.

In these terms, the goal of providing a naturalised informational account of the semantics of mental states crucially involves specifying what it is that makes this or that token of a mental state have this or that purpose. In other words, the question is: in virtue of what is it that presciptive idealisations can be assigned to tokens of mental states? Seen in these terms, it is hardly surprising that the task is so arduous - it is after all, a special case of the general problem of providing *physicalistic* basis for *purposive* explanation.

There have, nonetheless, been a variety of recent proposals about how naturalisation may proceed. In the present terms, each amounts to an attempt to provide a naturalistic account of what determines the prescriptive idealisation appropriate to the tokening of some internal state. Most accounts have taken the relevant *prescriptive* idealisation to be specified precisely by the relevant *descriptive* idealisation in some subclass of situations that the organism encounters. That is, within this subclass the process of belief fixation is assumed to track the state of the world as required - error occurs only when the organism is in a situation not in that subclass. The relevant subclass has variously been identified as the class of situations in which perceptual conditions are optimal (Fodor, 1984) or, as we saw above, with some fixed learning period (Dretske, 1981). A related approach is to attempt to characterise the purpose of some token as what it is naturally selected for (Millikan, 1984; Israel, 1987; though see Fodor, 1989). A further recent proposal (Fodor, 1987, 1989) appeals to an alleged asymmetry in the counterfactual properties of the laws which relate "true" and "false" tokenings. The claim is that the dependencies inducing "false" tokens are produced is parasitic on the dependency in virtue of which "true" tokens are produced. Each of these proposals is extremely controversial, and the intricate and unresolved debate as to their relative merits is beyond the scope of this thesis. However, it is not unreasonable to speculate that, given the disarray and fierceness of the debate, together with the intrinsic difficulty of the problem, that it is, to put it mildly, unlikely that the question of how or whether a naturalistic informational account of propositional attitudes may be provided will be speedily resolved.

6.9 Information and Psychology (Again)

It was noted above that, *prima facie*, the application of informational notions to psychology requires a detailed understanding of the nature of mental states and the mental processes operating over them - and that this is an understanding that we simply do not have. Hence, an assessment of the value of informational notions to the understanding of mentation may be premature. According to the advocates of a realist construal of folk-psychology, there must be mental states which correspond to the contents of propositional attitudes and an important test of the applicability of informational notions to psychology is the feasibility of the reconstruction of propositional attitudes in informational terms. Yet even here, we have seen that given the problems raised by Detectability and Misrepresentation, it is extremely unclear whether or not an informational account is viable.

On a more positive note, we have seen that many of Dretske's ideas, despite certain difficulties in their original formulations, can be formalised in propositional logic. The original definitions of information content and the analog-digital distinction were recast, and we were forced to recognise that the informational properties of a situation are necessarily idealisation-relative, and cannot be ascribed absolutely. Idealisation relativity was found to have significant implications for the application of informational ideas to information processing in general and human cognition in particular. For example, we found that Dretske's distinction between perception and cognition can be manipulated almost arbitrarily, by varying the informational idealisation chosen. Further, the notion of idealisation relativity is able to subsume the apparent knowledge dependence of informational properties. As we saw in the case of the cups and the peanuts, the knowledge of the cognitive agent involved crucially determines what is an appropriate idealisation of the situation, and, of course, which idealisation is chosen affects the informational properties that are ascribed. The importance of the what the cognitive agent knows is that it constrains the way in which the theory is appropriately applied - the agent's knowledge plays no *direct* role in the theory of information content. The primacy of idealisation relativity and knowledge relativity is more than a terminological change. Firstly, many different knowledge states of the observer may correspond to the same informational idealisation - since, for example, much of a cognitive agent's knowledge will be irrelevant. Secondly, the import of idealisation relativity is more general than that of knowledge relativity, and applies equally to situations in which there are no cognitive agents. Thirdly, only by putting considerations of knowledge outside the domain of the theory of information can a formal account of information content be provided. As we have seen, however, the realisation that informational properties are idealisation relative creates severe difficulties for the direct application of informational ideas to the study of mind.

It is perhaps disappointing that we can do no more than draw the weak conclusion that the value of the application of informational ideas to understanding mental life is undecided. So whether or not the brain may be appropriately (parsimoniously, predictively, explanatorily) described as processing information, in the sense which we have discussed here, must remain an open question. Since we have only the tentative beginnings of a theory of information and only the most naive understanding of mentation, it is perhaps only to be expected that the degree to which the one can illuminate the other is unclear. This unclarity will be resolved as our theories of information become less tentative, and our understanding of mentation becomes less naive. This thesis is intended to make a small contribution to the former project, and derivatively perhaps also to the latter.

References

Attneave, F. (1959) *Applications of Information Theory to Psychology*. Holt, Rinehart & Winston.

Banks, W. P. (1977) Encoding and Processing of Symbolic Information in Comparitive Judgements. In Bower, G. H. (ed.) *The Psychology of Learning and Motivation*, Volume 11. New York: Academic Press.

Barwise, J. and Perry, J. (1983) *Situations and Attitudes*. Cambridge, Mass.: MIT Press.

Barwise, J. (1989) *The Situation in Logic*. CSLI.

Braddick, O. J. (1980) Commentary on Ullman. *BBS*, **3**, 381-382.

Braddick, O. J. (1982) Binocular vision. Chapter 10 in Barlow, H. B. and Mollon, J. D. (eds.) *The Senses*, pp192-200. Cambridge: Cambridge University Press.

Churchland, P. M. (1981) Eliminative Materialism and Propositional Attitudes. *Journal of Philosophy*, **77**.

Churchland, P. S. (1986) *Neurophilosophy*. Cambridge, Mass.: MIT Press.

Dennett, D. C. (1979) Intentional Systems. Chapter 1 in *Brainstorms: Philosophical Essays on Mind and Psychology*. Brighton: Harvester Press.

Dennett, D. C. (1979) A Cure for the Common Code?. Chapter 6 in *Brainstorms*. Brighton, Sussex: Harvester Press.

Devlin, K. (1988) *Logic and Information*, Volume I: *Situation Theory*, (Draft). CSLI, Stanford University.

Dretske, F. (1981) *Knowledge and the Flow of Information.* Cambridge, Mass.: MIT Press.

Dretske, F. (1983) Author's Response. *BBS*, No. 6, 88-90.

Field, H. (1978) Mental Representations. *Erkenntnis*, **13**.

Fodor, J. A. (1975) *The Language of Thought.* New York: Thomas Crowell.

Fodor, J. A. (1978) Propositional Attitudes. *The Monist*, **61**, 501-523.

Fodor, J. A. (1980) Methodological Solipsism Considered as a Research Strategy in Cognitive Psychology *Behavioural & Brain Sciences*, **3**.

Fodor, J. A. and Pylyshyn, Z. (1981) How direct is visual perception? *Cognition*, **9**, 139-196.

Fodor, J. A. (1983) *Modularity of Mind.* MIT.

Fodor, J. A. (1984) Psychosemantics. MS, Massachusetts Institute of Technology, Cambridge, Mass., 1984.

Fodor, J. A. (1986) Why Paramecia Don't Have Mental Representations. In *Midwest Studies in Philosophy*, Volume X, pp3-23. Minneapolis: University of Minnesota.

Fodor, J. A. (1987) *Psychosemantics: The problem of meaning in the philosophy of mind.* Cambridge, Mass.: MIT Press.

Fodor, J. A. (1989) A Theory of Content. MS, Massachusetts Institute of Technology, Cambridge, Mass., 1989.

Frisby, J. (1980) *Seeing: Illusion, Brain and Mind.* Oxford: Oxford University Press.

Gibson, J. J. (1966) *The Senses Considered as Perceptual Systems.* London.

Gibson, J. J. (1979) *The Ecological Approach to Visual Perception.* Boston, Mass.: Houghton Mifflin.

Goldman, A. (1986) *Epistemology and Cognition.* Cambridge, Mass.: Harvard University Press.

Goodman, N. (1968) *Languages of Art.* Indianapolis: Bobbs-Merrill.

Grayling, A. C. (1982) *An Introduction to Philosophical Logic*, 1. Sussex: Harvester Press.

Gregory, R. L. (1977) *Eye and Brain: the psychology of seeing*, 3rd. London: Weidenfeld and Nicolson.

Grice, H. P. (1957) Meaning. *Philosophical Review*, **66**.

Hake, H. W. and Garner, W. R. (1951) The Effect of Presenting Various Numbers of Discrete Steps on Scale Reading Accuracy. *Journal of Experimental Psychology*, **42**, 358-366.

Haber, R. N. (1974) Information Processing. In Carterette, E. C. and Friedman, M. P. (ed.) *Handbook of Perception, vol 1: Historical and Philosophical Roots of Perception*, pp313-333. Academic Press.

Haber, R. N. (1983) Can Information be Objectivized. *BBS*, No. 6, 70-71.

Hamlyn, D. W. (1977) The Concept of Information in Gibson's Theory of Perception. *Journal for the Theory of Social Behaviour*, **7**.

Haugeland, J. (1981) Semantic Engines: An Introduction to Mind Design. In Haugeland, J. (ed.) *Mind Design*, pp1-34. Montgomery, Vermont: Bradford.

Hirsch, M. W. and Smail, S. (1974) *Differential Equations, Dynamical Systems and Linear Algebra.* New York: Academic Press.

Israel, D. J. (1987) The Role of Propositional Objects of Belief in Action. Report No. CSLI-87-72, Center for the Study of Language and Information, January, 1987.

Israel, D. and Perry, J. (1987) What is Information? Technical Report, CSLI, Stanford University, Stanford, 1987.

Julesz, B. (1971) *Foundations of cyclopean perception.* Chicago: University of Chicago Press.

Kosslyn, S. M., Pinker, S., Smith, G. E. and Schwartz, S. P. (1979) On the demystification of mental imagery. *Behavioural and Brain Sciences*, **2**, 535-581.

Kosslyn, S. M. (1980) *Image and Mind.* Cambridge, MA: Harvard University Press.

Kosslyn, S. M. (1983) *Ghosts in the Mind's Machine.* New York: Norton.

Lee, D. N. (1980) Visuo-motor co-ordination in space-time. In Stelmach, G. E. and Requin, J. (eds.) *Tutorials in motor behaviour.* Amsterdam: N Holland.

Lewis, D. (1971) Analog and Digital. *Nous.*

Lindsay, P. H. and Norman, D. A. (1977) *Human Information Processing*, 2. New York: Academic Press.

Loewer, B. (1983) Information and Belief. *BBS*, No. 6, 75-76.

Marr, D. (1982) *Vision: A Computational Investigation in the Human Representation of Visual Information.* San Francisco: Freeman.

Merlis, M. R. and Jacks, O. (1952) Verbal Context and Memory Span for Meaningful Material. *American Journal of Psychology*, **65**, 298-300.

Miller, G. A. (1956) The magical number seven plus or minus two, or, some limits on our capacity for processing information. *Psychological Review*, **63**, 81-96.

Miller, G. A. and Selfridge, J. A. (1950) Verbal Context and the Recall of Meaningful Material. *American Journal of Psychology*, **63**, 176-185.

Millikan, R. G. (1984) *Language, Thought and other Biological Categories: New Foundations for Realism.* Cambridge, Mass.: MIT Press.

Minsky, M. (1967) *Computation: Finite and Infinite Machines.* Englewood Cliffs, N.J.: Prentice-Hall.

Moore, B. (1982) *An Introduction to the Psychology of Hearing.* London: Academic Press.

Neisser, U. (1977) Gibson's Ecological Optics: Consequences of a Different Stimulus Description. *Journal for the Theory of Social Behaviour*, **7**.

Padulo, L. and Arbib, M. A. (1974) *System Theory: A Unified State Space Approach to Continuous and Discrete Systems.* Saunders, Hemisphere Books.

Perry, J. (1985) Language, Mind, and Information. Report No. CSLI-85-44, Center for the Study of Language and Information, 1985.

Pollack, I. (1952) The Information of Elementary Auditory Displays. *Journal of the Acoustical Society of America*, **24**, 745-749.

Pylyshyn, Z. (1979) The rate of "mental rotation": a test of a holistic analogue hypothesis. *Memory and Cognition*, **86**, 383-394.

Pylyshyn, Z. W. (1980) Computation and cognition: issues in the foundations of cognitive science. *Behavioural and Brain Sciences*, **3**, 111-132.

Pylyshyn, Z. (1981) The imagery debate: Analogue media versus tacit knowledge. *Psychological Review*, No. 88, 16-45.

Pylyshyn, Z. W. (1984) *Computation and Cognition: Toward a Foundation for Cognitive Science.* Montgomery, Vermont: Bradford.

Rock, I. (1975) *An Introduction to Perception.* New York.

Rosen, R. (1985) *Anticipatory Systems.* New York: Pergammon Press.

Schiff, W. and Detweiler, M. L. (1979) Information used in judging impending collision. *Perception*, **8**, 647-658.

Seligman, J. and Chater, N. (1989) Devlin on Information and Cognition. Technical Report No. EUCCS/RP-31, Centre for Cognitive Science, University of Edinburgh, Edinburgh, May, 1989.

Shannon, C. E. and Weaver, W. (1949) *The mathematical theory of communication.* Urbana, Illinois: University of Illinois Press.

Shepard, R. N. and Chipman, S. (1970) Second-Order Isomorphism of Internal Representations : Shapes of States. *Cognitive Psychology*, **1**, 1-17.

Shepard, R. N. (1975) Form, Formation, and the Transformation of Internal Representations. In Solso, R. L. (ed.) *Information Processing in Cognition: The Loyola Symposium.* Hillsdale, N.J.: Erlbaum.

Shepard, R. N. (1978) The Mental Image. *American Psychologist*, **33**, 125-137.

Shepard, R. N. and Cooper, L. A. (1982) *Mental images and their transformations.* Cambridge, Mass.: MIT Press.

Smolensky, P. (1988) On the Proper Treatment of Connectionism. *BBS*, **11**, 1-74.

Stampe, D. (1977) Towards a Causal Theory of Linguistic Representation. In French, P., Euhling, T. and Wettstein, H. (eds.) *Midwest Studies in Philosophy*, Volume 2. Minneapolis: University of Minnesota Press.

Stich, S. (1983) *From Folk Psychology to Cognitive Science: The Case Against Belief.* Cambridge, Massachusetts: MIT Press.

Turvey, M. T., Shaw, R. E., Reed, E. S. and Mace, W. (1981) Ecological laws of perceiving and acting: In reply to Fodor and Pylyshyn. *COGNITION*, **9**, 237-304.

Ullman, S. (1980) Against Direct Perception. *BBS*, **3**, 373-485.

Woodworth, R. (1938) *Experimental Psychology*. London: Methuen.