

What is Information?

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1 Introduction

In this paper we provide an account of information and informational content, show how it accords with certain intuitive principles of information, and use it to resolve an apparent tension among those principles.¹

Our aim is not to provide a semantics for talk about information, but to provide an account of information itself. Still, it will be helpful to begin with some observations about the structure and logical properties of *information reports*.

- (1) The x-ray indicates that Jackie has a broken leg.
- (2) The acoustic waves from the speaker carry the information that the announcer said, “Nancy Reagan is irritated.”
- (3) The fact that the x-ray has such and such a pattern indicates that Jackie has a broken leg.

(1) and (2) have a structure similar to reports of propositional attitudes. We call an information verb or verb phrase (‘shows’, ‘indicates’, ‘carries the information’), together with the preceding noun phrase, an *informational context*. We shall call the proposition designated by the ‘that’-clause the *informational content*. The object designated by the initial noun phrase of a report like (1) or (2) we shall call the *carrier* of the information; the fact designated by the initial noun phrase of a report like (3) we shall call the *indicating fact*.

Both styles of information reports are *factive*. That is, if the report is true, the informational content is true too. If the x-ray indicates that Jackie has a broken leg, then she does. In particular, if the fact that the x-ray has such and such a pattern indicates that her left hind leg is broken, then it is. In this way information reports differ from reports of some cognitive attitudes and linguistic acts, but are similar to others. What is believed or conjectured or asserted or denied need not be true, although what is seen

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or known must be. And in this way information reports differ from reports of what is possible, and are similar to reports of what is necessary.

Information contexts, like modal contexts and propositional attitude contexts, are clearly not truth-functional. Reports of cognitive attitudes and linguistic acts differ from modal statements, in that substitution of necessarily equivalent statements in the latter preserve truth value, while this is not so with the former. On this issue, information reports are like reports of cognitive attitudes and linguistic acts. For example it does not follow from (1) that the x-ray shows that Jackie has a broken leg and $7+5 = 12$.

Like ‘believes,’ and ‘is necessary,’ ‘indicates’ distributes across *and* but not across *or*.

If x indicates that P and Q , then x indicates that P and x indicates that Q .
 x may indicate that P or Q , even though x neither indicates that P nor indicates that Q .

Reports of linguistic acts and cognitive attitudes are notoriously opaque—substitution of codesignative terms in the content sentences does not always preserve the truth value of the whole report. As we might expect given the emphasis in recent philosophy of language on the different semantic properties of names and definite descriptions, it is important to distinguish two kinds of opacity. Opacity with respect to definite descriptions is relatively noncontroversial, common, and well understood. Modal, cognitive, linguistic, and informational reports all exhibit such opacity, when read in a certain way. Even though Jackie is Jonny’s dog, we cannot infer from (1) that the x-ray indicates that Jonny’s dog has a broken leg, *if* we take this to mean that Jonny’s ownership of the dog is part of what is indicated.

Opacity with respect to proper names is less common, more controversial, and less well understood. It seems that if Tully was necessarily human, so was Cicero; that if Cicero was possibly the best philosopher of his age, so was Tully. But it seems that someone might well say or believe that Cicero was the best Roman philosopher, while not believing or even explicitly denying that Tully was. Should we say that such a person said or believed that Tully was the best Roman philosopher, simply because he said or believed that Cicero was? This would be misleading. Would it be false? Philosophers differ over whether the opacity is real and semantic or apparent and pragmatic. If the former, then it seems that on this score, information reports are closer to modal statements than to reports of cognitive attitudes and linguistic acts. If the entrails of some animal showed that Tully had a broken leg, then they showed that Cicero did.

Information contexts, then, are factive and not truth-functional; substitution of necessarily equivalent content statements does not preserve truth; they distribute across *and* but not across *or*; they may support opaque readings with definite descriptions in the content sentences, but not with proper names.

With our intuitions thus sharpened, let us turn from information reports to information itself.

2 The Principles

We now turn to stating some intuitive principles of information. We use such terms as ‘fact’ and ‘situation’ in their ordinary senses; in the next section we give explications of them within situation theory.

We take the second sort of information report, exemplified by (3), as canonical. Where X is a noun phrase designating the carrier of the information, ‘ X indicates that such and such’ is elliptical for ‘ X ’s being so and so indicates that such and such’. For example, we bring Jackie, who has been limping badly, to the vet, who takes an x-ray of Jackie’s left hind leg, the one she’s been favoring. The x-ray is developed. At this point the vet might say something fully explicit like (3).

So our first principles are as follows:

- (A) Facts carry information.²
- (B) The informational content of a fact is a true proposition.

What underlies the phenomenon of information is the fact that reality is lawlike; that what is going in one part of reality is related to what is going on in some other part of reality, by laws, nomic regularities, or as we shall say, *constraints*. Our point of view may be taken as a generalization of Hume’s. He took constant conjunctions to be contingent matters of fact, that one type of event was *constantly conjoined* with another. We take constraints to be contingent matters of fact, that one type of situation *involves* another. Involving implies constant conjunction: if one type of situation involves another, then if there is a situation of the first type, there is one of the second type. But we leave open the question of whether constant conjunction implies involvement.

In a world knitted together by constraints—whether these be constant conjunctions or some more metaphysically potent connections—situations carry information. The fact that there is a situation of one type, carries the information that there are situations of the types that one involves. If it is a constraint that objects left unsupported near the surface of the earth fall, then the fact that a certain apple near the surface of the earth is left unsupported, carries the information that it will fall.

This conception licenses the notion of the information carried by a fact relative to a constraint. It is this relative notion of informational content that we think is implicit in our actual thinking about information and important for theoretical purposes. From it one *might* derive an absolute notion of the information carried by a situation, as that information carried by the situation relative to some constraint or other. We do not think this is a useful notion.

- (C) The information a fact carries is relative to a constraint.

Hume saw constant conjunction as supplying the world with enough structure so that events contained information, which experience enabled us to recognize. But this structure did not require that there be any intrinsic connections between events; no event contained information in virtue of its intrinsic properties. If the event were embedded in a different sort of world, where different constraints held sway, it would carry quite different information than it actually does.

²As we shall see, this is really shorthand for the following. Situations carry information in virtue of making certain states of affairs factual.

(D) The information a fact carries is not an intrinsic property of it.

The informational content of a fact can involve objects quite remote from those involved in the fact. Jackie is not a part or aspect of the x-ray mentioned in (3), nor is she a constituent of the fact that the x-ray has such and such a pattern, but something remote from it. The x-ray is not broken, and does not have bones. Information typically involves a fact indicating something about the way things are elsewhere and elsewhen, and this is what makes information useful and interesting.

(E) The informational content of a fact can concern remote things and situations.

This conception of information can explain how an x-ray could carry the information that some dog had been x-rayed and had a broken leg. But it is not clear how it can account for the specific information the x-ray carries about Jackie that is reported in (3). As we noted above, Jackie is not a part of the x-ray, and it does not seem that her having a broken leg could be constantly conjoined with x-rays exhibiting the pattern that the vet recognizes. So how can the informational content of the x-ray have her as a constituent?

We shall call the sort of information reported, e.g., in (3) *incremental* information. The conception is most easily grasped if we think of what the x-ray indicates *to* the vet. If she does not know which dog the x-ray is of, it simply indicates that some dog has been x-rayed that has a broken leg. We call this the *pure* information. But if she knows that Jackie was x-rayed, then the pattern on the x-ray indicates to her the additional or incremental information that Jackie has a broken leg. This is the incremental information carried by the x-ray, given the fact that the x-ray is of Jackie. The fact that is given *connects* the indicating situation and the specific objects the information is about, so we shall call it the *connecting fact*. We must be careful that this example does not mislead as to our intentions, however. Incremental information is important in understanding the use humans make of information, but humans and mental states need not be brought into its analysis. Incremental information about specific objects is an objective feature of the world that is there for us to use.

(F) Informational content can be specific; the propositions that are informational contents can be about objects that are not part of the indicating fact.

(G) Indicating facts contain such information only relative to connecting facts; the information is incremental, given those facts.

If we put the x-ray in a drawer for a day or a month, it will still indicate that Jackie had a broken leg. After a month, of course, it will not indicate that Jackie has a broken leg *then*, for the leg might have mended. It will still indicate that Jackie had a broken leg at the time the x-ray was taken. This illustrates two important points about information.

First, different facts can carry the same information. Suppose that t is the time the x-ray was taken, and t' is a month later. The fact that the x-ray exhibits a certain pattern at t and the fact that it exhibits that pattern at t' are different, yet they carry the same information. And of course many facts, exhibiting more radical differences from the original state of the x-ray, could carry the same information about Jackie's leg—the

way she limped, the vet's remarks after feeling the leg, the notations in Jackie's file years later.

In the case of the stored x-ray, though, the later fact contains the information that Jackie had a broken leg *because* the earlier one did. And this is the second point illustrated by the example. For this is a (very) simple case of the storage of information. Note that what goes on in this case is that the carrier of the information is itself stored, in the drawer say, whence it and the information it carries can be retrieved. This storage system works so long as the manner in which the indicating object is stored preserves the indicating property. The world is to be arranged in such a way that the carrier has the indicating property over a usefully long stretch of time. No storage system works forever.

Now imagine that a xerox is made of the x-ray and the copy sent to a vet in another city. It, too, will indicate that Jackie has a broken leg. That is, it's having such and such a pattern will indicate that Jackie has a broken leg. This is a simple case of the *flow of information*. Notice here that it's crucial that the copy be a copy, that is, that it be related in a certain way to the original carrier and its indicating property. But things can be otherwise. In some cases storage and transmission of information involves varying both the carrier and the indicating properties. Thus, the x-ray's indicating pattern could be digitized and sound waves produced by scanning the binary array. (This process could even be reversible, up to the stipulated quantization.)

Later we look closely at a more complex case of the flow of information due to Dretske.³ An announcer speaks into a microphone, the microphone is connected through a transmitter to a transmitting antenna. The modulation of the electromagnetic signal transmitted by the antenna contains information about what the announcer says, because it contains information about the way the microphone diaphragm vibrates, and that contains information about the voice.

(H) Many different facts, involving variations in objects, properties, relations and spatiotemporal locations, can indicate one and the same informational content—relative to the same or different constraints.

(I) Information can be stored and transmitted in a variety of forms.

The x-ray's being such and such at *t* carries the information that Jackie's left hind leg is broken; but what good does this do the x-ray? None. What good does it do Jackie? Perhaps, a lot. If, that is, the vet has the information that Jackie has a broken leg, the chances of her doing Jackie some good increase dramatically. It has often been noted that books contain a lot of information, too, yet that fact seems not to be of any use to books. There is a distinction between carrying or containing information and *having* information. We shall suggest that an agent or device has the information that P just in case it is in a state that both carries the information that P, and controls the behavior of the device in a way appropriate to the truth of P.

(J) Having information is good; creatures whose behavior is guided or controlled by information (by their information carrying states) are more likely to succeed than those which are not so guided.

There is a certain tension between (J) and the rest of our principles. They all emphasize that the information carried by an agent or device being in a certain state is

³*Knowledge and the Flow of Information*, Bradford Books at MIT Press, 1981, p. 58.

a contingent, extrinsic fact about that agent or device. Given different constraints or specific facts, the information carried by the agent or device being in the state would be quite different. Yet the effect that being in the state has on the device, cannot depend on these remote contingencies. How then can such states control behavior in ways that are appropriate to this information? We shall see, however, that when we think through our principles in a careful way, this tension is only apparent.

3 The Framework

We have noted that indication is a relation between facts and propositions. We have also said that what underlies information are laws or constraints involving types of situations. So what are all these things? And what precisely are we saying about them?

3.1 Situations

A basic idea of situation theory is that there is a concrete reality, which has concrete parts but not concrete alternatives. This reality can be thought about, perceived, studied and analyzed in a variety of different ways, from a variety of different perspectives, for a variety of different purposes. But ultimately everything that exists, everything that happens, everything that is true, has its status because of the nature of this reality. The parts of reality are what we call *situations*. Situation theory is committed to there being situations, but not to there being a largest total situation of which the rest are parts.

3.2 Relations, argument roles, locations, individuals, issues, positive and negative states of affairs

When we think or talk about reality, we need some way of analyzing it. This we call a *system of classification and individuation*. Such a system consists of domains of situations, relations, locations and individuals. The commonplace that different schemes can be used to study the same reality is one to which situation theory subscribes. But this fact should not be thought of as showing that situations are structureless, with their properties projected onto them by language or thought. Rather, situations are rich in structure, and support a variety of schemes, suited (or unsuited) to various needs.

Each relation R comes with a set of argument roles. For example, the relation of *eating* comes with the roles of *eater*, *eaten*, and *location of eating*. Objects of appropriate sorts play these roles. The eater must be some sort of organism. The eaten must be a physical object or quantity of stuff. The location of eating must be a spatio-temporal location.

A relation, together with appropriate objects assigned to its roles, gives rise to an *issue*, namely, the issue of whether or not the objects stand in the relation. There are two possibilities, and each of these we call a *state of affairs*.

Example. If *eating* is the relation, Reagan is the eater, a certain quantity of succotash is the eaten and the White House at a certain time is the location (call it l), then there are the following two states of affairs:

$\langle\langle \text{Eats, Loc : } l, \text{ Eater : Reagan, Eaten : the succotash; } 1 \rangle\rangle$
 $\langle\langle \text{Eats, Loc : } l, \text{ Eater : Reagan, Eaten : the succotash; } 0 \rangle\rangle$

The first state of affairs resolves the issue positively, the second, negatively. We say the first has a positive and the second a negative *polarity*. Each of these two is the *dual* of the other.

The relation of *eating* is the major constituent of these states of affairs; Reagan, the location *l* and the quantity of succotash are the minor constituents. The polarities should not be thought of as constituents at all.

Officially, we don't assume that the argument roles of a relation have a natural order—that is, an order independent of the order in which they are expressed in a given language or in a given construction in a language. But in this paper we shall often use the order suggested by English to identify argument roles, without explicitly mentioning them.⁴ For the first state of affairs above we write:

$\langle\langle \text{Eats}, l, \text{Reagan}, \text{the succotash}; 1 \rangle\rangle$

3.3 Facts and other states of affairs; makes-factual; the partiality of situations

Situations determine whether a given state of affairs or its dual is a fact. This primitive relation we call *making factual* or *supporting*. We write this as follows.

$s \models \sigma$ means that *s makes σ factual*.

We will also make use of the property of *being factual*. A state of affairs is factual iff some real situation supports it.

$\models \sigma$ means that *σ is factual*.

The following are uncontroversial theses about the \models relation:

Given a state of affairs and its dual,

- Some situation will make one of them factual.
- No situation will make the other one factual.
- Some situations will leave the issue unresolved, i.e., will make neither of them factual.

The following is a controversial thesis about this important relation:

- Some situation resolves all issues

—this, of course, is the thesis that there is a largest total situation.

The third thesis tells us that situations are partial. They do not resolve all the issues (except, perhaps, for the total situation called for in the fourth thesis.) Because of the partiality of situations, we must distinguish between two ways a situation *s* can fail to make a given state of affairs σ factual:

- s* may make the dual of σ factual
- s* may fail to resolve the σ -issue one way or the other.

⁴The argument role for spatiotemporal locations will always be displayed either first or last.

3.4 Parameters and anchors

For theoretical purposes, it is useful, though not strictly necessary, to have a domain of *parameters* corresponding to individuals and locations.⁵ Where $\langle\langle \dots, a, \dots \rangle\rangle$, is a state of affairs with a as a minor constituent, and \mathbf{a} is a parameter, $\langle\langle \dots, \mathbf{a}, \dots \rangle\rangle$ is a *parametric state of affairs* or *infon*⁶.

The step from states of affairs to infons is a sort of abstraction.⁷ To get from the infons back to states of affairs, we need *anchors*. An anchor is a partial function from the domain of parameters to appropriate objects. Where f is an anchor, $\langle\langle \dots, \mathbf{a}, \dots \rangle\rangle[f] = \langle\langle \dots, f[\mathbf{a}], \dots \rangle\rangle$.

An anchor f *satisfies* an infon i relative to a situation s iff $s \models i[f]$. An anchor f satisfies an infon i *simpliciter* iff $\models i[f]$, i.e. if there is a situation s such that $s \models i[f]$.

3.5 Compound infons

We need to characterize two sorts of compound infon, the *meet* of a set of infons, $\bigwedge I$, and the *existentialization* of an infon with respect to parameter \mathbf{x} , $\exists \mathbf{x}(i)$. We characterize the conditions under which an anchor satisfies each:

- f satisfies $\bigwedge I$ iff $i[f]$ is factual for each $i \in I$.⁸
- f satisfies $\exists \mathbf{x}(i)$ iff for some object a , $i[f_{\mathbf{x}/a}]$ is factual.

3.6 Types, constraints and involvement

Now we need to define the notions which are at the heart of our account of information.

Where σ is a state of affairs, $[s \mid s \models \sigma]$ is the *type of situation* that supports σ . Where i is an infon (i.e. a parametric state of affairs), $[s \mid s \models i]$ is a *parametric type*, and i is the *conditioning infon* of T ($\text{cond}(T)$). A situation s is of parametric type T relative to f if $s \models i[f]$, where i is the conditioning infon of T and f is defined on all of the parameters of i .

Since infons and parametric types are the entities most used from now on, we shall mean parametric types when we say ‘types’; nonparametric types may be thought of as the special case.

We take constraints to be states of affairs with types of situations as constituents. *Simple involvement* is a binary relation. If T involves T' , then for every situation of type T , there is one of type T' .⁹ We write:

$$\langle\langle \text{Involves}, T, T', 1 \rangle\rangle$$

⁵In our paper *What Are Parameters*, (in preparation), we address the issue of what parameters are, and whether they are a necessary part of situation theory.

⁶The term “infon” is to suggest that parametric states of affairs are theoretical entities that are the basic units of information. It is due to Keith Devlin. ‘Infon’ and ‘state of affairs’ are close in meaning: an infon is a parametric state of affairs; a state of affairs in a nonparametric infon.

⁷This is a bit misleading; see *What Are Parameters?*.

⁸This characterization partially reflects the postulation of a complete lattice of infons. For the meet of two infons σ, σ' , we use the notation $(\sigma \wedge \sigma')$. Note that we are not here defining satisfaction with respect to a situation, but satisfaction *simpliciter*.

⁹Note that the definition does not require that when s is of type T that it also be of type T' .

Relative involvement is a ternary relation. If T involves T' relative to T'' , then, for any pair of situations of the first and third types, there is a situation of the second type. We write:

$$\langle\langle \text{Involves}_R, T, T', T''; 1 \rangle\rangle$$

3.7 Propositions

We take propositions to be nonlinguistic abstract objects that have absolute truth values. From the perspective of situation theory, this means that a proposition requires not only a type—that which corresponds or doesn't correspond to the way things are—but also a situation for the type to correspond to. Two basic kinds of propositions are recognized in situation theory. An *Austinian proposition* is determined by a situation and a type and is true if the situation is of the type. A *Russellian proposition* is determined by a type alone, and is true if some situation or other is of that type. If we adopted the fourth thesis, that there is a total situation, Russellian propositions could be taken as Austinian propositions determined by this total situation.¹⁰

Propositions are not infons. Infons characterize situations; propositions are truth bearers. We shall assume that for each type of situation and each situation there is an Austinian proposition that is true just in case that situation is of that type. With respect to Russellian propositions, we shall assume that for each type, there is a proposition that is true just in case some situation is of that type. This last is a strong assumption, that can lead to paradox. We shall not concern ourselves with such issues in the present essay; instead we urge all interested parties to consult the treatment in Barwise and Etchemendy's *The Liar*.¹¹

Infons may have individuals and locations as constituents. When an infon with an individual or location as a constituent is the conditioning infon of a type, then we also say that the type has that individual or location as a constituent, as does the proposition determined by that type. A proposition whose type contains no such constituents, because each argument role has been quantified over, is *general*, in Kaplan's terminology; others are *singular*. We shall say that a singular proposition is *about* its constituents.

4 Information

We now turn to constructing our theory of information within the version of situation theory just sketched.

Let \mathcal{C} be some constraint. The fact σ carries the pure information that P relative to \mathcal{C} iff

1. $\mathcal{C} = \langle\langle \text{Involves}, T, T'; 1 \rangle\rangle$.¹²

¹⁰See Jon Barwise and John Perry, *Situations and Attitudes*, 139-40. The distinction is further clarified and the present terminology introduced in Jon Barwise and John Etchemendy, *The Liar*, where it plays a key role in the treatment of semantic paradox. See also the postscript to the 2nd edition, forthcoming.

¹¹In what follows, we will avail ourselves of propositions in which the situation parameter is existentially quantified. The reader should not take this as the expression of a substantive commitment on our part.

¹²We simplify by treating the *involves* relation, as well as the relation of *relative involvement* as not having an argument role for locations. We should also note that relative constraints are not to be confused with what in *Situations and Attitudes* were called conditional constraints.

2. For any anchor f such that $\sigma = \text{cond}(T)[f]$, P = the proposition that $\exists s'(s' \models \exists a_1, \dots, a_n(\text{cond}(T')[f]))$.

Informally, we would have the following in the case of the x-ray:

The x-ray's being Φ -ish indicates that there is a dog, of whom this is an x-ray, and that dog has a broken leg.¹³

We are often interested in more specific information. For instance, to guide her action appropriately, the vet has to know which dog. It is not enough for her to be acquainted with the indicating fact and aware of the constraint. She must know that the x-ray was of Jackie's left hind leg; she must know that the information it carries is *about* Jackie—what we have called *incremental* information. To capture the notion of incremental information, we need a more complex constraint, one of relative involvement, the third type being the *connecting type*, the type of the *connecting situation*. We also call such constraints, *relative constraints*.

Let \mathcal{C} be some relative constraint, then the fact σ carries the incremental information that P relative to \mathcal{C} and the fact σ' iff

1. $\mathcal{C} = \langle \langle \text{Involves}_R, T, T', T''; 1 \rangle \rangle$.
2. For any anchor f such that $\sigma = \text{cond}(T)[f] \wedge \sigma' = \text{cond}(T'')[f]$, P = the proposition that $\exists s'(s' \models \exists a_1, \dots, a_n(\text{cond}(T')[f]))$.

Again, informally, in our case, the connecting fact is that the x-ray in question is of Jackie's left hind leg, and it is in virtue of Jackie's being a constituent of this fact that she is a constituent of the indicated proposition, the proposition that Jackie's left hind leg is broken.¹⁴

4.1 An Application of the Theory

Let's now apply the theory more formally and fully to our example involving Jackie's leg and the x-ray. We can consider this as a case of *pure information* or of *incremental information*.

In both cases, the indicating fact σ is the x-ray's being of a certain type at t . When we consider the pure information, we have in mind the following simple constraint: whenever there is a state of affairs consisting of some x-ray's having such and such a pattern at some time t , then there is a state of affairs involving a dog's leg having been the object of that x-ray and that leg's being broken at t .¹⁵ So the indicated proposition is that there is a dog of which this is the x-ray, and it has a broken leg. The pure information is about the x-ray, but not about Jackie, or her leg.

Using the resources of situation theory, we represent the simple constraint as follows:

¹³In what follows, we shall simply assume that the x-ray's being Φ -ish indicates that it is of a dog's leg.

¹⁴As we shall see, this reflects the fact that the anchor for the connecting type, that is for T'' , must assign Jackie to the role of being the object whose leg is x-rayed and thus the indicated type, T' —and the indicated proposition—will be about her.

¹⁵For the sake of simplicity, we shall assume that the x-ray is developed essentially instantaneously.

$$\begin{aligned}
T &= [s \mid s \models \langle\langle \text{X-ray}, \mathbf{x}, \mathbf{t}; 1 \rangle\rangle \wedge \langle\langle \text{Has-pattern-}\Phi, \mathbf{x}, \mathbf{t}; 1 \rangle\rangle] \\
T' &= [s \mid s \models \langle\langle \text{Is-xray-of}, \mathbf{x}, \mathbf{y}, \mathbf{t}; 1 \rangle\rangle \wedge \langle\langle \text{Has-broken-leg}, \mathbf{y}, \mathbf{t}; 1 \rangle\rangle] \\
\mathcal{C} &= \langle\langle \text{Involves}, T, T'; 1 \rangle\rangle
\end{aligned}$$

The indicating situation, σ , is

$$\langle\langle \text{X-ray}, a, t'; 1 \rangle\rangle \wedge \langle\langle \text{Has-pattern-}\Phi, a, t'; 1 \rangle\rangle$$

where a is the x-ray and t' the time. We assume that σ is factual, that is that $\exists s (s \models \sigma)$. Now let f be any anchor defined on \mathbf{x} and \mathbf{t} (at least) such that

$$\sigma = \text{cond}(T)[f] = \langle\langle \text{X-ray}, \mathbf{x}, \mathbf{t}; 1 \rangle\rangle \wedge \langle\langle \text{Has-pattern-}\Phi, \mathbf{x}, \mathbf{t}; 1 \rangle\rangle[f]$$

(Thus, $f(\mathbf{x}) = a$ and $f(\mathbf{t}) = t'$.) Then P = the proposition that

$$\exists s' (s' \models \exists y (\langle\langle \text{Is-xray-of}, \mathbf{x}, y, \mathbf{t}; 1 \rangle\rangle \wedge \langle\langle \text{Has-broken-leg}, y, \mathbf{t}; 1 \rangle\rangle)[f])$$

Thus P is the proposition that the state of affairs which consists of some dog being the object of a , the x-ray in question (at t' , the time in question) and that dog's having a broken leg (at the time in question) is factual. Or, more simply, it is the proposition that there is some dog whose leg is depicted by a at t' and whose leg is broken at t' .

When we consider this as a case of incremental information, we have in mind the relative constraint that if an x-ray is of this type, and it is the x-ray of a dog, then that dog had a broken leg at the time the x-ray was taken. The fact that the x-ray was of Jackie is the connecting fact, and the incremental informational content is the proposition that Jackie has a broken leg. This proposition is about Jackie, but not about the x-ray.

The relevant relative constraint is:

$$\mathcal{C}' = \langle\langle \text{Involves}_R, T, T', T''; 1 \rangle\rangle$$

where T , the indicating type is as before. T' , the indicated type is

$$[s \mid s \models \langle\langle \text{Has-broken-leg}, \mathbf{y}, \mathbf{t}; 1 \rangle\rangle]$$

and T'' , the connecting type is:

$$[s \mid s \models \langle\langle \text{Is-xray-of}, \mathbf{x}, \mathbf{y}, \mathbf{t}; 1 \rangle\rangle]$$

As before, σ is:

$$\langle\langle \text{X-ray}, a, t'; 1 \rangle\rangle \wedge \langle\langle \text{Has-pattern-}\Phi, a, t'; 1 \rangle\rangle$$

Again, we assume that σ is factual. Further, we assume that the connecting state of affairs, σ' is factual. Where b is Jackie, σ' is

$$\langle\langle \text{Is-xray-of}, a, b, t'; 1 \rangle\rangle.$$

Any anchor f , such that $\sigma = \text{cond}(T)[f]$ and $\sigma' = \text{cond}(T')$, must be defined on the parameter \mathbf{y} of the connecting type, in particular, it must anchor \mathbf{y} to Jackie. Thus, for any such anchor f , the proposition carried incrementally by σ relative to \mathcal{C} and σ' is the proposition that

$$\exists s'' (s'' \models \langle\langle \text{Has-broken-leg}, b, t'; 1 \rangle\rangle).$$

This is a singular proposition about Jackie, and not at all about the x-ray. And it is, after all, Jackie that we're concerned about.

4.2 The Flow of Information

Now consider a case in which it is natural to speak of “information flow”. The manner in which the diaphragm of a certain microphone is vibrating carries information about what a certain announcer is saying. The modulation of the electromagnetic signal arriving at a certain antenna carries information about the way in which that microphone diaphragm is vibrating. And finally, the modulation of the electromagnetic signal arriving at the antenna carries information about what the announcer is saying, for instance, “Nancy Reagan is irritated”.

How does the modulation of the electromagnetic signal at the antenna carry information about the words the announcer spoke? Let’s look at the constraints and connecting facts that are involved.

The first constraint we call $\mathcal{C}_{voice-info}$: If the diaphragm of a microphone vibrates in a certain way (T_{mike}), then the announcer’s voice produced certain sounds (T_{voice}), given that the announcer was speaking into the mike ($T_{mike-voice}$).

$$\mathcal{C}_{voice-info} = \langle\langle \text{Involves}_R, T_{mike}, T_{voice}, T_{mike-voice}; 1 \rangle\rangle$$

The connecting fact, that the announcer was speaking into the microphone we call $\sigma_{mike-voice}$.

The second constraint we call $\mathcal{C}_{mike-info}$: if the electromagnetic signal reaching the antenna is of a certain type ($T_{antenna}$), then the diaphragm of the microphone vibrates in a certain way (T_{mike}), given that the antenna and the microphone are connected in a certain way ($T_{antenna-mike}$).

$$\mathcal{C}_{mike-info} = \langle\langle \text{Involves}_R, T_{antenna}, T_{mike}, T_{antenna-mike}; 1 \rangle\rangle$$

The connecting fact, that the antenna and the mike are connected in this way, we call $\sigma_{antenna-mike}$.

The third constraint we call $\mathcal{C}_{info-flow}$: if the electromagnetic signal reaching the antenna is of a certain type ($T_{antenna}$), then the announcer’s voice produced certain sounds (T_{voice}), given that the announcer was speaking into the mike and that the antenna and the microphone are connected in a certain way ($T_{antenna-mike} \wedge T_{mike-voice}$).¹⁶

$$\mathcal{C}_{info-flow} = \langle\langle \text{Involves}_R, T_{antenna}, T_{voice}, (T_{antenna-mike} \wedge T_{mike-voice}); 1 \rangle\rangle$$

The connecting fact, that the antenna, mike and voice are connected in this way, we call $(\sigma_{antenna-mike} \wedge \sigma_{mike-voice})$.

Let P be the proposition that the announcer said “Nancy Reagan is irritated”. Let Q be the proposition that the diaphragm of the mike in question is vibrating in such and such a way—the way that is the major constituent of type T_{mike} . Then

- $\sigma_{antenna}$ carries the information that Q relative to $\mathcal{C}_{mike-info}$, given the connecting fact $\sigma_{antenna-mike}$.

Moreover, we say that

¹⁶The complete lattice of infons induces a complete lattice of types. A situation s is of $(T_1 \wedge T_2)$ iff s is of T_1 and s is of T_2 .

- $\sigma_{antenna}$ carries the information that P relative to $C_{info-flow}$, given $(\sigma_{antenna-mike} \wedge \sigma_{mike-voice})$.

In such a case, we also say information of type T_{voice} flows along channels of type $(T_{antenna-mike} \wedge T_{mike-voice})$. We can derive something more like the normal use of the term if we move to the individual objects, the carriers, that are constituents of the connecting types.¹⁷

We might as well generalize, and state the following principle of information:

(*K*) There are laws of information flow.

Laws of information flow involve compound infons and relations among the parameters of those infons. In plain(er) English: laws of information flow involve relations among states of various components of information systems, states of various objects remote from those systems and connections between these. These laws are useful or exploitable to the extent that these relations and connections are controllable or at least knowable.¹⁸

5 The Helpfulness of Information

Now we must face the question of how information, as we conceive it, can be helpful. Clearly, for information to be of use to some agent, or to enable some device to do what it is supposed to, it is not enough that the states of the agent or device *carry* the information. The agent or device must in some sense *have* the information.

We want to develop an account of having information as being in a state that plays two roles. First, the agent's being in the state carries certain information relative to a constraint. Second, an agent's being in that state has an effect (relative to some other constraint) that is appropriate given the information. In that case, we want to say that the agent not only carries but has the information.

But there seems to be a large problem standing in the way of developing such an account on the basis of an approach to information of the sort we have been putting forward. On our account, the information that an object carries in virtue of being in a certain state, is not *intrinsically* connected to the object's being in that state. The x-ray's being in state Φ carries the information that Jackie's leg is broken *only* relative to a constraint and a fact. Relative to other constraints and facts, that very same state will carry different information.

But the effect of that state on other parts of the system of which it is a part will not depend on these constraints and facts. How then can the resulting response be appropriate to the information? Our strategy for analyzing the having of information, given our account of information, seems to require something like action at a distance.

These problems, however, are merely apparent.

Let's consider a simple example. I stick a pencil in an electric pencil sharpener; a lever is depressed; a circuit is closed; the motor turns on, the blade spins; the pencil is sharpened. In this case, the insertion of the pencil caused the pencil sharpener to be in a certain state, having a lever depressed, that carried information. Under normal usage,

¹⁷Strictly speaking, such objects figure as the values of anchors for the parameters of the conditioning infons.

¹⁸The reader should compare the above with what Dretske, op. cit., calls the *Xerox Principle*.

this state only occurs when a pencil is inserted, and so carries the information that this is so. This state causes things to happen inside the pencil sharpener: the circuit closes, the motor starts, the blades spin. So, the state of having the lever depressed plays two roles. It carries information, relative to constraints, about the wider circumstances in which the system finds itself—that a pencil has been inserted. And it causes things to happen in the system.

Note that we say that the electric pencil sharpener worked, or did what it was supposed to do, or responded appropriately because we have in mind the goal of sharpening pencils. Relative to another goal, say frustrating people who want their pencils sharpened, it did not work. One might convert a device that works, relative to the first goal, to one that works, relative to the second, by putting in a different kind of blade—say one that leaves the end of the inserted pencil blunt. Whenever we talk about success or failure, or the appropriateness of an action, we have in the background some goal or measure of success.

Let us suppose:

1. G is a goal, say of sharpening pencils.
2. *lever-depressed*, *circuit-closed*, and *blades-spinning*, etc. are states of systems of a certain kind \mathcal{K} .
3. There is a constraint $\mathcal{C}_{pure-info}$: if a system a of kind \mathcal{K} is in *lever-depressed* at location l , then there is a pencil inserted in a at l .
4. There is a constraint $\mathcal{C}_{\mathcal{K}}$ that governs the internal workings of the system: if a is in state *lever-depressed* at l , a will go into state *circuit-closed*, then state *blades-spinning*.
5. There is a constraint $\mathcal{C}_{pure-result}$: if a is in state *blades-spinning* then if there is a pencil in contact with the blades of a , that pencil will be sharpened.

The pencil sharpener (of kind \mathcal{K}) has been designed so that the state that carries the information that a pencil has been inserted sets in motion a chain of events that promote the goal for which it was designed, sharpening pencils. The design will be successful only in an environment in which the depressing of the lever will carry the information that a pencil has been inserted, and the motion of a blade against a pencil will leave it sharpened. We say that the system is *attuned* to these constraints, relative to the goal of sharpening pencils.

Thus there is no particular problem about how an agent or device may be caused, by the state that carries remote information, to respond in ways appropriate to that information, and so be said not merely to carry but to have that information. The problem may still seem to apply to the case of incremental information, however. What can be the point of saying that the state of a device or an agent has the information that ... b ...? In such a case, the state of the agent or device will *carry* the information that ... b ... relative to some fact that connects the agent or device with b . It could have been connected with some other object, c , in which case it would carry the information that ... c But it could be in exactly the same state S in the two cases. In this case the effects would be the same, so in what sense can the presence of b rather than c be relevant?

This argument is fallacious, however, for the effects need not be the same. The immediate effects of being in state S will be the same, no matter what the remote cause of being in state S might be. But the remote effects of being in state S may depend on facts that vary with the remote causes. These remote effects may be the ones that are relevant to the success or failure of the system's response, relative to a given goal.

In our example, the insertion of a pencil p into our sharpener depresses a lever, which closes a circuit, causing a motor to impel the blades. The lever would have been depressed in the same way, had another pencil p' been inserted rather than p . But given that p is inserted, p gets sharpened; had p' been inserted, p' would have been sharpened. The remote effects of inserting the different pencils differ, even though the local effects are the same.

The following factors are involved:

1. G is a goal.
2. *lever-depressed*, *circuit-closed*, and *blades-spinning*, etc. are states of systems of a certain kind \mathcal{K} .
3. There is a relative constraint $\mathcal{C}_{inc-info}$: if a system a of kind \mathcal{K} is in *lever-depressed* at location l , then pencil c is inserted in a , given that c is depressing the lever of a .
4. There is a constraint $\mathcal{C}_{\mathcal{K}}$ that governs the internal workings of the system: if a is in state *lever-depressed* at l , a will go into state *circuit-closed*, then into state *blades-spinning*.
5. There is a relative constraint $\mathcal{C}_{inc-result}$: if a is in state *blades-spinning*, pencil c will be sharpened, given that c is in contact with a 's blades.
6. There is a constraint, $\mathcal{C}_{how-things-are}$: if a pencil c is depressing the lever of a device of kind \mathcal{K} , it will be in contact with the blades of that device.

Note the last constraint, that connects the fact of a pencil depressing the lever of the sharpener, and the pencil being in contact with the blades of the sharpener. These facts are rather intimately connected, given the construction of an electric pencil sharpener.¹⁹ In cases involving information flowing to an agent from more remote events, which then performs actions whose appropriateness moreover depends on remote effects, the analogous connection between facts, that accounts for the agent's success, may be quite a bit more complex and fragile. When such contingencies relate the objects an agent has information about with the objects its actions need to affect to promote its goals, mere *attunement* may not suffice. In such cases, having information may require a system of representation to keep track of these contingencies.²⁰

¹⁹Given, that is, *how-things-are*.

²⁰For more on these issues, the reader may consult Israel's *The Role of Propositional Objects of Belief in Action*, CSLI Report No. 72 and Perry's *Circumstantial Attitudes and Benevolent Cognition*, CSLI Report No. 53, reprinted from J. Butterfield, ed., *Language, Mind and Logic*, Cambridge University Press, 1986, pages 123-133. We hope to address these issues further in a series of papers.