Information and Architecture

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1 Incremental and reflexive information

Elwood lies on a hospital bed, a thermometer—we'll call it **t**—in his mouth. Bad news about Elwood:

(1) The fact that the mercury in **t** is above 98.6 carries the information that Elwood has a fever.

The fact referred to we call the *signal* or *indicating fact*. The thermometer is the *carrier*, the property of containing mercury that has risen past 98.6 is the *indicating property*. The proposition that Elwood has a fever is the *incremental informational content* of the signal. The property of having a fever is the *indicated property*; Elwood is the *subject matter*. A signal has *incremental* content, given a *connecting fact* and relative to a *constraint*.[1] In this case, the connecting fact is that the thermometer is in Elwood's mouth, the *connecting relation* is that of one thing being in the mouth of another, and the constraint $\mathcal{C}_1$ is:

($\mathcal{C}_1$) Given that a thermometer is in a person's mouth, if the mercury goes above 98.6, that person has a fever.

Informational content is only information when the constraints and connecting facts are actual. If a signal carries the information that P, then P is true. A signal can have the informational content that P relative to a constraint and a connecting fact, even though P is not true. This happens when the constraint or connecting "fact" or both are not factual. We shall often use "information" more casually than this suggests, however, noting the distinction only when it is relevant to a point we are making.

Incremental information contasts with various sorts of *reflexive information*, which are relative to constraints, but not connecting facts. Suppose that in the physician's office thermometers are always shaken down after they are used and stored in a cool place until their next use. Then this somewhat stronger constraint is in force:

[1] This paper is a continuation of [1] and builds on both the theory and the terminology of that earlier work. However, our treatment of reflexive content is different.

($\mathcal{C}_2$) If the mercury in a thermometer goes above 98.6, there is a person whose mouth it has been in, and that person has a fever.

Relative to $\mathcal{C}_2$, setting the connecting fact to one side, our signal carries the *pure information*:

(2) The fact that the mercury in **t** is above 98.6 carries the information that there is a person whose mouth it has been in, and that person has a fever.

The informational content of (2) quantifies over people and has the thermomenter itself as a constituent; in these ways it differs from the informational content of (1), which has Elwood as a constituent and does not mention thermometers. It is the presence of the thermometer itself, the carrier of the information, in the information itself that leads us to call it *reflexive*. If we consider just our original constraint ($\mathcal{C}_1$), setting the connecting fact aside, we have what we might call the *conditional* information, which is similarly reflexive.

(3) The fact that the mercury in **t** is above 98.6 indicates that if there is a person in whose mouth it has been, that person has a fever.

In many cases, the most useful way to express reflexive information will be in the form of a statement in which the subject matter is identified by a description in terms of the carrier of the signal, reformulating (2) as :

(4) The fact that the mercury in **t** is above 98.6 indicates that the person in whose mouth **t** was, has a fever.[2]

In [1].we developed the notions of pure and incremental information, and stressed the importance of both in fully understanding the way we handle information. (See also [3, 4]). In this paper we will use the term *signal structure* for a signal together with a constraint, connecting facts, and the contents generated thereby. We introduce the notion of an *information system* for a system of signal structures, in which relations are established among the carriers of the signals in order to induce or reflect relations among the contents. We call these relations *architectural*. To analyze information systems, we need a further type of informational content, which we call *architectural content*. We shall consider three types of informational structures: *coincident architectures*, *combinative architectures* and *flow architectures*. We then show how the notion of architectural content is important to the analysis of information using devices.

2 Coincident Architectures

Consider the familiar apparatus doctors use to check height and weight. Elwood stands on the platform of the scale; weights are moved on the weight bar and the height bar is

[2](4) can also be understood as a reformulation of (3), with an implicit "if there is one", after the definite description.

lowered; we learn that Elwood needs to grow taller or lose weight. Given the concepts of [1] we can distinguish the reflexive and incremental contents:

(5) The fact that the weights on the weight bar are at 100 and at 80 carries the information that the man affecting the weight bar weighs 180 pounds.

(6) The fact that the weights on the weight bar are at 100 and at 80 carries the information that Elwood weighs 180 pounds.

(7) The fact that the height bar is at 5 carries the information that the man whose head it contacts is 5 feet tall.

(8) The fact that the height bar is at 5 carries the information that Elwood is 5 feet tall.

There is an intermediate kind of information (5)-(8) don't capture. The weight bar and the height bar are connected to each other independently of their connection to Elwood, in a way that assures that they will generate information about the same person. In this case, we can distinguish the following informational contents that are available to the physician, when he considers the two signals—that the weights are on 100 and 80, and that the height bar is at 5

(9) The fact that the height bar is at 5 carries the information that the man affecting the weight bar is 5 feet tall.

(10) The fact that the weights on the weight bar are at 100 and at 80 carries the information that the man whose head the height bar contacts weighs 180 pounds.

(5) and (7) are purely reflexive. The subject is identified only via the carrier of the signal. (9) and (10) are similar in that the subject is identified via the carrier of a signal. As between (9) and (7), however, the *mode of presentation* has been changed. It is not height bar (the carrier of the indicating signal) that is used to identify the subject matter, but the weight bar.

(9) and (10) are also similar to (6) and (8), in that the information is carried only relative to connecting facts. With (9) and (10) a new sort of connecting fact and a new sort of constraint is involved. The fact is just that the height bar and the weight bar are parts of an apparatus of this sort. We shall call such facts *architectural connecting facts*, and the relations involved in them *architectural relations.* The weight bar is the *architecturally connected carrier* in (9); it is the height bar in (10). The constraint reflects the architecture of the apparatus and facts about the shape and size of humans: if a weight bar and height bar are connected that way, the person whose head contacts the height bar is the person who is affecting the weight bar. We call the sort of constraint involved in (9) and (10) an *architecural constraint* and the relation between persons (in our case, identity), the *architecturally grounded relation*. Information relative to architectural connections and constraints, we call *architectural*.

We will discuss information structures in terms of four questions about how the architectures organize the informational content:

(i) What are the architectural relations—that is, how are the carriers related?

(ii) What is the architectural constraint?

(iii) What relationship among the contents is determined by this architecture? Is this relationship induced or reflected by the architecture?

(iv) How are the constraints and connecting facts in the signal structures related to one another and to the architectural constraints and connections?

Let's consider our example

(i) The doctor's apparatus is constructed so that the height bar is directly above the platform, force upon which affects the weight bar.

(ii) This relation, in virtue of facts about the shapes and sizes of human beings, guarantees that the person whose head is in contact with the height bar is the very one whose feet are on the platform, and hence the one whose weight is registered by the position of the weights on the weight bar.

(iii) Thus, the subject matter of the two signal structures is the same; this is induced by the architecture, not merely reflected by it.

(iv) In this case, the original constraints are independent of one another, and of the architectural constraint. If the weight bar is broken, the appartus can still be used to measure height, and vice versa.

This is the pattern we take to be characteristic of coincident architectures, with one exception. In our case, the relation between subject matters induced by the architecture is identity. Coincident architectures allow for relations other than identity. To take a simple example, the fact that a given fuel gauge and temperature gauge are mounted in the same dashboard carries the information that the fuel tank and cooling system about which the gauges carry information are in the same car.

3 Combinative architectures

In *combinative architectures*, the architectural relation reflect, rather than induce, the relations among contents. We begin by contrasting combinative architectures with two sorts of case in which the relations between the carriers of signals don't carry information.

(11) An x-ray has been taken of Elwood's chest. It exhibits property ϕ, which clearly shows that the person x-rayed had a cracked rib, but there is no indication of whom—there is no label on the x-ray. An unlabeled printout of Elwood's blood test lies next to the x-ray on the physician's desk. There is no way for the physician to tell that they they carry information about the same patient.

This pair of carriers sitting beside each other on the desk is what we might call a (mere) pile. There is, of course, a relation between the x-ray sheet and the printout—they are on the same desk—but that fact does not itself indicate anything. That is, within the information using system (the physician, the materials on her desk) there is no relevant constraint that generates the pertinent information from the relation between the carriers. Although the signals have the same subject matter, this is in no way determined (either reflected or induced) by the relation between the two carriers.

(12) On the physician's desk are two x-rays, the one mentioned in (11) and another taken of Elwood a short time later, showing a recently mended rib. Again, there is nothing in the fact that the x-rays are both on the desk that indicates that they have the same subject matter. But in this case the physician can tell, by careful examination, that they are earlier and later x-rays of the same person.

In (12), unlike (11), there is something in the system of signals to indicate identity of subject matter: an *internal* indication of an external identity. But the internal indication is not architectural. We call this type of case one of *convergence*.

(13) This is example (11) but with an important change. The print-out has been stapled to the x-ray. In the physician's office the practice is to staple together only documents that concern the same patient.

This is an example of a combinative information system, in particular of what we call a *file*. As in (12), we have an internal indication of an external identity. In the case of (13), however, the indication is architectural. A relationship has been established between the carriers that indicates that the signals have the same subject matter.

In both files and convergences, some relation between two or more signals carries the information that they have the same subject matter. In the case of a file, this will be a relation between the carriers; in the case of convergence, a relation between the indicating properties. This difference reflects a difference in the constraints that generate the information. In the case of a convergence, the constraint meshes with the constraints involved in the original signal structures. In (12), these original constraints generated the information that the rib the first signal was of was cracked in a certain way, and that the rib the second signal was of had recently mended from a crack of that sort. There is then a third constraint, a nonarchitectural constraint, that generates the information that the ribs are the same. It is about ribs in both its antecedent and consequent: a rib that looks like this when broken, and one that looks like that when recently mended, are the same rib. In (13), the constraint that generates the information that the signals are of the person does not mesh with the original constraints. Its antecedent is about carriers being stapled together, and its consequent is to the effect that the contents of the salient signals involving those carriers—the signals salient given the purposes and practices of the information using system—all have the same subject matter.

Let us look at one more case of a combinative architecture.

(14) The x-ray and the print-out have been put into a manila file-folder labeled "Elwood Fritchey". The physician's staff are very careful so that only data about the right person get into such a file-folder.

We call this a *labelled file*. We can use the notion of architectural information to get at the usefulness of such file-folders.

The file-folder itself is a signal that combines with the signals provided by the carriers in it. Such labelled files are likely to have many uses in our doctor's office, but let's simplify matters by supposing that the sort of label in question is reserved for patients. The relevant constraint is:

($\mathcal{C}_{label}$) If a file-folder f is labelled α, there is a patient to which α refers, and all of the signals provided by the carriers in f have that patient as subject-matter.

Relative to $\mathcal{C}_{label}$ and the fact that it is in a file-folder *f*, we have:

(15) The fact that the x-ray exhibits ϕ indicates that the patient to whom the label of *f* refers had a cracked rib.

The value of a labelled file is that it provides a useful mode of presentation of the subject matter of the information in the file. If the nurse were just to find the x-ray by itself, he will know that it is of the person who is x-rayed, but this knowledge probably won't be of much use to him by itself. Unless the x-ray has just been taken, he won't know how to contact that person, or how to refer to him in a way that the doctor will find useful—or how to send him the bill. If he finds the x-ray in the file, he will get the architectural information that the patient the label refers to had a cracked rib. The mode of presentation provided by the label—perhaps the name "Elwood Fritchey" or a patient I.D. number that is connected in the office records with this name—will be useful. It will be connected in various ways to addresses, phone numbers and other modes of interaction with Elwood.

We now turn to our four questions.

(i) In (13), the carriers were related by being stapled together; in (14), they were put into the same (labelled) file-folder.

(ii) In (13), the architectural constraint is that if documents are stapled together, then the relevant signals share a subject matter; in (14) it was $\mathcal{C}_{label}$.

(iii) In both cases, the relation among contents determined by the architecture is identity, and in both this relationship is reflected in the architecure, not induced. The apparatus involved in generating and carrying x-ray signals and that involved in generating and carrying blood-test signals are not related in such a way that the person who is the subject matter of signals generated and carried by the first is the same as that involved in the second. In combinative architecures, some relation must be established between the carriers that reflects the fact that a relation of interest holds among the subject matters of the signals.

(iv) Here, too, the constraints involved in the signal structures can be quite independent of one another, and of the architectural constraint.

4 Flow architectures

Coincident and combinative architectures yield *architecturally co-ordinated* information; because of the architectural relations, the signals involved carry information about the same subject matter (or subject matters with a fixed relationship). We now consider information flow, which involves *architecturally mediated* information, in which signals contain information about a certain subject matter in virtue of carrying information about other signals to which they are architecturally connected.

In *Knowledge and the Flow of Information*, Fred Dretske states the following basic principle of the flow of information:

Xerox principle: If A carries the information that B, and B carries the information that C, then A carries the information that C.[2], p. 57.

Dretske says that this is "a regulative principle, something inherent in and essential to the ordinary idea of information, something that any *theory* of information should preserve."[2] We'll try to explain why our theory preserves the xerox principle, and say what we think this regulative principle regulates.

One of Dretske's examples of the flow of information involves a radio:

> The acoustic waves emanating from a radio speaker carry information about what is happening in the broadcasting studio *because* they carry accurate information about what is happening in the audio circuit of the receiver; these events in turn carry information about the modulation of the electromagnetic signal arriving at the antenna; and the latter carries information about the manner in which the microphone diaphragm (in the broadcasting studio) is vibrating. The microphone's behavior, in turn, carries information about what the announcer is saying. This whole chain of events constitutes a communication system, a system whose output carries information about its input, because of iterated applications of the xerox principle.[2], p. 58.

This is an example of an information system. We'll make the example more concrete by supposing it is John Madden who is sitting in the sportscasters' booth, speaking into the microphone, announcing a 49ers game. We can take the first signal to be the pattern of sound waves that fill the booth. These carry information about what the occupant of the booth is saying; in our example the occupant is Madden, and they carry the incremental information that he said "The 49ers score." The second signal is the pattern of vibration of the microphone's diaphragm; the architectural fact is that this is the microphone in the booth. The third signal is the modulation of the electromagnetic signal arriving at the antenna; this is of course the antenna that is connected by the

circuitry to the microphone in the broadcasting booth. The next signal is what is happening in the audio circuit of the receiver. This receiver is within the range of the signal from the antenna, and is tuned to the relevant frequency. Finally, there are the waves emanating from the speaker of that radio. Of course, this system could be broken up into signals and connections in a variety of different ways, and this way of doing it is relatively crude.

According to Dretske, in the flow of information some information is to be carried along the signals, so that the last signal carries the information of interest that was carried by the first signal. We'll call that the *target* information. In this example the target information is the incremental information that Madden said "The 49ers score". Each signal in the system, from the sound waves in the booth, to vibrations of the mike to the sound waves emanating from the speakers, carries this information, which is incremental information about Madden. But this is not the *only* information carried by the signals.

In the first place, it's not just the target information that flows. The reflexive information that the occupant of the booth said "The 49ers score" also flows. In designing an information flow architecture, one would naturally focus on this sort of reflexive information.

More germane to the present point, the later signals also each carry architectural information about the earlier ones. As Dretske points out, it is only because they do this that they carry any information about Madden's activities.

The second signal in our chain is the fact that the diaphragm in the mike is vibrating in a certain way. The first link in the architecture is the fact that the microphone is located in the booth. The architectural constraint associated with this fact is that the vibrations of the diaphragm of the microphone are correlated with a certain type of sound-wave in the booth. The second signal carries information about the first signal, in virtue of this architectural connection and constraint

The second signal also carries the target information about Madden. It does so in virtue of the architectural connections and constraints just mentioned, together with the connections and constraints associated with the first signal. So, considering the first two signals, and using w for the sound wave, d for the diaphragm, and Φ_i for the indicating property involved in signal i, we have the following constraints, connecting facts, and contents.

First, the connecting fact and constraint involved in the first signal structure:

($\mathcal{C}_1$) Given that an acoustic wave is produced by the vocal activities of an occupant of the booth, the wave will be of type Φ_1 only if the announcer said "The 49ers score".

($\mathbf{C}_1$) Madden is occupying the booth and producing acoustic wave w.

The incremental content of the first signal relative to $\mathcal{C}_1$, given C_1 is that Madden said "The 49ers scored". Next, the architectural fact and constraint that are relevant to the second signal:

($\mathcal{C}_2$) If a diaphragm of a mike is being bombarded by an acoustic wave, the diaphragm will exhibit Φ_2 only if the wave is of type Φ_1.

($\mathbf{C}_2$) Acoustic wave w is bombarding d.

The architectural content of the second signal, relative to $\mathcal{C}_2$ and given C_2, is that the wave w is of type Φ_1.

Next, we have the combined constraints and connecting facts:

($\mathcal{C}_{1-2}$) If the diaphragm of a mike is vibrating because it is being bombarded by acoustic waves and the acoustic waves are produced by an announcer's vocal activities, the vibrations will be of type Φ_2 only if the announcer said "The 49ers score."

($\mathbf{C}_{1-2}$) Madden is in the booth and is producing w and w is bombarding d.

The incremental information content of the second signal, relative to $\mathcal{C}_{1-2}$ and given C_{1-2}, is just the same as the incremental content of the first signal, that Madden said "The 49ers score".

Each signal further along the flow architecture repeats the same pattern; it carries architectural information about the previous signals, and, in virtue of that, the target information about Madden.

Let's turn to our five questions.

(i)-(ii) The architectural connections in a case of information flow are causal connections, whereby the indicating properties of the earlier signals causally determine those of the later ones. In virtue of the architectural facts and constraints, the later signals carry information about the earlier ones.

(iii) It is in virtue of this that the later signals can carry the same incremental information content as the first. The architecture does not reflect the relation between contents that the signals would have independent of it, but induces the identity among contents.

(iv) The constraints and connecting facts for the later signals are combinations of the architectural facts and constraints and the connecting facts and constraints of the earlier signals.

The hallmark of information flow systems, then, is that the incremental information of the later signals in the system depends on their architectural information. The state of the antenna carries information about Madden only because it carries information about the mike. This wasn't the case with coincident and combinative systems.

Let's return to the Xerox principle. Although Dretske distinguishes the signal from the information it carries, he conflates them in his statement of the principle. Given our terminology, it should be stated as follows:

> If s carries the information that b is F, and the fact that b is F carries the information that Q, then s carries the information that Q.

Given the relativity of information content to constraints and connecting facts, this principle is really a statement to the following effect:

If (i) there are architectural constraints $\mathcal{C}$ and architectural connections C such that s carries the architectural information that b is F, relative to $\mathcal{C}$ given C, and (ii) there are constraints $\mathcal{C}'$ and connecting facts C' such that the fact that b is F carries the information that Q relative to $\mathcal{C}'$and C',

then there are constraints $\mathcal{C}''$ and connecting facts C'' such that s carries the information that Q relative to $\mathcal{C}''$ given C''.

On our theory, this conditional is true. The constraints and connecting facts called for in the consequent are simply the combinations of the constraints and connecting facts provided by the antecedent, as in the example above.[3]

We can now see one sense in which the Xerox Principle is regulative. It regulates the way information flow architectures are constructed. The point of such systems is to insure that the signals at the terminus of the architecture will contain incremental information about objects connected to the initial signals. The way to get this relationship between the incremental contents is to design the architecture so that each signal carries the architectural information about the indicating properties of earlier signals.

5 Using Information

The architectures of information using devices rely on both co-ordinated and flow architectures.

Consider a simple mousetrap. A small lever is attached to a rod which engages a cam on a spring, which is attached to a stiff wire blade. The rod prevents the spring from releasing. When the lever moves, the rod slips, the spring is released and the blade snaps down on the base of the trap.

This is a simple device that converts information into action. Cheese is placed on the lever. When a mouse eats the cheese, the lever moves, the rod slips, the spring is released and the mouse is crushed.

To analyze this, we need an additional concept, the *success conditions* of an action relative to a constraint and a chosen end-state or goal. In this case, the goal is the killing of mice. The action of the blade moving will succeed in bringing about this goal, only if the thing in its path is a mouse, not a toe or mere empty space. *P* is a success condition of act a relative to constraint and a goal, if *P* is a requirement, according to the constraint for a to bring about the goal. Relative to the goal of killing mice and the constraint that a mouse in the path of this sort of blade will be crushed when it snaps shut, we have, as a success condition of the blade's moving:

[3]We need to be careful here, though. We have stated the Xerox Principle in terms of information, not informational content. We assume that reality is coherent, so that there are combined facts and constraints of the sort we relied on in the example. Attributions of informational content, however, are made relative to possible facts and constraints; the principle will only hold if the facts and constraints relevant to the antecedent and consequent don't interfere with one another.

(P) The thing in the path of the blade is a mouse.

In a well-run household, in which mousetraps are located in an area in which dogs can't roam and children don't play, the lever of a mousetrap will move only if a mouse in standing on the platform nibbling on the cheese spread on the lever. Thus the reflexive information carried by the lever moving relative to this latter constraint is:

(Q) The thing nibbling on the cheese on the lever is a mouse.

The gap between *P* and *Q* is bridged by a combination of coincident architectural content and information flow. The movement of the blade carries the architectural information that the lever is moving, which carries the reflexive information that the thing nibbling at the lever is a mouse. The relevant architectural connection is the rod and cam structure that insures that the blade will be released only when the lever moves. So the information that *Q* flows, and is also carried by the movement of the blade. This doesn't get us from *Q* to *P*, though. Notice that this flow might take place, even if the architecture were defective—say because the platform is too long—and the blade will miss the mouse. If the trap is well-designed, however, the information that *Q* will not only flow, but be coordinated with the success condition. This is not due to the rod and cam connection, but to the fact that the distance between the blade and the lever is about the size of the average mouse. The constraint associated with this architectural feature is that the thing nibbling at the lever is the thing the blade will hit. This constraint justifies the shift in modes of presentation that gets us from *Q* to *P*.

6 Conclusion

As we pointed out in [1], ordinary information reports focus on incremental content. There we argued that to understand the way in which the information content of a signal is derived from the regularities that generate that content, one also needs to recognize reflexive information. Here, we have argued that to understand how devices generate, combine, and use information, we need to recognize architectural information of various sorts.

References

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