Forthcoming in the *Encyclopedia of Science, Technology, and Ethics*, (ESTE) edited by Carl Mitcham (Macmillan).

Information

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1. Introduction

Science, technology and ethics are all forms of information. They also depend for their workings on information. Furthermore, there exist sciences, technologies, and ethics of information. So it seems that it is information all the way up and all the way down. To disentangle some of the main relations between these different aspects of information, it will be helpful to start with a simple example.

Monday morning. You turn on the ignition key of your car, but nothing happens: the engine does not even cough. Unsurprisingly, the red light of the low battery indicator is flashing. After a few more attempts, you ring the garage and explain that, last night, your wife forgot to switch off the lights of the car – it is a lie, you did, but you are too ashamed to confess it – and now the battery is flat. You are told that the instruction manual of your car explains how to use jump leads to start the engine. Luckily, your neighbour has everything you need. You follow the instructions and drive to the office.

This everyday episode provides enough details to illustrate the many ways in which we understand one of our most important resources: *information*. The information galaxy is vast, and in this article only two of its main regions will be explored: information as content and information as communication. The reader interested in knowing more on the philosophical analysis of the concept may wish to consult Hintikka and Suppes [1970]; Hanson [1990]; Dretske [1999] and Floridi [2003].

2. Information as Content

It is common to think of information as consisting of *data* (Floridi [2004a]). An intuitive way of grasping the notion of “data” is to imagine an answer without a question. Ultimately, data may be described as relational differences: a 0 instead of a 1; a red light flashing; a higher or lower charge in a battery.

To become information, data need to be *well-formed* and *meaningful*. “Well-formed” means that data have been put together correctly, according to the rules (*syntax*) of the chosen language. For example, the booklet shows the batteries of the two cars placed one near the other, not one on top of the other. "Meaningful" means that the data must also comply with the meanings (*semantics*) of the chosen language. So the booklet makes sure that the pictures are immediately recognisable.

When meaningful and well-formed data are used to talk about the world and describe it, the result is *semantic content* (Bar-Hillel and Carnap [1953]; Bar-Hillel [1964]). Semantic content has a twofold function. Like a pair of pincers, it seeks both to pick up or "about" a situation, a fact, or a state of affairs *f*, and to model or describe *f*. "The battery is flat" carves and extracts this piece of information – that the battery of the car is flat – and uses it to model reality into a semantic world in which the battery is flat. Whether the work done by the specific pair of pincers is satisfactory depends on the resource *f* (realism) and on the purpose for which the pincers are being used (teleologism). Realistically, "the battery is flat" is true. Teleologically, it is successful given the goal of communicating to the garage the nature of the fault. "The battery is flat" would be realistically false and teleologically unsatisfactory if it were used e.g. to provide an example of something having a smooth or even surface.

2.1. Information as True Semantic Content

True semantic content is perhaps the most common sense in which information may be understood (Floridi [2004a]). It is also one of the most important, since information as true semantic content is a necessary condition for knowledge. Some elaboration is in order. First, the data that are going to constitute information allow or invite certain constructs and resist or impede some others. Data in this respect work as *constraining affordances*. Second, data are never accessed and elaborated independently of a *level of abstraction* (LoA). A LoA is like an interface, which establishes the scope and type of data that will be available as a resource for the generation of information (Floridi and Sanders [2004]). "The battery is what provides electricity to the car" is a typical example of information elaborated at a driver's LoA. An engineer's LoA may output something like "12-volt lead-acid battery is made up of six cells, each cell producing approximately 2.1 volts", and an economist's LoA may suggest that "a good quality car battery will cost between $50 and $100 and, if properly maintained, it should last five years or more". Data as constraining affordances – answers waiting for the relevant questions – are transformed into information by being processed semantically at a given LoA (alternatively: the right question is associated to the right data always at a given LoA).

Once information is available, knowledge can be built in terms of *justified* or *explained information* (one knows that “the battery is flat” not by merely guessing rightly, but because one sees the red light of the low battery indicator flashing and one perceives that the engine does not start), thus providing the basis of any further scientific investigation. The fact that data count as *resources* for information, and hence for knowledge, rather than *sources* is a constructionist argument against any representationalist theory that interprets knowledge as a sort of picture of the world.

When some *semantic content* is *false*, this is a case of *misinformation* (Fox [1983]). And if the source of misinformation is aware of its nature, one may speak of *disinformation*, e.g. “my wife forgot the lights on”. Disinformation and misinformation are ethically censurable but may be successful teleologically: tell the mechanic that your wife left the lights on last night, and he will still be able to provide you with the right advice. Likewise, information may still fail to be teleologically successful; just imagine telling the mechanic that your car is out of order.

2.2. Instructional Information

True semantic content is not the only type of information. The booklet, for example, also provides *instructional information*, either imperatively – in the form of a recipe: first do this, then do that – or conditionally, in the form of some inferential procedure: if such and such is the case do this, otherwise do that. Instructional information is not about *f* and does not model *f*: it rather constitutes or instantiates *f*, that is, it is supposed to make *f* happen. The printed score of a musical composition or the digital files of a program are typical cases of instructional information. So the latter clearly has a semantic side. And semantic and instructional information may be joined in performative contexts, such as christening – e.g. “this ship is now called *HMS The Informer* – or programming – e.g. as when declaring the type of a variable. Finally, the two types of information may also come together in magic spells, where semantic modelling is confused with instructional power and control. Yet, as a test, one should recall that instructional information does not qualify alethically (from *aletheia*, the Greek word for truth). In the example, it would be silly to ask whether “only use batteries with the same rated voltage” is true or false.

2.3. Environmental Information

When you turned the ignition key, the red light of the low battery indicator flashed. You translated the flashing into (a) semantic information: "the battery is flat"; and (b) instructional information: the battery needs to be charged or replaced. However, the flashing of the indicator is actually an instance of *environmental information*.

Environmental information may be described as "natural data": it requires two systems *a* and *b* to be coupled in such a way that *a*'s being (of type, or in state) *F* is correlated to *b* being (of type, or in state) *G*, thus carrying for the observer the information that *b* is *G* (Barwise and Seligman [1997] provide a similar analysis based on Dretske [1999]). The correlation is usually *nomical* (it follows some law). It may be engineered – as in the case of the low battery indicator (*a*) whose flashing (*F*) is triggered by, and hence it is informative about, the battery (*b*) being flat (*G*). Or it may be natural, as when litmus – a colouring matter from lichens – is used as an acid-alkali indicator (litmus turns red in acid solutions and blue in alkaline solutions). Other typical examples include the correlation between fingerprints and personal identification, or between the age of a plant and its growth rings.

One may be so used to see the low battery indicator flashing as carrying the information (that is, meaning) that the battery is flat to find it hard to distinguish with sufficient clarity between environmental and semantic information. However, it is important to recall that environmental information may require or involve no semantics at all. It may consist of correlated data understood as mere differences or affording constraints. Plants (e.g. a sunflower), animals (e.g. an amoeba) and mechanisms (e.g. a photocell) are certainly capable of making practical use of environmental information even in the absence of any (semantic processing of) *meaningful* data. Figure 1 summaries the main distinctions introduced so far.

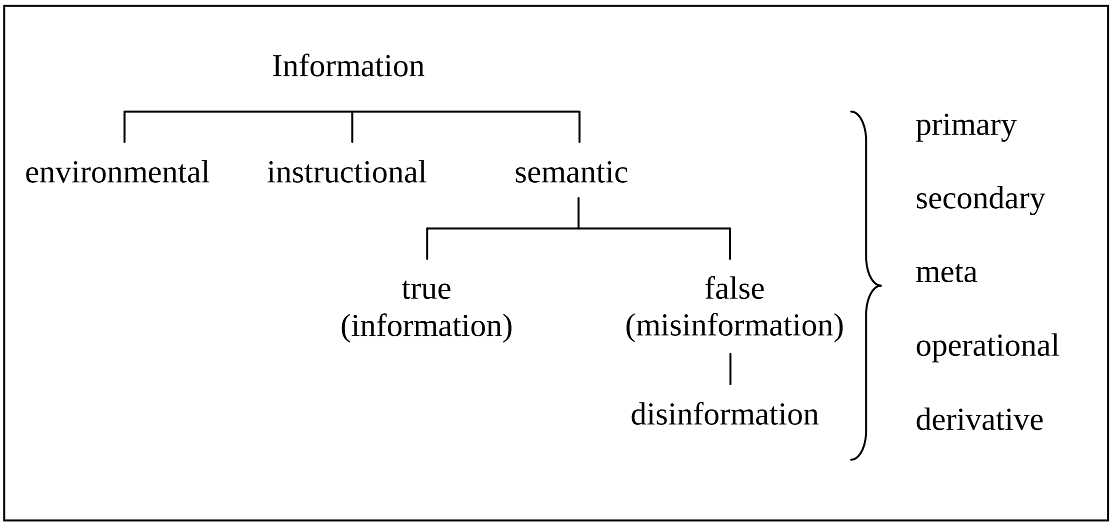

Fig. 1 The taxonomy of information

2.4. Five Types of Information

A few more details may now be added. First, it is worth stressing that the actual *format, medium* and *language* in which information is encoded is often irrelevant. The same semantic, instructional and environmental information may be analog or digital, printed on paper or viewed on a screen, in English or in some other language. Second, so far it has been implicitly assumed that *primary* information is what is in question: things like the red light of the low battery indicator flashing, or the sentence "the battery is flat" spoken over the phone. But recall how you discovered that the battery was flat. The engine failed to make any of the usual noise. Likewise, in *Silver Blaze*, Sherlock Holmes solves the case by noting something that has escaped everybody else, the unusual silence of the dog. Clearly, silence may be very informative. This is a peculiarity of information: its absence may also be informative. When it is, the difference may be stressed by speaking of *secondary information*.

Apart from secondary information, three other typologies are worth some explanation, as they are quite common (the terminology is still far from being standard or fixed, but see Floridi [1999b]). *Metainformation* is information about the nature of information. "'The battery is flat' is encoded in English" is a simple example. *Operational information* is information about the dynamics of information. Suppose the car has a yellow light that, when flashing, indicates that the car checking system is malfunctioning. The fact that the light is off indicates that the low battery indicator is working properly, thus confirming that the battery is indeed flat. Finally, *derivative information* is information that can be extracted from any form of information whenever the latter is used as a source in search of patterns, clues, or inferential evidence, e.g. for comparative and quantitative analyses. From someone's credit card bill concerning the purchase of some petrol one may derive the information of her whereabouts at a given time.

3. Information as Communication

Very little has been said so far about information in the communication sense of transmission of a message (Cherry [1978]). In the example, it is time to take into consideration the telephone call to the garage.

Some features of information are intuitively quantitative. Information can be *encoded*, *stored* and *transmitted*. One also expects it to be *additive* (information *a* + information *b* = information *a* + *b*) and *non-negative*. Similar properties of information are investigated by the *mathematical theory of communication* (MTC, also known as *information theory*, for an accessible introduction see Jones [1979]).

MTC was established by Claude E. Shannon (Shannon and Weaver [1949 rep. 1998]) with the primary aim of devising efficient ways of encoding and transferring data. Its two fundamental problems are the ultimate level of data compression (how small can a message be, given the same amount of information to be encoded?) and the ultimate rate of data transmission (how fast can data be transmitted over a channel?). To have a sense of the approach, let us return to our example.

The telephone communication with the mechanic is a specific case of a general communication model, described in Fig. 2.

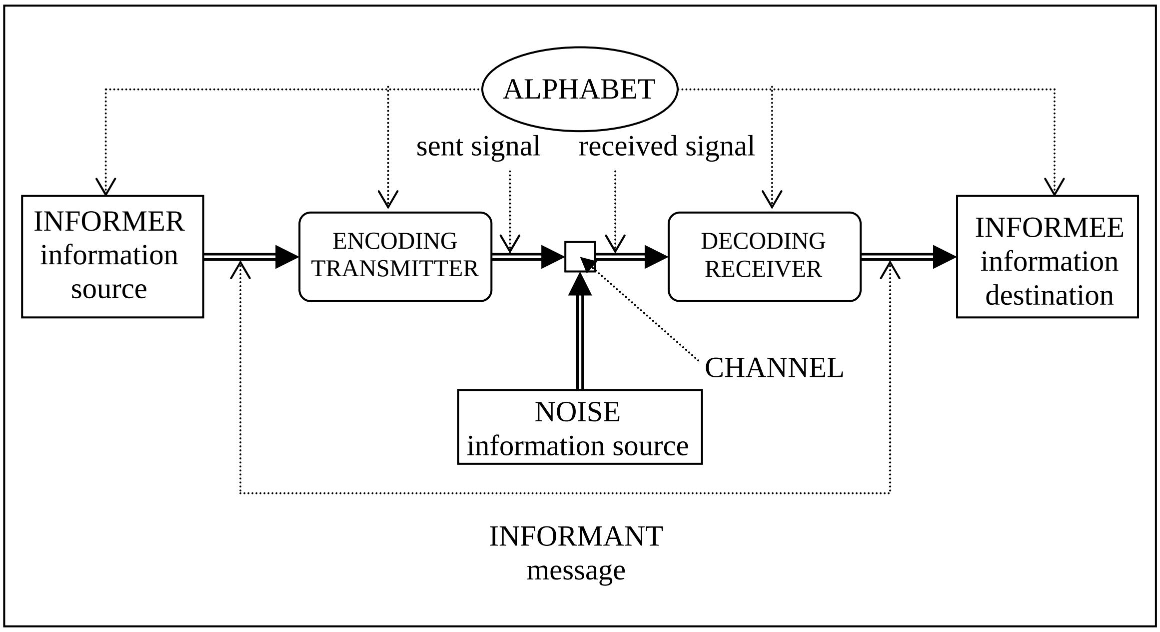

Fig. 2 The communication model

You are the *informer*, the mechanic is the *informee*, “the battery is flat” is the message (the *informant*), there is a coding and decoding procedure through a language (English), a channel of communication (the telephone system) and some possible noise. Informer and informee share the same background knowledge about the collection of usable symbols (the *alphabet*).

MTC treats information as only a selection of symbols from a set of possible symbols, so a simple way of grasping how MTC quantifies raw information is by considering the number of yes/no questions required to guess what the informer is communicating. When a fair coin is tossed, one question is sufficient to guess whether the outcome is head (*h*) or tail (*t*). Therefore, a binary source like a coin is said to produce 1 bit of information. A 2-fair-coins system produces 4 ordered outputs: <*h*, *h*>, <*h*, *t*>, <*t*, *h*>, <*t*, *t*> and therefore requires two questions, each output containing 2 bits of information, and so on. In the example, the low battery indicator is also a binary device: if it works properly, it either flashes or it does not, exactly like a tossed coin. And since it is more unlikely that it flashes, when it does, the red light is very informative. More generally, the lower the probability of *p* the more informative the occurrence of *p* is (unfortunately this leads to the paradoxical view that a contradiction – which has probability 0 – is the most informative of all contents, unless one maintains that, to qualify as information, *p* needs to be true Floridi [2004b]).

Before the coin is tossed, the informee does not "know" which symbol the device will actually produce, so it is in a state of *data deficit* equal to 1 (Shannon's "uncertainty"). Once the coin has been tossed, the system produces an amount of raw information that is a function of the possible outputs, in this case 2 equiprobable symbols, and equal to the data deficit that it removes. The reasoning applies equally well to the letters used in your telephone conversation with the mechanic.

The analysis can be generalised. Call the number of possible symbols N. For $N = 1$, the amount of information produced by a unary device is 0. For $N = 2$, by producing an equiprobable symbol, the device delivers 1 unit of information. And for $N = 4$, by producing an equiprobable symbol the device delivers the sum of the amount of information provided by coin *A* plus the amount of information provided by coin *B*, that is 2 units of information. Given an alphabet of N equiprobable symbols, it is possible to rephrase some examples more precisely by using the following equation: $\log_2(N)$ = bits of information per symbol.

Things are made more complicate by the fact that real coins are always biased, and so are low battery indicators. Likewise, in your conversation with the mechanic a word like "batter" will make "y" as the next letter almost certain. To calculate how much information a "biased" device produces, one must rely on the frequency of the occurrences of symbols in a finite series of occurrences, or on their probabilities, if the occurrences are supposed to go on indefinitely. Once probabilities are taken into account, the previous equation becomes Shannon's formula (where H = uncertainty, what has been called above *data deficit*): $H = -\sum_{i=1}^{N} P_i \log P_i$ (bits per symbol)

The quantitative approach just sketched plays a fundamental role in coding theory, hence in cryptography, and in data storage and transmission techniques, which are based on the same principles and concepts. Two of them are so important to deserve a brief explanation: *redundancy* and *noise*.

Redundancy refers to the difference between the physical representation of a message and the mathematical representation of the same message that uses no more bits than necessary. It is basically what can be taken away from a message without loss in communication. Your mentioning of your wife as the person responsible for the flat battery was redundant.

Compression procedures work by reducing data redundancy, but redundancy is not always a bad thing, for it can help to counteract *equivocation* (data sent but never received) and *noise* (received but unwanted data, like some interference). A message + noise contains more data than the original message by itself, but the aim of a communication process is *fidelity*, the accurate transfer of the original message from sender to receiver, not data increase. The informee is more likely to reconstruct a message correctly at the end of the transmission if some degree of redundancy counterbalances the inevitable noise and equivocation introduced by the physical process of communication and the environment. This is why, over the phone, you said that "the battery is flat" and that "the lights were left on last night". It was the "by whom" that was uselessly redundant.

MTC is not a theory of information in the ordinary sense of the word. The expression "raw information" has been used to stress the fact that in MTC information has an entirely technical meaning. Two equiprobable "yes" contain the same quantity of raw information, no matter whether their corresponding questions are "is the battery flat?" or "is your wife missing?". Likewise, if one knows that a device could send with equal probabilities either this whole encyclopaedia or just a quote for its price, by receiving one or the other message one would receive very different quantities of data bytes but only one bit of raw information. Since MTC is a theory of information without meaning, and (information – meaning) = data, *mathematical theory of data communication* is a far more appropriate description than *information theory*.

MTC deals not with semantic information itself but with messages constituted by uninterpreted symbols encoded in well-formed strings of signals, so it is commonly described as a study of information at the *syntactic* level. This generates some confusion because one may think the syntactic vs. semantic dichotomy to be exhaustive. Clearly, MTC can be applied in ICT (information and communication technologies) successfully because computers are syntactical devices. It is often through MTC that information becomes a central concept and topic of research in disciplines like chemistry, biology, physics, cognitive science, neuroscience, the philosophy of information (Floridi [2002]; Floridi [2004a]) and computer ethics (Floridi [1999a]).

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