

Informational Networks: A Meta-architecture for Situated Cognition

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Abstract

The paper attempts to provide a conceptual basis for allusions to information processing in discussions about cognition. It defines the notions of informational medium as a subsystem within a larger dynamical system, the notions of information processing and information management operations, and the notion of informational network — a network of informational media. It suggest that situated cognitive systems can be modeled with the help of informational networks at a high level of abstraction. Finally, it examines various properties that informational media may need to possess to participate in an informational network. Understanding those properties helps understand some of the design constraints on various cognitive/AI mechanisms.

1 Introduction

1.1 Informational discussions in cognitive science

Cognitive scientists of all fields resort to loose *informational* descriptions of various cognitive phenomena. Neuroscientist and psychologist often describe neural mechanisms as engaging in information processing. There are allusions to neural or mental “coding” mechanisms. Cognitive agents are assumed to gather, process, and utilize information from the environment. Communication mechanisms in animals and humans are often described as operating on

meaningful information—communication is viewed as *communication of (useful) information*. In the field of artificial intelligence (AI) similar, informational locutions are common. The classical, symbolic approach to AI, as crystallized by Newell and Simon (1981), is often described as the “information processing paradigm”. While this is a misnomer—for, the description is more general than the classical AI warrants—still, AI has been deeply infused by informational, even information theoretic concepts.¹ Later approaches to AI and theoretical cognitive science, e.g. connectionism, rejected the centrality of symbols and symbol manipulation, yet they still kept informational descriptions. (Smolensky, 1986) More recently, dynamical approaches (Thelen & Smith, 1994) and situated robotics approaches (Brooks, 1991) to cognition, which reject even representational descriptions, also continue to utilize informational descriptions. With few exceptions² however, informational descriptions are only loose and informal. At best, they serve a heuristic role in thinking about cognitive mechanisms and architecture; and at worse, they serve only a rhetorical role, as intuition shapers for the audience. Even if used loosely, informational descriptions can be quite useful, but the question is: Is there more to informational descriptions of cognitive mechanisms?

There is a case to be made that too much should not be expected. Cognitive science, embodied in its many branches, studies and models probably the most complex, organized structures in the known universe. Brute, mind boggling details matter. Ground level research needs to look at those details, and it is unlikely that an abstract, purely informational account will suffice. Cognitive science, especially empirical work, needs to operate primarily on a lower level of abstraction, closer to the specific subject matter, whether it is neurons, psychological states, etc. Only *loose* informational descriptions should be expected because the real work is performed with more specific concepts and language. Informational descriptions, however, should be taken seriously because they are up to something. The structure, function, and genetic origin of most cognitive mechanisms is tightly connected to their capacity to operate on information. Viewing cognitive systems as engaged in the information manipulation and utilization business is not only helpful, but essential for a mature cognitive science.

¹It is important to distinguish between the collection of concepts around the term information and the formal theory of information (or communication) *à la* Shannon or Kolmogorov. The formal theories of information are insufficient to capture the richness of the use of the term in cognitive science.

²See (Ghahramani, 2000) for some examples of use of application of formal information theory to problems in cognitive science.

Therefore, cognitive science needs a more systematic, abstract account of general cognitive systems that emphasizes their informational character. Such an account must operate together with more concrete empirical or AI theories of cognition. An informational account can serve two important roles for cognitive science: (1) as an account formulated at a higher level of abstraction, it may guide lower level theoretical work, (2) it can play a metatheoretical role for comparative analysis of lower level competing (or apparently competing) theories, especially theories of cognitive architecture.

The purpose of this paper is to initiate an information based general approach to cognition. It suggests that cognitive systems be modeled with *informational networks*. Informational networks are systems of informationally and causally interconnected informational media that extract, integrate and manipulate information from the environment, the organism, and the network itself, and utilize this information for the purpose of controlling the agent's behavior in the environment, as well as (optionally) for controlling the structure of the very informational network. The following section, "Informational Media", discusses the basic properties of informational media and informational transformations. It discusses several important examples of informational media particularly relevant for architectural debates. The section "Cognitive Systems as Informational Networks" demonstrates how the notion of informational network can be used to model cognitive systems (at a fairly high level of abstraction). It looks at the kinds of properties the various media within an informational network need to possess and how a network can be constructed by coordinating media with different sets of "skills". Meanwhile, the remaining of this section lays out some assumption about the nature of cognition and the notion of information, that are useful for understanding some of the moves made in the later sections. No attempt is made to justify or extensively support those assumptions.

1.2 Overcoming the informational bottleneck

Cognition is essentially a situated, embodied phenomenon. Although certain cognitive mechanisms may be investigated and modeled independently as disembodied systems, they are not properly cognitive unless they are viewed as existing within an operational agent and as serving some control role for the agent (coupled with other cognitive and noncognitive mechanisms within the agent and the proximate environment.) An agent is a complex, sufficiently isolatable system of the world existing high in the hierarchy of organizational

complexity. A cognitive system is a subsystem of the agent (and possibly incorporating mechanisms outside of the agent as a metabolic unit) utilized for controlling the agent's successful interaction with the environment, helping in the achievement of whatever naturally endowed goals the agent may have. A successful agent needs to make the state of the environment relevant to its control mechanisms. Thus, the control mechanisms need to utilize *information* from the environment. An agent, however, is informationally deprived—there exists an informational bottleneck between the agent and the environment, due to the agent's relatively low complexity in comparison to the information available in the environment, and the limits of the sensing surface of the agent. More formally, an agent is connected to the environment through a low capacity information channel. Information theory suggests that a low capacity channel can be overcome if the states of the receiver are naturally correlated with the states of the source of the information.³ For example, if one knows that the Allied forces will begin invasion of France when the poem line "*Bercent mon coeur d'une langueur monotone*" is played on BBC, the single bit of information encoded by the presence of the line is sufficient to induce the informationally rich state that the Allied invasion has begun.⁴ An informationally deprived agent can begin to overcome the limitation (possibly on an evolutionary time scale) by increasing the organizational complexity of its control mechanisms so that they can manipulate and utilize more accurate information about the environment. More generally, we can think of cognition as the capacity of the control systems to overcome the agent's inherent lack of immediate information.⁵ Skills such as memory, learning, representation, planning etc. can be seen naturally as playing this general role.

1.3 Information from dynamics: a structural approach

An agent, with its cognitive system, is a part of the natural dynamics of the world. The existence of the agent as a unit separable from its environment, and the existence of the cognitive system separable from other systems of the agent, depends on the existence of various structural, organizational constraints on the underlying dynamics. Constraints may be things like cell membranes,

³There can be a precise characterization of this within information theory: the relative information entropy between the source and the cognitive system is low. See (Cover & Thomas, 2006) for some basic notions of information theory.

⁴Thanks to Luciano Floridi for this example.

⁵Again, more precisely, the purpose of cognitive complexity is lowering the *relative information entropy* with the environment in order to improve the effectiveness of action.

links among cells (e.g. synaptic connections), molecular structures, structures of tissues, etc. The agent is determined by the natures of those organizational constraints. A dynamical system where there is an agent and an environment is categorically different from a system such as a cloud of particles. The existence of an agent is a macroscopic property of the dynamical system. The existence of an information driven control system within the agent, similarly, is a macroscopic property of the dynamical system. It is possible only if appropriate organizational constraints exist within the dynamical system that allow a macroscopic description of the system in terms of informational notions.

Information is about coordination (or coupling) between dynamical (sub)systems in a way that one system can exert a control role on the other in virtue of the possible macroscopic (informational) states that it can enter. Information is not a *thing* that systems contain. Rather, it is determined by the way systems interact, and the way the nature of the integration is invariant under appropriate dynamical (informational) transformation. Thus, the basic notion in an account of information should be the notion of informational transformation. Information, if anything, is only invariance under certain type of informational transformations. Whether or not an informational transformation takes place depends on the nature of the underlying dynamics (including its modal nature, what happens in all possible alternative dynamical states). In what sense can we say that a Compact Disk contains information? One answer is, the CD contains physical structure that encodes the information—microscopic hills and valleys on its surface. But what structure is that? Why is *this* the structure encoding the information and not some other structure of the physical disk? The reason this is the structure is because there are mechanisms that can read and write this structure and correlate it to other structures (e.g. bits in a hard drive). It is the possibility of the transformations that determine what information is in the CD. The structure of the CD only facilitates the possibility of the transformation (it is what a laser can read). When we describe a cognitive system in informational terms, we describe the nature of its dynamical properties, particularly, its disposition to engage in coordination with other systems and use that coordination for its control.

2 Informational Media

2.1 Basic definitions

Informally, we can think of an informational medium as a system capable of entering in states that can be interpreted as containing information.⁶ An informational medium may be a physical system, or it may be a system of a more abstract kind, such as a virtual machine. We can assume that the system can exist in one of among a determined collection of states. We must also assume that the system is a part of a larger super-system, i.e. it is not closed, and the state of the system are substates of the super-system. The states of the system can change in time. Thus, the system is an instance of a dynamical system. No assumptions are made about the mathematical characterization of the dynamical system.

Not all states of the system must be interpreted as containing unique information. It is important that a medium may be able to take some bitting and still be able to maintain its informational integrity. Thus, we demand that different dynamical states of the system may correspond to the same information-carrying state. Consider an example: Let the system be 100×100 pixel grid where each pixel can be either black or white. The system can be in one of 2^{10000} possible states. We assume that the grid is used to present handwritten text. Imagine it is in a state where the pixels depict the script letter *a*. We want to say that different renditions of the letter, one more elongated, another with a curvier tail, yet another a bit shifted, etc., depict the same information-carrying state. If the grid depicts gibberish, a random pattern of dots, we think of the dynamical state as playing no informational role. We may want to distinguish gibberish from an empty page, which may be the state of absence of text. In such a system some states are informationally useful, others are not; and, many states depict the same information carrier. It is extremely important to distinguish

⁶The system, being in a given state, does not contain the information intrinsically. As alluded in 1.3 what information the system contains depends on the relation of the system to other systems. However, what states the system is in is, in general, intrinsic to the system. This being said, there is a notion of “intrinsic information” that is relevant to a theory of informational media. The term “intrinsic information” is sometimes used to describe the organization of the system (Collier, 1990). “Intrinsic information” is formally related to Kolmogorov information, which provides a measure of the algorithmic complexity of a system — which is intrinsic to the system. The capacity of a medium to enter in informational relations with other systems depends crucially on its organizational characteristics. Thus extrinsic information requires the Collier notion of “intrinsic information” as a characteristics of the medium. However, the precise connection between what I call information here and the notion of “intrinsic information” is beyond the scope of this paper.

between an information-carrying *state* and the *information* carried by the state. We must be able to distinguish between a state where the script *Phosphorus* appears from a state where the script *Hesperus* appears, yet both may contain the same information in the sense that somebody using the system may not care which of the two words (or other possible words, say *Venus*) appears when pointing a telescope. Thus, in a medium we must distinguish between dynamical states, information-carrying states, and information-carrying states containing the same information (or simply informational states).

An *informational medium* is a triple $\mathcal{M} = \langle \mathcal{D}, \mathcal{IC}, \mathcal{F} \rangle$ where \mathcal{D} is a dynamical system, \mathcal{IC} is a collection of disjoint sets of states of \mathcal{D} , where we think of the sets as being the different information-carrying states, and the states in each set as the possible dynamical states that depict the same information-carrying state. \mathcal{F} is a collection of functions from \mathcal{D} to \mathcal{D} that respect the information-carrying states—i.e. $\forall f \in \mathcal{F}$, if $I, J \in \mathcal{IC}$ and $x, y \in I$ and $f(x) \in J$, then $f(y) \in J$ —and we think of the functions in \mathcal{F} as *information-preserving transformations*. In other words, the operations of the functions are such that if the state of the system changes according to one of the functions, then the system contains the same information. The orbits⁷ of the functions in \mathcal{F} define an equivalence class on \mathcal{IC} and thereby on the states of \mathcal{D} . We call the elements of the class the informational states of the medium. We think of the informational states as the possible different kinds of information that the medium may contain.⁸

A function $f : \mathcal{D} \rightarrow \mathcal{D}$ on the dynamical system that respects the information-carrying states for a medium \mathcal{M} is called an *information processing* operation on the medium.⁹ The information preserving operation in the definition of an informational medium are examples of information processing operations. If an appropriate informational measure is provided, information processing operations can also be information reducing or information increasing (or both). Whether they are such depends on what information is contained by the information-

⁷An *orbit* of a function is a minimal subset of its domain closed under operations of the function. Intuitively, an orbit is the collection of points one can reach with the function from a fixed point. It is clear from this definition that the collection of orbits form an equivalence class on the domain.

⁸The notion of informational medium can be regarded as a special case of the formal notion of classification with a set of isomorphisms developed in Barwise and Seligman (1997), especially the classifications based on state spaces. The category theoretic framework of Barwise and Seligman is unnecessarily abstract for our purpose, where the goal is to isolate informational media from the dynamical interactions of systems within cognitive agents.

⁹Here the information processing operation is assumed to be deterministic — it determines uniquely how a state transforms into another. The definitions may be modified to allow probabilistic operations, where each operation defines a conditional probability distribution for each state to evolve into the others.

carrying states and how they are related. Because we assume that an informational medium is a dynamical system, it naturally evolves through time. If the natural evolution respects the information-carrying states, then we say that the medium has a *canonical information processing operation*. Many media are designed or selected exactly to take advantage of such canonical operations. For example, computer hardware is designed in such a way that its temporal dynamics respects the digital states of the memory, and facilitates the flow of computation — a special case of an information processing operation on the states of memory. Because an informational medium usually is a subsystem of a larger system, its evolution may depend on the state of other subsystems. If this is the case, the notion of *canonical information processing operation* may be extended to canonical *set* of information processing operations whose members are context dependent. This can be very useful in cases where one wants to control the processing operations a medium may engage in. A computer that interacts with an external system, e.g. user with a keyboard, defines such a set. If the operation is not the result of the natural, unintervened dynamical evolution, but is produced by an external intervention on the medium, we say that the processing operation is *external*.¹⁰ When a mathematician is performing sequential algebraic operation on a set of syntactics expressions, the operations are external information processing operations.

One example of a medium with information processing operations can be a system of logic with reasoning operations. The information-carrying states may be regarded to be sequences of well-founded formulae. Deductive operations can be regarded as information preserving operations of the medium; while, inductive operations maybe information reducing or information increasing operations.¹¹ Another example of an informational medium with processing operations can be considered a trained neural network. Setting the input nodes of the network can be regarded as setting the medium in a fixed dynamical/information-carrying state. The propagation of activation, (or relaxation of the network, if it is a more complex network) can be viewed as a

¹⁰Strictly speaking, every external operation may be interpreted as a member of the canonical set, if the different contexts are taken to be wide enough. But, for most purposes it is convenient to make such a distinction.

¹¹For example, enumerative induction or statistical syllogism, where one goes beyond the data, so to say, may be regarded as operations that increase the information of the system — in a sense, the uncertainty is reduced. An inference where the data is simplified because some outliers are regarded as erroneous, can be regarded as information reducing (filtering) operation. The same can be said when one utilize regression analysis, whereby a simplified model is extracted form the data.

sequence of applications of information processing operations. In many cases, it is convenient to think of these operations as canonical information preserving operations on the network, such that the dynamic of the network transforms the information in a form where the output nodes get fixed in a particular way based on the initial information set at the input nodes. Note that the operation of reading the output nodes is not a processing operation as it involves external to the network media.

If \mathcal{M}_1 and \mathcal{M}_2 are two media, a function $m : \mathcal{D}_1 \rightarrow \mathcal{D}_2$ from the dynamical states of one to the dynamical states of the other, that respects the information-carrying states, is called an *information management operation* between the two media. An information management operation can be information preserving, reducing, or increasing. The similar notions of *canonical (set of) information management operation(s)* and *external operations* can be also defined. It is possible (and interesting) to define management operations that jointly operate on several media simultaneously, however we will not concentrate on such operations here. Here are few examples of information management operations: Let one medium be the collection of diagrams of Euclidian geometry. A geometric problem can be solved by manipulation of the diagrams (together with other nondiagrammatic steps). Another medium, however, can be the collection of symbolic linear and quadratic equations. The same problem may be solved using analytic symbolic operations on the equations. A problem can be converted from diagrammatic form to analytic form. The transformations and associations involved in the conversion can be viewed as information management operations. Note that while there can be easy transformations between the diagrammatic and analytic media, the processing operations of the media are quite different, which allows the same problems to be solved with different levels of complexity and systematicity.¹² Often, as we shall see below, management operations are useful to reformulate the information in a medium that has a particular advantage in a given desirable property. Another example, this time more relevant to cognition, is the transformation of information from the visual system, where an object is identified in virtue of its visual features, to the language production system, where the object is identified via a word (a phonetic or letter representation). We can interpret the neural machinery that performs

¹²As a personal historical fact, it is the use of selected traformations between different meta-mathematical representation of a given problem, selected because of their capsity so simply sutain featur of a problem, that lead me to thinks about representaonal networks as mekanisms for problem solving. I generalised to informational networks when I realised that strategy is sentral for cogition in general.

the transformation as implementing an information management operation.

Finally, an *informational network* is a collection of informational media $\{\mathcal{M}_i\}_{i \in \alpha}$, each with a collection of processing operations $\{\mathcal{P}_i\}_{i \in \alpha}$, and with various information management operations defined among the media.¹³

2.2 Dual nature of informational media

An informational medium is, after all, just a dynamical subsystem of a larger system. As such, it is affected by other systems and it can affect other systems. Loosely, we can say that an informational medium participates in the causal happenings of its world. Every informational medium, thus, has a dual nature: it has informational nature, *qua* an informational medium, and it has causal/dynamical nature, *qua* an open dynamical system. The interesting question is related to how these two natures interact. Of course, the informational nature is facilitated by the dynamical base, but it is a separate question how the information contained and processed by the medium is effected and effect the causal/dynamical interactions of the medium. There are two important ways the informational and causal natures interact: (1) An external system S may be causally correlated with the medium in a way that the information-carrying states become correlated (possibly probabilistically) with some of the (possibly macroscopic) states of S . In this case one can think of S as the source of the information, and of the information as being, in a sense (not to be analyzed here), about S . We say that there exist an *informational connection* between the medium and S .¹⁴ (2) An external system C may be effected by the medium in a way that it is coordinated with the information contained by the medium. For many informational states there may be particular dynamical states that have appropriate causal effects on C . For example, the informational states may control the movement of the head of a printer. Ultimately, as it was suggested in the introduction, it is this kind of systematic participation of the medium in the causal/dynamical world- coupling with other systems, and utilizing that coupling for external control-that make the notion of information both available and theoretically useful.

¹³A more accurate name would be informational media network, however, the name is unnecessarily long.

¹⁴If S is itself a medium, the connection may define a management operation. S , however, need not be a medium.

2.3 Characteristics of informational media

The dual nature of informational media and the roles they can play in an informational network provide several dimensions of properties of the media. A medium can be evaluated according to: (1) its ability to enter in an appropriate and sufficiently rich informational connection with a source; (2) its ability to have desirable causal consequences; (3) its ability to contain detailed information; (4) its ability to process the information appropriately; (5) its ability to enter in appropriate management operations (5a) from it, and (5b) to it. Different media may excel in only some of these dimensions. Some media may be good at coordinating naturally with an informational source (let us call these *sensing* media), however, they may not be able to process the information appropriately (*computing* media), or be able to utilize it well (*active* media). Other media may excel at processing or utilization. In order for a control system to act well, it may need to (e.g.) convert the information, *via* some sequence of management operations, to a computing and then to an active medium. What if the sensing and the computing media do not share the same “language”, i.e. there is no direct information management operation from one to the other? There may need to be a translator or transducer of some sort in between-a medium that is good at communicating with both (or more in between). This is only a small sample of possible roles for a medium within an informational network. The notion of informational network is interesting, especially for cognition, exactly because it allows us to model integration and coordination of skill specific systems that can accomplish a complex task *via* a distributed effort. We examine the application of informational networks to cognitive systems next.

3 Cognitive Systems as Informational Networks

All cognitive agents are, essentially, informational networks whose organization and dynamical interaction with the environment facilitates various informational media to be coordinated with some informational sources in the environment, these media (in the simplest case, the sensory surface) participate in various processing operations, management operations with other (internal) media, and causal effects that, in the course of the natural dynamics of the systems, produce the agent’s behavior. The complexities of cognition are the complexities and intricacies of the informational network and its utilization (including, in more advance systems, utilization that modifies the informational properties of the

media, or even generates novel media and integrates them into the network).

3.1 Finding the right candidate for the job

Viewing a cognitive system as an informational network puts upfront the idea that cognition is achieved by careful integration of dynamical systems with various and varied skills. Historically, theoretical approaches to cognition have attempted to propose unified, single medium architectural frameworks. The information network approach instead allows for many distinct, multiskilled media. Instead of searching for the one super job candidate to implement all cognitive capacities, it searches (or allows the search for) a carefully tuned collection of limited skill candidates that can work together. A significant part of the approach consists of characterizing the various general job descriptions that media may need to fill in the network of an active cognitive agent.

3.1.1 Informational connection with a source

It is important that the human eye has 105 million photoreceptors to be able to channel information about the world; if it had 1000 it would have been a poor medium. Floppy disks are getting obsolete because the limit they place on size of the files is unacceptable for many modern applications of files. Information carrying potential is useless unless it can be connected to the appropriate source. The eyes work well as eyes because they contain photoreceptors. The medium of photoreceptors works as an information medium on its location because it is naturally sensitive to the mechanism that transmits information from the external objects.

In some cases however, a medium is too valuable for other reasons to be scraped simply because it does not connect to the source naturally, i.e. as a result of the underlying dynamics of the system. If this is the case, one has a natural solution: one needs an intermediary medium to “translate” the information. The brain works primarily with the transmission of electric signals. Whatever the eye does, it better spit electric signals. The photoreceptors, unfortunately, cannot fire action potential. Due to their unique ability, they are forgiven if they spit something else—they spit (less) glutamate. The compromise is: add an intermediary level—something that can read glutamate and translate into action potentials. This is what happens in the eye. The translation is performed by the bipolar and ganglion (and other) cells.

Some media are easier to accommodate than others. Some are very adapted to particular informational structure; others are capable of carrying more generic information. Some media always need an intermediary to engage in an informational connection. Such media are flexible as to what informational connections they enter. They are *content flexible*. Computer files, for example, are flexible in this sense: files can be associated with an unlimited collection of sources. Symbolic media in general are examples of content flexible media.

3.1.2 Information processing skills

Some media can do a lot with the information that they contain and others can merely hold it. Some media are very efficient at what they do, others take a lot of time and effort to do simple things. A universal Turing machine is extremely good at doing many things with its states. It is a medium that specializes in processing. A file, on the other hand, cannot do anything; it only stores information.

Even though a universal Turing machine can do a lot, it does it extremely inefficiently. A fairly simple processing task can take enormous number of transformations. A neural network, on the other hand, processes information very efficiently—often, independently of the complexity of the input. It, however, can do only one task.

Processing power and efficiency are not the only characteristics of an information processing system. These characteristics deal with what happens when everything is right, when the medium has gotten “good information”, so to speak. A cognitive system must be able to work in less than perfect conditions. Processing is not valuable by itself. It is valuable because it allows the appropriate utilization of the medium. Can the medium maintain utilizability in less than perfect conditions? Often symbolic media can be extremely sensitive to small modifications to the input (unless the systems incorporates sufficient redundancy in the informational states; this is what happens with natural language). A deductive system usually fails completely if the input is modified. Such systems exhibit extremely low *rigidity*. Some media, on the other hand, can obtain partial success (and even recover) when the input is incomplete or vague. Neural networks, for example, are capable of working with incomplete inputs and obtain reasonable results. They exhibit *graceful degradation*. It is clear that for situated cognitive agents media exhibiting graceful degradation would be invaluable.

3.1.3 Informational/Causal coordination skills

Real cognitive agents need to do stuff with the information they gather—the informational network must facilitate effective actions. Somewhere along the information path there must be places where “words turn into action”. Whether it is turning bits into movement of the printer head, or moving a muscle, somewhere a medium coordinates the informational state with a cause. Every informational control system requires media that are especially formulated to interact with the system that is controlled in purely dynamical term—active media.

Media that connect information to causes are least free in their design parameters. They place the strongest constraints on the design of the informational network. Everything else is an adaptation to allow these media to be serviceable via the manipulation of the information. It is these media that, ultimately, shape the structure of the informational states within the entire system.

Some media, however, especially some that *we* operate with, appear not to be rigidly connected to the causal effects that they portray to have. When we think about actions, for example, it seems as if the very content of the thought is the causal consequence of the medium entertaining the “thought”. Clearly, having media that have the capacity to process information related to the causal consequence of the informational network is not the same thing as engaging in the action itself—there is a difference between an action and a “representation” of an action. Nevertheless, the fact that it is possible for the system to regard actions as processable informational states and then materialize them—i.e. generate causal consequences that are results (in part) of informational state that track the very consequences—suggest the existence of media that can be flexibly utilizable. It would be a mistake to think that such flexibly utilizable media are themselves the media, *qua* dynamical systems, that coordinate the information with the causal consequences. The flexibly utilizable media are not media that can *do* many things. Instead, they are media that, in virtue of their position in the informational network, can be coordinated flexibly to the informational states of various active media.

3.1.4 Information management skills

Media can have one of two uses (or both): they can be used as active media, or they can be used as sources of information. If a medium is not active, its role must be to make information available to other media—to engage in management transformations, and also sometimes to act as a novel source.

Management is a form of informational coordination between media that usually depends on the nature of the global dynamical system within which the network is implemented. Thus, in order for the information of one medium to become available to another, the first must be able to enter in the correct dynamical states that affect the appropriate informational state of the second, receiver medium. If a receiver medium is only sensitive to light, the source may shout all it wants, it will not be able to communicate with the receiver. It would be a design requirement for any medium that must communicate with the receiver that it must be able to enter in dynamical states that emits or reflect light in the appropriate form.

Management transformations don't serve only to transfer "message" between media. The dynamics that facilitates the informational connection may "modify" the information. It may introduce selective loss of information in order to simplify the work of successive media or to improve the coordination to a remote source by eliminating unnecessary complexity or noise introduced by the intermediary media. It may also increase the complexity of the informational states in a productive way, etc. All of these capacities of management transformations require the appropriate involvement of the participating media. The media must be able to provide the information in the appropriate way that the transformations do their job correctly.

Similar to processing, management operations must be evaluated according to how rigid the connection is. This is especially important, for example, in coding schemata. Media acting as intermediary between other media often can be described as coders or decoders. We can think of the structure of the coding system as the capacity of the medium to engage in management. An important necessary component of that capacity is the code to be "understandable" by the receiver, but there are other important characteristics of the coding systems. One is how sensitive the code is to noise—random modifications introduced by the transformation. Noise is overcome by introduction of redundancy in the coding system. Some of the most important results of Information Theory relate to such problems. We can view the existence of a coding system with a particular type of redundancy mechanism as a property of the medium to engage in management transformations with certain level of rigidity.

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