Weaver's Model of Communication and its Implications

I. Fallacies in the Usages of Information and Communication

The most common usages of the terms "information" and "communication" are not applicable with objective validity when the object of discourse is the mind-brain system. Neither can these terms be validly employed in the description of biological objects except in a very specific and limited context. Over the past several years some writers have adopted some very careless habits of misusing these terms in ways that promote ontological fallacies and misguided metaphors. Softening the meaning of technical terms used in any science damages the science, and persistent misusages over time tend to render the words we use to explain Nature meaningless.

All sciences adopt common words found in everyday use and put them to some more specific use within the contexts of the sciences in question. A great deal of the time expended in a science education is devoted to teaching and learning the special and limited contexts of the technical vocabulary of the science. It is not a misleading metaphor to say that a student in one of the special sciences a learns a new language that to people outside his chosen field of study is nothing else than a foreign language. The inability of many scientists to be able to meaningfully communicate with laypersons is due in large part to this. When a technical word is highly abstract to begin with yet is also a word in the common vocabulary of society, the potential for serious misunderstandings and even mischief is great. Such is the case with "information" and "communication" as these terms are used and misused in psychology, neuroscience, and biology. Let us examine this.

The common dictionary definitions of the noun "information" derive from the verb "inform." There are three primary usages of this word in English:

> **inform**, *v.t.* [M.E. *informen*; OFr. *enformer*; L. *informare*, to shape, fashion, represent, instruct; *in*, in, and *formare*, to form, from *forma*, form, shape.]
>
> 1. (a) to give form or character to; to be the formative principle of; (b) to give, imbue, or inspire with some specific quality or character; to animate.
> 2. to form or shape (the mind); to teach. [Rare.]
> 3. to give knowledge of something to; to tell; to acquaint with a fact, etc.
>
> **syn. –** acquaint, apprise, instruct, notify, tell, teach, enlighten.

As one might guess from the list of synonyms, the most common usages of "inform" take their context from definition (3) and, to a lesser extent, from definition (2). Neither of these contexts, however, are objectively valid in neuroscience or biology and have only a sharply limited valid context in psychology. Definition (1), particularly (1a), is the only context having scientific validity for mind-brain theory, for neuroscience, for biology, and for much of psychology. Now consider the word "information":

> **information**, *n.* [OFr. *information*; L. *informatio* (*-onis*), a representation, an outline, sketch, from *informare*, to give to, to represent, to inform.]
>
> 1. an informing or being informed; especially, a telling or being told something.
> 2. something told; news; intelligence; word.
> 3. knowledge acquired in any manner; facts; data; learning; lore.
> 4. a person or agency answering questions as a service to others.
> 5. in law, an accusation of a criminal offense, not by indictment of a grand jury but by a public officer such as a prosecutor.
>
> **syn. –** intelligence, notice, advice, counsel, instruction, news.

None of these definitions are objectively valid for neuroscience, biology, or mind-brain theory.

The root meaning of "information" in English is tied to the idea of representation, and this term, within the contexts relevant to these sciences, denotes an *epistemological* primitive having a very tightly restricted *Realdefinition*. It is worth noting that while *information* is an entirely appropriate English translation of *informatio*, a *precise* English rendering from Latin grammar would mean *informing*, just as the noun *hunting* (L. *venatio*) is defined from *to hunt* (*venor*, *-ari*) an denotes an action *as in process*. The key point here is the context of information as one that involves a minimum of two people, who we will here call the ***informer*** and the ***informee***.

It is this context that invalidates the word in neuroscience usages. Furthermore, the term as defined above is invalid for biology because the objects of biology (molecules, cells, etc.) cannot *in any objectively valid way* be said to "know something." The very popular phrase "DNA information" is misused in such a way as to suggest that a cell's DNA in some mysterious manner "informs the cell" how to develop or behave. A scientist who understands DNA molecules might know how a cell will develop or behave, but this information (in the context of definition 1 above) is in the *mind of the scientist*, not a fictitious "mind of the cell." Even in this context, the scientist will not understand how to interpret the appearance of a strand of DNA unless he has first learned DNA theory. To say a *cell* "has DNA information" as some kind of inner quality or property of the cell *qua* cell is vitalism – nothing more and nothing less. A scientist should never say, "the DNA tells me such-and-such"; he should say "I infer such-and-such based on the DNA structure of the cell." *The* DNA *qua* molecule *tells* him *nothing*.

The current fallacies in the scientific usages of "information" in biology and neuroscience stem from a false ontology known as the mind-body division. This is Descartes' error, *viz*. the regarding of mind and body as two different *real* substances (*res cogitans* and *res extensa*). The metaphysical fallacy has long been recognized, and modern empirical science is attempting to deal with it by reductionism: "mind is not a thing; it is an emergent property of brain and a mere epiphenomenon." But this *also* posits a real division between mind and body and then declares the former to be not-objectively-real after all. It takes a high degree of training to effect this sort of delusional hypnosis in scientific habits of thinking. However much a scientist may contemn the idea of mind when it comes to applying the term to other people, he does not really doubt the reality of *his own* mind. The seeming paradoxes that swirl around "the mind-body problem" all disappear as soon as one recognizes that the *actual empirical object* of neuroscience and psychology is the Organized Being (human being) *as a whole*, and that the division of science concepts into mind-concepts and body-concepts is nothing more than a convenient *logical and mathematical* division with no *ontological* import whatsoever. Mind and body are not physical concepts; they are mathematical concepts. Critical epistemology teaches us this (Wells, 2006), and the theory of mental physics is based in part on this recognition (Wells, 2009).

Once the idea of information gains a foothold in neuroscience, biology and psychology, it is quite natural that ideas from the discipline of communication theory should likewise become incorporated into the lexicons of these sciences. It is not the contention of this paper that either information or communication should be banned as legitimate concepts by these sciences; quite the contrary. It *is* the contention of this paper that we should know what we're talking about and use these concepts with precision and objective validity for the sciences' contexts. With that in mind, let us review the common dictionary definitions of the word *communication* and its associated verb, *communicate*:

> **communicate**, *v.t.* [L. *communicatus*, pp. of *communicare*, to impart, share, from *communis*, common.]
>
> 1. to impart to another or others; to make known, generally something intangible; as, to *communicate* the news.
> 2. to share in or participate. [Obs.]
> 3. to administer to the sacraments of the church.

syn. – reveal, disclose, divulge, impart, announce, publish, promulgate.

communicate, *v.i.*

1. to share; to participate. [Obs.]
2. to have a connection or passage from one to another: said of things and generally followed by *with*.
3. to have or hold intercourse or exchange of thoughts; to give and receive information, signals, or messages in any way.
4. to partake of the Lord's Supper; to receive Holy Communion.

communication, *n*. [Fr. *communication*; L. *communicatio*, to communicate, share.]

1. the act of imparting, conferring, or delivering from one to another; *as*, *communication* of knowledge.
2. intercourse by words, letters, or messages; interchange of thoughts or opinions by conference or other means.
3. the science and art of communicating.
4. means of communicating; specifically, (a) connecting passage; means of passing from place to place; (b) [*pl*.] a system for sending and receiving messages.
5. that which is communicated or imparted; information or intelligence imparted by word or writing.
6. participation in the sacrament of the Lord's Supper. [Obs.]

If definition (1) of communication is employed in a sufficiently narrow context, namely that of delivering something from one place to another, biology can validly employ "communication" as a technical term. Biologists must, however, be specific about what that "something" being delivered is, where its source originates, and where its destination is. Definition (4a) is the more accurate context. Language does not want for other words that mean the same thing as this, and it is unnecessary to set up conditions for a subsequent homonymous use of the word "communication" when other more specific terms are in no short supply.

We should also take note of the other terms, such as "message," "knowledge" and "information" used in the definitions above, as well as the absence of these connotations in definitions (1) and (4a) of communication. The *pragmatic* usefulness of employing concepts from mathematical communication theory (also known as information theory) in neuroscience, biology and psychology can hardly avoid importing these ideas into its structure. Indeed, a large part of the excitement over information theory in the 1950s and early 1960s was due in no small part to the expectation that this science would help to extend mankind's understanding of mind and brain. Today, half a century later, this expectation has largely gone unmet and interest in information theory, even in engineering education, has almost completely faded away in the United States. (It is a far different matter elsewhere in the world). I do not deny there is a great deal of pragmatic fecundity awaiting the proper mating of mathematical communication theory and biology; quite the contrary. I do propose that the failure to realize this potential is due to inattentiveness in regard to *how* to use it. The brain is not a telegraph network and metaphors like this one are of utterly no use to neuroscience. Yet recent years have witnessed attempts to apply information theory to brain theory that are carried out by means that are nothing else than the employment of this sort of metaphor or simile. It is little wonder that the National Institutes of Health in the U.S. have scant interest in information-theory-based research programs.

II. The Weaver Model of Communications Problems

It is instructive to review the roots of modern mathematical communication theory as developed at the end of the 1940s by Claude Shannon. Such a review informs us much more than

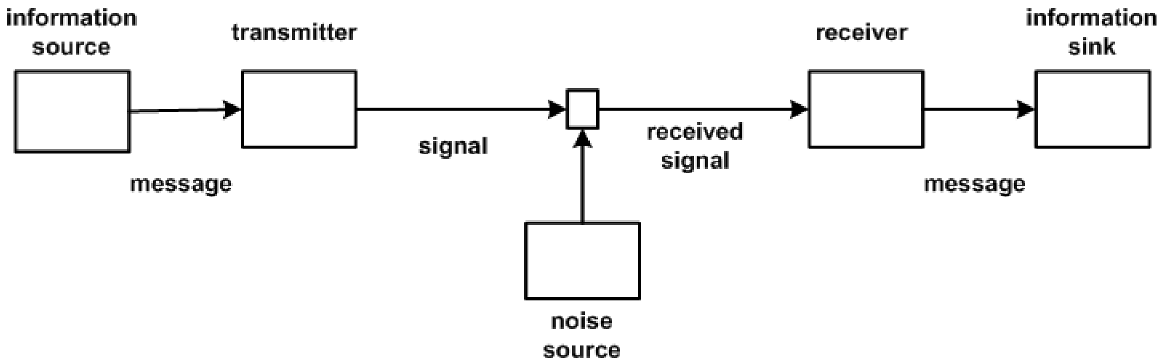

Figure 1: Shannon's model of the fundamental communication system.

merely about the mathematical formalism of the doctrine or the useful insights that have been developed in its typical applications. It tells us about the underlying paradigm or model upon which the theory was originally raised and clarifies important specifying concepts that delimited its methodology and its application. In the case of the mathematical theory of communication in general, and information theory in particular, the baseline model for all that followed afterwards is the model depicted in figure 1, Shannon's model of the fundamental communication system. The reader not versed in communication or information theory should take a close look at this figure right now – not with the intent to understand it at once but, rather, *with the intent to become cognizant of which ideas depicted in it you do* ***not*** *presently understand* ***in detail***. What, for example, does "message" mean in this figure? What is a "message" *in general*? The word as used here is a technical one and its concept is abstract. To say, "A telegram is a message" tells you something about what a telegram is; it doesn't tell you what a message is[1].

Knowing the history of a science is often crucial for productive research. Historical knowledge of a science helps one to shape and develop scientific methodologies [Wells (2011a)]. This is not at all a fresh realization. John R. Pierce, formerly of Bell Telephone Laboratories and Professor of Engineering at the California Institute of Technology, wrote

> Men have been at odds concerning the value of history. . . I will . . . maintain that we can learn at least two things from the history of science.
>
> One of these is that many of the most general and powerful discoveries of science have arisen, not through the study of phenomena as they occur in nature, but, rather, through the study of phenomena in man-made devices, in products of technology, if you will. This is because the phenomena in man's machines are simplified and ordered in comparison with those occurring naturally, and it is these simplified phenomena that man understands most easily. . .
>
> The second thing history can teach us is with what difficulty understanding is won. Today, Newton's laws of motion seem simple and almost inevitable, yet there was a day when they were undreamed of, a day when brilliant men had the oddest notions about motion. Even discoverers themselves sometimes seem incredibly dense as well as inexplicably wonderful. . .
>
> Thus, a study of the origins of scientific ideas can help us to value understanding more highly for its having been so dearly won. We can often see men of an earlier day stumbling

[1] If you are a well-trained engineer and feeling a little bit smug about this example, here's another version of the same class of questions just for you: What is *mass* in physics? Here's a hint: it does *not* mean "weight" nor does it mean "quantity of matter." If you define it as either of these then there are problems in physics for which your solution will be wrong and your design will be gainsaid by experiment. You won't know in advance what problems these will be, either.

> along the edge of discovery but unable to take the final step. Sometimes we are tempted to take it for them and to say, because they stated many of the required concepts in juxtaposition, that they must really have reached the general conclusion. This, alas, is the same trap into which many an ungrateful fellow falls in his own life. When someone actually solves a problem that he merely has had ideas about, he believes that he understood the matter all along.
>
> Properly understood, then, the origins of an idea can help to show what its real content is; what the degree of understanding was before the idea came along and how unity and clarity have been attained. But to attain such understanding we must trace the actual course of discovery, not some course we feel discovery should or could have been taken, and we must see problems (if we can) as the men of the past saw them, not as we see them today. [Pierce (1979), pp. 19-21]

Another lesson history teaches quite clearly is that while many of the most important advances in science were the products of exporting knowledge from one discipline to apply it in another, the practice of science has exhibited a pronounced bias to move from interdisciplinarity to narrow specialization under the ancient Greek prejudice that only by specialization would the key to unlock all the benefits of science be found. History reveals that over time the specialties become more and more narrow, the specialist "schools" become unable to communicate their fecund ideas to members of different "schools" or specialties, and, like one of Toynbee's civilizations, the general scientific enterprise eventually collapses and disintegrates. We call the periods of interregnum "dark ages" and tend to think these are a thing of the past merely because we haven't seen one take place in the physical sciences from the 17th century until today. Or, at least, we haven't recognized one *taking place* – however incongruous this attitude is when stood next to the rather amazing fact that many present day Americans believe in witchcraft, demonic possession and ghosts. When, precisely, did flying saucers, ghost stories, or the alleged prophesies of ancient Mayans or Nostradamus become fit fare for television shows that claim to be about science? But neither did the ancients recognize the disintegration of their civilizations when these were in progress. That recognition came from their impoverished descendents.

One of the clearest examples of repetitive cycles in the rise and fall of science is presented by the oldest of the sciences in the historical record: philosophy. Few people today recognize philosophy as a science. Most educated people might admit that it began as not only a science but as, at least in intent, the *prime* science. Most of these people might also be inclined to add, "Well, it was a nice idea but in the end it proved to be a *failed* science, just like astrology." Certainly philosophy has not been particularly fecund for the natural sciences lately[2] and for a long time. But to presume it can never become so is rather, to put it bluntly, presumptuous. Never is a long time. Still, the fact remains that philosophy has undergone many cycles in which it rose to peak heights before collapsing back into its own interludes of darkness. This regular historical cycle in philosophy is so prominent that noted philosopher C.E.M. Joad once warned prospective students of philosophy,

> It is usual to introduce a book on philosophy intended for the general reader with some account of the subject matter of philosophy, the nature of its results and the methods which it pursues. The reader is told that he will not be made free of any definite and agreed body of knowledge; he is warned that philosophers frequently do not even discuss the same questions and that, when they do, it is only to give diametrically opposite answers; and he is warned that he will be asked to take part not in a steady and orderly advance from speculation to knowledge but in a series of marches and countermarches, in the course of which he will traverse and retraverse the same territory in the company of travelers whose concern seems less to arrive at a goal than to obliterate the footsteps of their predecessors.

[2] although it is worth noting that Isaac Newton regarded himself as a natural philosopher, not as a physicist.

> [Joad (1936), pg. 9]

By the beginning of the 1960s there was a high degree of enthusiasm for, and expectations of great things from, communication and information theory. Some of its pioneering developers helped to promote this. This was a time when hymns to the virtues of interdisciplinary science were being sung, although subsequent history shows that this turned out to be a faint voice crying out in a very large wilderness. Most of these enthusiastic visions quickly faded in the decade that followed, lost in a stampede of disciplinary successes. Nonetheless there was one still-unfulfilled vision that has lost none of its pertinence for neuroscience, for psychology, or for the engineering field of computational intelligence. This was a vision for a broader definition of communication – which is to say, the mathematical theory of communication, i.e., information theory – espoused in 1948 by information theory pioneer Warren Weaver. Weaver wrote,

> Relative to the broad subject of communication, there seem to be problems at three levels. Thus it seems reasonable to ask, serially:
>
> LEVEL A. How accurately can the symbols of communication be transmitted? (The technical problem.)
>
> LEVEL B. How precisely do the transmitted symbols convey the desired meaning? (The semantic problem.)
>
> LEVEL C. How effectively does the received meaning affect conduct in the desired way? (The effectiveness problem.)
>
> The *technical problems* are concerned with the accuracy of transference from sender to receiver of sets of symbols (written speech), or of a continuously varying signal (telephonic or radio transmission of voice or music), or of a continuously varying two-dimensional pattern (television), etc. . .
>
> The *semantic problems* are concerned with the identity, or satisfactorily close approximation, in the interpretation of meaning by the receiver, as compared with the intended meaning of the sender. This is a very deep and involved situation, even when one deals only with the relatively simpler problems of communicating through speech. . .
>
> The *effectiveness problems* are concerned with the success with which the meaning conveyed to the receiver leads to the desired conduct on his part. It may seem at first glance undesirably narrow to imply that the purpose of all communication is to influence the conduct of the receiver. But with any reasonably broad definition of conduct, it is clear that communication either affects conduct or is without any discernible and probable effect at all.
>
> The problem of effectiveness involves aesthetic considerations in the case of the fine arts. In the case of speech, written or oral, it involves considerations which range all the way from the mere mechanics of style, through all the psychological and emotional aspects of propaganda theory, to those value judgments which are necessary to give useful meaning to the words "success" and "desired" in the opening sentence of this section on effectiveness.
>
> The effectiveness problem is closely interrelated with the semantic problem, and overlaps it in a rather vague way; and there is in fact overlap between all the suggested categories of problems.
>
> So stated, one would be inclined to think that Level A is a relatively superficial one, involving only the engineering details of good design of a communication system; while B and C seem to contain most if not all of the philosophical content of the general problem of communication.
>
> The mathematical theory of the engineering aspects of communication, as developed by Claude Shannon at the Bell Telephone Laboratories, admittedly applies in the first instance only to problem A, namely, the technical problems of the accuracy of transference of

various types of signals from sender to receiver. But the theory has, I think, a deep significance which proves that the preceding paragraph is seriously inaccurate. . . But a larger part of the significance comes from the fact that the analysis of Level A discloses that this level overlaps the other levels more than one could possibly naively suspect. Thus the theory of Level A is, at least to a significant degree, also a theory of levels B and C. [Shannon and Weaver (1949), pp. 4-6]

Weaver went on to briefly sketch out, verbally, his conception of a more general context for the communication problem [*ibid.*, pp. 24-28]. Figure 2 provides an illustration of Weaver's model. Weaver began with Shannon's model and replaced Shannon's non-specific information source and sink with what can be called a zeroth-order psychological model of an informer and an informee. The information source (in both models) is regarded as an abstract set of possible messages from which one *intended* message is selected and emitted. The intended message is modified by what Weaver called *semantic noise*, which he described as "perturbations or distortions of meaning which are not intended by the source but which inescapably affect the destination" (informee) [*ibid.*, pg. 26]. The information sink becomes an informee in Weaver's model by the addition of what he called a *semantic receiver* which "subjects the message to a second decoding, the demand on this one being that it must match the statistical semantic characteristics of the message to the statistical semantic capacities of . . . receivers which constitute the audience one wishes to affect" [*ibid.*]. The transmitter, noise and receiver functions in Shannon's model are retained unaltered and merely re-designated as *engineering* transmitter, etc. in order to specifically denote that these functions represent the man-made instruments of communication and distorting properties of the physical communication medium.

Weaver was vague in his descriptions of the information source and sink functions in figure 2, but it is not difficult to analyze his descriptions to produce the sub-models shown in figure 3. The

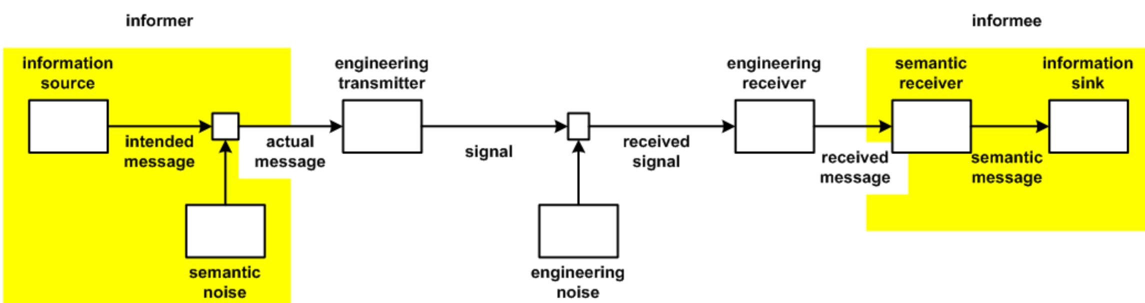

Figure 2: Weaver's model of the general communication problem.

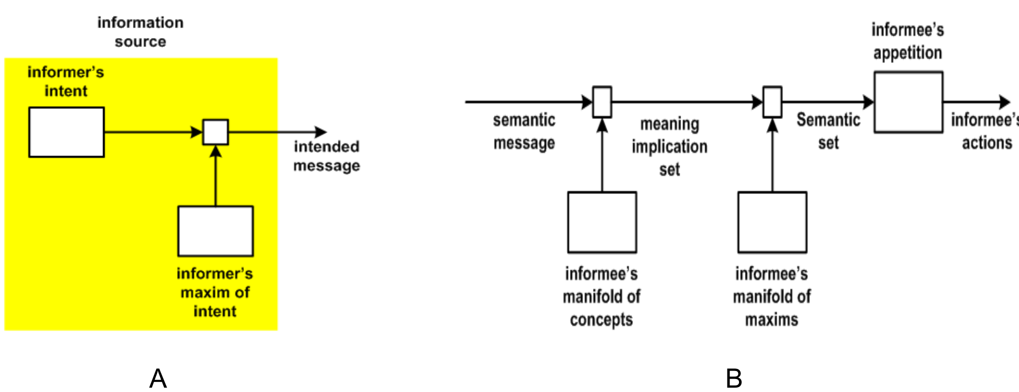

Figure 3: Details of Weaver's information source (A) and sink (B).

two illustrations there describe the information source (A) and sink (B) in terms of the informer's intentions for his message and the informee's interpretation of and response to the received message (B). That Weaver intended such a psychological interpretation is clearly evident in his paper. The *informer's intent* (figure 3-A) denotes a set of possible message intentions the informer could form. The informer's *maxim of intent* represents the psychological factors that determine his *choice* of the specific intended message.

As for the informee information sink, in order for a semantic message to be regarded *as* semantic (that is, for it to have a relationship to meanings), the informee must first of all be capable of understanding it. This capacity is denoted in figure 3-B by the informee's *manifold of concepts*. The manifold of concepts function operates on the semantic message to produce a set of *meaning implications* [Piaget and Garcia (1987), pp. 160-163]. The work of Piaget, Garcia and their colleagues has shown that at root all meanings are practical, i.e. are in relationship to actions that result due to representation said to "carry a meaning." This set of meaning implications must then be operated on by an informee capacity for translating meaning implications into specific possible actions. This function is denoted as the *manifold of maxims* in figure 3-B. The transformation produces a *Semantic set*. Here the term *S*emantic (capitalized) denotes the object (generally a possible action) of a meaning implicated by the informee's interpretation of the semantic message. The technical term "Semantic" corresponds to the Greek noun *sēmasia* (meaning; importance). The Semantic set represents a set of action-options the informee will choose from in determining the action he takes in response to the received message. This choice operation is denoted by the *informee's appetition* function in figure 3-B.

III. Implications and Shortcomings of the Weaver Model

Weaver's model is an interesting proposal for a possible systematic approach to tying the basic mathematical rudiments of information theory to a broader class of psycho-semantic phenomena. Whether or not this approach will prove fecund remains untested because in the more than half-century since he proposed it, it has not received very much serious attention or development. The model does not propose any modifications to Shannon's theory (which is itself taken as a pre-supposition of the model), but seeks to extend the reach of that theory from the engineering aspects of mathematical communication theory into the domains of psychology and semantics.

It is because Shannon's theory is taken as a starting point that Weaver's model proposes a statistical approach to the problems of semantics rather than an approach based upon a conventional theory of mathematical semantics such as represented, e.g., by the work of Tarski (Tarski 1934, 1934-5, 1935, 1936a, b; Łukasiewicz and Tarski 1930). There seems to be little room to doubt that a primary factor in Weaver's presupposition is that without it there is no clear way to link semantics and "effectiveness" to information theory. However, this pragmatic aspect is not isolated from broader considerations arising from the then-new theory of automata and work that was going on in that field at that same time by von Neumann. Von Neumann said,

> There exists today a very elaborate system of formal logic, and, specifically, of logic as applied to mathematics. This is a discipline with many good sides, but also with certain serious weaknesses. . . [Formal] logic is, by the nature of its approach, cut off from the best cultivated portions of mathematics, and forced onto the most difficult part of the mathematical terrain, into combinatorics.
>
> The theory of automata . . . is certainly a chapter in formal logic. It would, therefore, seem that it will have to share this unattractive property of formal logic. . . Now it seems to me that this will in fact not be the case. In studying the functioning of automata, it is clearly necessary to pay attention to a circumstance which has never before made its appearance in formal logic. . . In the case of automata the thing that matters is not only whether it can reach a certain result in a finite number of steps at all but also how many such steps are

> needed. There are two reasons. First, automata are constructed in order to reach certain results in certain pre-assigned durations, or at least in pre-assigned orders of magnitude of duration. Second, the componentry employed has on every individual operation a small but nevertheless non-zero probability of failing. In a sufficiently long chain of operations the cumulative effect of these individual probabilities of failure may (if unchecked) reach the order of magnitude of unity – at which point it produces, in effect, complete unreliability.
>
> . . . Thus the logic of automata will differ from the present system of formal logic in two relevant respects.
>
> 1. The actual length of "chains of reasoning," that is, of the chains of operations, will have to be considered.
>
> 2. The operations of logic (syllogisms, conjunctions, disjunctions, negations, etc., that is, in the terminology that is customary for automata, various forms of gating, coincidence, anti-coincidence, blocking, etc., actions) will all have to be treated by procedures which allow exceptions (malfunctions) with low but non-zero probabilities. All of this will lead to theories which are much less rigidly of an all-or-none nature than past and present formal logic. . . In fact, there are numerous indications to make us believe that this new system of formal logic will move closer to another discipline which has been little linked in the past with logic. This is thermodynamics, primarily in the form it was received from Boltzmann, and is that part of theoretical physics which comes nearest in some of its aspects to manipulating and measuring information. . .
>
> All of this re-emphasizes the conclusion that was indicated earlier, that a detailed, highly mathematical, and more specifically analytical theory of automata and of information is needed. We possess only the first indications of such a theory at present. [Neumann (1948)]

Some considerable progress has been made since 1948 in the general direction of von Neumann's vision. We see this, for example, in the expansion of the use of Markov process models, Bayesian network theory, set membership theory [Combettes (1993); Combettes and Trussell (1991)] and in the development of fuzzy system theory and neuro-fuzzy computing theory [Jang, *et. al* (1997)]. However, it would be too much to claim that von Neumann's proposed new system of probabilistic logic has now been attained or that the unification of such a doctrine with a semantic-intentional extension of information theory as proposed by Weaver has seen much real progress at all.

In regard to the latter, there are some important fundamental problems that inhere in the basic paradigms of both Weaver and von Neumann insofar as extending the reach of information theory to take in human psychology and the mental physics of mind[3] is concerned. The first of these is due to the fact that the basic Shannon-Weaver model minimally involves the actions and reactions of two people, the informer and the informee. The context of these models is taken from the first usage of the verb communicate (to impart to another) and the third usage of the verb inform (to give knowledge of something to). Strictly, "information" is not "knowledge." As understood from Critical epistemology, knowledge is any conscious representation or capacity for making such a representation by or through which meanings are determined. Reber (2001) defines semantics as the study of meaning in any and all of its manifestations. Weaver is correct in introducing the semantic concepts shown in figure 2 into the model and to introduce the idea of meaning into levels B and C of the general communication problem. But by doing so, one introduces *specifying concepts* into the context of this general problem, and by doing so the undefined vagueness of the word "information" as this term is used in Shannon theory is made an issue. The mathematical theory uses "information" as an undefined primitive term, but in introducing ideas of meaning

[3] Mental physics is the science of the phenomenon of mind [Wells (2009)]. This term, as it is used in all the author's works, is not to be mistaken for having any relationship whatsoever to a cult of New Age hogwash headquartered in California that calls itself by this same name.

and semantics into the problem's scope, this scope is made extra-mathematical and its key notion, information, can then no longer be left in an abstract condition for which its only scope lies entirely within mathematical formalism. Weaver wrote,

> It was suggested that the mathematical theory of communication, as developed by Shannon, Wiener, and others, and particularly the more definitely engineering theory developed by Shannon, although ostensibly applicable only to Level A problems, actually is helpful and suggestive for the level B and C problems. . .
>
> The obvious first remark, and indeed the remark that carries the major burden of the argument, is that the mathematical theory is exceedingly general in its scope, fundamental in the problems it treats, and of classic simplicity and power in the results it reaches.
>
> This is a theory so general that one does not need to say what kinds of symbols are being considered – whether written letters or words, or musical notes, or spoken words, or symphonic music, or pictures. The theory is deep enough so that the relationships it reveals indiscriminately apply to all these and to others forms of communication. This means, of course, that the theory is sufficiently imaginatively motivated so that it is dealing with the real inner core of the communication problem – with those basic relationships which hold in general, no matter what special form the actual case may take. [Shannon and Weaver (1949), pp. 24-25]

Weaver is correct in these remarks, but only in one quite particular context and one quite particular point of view. It is true that Shannon *theory* is indifferent to what particular context or meaning a person attaches to the symbols that serve as its mathematical variables; these "make no difference" *to the theory*. It is, however, an entirely different matter when it comes to asking *whether or not the theory is applicable* with real meaning in the context of some one particular question. A theory is *applicable* if and only if it can be employed in the application to produce useful practical outcomes. If it *is* applicable then it does not matter what the symbols represent *insofar as these symbols are used within the mathematical operations of the theory*. But it *does* matter what the symbols represent when the question is, "Does the Shannon theory apply to this particular case?" Merely because abstract mathematics is protean in its many applications, this does not mean mathematics is a "theory of everything." Equations do not come with an owner's manual that says, "Use me here and here, but not over there." The decision about what sort of mathematic to employ rests with he who employs mathematics, and mathematics itself is, at its most practical roots, nothing more and nothing less than a *language* for saying things extremely precisely and in such a way that the consequences of what has been said can be deduced. This is almost the same as to say that mathematical concepts are subject to a semantic differential with activity, potency, and evaluative dimensions. Is Shannon theory (Level A) "actually helpful and suggestive for" level B and C problems? The answer will hinge on finding a precise *specifying concept* that *sets it within a context* in which it has *real* application to those issues.

Here is where information theory currently faces a real problem of its own, namely, *information theory does not know what information is*. The word is left an undefined primitive and the theory itself is devoted to such questions as "how does one measure the amount of information in a message?" A reasonable person would at once ask, "How do you know you are measuring this correctly and accurately if you do not know what you are measuring?"

Here the information theorist is forced to respond by mathematical fiat, and his attempts to explain to others what he means by "information" are comparable to attempts by jurists to define pornography. The problem is the same: how a *subjective* judgment is to be applied *objectively* and *generally*. Without claiming he had a definition for it, Weaver described "information" in the following words:

> The word *information*, in this theory, is used in a special sense that must not be confused

> with its ordinary usage. In particular, *information* must not be confused with meaning.
>
> In fact, two messages, one of which is heavily loaded with meaning and the other of which is pure nonsense, can be exactly equivalent, from the present viewpoint, as regards information. It is this, undoubtedly, that Shannon means when he says that "the semantic aspects of communication are irrelevant to the engineering aspects." But this does not mean the engineering aspects are necessarily irrelevant to the semantic aspects.
>
> To be sure, this word information in communication theory relates not so much to what you *do* say as to what you *could* say. That is, information is a measure of one's freedom of choice when one selects a message. . . The concept of information applies not to the individual messages . . . but rather to the situation as a whole. [*ibid*., pp. 8-9]

What determines "one's freedom of choice in selecting a message" involves psychological phenomena and processes of mental physics that the information theorist treats, in effect, as *uncontrolled factors* in the system model. The way he carries out this treatment is to posit that the uncontrolled factors exhibit their effects in manners describable by means of probability distributions. This treatment has no *ontological* import but is merely a mathematical trick for formulating a range for "what one *could* say." It is, in other words, an acceptable formal construct that functions *exclusively* as what Slepian called "a secondary quantity in a mathematical world" [Slepian (1976); Wells (2011a)]. If one tries to endow a probability distribution with ontological import, this is the same as to countenance miracles arising from acts of a "god of probability," and that is not science. What Weaver came to describe as "information" when he gave Shannon's mathematical definition is in fact only the name of a class of statistical functions employed in information theory, e.g. entropy, entropy rate, mutual information, &etc. [Wells (1999)]. He leaves the ontology of information *per se* merely a ghost in the machine. What he and many other information theorists call "information" would probably better be called the *informatic*[4].

A second caution, the importance of which rises to the level of an injunction, is to avoid the common ontological fallacy of regarding the symbols and represented messages of the system as *having* any meaning *in and of themselves*. In the context of figures 1 and 2, messages, and the symbols that compose them, are *data* representations and information theory draws a crisp distinction between data (the representation of information) and information (regarded as that-which-is-represented-by-data). This distinction is what, for example, makes various kinds of codes (data compression codes, modulation codes, error-correcting codes) possible and useful in engineered communication systems. An engineered communication system, properly designed, can tolerate *data* errors up to a point without the occurrence of an *information* error [Wells (1999)]. If a message or a symbol *had* meaning in and of itself, every *data* error in the received message (figure 2) would necessarily produce a *meaning* error in the informee's understanding of the message.

To carry out Weaver's proposed program for the extension of the application of information theory to what he called "the general communication problem," it is clear we must study what the linkages are (assuming that any can be made) between information theory and the broader topic of semantics-in-general. Here, though, we encounter another fundamental issue, namely, that there is no *general* theory of semantics. There are particular mathematical formalism, e.g. those of Tarski and others, and there are empirical linguistic hypotheses, e.g. theories of generative grammars and grammatical transformations [Chomsky (1965)], but there is no unified and systematic *natural* doctrine of semantics. The deeper obstacles to obtaining one seem to be little different, and perhaps ultimately no different, from those confronting the objectively valid *real* definition of information. Chomsky tells us,

[4] In English, the suffix –matic derives from the Greek *matenein*, to seek to do. An informatic is that which seeks to represent.

> The central fact to which any significant linguistic theory must address itself is this: a mature speaker can produce a new sentence of his language on the appropriate occasion, and other speakers can understand it immediately, though it is equally new to them. Most of our linguistic experience, both as speakers and hearers, is with new sentences. . .
>
> On the basis of a limited experience with the data of speech, each normal human has developed for himself a thorough competence in his native language. This competence can be represented, to an as yet undetermined extent, as a system of rules that we can call the *grammar* of his language. To each phonetically possible utterance . . . the grammar assigns a certain *structural description* that specifies the linguistic elements of which it is constituted and their structural relations (or, in the case of ambiguity, several such structural descriptions). . .
>
> The grammar, then, is a device that (in particular) specifies the infinite set of well-formed sentences and assigns to each of these one or more structural descriptions. Perhaps we should call such a device a generative grammar to distinguish it from descriptive statements that merely present the inventory of elements that appear in structural descriptions and their contextual variants.
>
> The generative grammar of a language should, ideally, contain a central *syntactic component* and two *interpretive components*, a *phonological component* and a *semantic component*. The syntactic component generates strings of minimal syntactically functioning elements [*formatives*] and specifies the categories, functions and structural interrelations of the formatives and systems of formatives. The phonological component converts a string of formatives of specified syntactic structure into a phonetic representation. The semantic component, correspondingly, assigns a semantic interpretation to an abstract structure generated by the syntactic component. Thus each of the two interpretive components maps a syntactically generated structure onto a "concrete" interpretation, in one case phonetic and in the other semantic. The grammar as a whole can thus be regarded as, ultimately, a device for pairing phonetically represented signals with semantic interpretations, this pairing being mediated through a system of abstract structures generated by the syntactic component. Thus the syntactic component must provide for each sentence (actually, for each interpretation of each sentence) a semantically interpretable deep structure and a phonetically interpretable surface structure, and, in the event these are distinct, a statement of the relation between these structures. . . Roughly speaking, it seems that this much structure is common to all theories of generative grammar, or is at least compatible with them. Beyond this loose and minimal specification, however, important differences emerge. [Chomsky (1964), pp. 7-10]

It takes very little reflection to recognize that Chomsky's "specifications" are specifications of a system for which its idea is contained within precisely the same context as Weaver's system of figure 2. In those cases where speaker and hearer are different people, the congruence of Chomsky's system and Weaver's system becomes apparent as soon as one replaces the label "engineering" in figure 2 with another term – perhaps "instrumental" – that generalizes the ideas represented in the engineering blocks of figure 2. It also provides a clue by which the degree of completeness of a science of Weaver's communication problem can be evaluated. It is this: a science that understands Weaver's general communication problem also understands Chomsky's linguistics problem.

Yet it is also soon made clear by additional reflection that the Weaver problem and the Chomsky problem are both special cases (species) of a more encompassing genus. This recognition stems from the fact that both system problems explicitly display an informer-informee/speaker-hearer division. Yet it is also commonly conceded that natural language is an important instrument in the human capacity for thinking and reasoning. Indeed, there was a long interval in human history when many renowned thinkers regarded thinking as nothing else than a "discourse one holds with oneself."

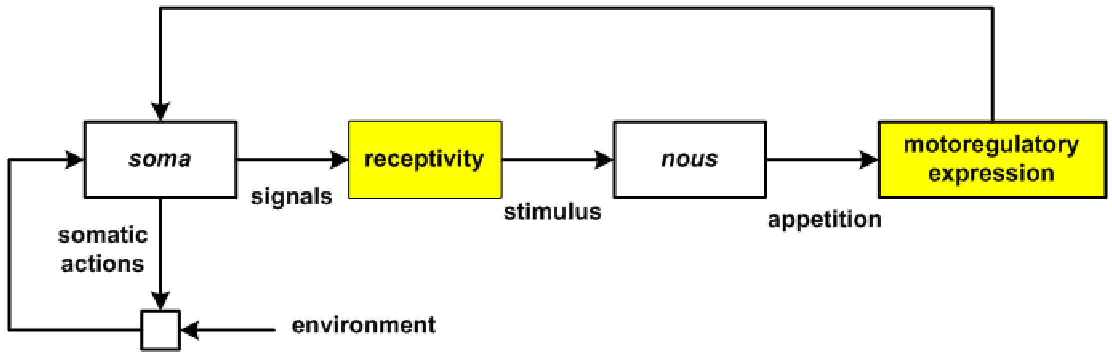

Figure 4: The *commercium* model of Organized Being.

This is, or at least should be, an objectively sufficient ground for us to conclude that the general context, of which Weaver's problem and Chomsky's problem are special cases, is none other than the context of *the experience of being a human being*. This, however, is the context with which the science of mental physics deals. Within this context there are further significances unearthed by exploration of Weaver's and Chomsky's theses.

IV. The *Commercium* Model of the Organized Being

In mental physics the model of the phenomenon of being a human being is called the Organized Being (OB) model [Wells (2009), chapter 1]. The point of connection between the OB model and the context of Weaver's general communication problem is made when we relax the informer-informee *ontological* distinction and regard informer-*function* and informee-*function* as two complementary functions within one and the same individual (one particular human being). When we do so, we obtain another model form, namely that illustrated by figure 4. This is called the *commercium* model of the Organized Being.

It was stated earlier that the mind-body division is nothing more than a logical (mathematical) division of the OB. These mathematical divisions are called *nous* (from the Greek word for mind) and *soma* (from the Greek word for body). Because the division of the OB into these logical parts is merely mathematical, the real unity of the OB *requires* a further third part to this division, and this logical division is called *psyche*. It is the logical faculty of *animating principles* of thorough-going reciprocity between those objects contained in the division of *nous* and those of *soma*. *Nous* and *soma* are explicitly depicted in figure 4, whereas *psyche* is represented in terms of its two main subdivision (receptivity and motoregulatory expression). Receptivity can be regarded as the functional structure of transformations that describe how effects in the corporeal body affect mind; motoregulatory expression is the complementary functional structure of transformations that describe how effects in *nous* (mental effects) affect the corporeal body (*soma*). In addition, the OB does not exist in isolation but, rather, is one object among other objects in Nature. This is represented by the *environment* in figure 4. The OB-environment division *is* a real division.

Weaver described the idea of effectiveness (Level C) in his model as "how effectively does the received meaning affect conduct in the desired way." This is quite obviously an explanation offered strictly from the viewpoint of the informer or, in the most abstract context, the viewpoint of a superobserver – a fictional artifact, regarded as endowed with the power to know all that is taking place in the informer-informee interaction, introduced by the model-maker himself and, often, represented in the person of the theoretician or model-maker. For this reason, what Weaver called effectiveness should strictly be called the *efficacy* of the informer's communicating. When informer and informee are one and the same person, however, the context of this efficacy is lost because the "informer's desires" and the "informee's desires" are always one and the same insofar

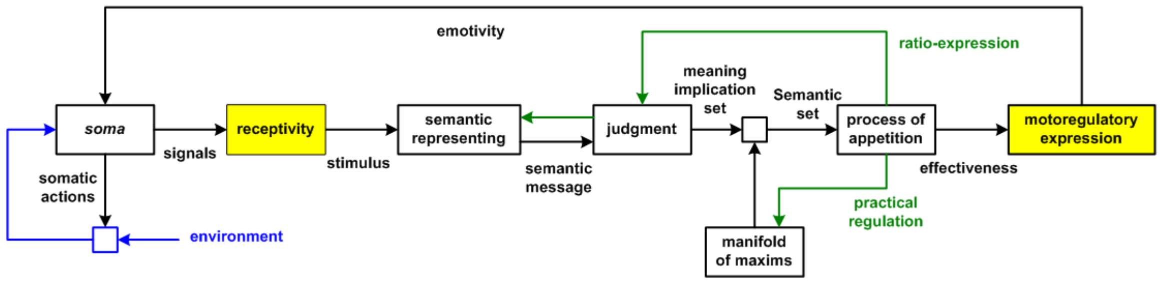

Figure 5: Weaver's problem when informer-function and informee-function reside in one OB. Blue lines/boxes denote environmental factors. Green pathways denote feedback processes. The yellow boxes denote transformations of the logical division of *psyche* in the OB model. The five inner processes denoted by black boxes belong to the logical division of *nous* in the OB model.

as the OB's *actual* conduct is concerned. The Level C problem then clearly requires a more general restatement, namely *how is participant(s) conduct determined globally in the system as a whole*? This restatement is not directly congruent with Weaver's statement, but this is only because that statement gave an arbitrarily preferential viewpoint to the informer. The restatement is consistent with the viewpoint of a superobserver and is made independent of the number of participating OBs in the *overall* system. Note that "effectiveness" *explicitly* appears *nowhere* in figure 2. The system depicted in that figure is explicitly open loop and any "closing of the loop" requires the addition of explicit augmenting constructs. The re-statement of Level C just proposed addresses this short-coming, either through the artifact of a superobserver or through the unity of the OB himself when only a single OB is involved.

When the ontological division between informer and informee (or speaker and hearer) is abolished and the informer-function and informee-function both reside within the same OB, some modification of Weaver's system (figure 2) is obviously required. It is not difficult, given the theory of mental physics, to see what form the modified system must take. Figure 5 illustrates the outcome of this analysis. Note that in this model the effectiveness factor appears explicitly. With this model, though, comes a requirement to re-orient how the communication problem must be regarded in a more general context. This is because the former context of "to communicate" has changed and definition (1) of the transitive verb "to communicate" is no longer appropriate. At best, this new context applies only in the sense of some "passage" or "connection" of information from one *logical* part of the system to another logical part (definition 2 of the intransitive verb). The context has become an *epistemological* rather than an ontological context.

Mathematically-minded theorists in neuroscience, psychology, cybernetics, computational intelligence and linguistics often maintain an *analogy* between their systems of interest and the systems of interest in communication engineering. Metaphorical thinking empowered by such an analogy often proves to be fecund for theory development and, provided one remembers he *is* making an analogy, there is nothing wrong with using this as an instrument to stimulate one's imagination. At the same time, however, it is also crucially important to clearly delimit the context within which the analogy can be employed and to mark the boundaries beyond which the analogy loses its objective validity. One of the most important of these boundary limitations is the clear recognition and cognizance of the fact that the model being developed or used is a denizen of Slepian's facet B, i.e., that it belongs to a mathematical world and not facet A, the physical world of appearances in Nature [Wells (2011a)]. Correspondence between facets A and B is established by means of associations between natural phenomena (the objects of experience in nature) and what Slepian termed the *principal quantities* of the mathematics of facet B.

In this regard, when the system involves only a single OB it is no longer strictly correct to use the word "communication" in describing how the OB's informer-informee actions affect itself. In particular, it is not objectively valid to say "mind communicates with body" or "body communicates with mind." To communicate, in the normal usages of that word, is to present or represent meanings, but "meaning" is entirely an object of the noetic division of the OB model. "The body" (*soma*) *understands* nothing, *knows* nothing, and for this division *meaning* is a semantic null, a word *without* real meaning in the context of *soma*. To endow "the body" with a capacity for meanings is to imbue it with "mind dust" or a "spirit" or some sort of homunculus – all notions that have been tried in the past and which carried those bygone theorists straight into unanswerable antinomies and paradoxes. The consequence of all this is simple enough: neither the informer-function nor the informee-function can reside in the logical division of *soma*. We have not a situation of mind-body communication but, rather, one of mind-body *commercium*. This is to say we are inquiring into a *functional* mind-body *connexion* we seek to understand in facet B. This requires, as may be all too evident, a rather deep *scientific* plunge into Critical metaphysics[5], but if we would pursue Weaver's idea in its full import there really is no other option but to take that plunge.

Few topics of discourse expand in scope more than those pertaining to philosophy and metaphysics. This is the case for our present topic, and for that reason I postpone the Critical discourse for treatment in a sequel I am planning to present at a later date. The purposes of *this* paper are served by focusing the discussion on figure 5 and providing some explanations for the blocks depicted within it. In addition to relative brevity, this tactic also serves to benefit the aforementioned sequel by providing a context for why one might want to undergo the labor of reading and studying such a sequel.

The process labeled *soma* is the mathematical model of the anatomical and physiological processes of the OB's physical body relevant to the purposes of the modeler. Signals are physico-chemical variables of *soma* standing in correspondence to psychological sensation. Receptivity denotes a mathematical transformation process by which signals are re-presented in terms of sensation variables. Note that receptivity belongs to the logical division of *psyche* and that the sensation effects, labeled *stimulus*, are mental representations belonging to the logical division of *nous*. The process of *semantic representing* transforms the stimulus variables into cognitive and affective perceptions that are linked (through *judgment*) to a set of meaning implications. For this reason, these objective (cognitive) and affective perceptions constitute the *semantic message* and correspond to the representation given the same name in Weaver's model. The process of semantic representing corresponds to the OB's capacities for apprehension, imagination and empirical apperception. This process both affects and is affected by the processes of *judgment*, an interrelationship denoted by the feedback pathway from judgment to semantic representing shown in figure 5.

Within the OB's rational capacity (its faculty for practical reasoning) is a represented *manifold of practical maxims* that the OB has developed through experience. Because all meanings are ultimately practical (that is, pertain to actions), the *meaning implication set* (which denotes merely possible actions the OB might take) are regulated and mapped by the manifold of maxims to produce meaning implications that are congruent with limitations and restrictions self-imposed by the OB. This is the *Semantic set* in figures 4 and 5. The OB's ability to choose to take action based upon the representation of the Semantic set is denoted the process of *appetition*. This process, which belongs to the OB's capacity for practical reasoning, has three effects within *nous*. First, motor actions that are approved by the OB's process of reasoning are transformed, by the *psyche* function of motoregulatory expression, into corresponding physico-chemical actions in the division of *soma*. This linkage from motoregulatory expression to *soma* is called the *emotivity* of

[5] specifically, in this case, the metaphysics of *commercium* discussed by Kant [Kant (1783), 29: 907-908]

the OB, a term denoting the "moving out" of noetic representations by determination of somatic actions. The second outcome of the process of appetition is *practical regulation* in adapting the manifold of maxims under a practical master principle of self-regulation Piaget has called the central process of equilibration [Piaget (1975)]. By this process of adaptation, the OB forms new practical schemes of behavior and accommodates its existing schemes under the pressure of new experiences. The manifold of maxims thus comprises what are known as policy and value functions in the theory of reinforcement learning [Barto (2003)]. The third outcome of the process of appetition is feedback regulation, called *ratio-expression*, of the OB's processes of judgment. This feedback closes a loop between judgment and reasoning, a process mental physics terms the judgmentation loop of the OB. One of the effects of ratio-expression is the possible adaptation of the OB's *manifold of concepts* previously depicted in figure 3B. (The manifold of concepts resides within the judgment process depicted in figure 5).

The various noetic processes just summarized are discussed in much more detail in Wells (2009). The model of figure 5 presents a systematic *schematic* approach for theory development by which the currently separate specialties of mathematical communication theory, linguistics and semantics theory, empirical psychology and neuroscience can be brought together in a more broadly encompassing overall theory – and by which mathematical information theory can be provided with linkages to Slepian's facet A that can turn this branch of engineering mathematics into a full-fledged *natural* science. None of this unification has yet been accomplished as of the date of this writing, and much work remains to be done, but the purpose of this paper is not to present such a new science as fully developed, but, rather, to provide the orienting context for its development.

The application of the OB-Weaver model of figure 5 to Weaver's communication problem is straightforward insofar as modeling this problem as a specific case of a generalized *network* of interpersonal interactions is concerned (figure 6). This is not to say that any specific application model will be a straightforward outcome of applying figure 5; to say that would clearly be false. It is to say that structuring of systems of human interactions follows the schematic approach in a direct way. That this has implications for psychology and sociology is, hopefully, clearly evident.

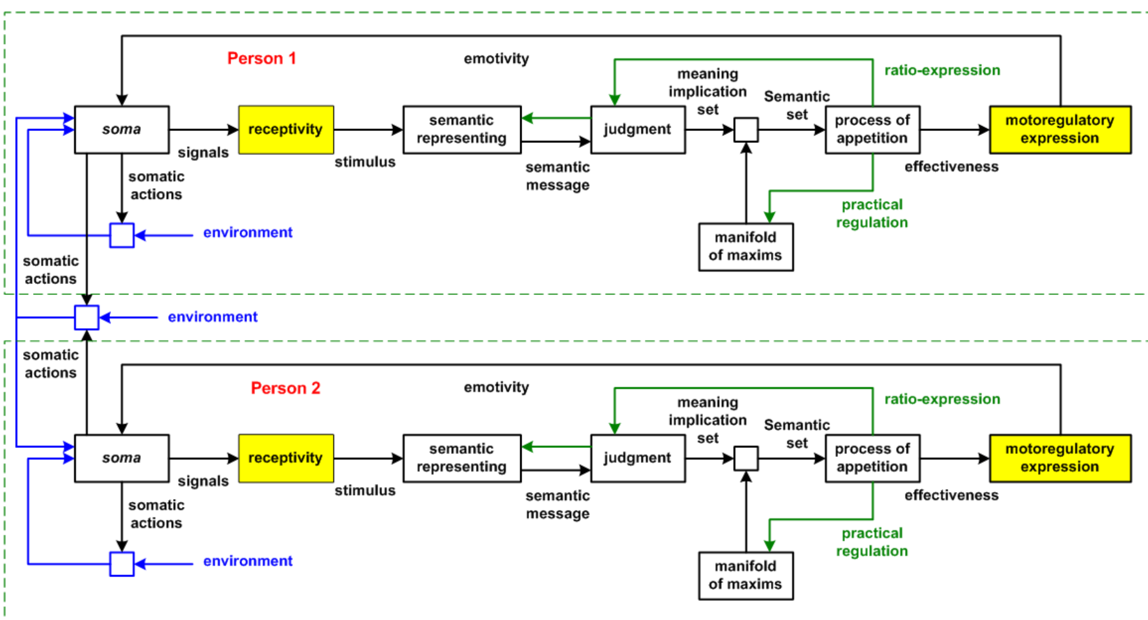

Figure 6: Interpersonal interaction model based upon the OB-Weaver model of figure 5. This figure depicts two Organized Beings (Person 1 and Person 2) interacting (e.g. communicating) with one another.

The OB is in continual interaction with its environment. There is in all occasions a local *soma*-environment interaction loop (depicted in both figures 5 and 6). In extending the model to Weaver's communication system context, the engineering instruments of Weaver's model (figure 2) become a part of the *somata*-environment loop depicted in figure 6 by which the actions of one OB affect the other and vice versa. One can see that the modeling schematic proposed in this paper is very general and can be applied in research programs for studying quite complex technico-psycho-social systems. To date there are few examples of this available. One very recent one is available in which the principles of mental physics have been applied to develop a theory of the phenomenon of *leadership* [Wells (2010)]. This work emphasizes the theme that leadership is a psycho-social natural phenomenon and that a social-*natural* science of leadership is possible. The model presented in this paper does not appear in explicit form in that work, but its incorporation into that theory has a great potential for setting the foundations for social-natural sciences of organization engineering, political science, organization management, economics and almost certainly numerous other applied human sciences as well.

V. Concluding Remarks

It has often been remarked that mankind's technological achievements have far out-paced his advances in the social sciences. It has likewise been correctly noted that new technological advances usually bring with them new social, political, and other issues and problems for society. The recognition of this is one of the factors that has been fueling a call for greater investment of effort in interdisciplinary research and interdisciplinary education for the past few years. To deny that attempts to accomplish these things has faced some very formidable obstacles is to close one's eyes to the reality of experiences encountered in making these efforts. A most fundamental issue interdisciplinarity faces has been: *How* can interdisciplinary research and development be accomplished? Sufficient enough practical experience has already been gained for us to know that interdisciplinarity does not emerge as an automatic consequence of putting specialists from various disciplinary silos together in the same room and telling them "work together." The result one should expect from that simple-minded approach is a mixing, not a compounding, of disjoint knowledge. Relative to the scale of problems involving technico-humane gaps evident in society, and by any dispassionate and objective standards for judging successes, interdisciplinary efforts to date have been too modest and too small of scale to have had broad-enough impacts. Nearly a quarter-century ago Allan Bloom wrote,

> [Where] natural science ends, trouble begins. It ends at man, the one being outside of its purview, or to be exact, it ends at that part or aspect of man that is not body, whatever that may be. Scientists as scientists can be grasped only under that aspect, as is the case with politicians, artists and prophets. All that is human, all that is of concern to us, lies outside of natural science. This should be a problem for natural science, but it is not. It is certainly a problem for us that we do not know what this thing is, that we cannot even agree on a name for this irreducible bit of man that is not body. Somehow this fugitive thing or aspect is the cause of science and society and culture and politics and economics and poetry and music. We know what these latter are. But can we really, if we do not know their cause, know what its status is, whether it even exists? [Bloom (1987), pp. 356-357]

Bloom was correct at the time in saying that humanities concerns "should be a problem for natural science, but it is not." Mental physics is a still-nascent science, less than five years old, and only a tiny handful of individuals have even heard about it to date. It does, however, provide what was not available in Bloom's day, namely a point of nucleation where physical-natural science and social-natural science can merge *as* interdisciplinary science. There exists an enormous corpus of specialized literature, products of independent and separate disciplinary silos, wherein potentially fecund hypotheses and empirical knowledge pertinent to various small pieces of interdisciplinary systems reside. It goes without saying that there can be no inter*disciplinary* science without disciplines. But there can also be no interdisciplinary science with the general system scientist. Here I say "general *system* scientist" rather than "generalist" because the former denotes a kind of middle-ground between the extremely specialized and the extremely abstract. There is a great deal of truth in the old quip, "A specialist is a person who knows more and more about less and less until eventually he knows everything about nothing; a generalist is a person who knows less and less about more and more until eventually he knows nothing about everything." It is also true that many deep specialists mistake the depth of their specialized knowledge to imply objectively valid cross-disciplinary knowledge. It does not. Metaphors and similes all have limitations in the scopes of their applications. To an educator, every problem is an education problem; to a sociologist, every problem is a sociology problem; to an engineer, every problem is an engineering problem. In fact, though, the major important problems are not any of these; they are *inter*disciplinary.

Successful interdisciplinary enterprise does require a common glue-point – a shared paradigm, if you will – where the acknowledged contributions (or potentials for contribution) of the disciplinarians can *compound*, not merely *mix*, with those of other disciplinarians. Mental physics is the science of the phenomenon of human mind, and its special contribution will come from filling the missing piece Bloom pointed to in the quote above. That mental physics itself still has much development to undergo, and that its application *in* the various special sciences is not automatic but, rather, requires significant efforts in developing appropriate systems of *applied* metaphysics [Wells (2011b)] does not alter its schematizing role in interdisciplinary science. Did physics have to wait for Einstein before orienting the industrial revolution? This, I hope, is well-enough illustrated by having the main topic of this paper serve as one *example*.

Let us briefly recap the interdisciplinary linkages illustrated in this paper. Weaver had already long ago speculated upon the possibility of linking the mathematical theory of communication to semantics (as the study of meaning in any and all of its manifestations). What was missing at that time was an established schematic for how to approach the forging of this linkage. His idea also predated coming developments in linguistics that were to emerge at the end of the 1950s and early 1960s. Chomsky would later write,

> To study actual linguistic performance, we must consider the interaction of a variety of factors, of which the underlying competence of the speaker-listener is only one. In this respect, the study of language is no different from empirical investigation of other complex phenomena. [Chomsky (1965), pg. 4]

This linkage to linguistics and semantics is in addition to, and indeed more important than, the linkages exhibited by the citations of Tarski and von Neumann.

Linkages between the OB model and theories of psychology, especially developmental psychology, have also been exhibited, e.g. by the Piaget citations. That these are also aspects of interest and concern to computational intelligence is evidenced by the citations relating to reinforcement learning (Barto) and the citation of Jang, *et al*. The idea of transforming the current social sciences into social-*natural* sciences has been raised here, and is covered in much greater detail in Wells (2010). The linkage to information theory and to mathematics in general is directly implicated by the citation of Slepian and of Combettes, and indirectly implicated by the repeated references made earlier in regard to principal and secondary quantities of mathematics. Direct implications are more fully discussed in Wells (2011a) and in chapter 23 of Wells (2006).

In conclusion of this paper, Weaver's model and proposition implicates one starting point for future developments in a widely-expansive unification of the currently disjointed silos of special disciplines. The practical aims of this interdisciplinary effort are evident from the specific application that has served as the vehicle of exposition in this paper. In the slightly more than half century since Weaver first made his proposal, very little progress towards its realization has been made. But this has itself been a consequence of disjointed specializations. There has been a major gap that has been a roadblock to the effort, but it is my claim that this gap has been filled adequately enough now, even if some firming up and curing of the bridgework still remains to be accomplished, for the then-idealistic 1950s and 60s visions of Weaver, von Neumann and others to rise from mere idealism to concrete actualities.

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