Interdisciplinary Seminar on Peirce[1]

Toward Understanding the "Biology of Mind" Hypothesis

Abstract: Research in neuroscience continues to expand and progress (for example, Kandel 2006), but the prevailing notions used to describe neuroscientific findings—in the context of biology of mind—lack logical precision. A more formal relational system is needed to translate these laboratory findings about neural interactions into cognitive aspects of mind. As developed by C. S. Peirce, Semeiotic—a scientific study of natural processes known as Semeioses—is an analytical tool that provides for such translations by avoiding gaps in reasoning that may obscure our understanding of the neural processes underlying cognition.

For example, in neuroscience we have the "binding" process, wherein the input and output of many neurons is said to "come together," "merge," "computationally combine," or "converge." But it is not made clear how/where/when this "binding" comes to pass—hence *The Binding Problem*. In contrast to such descriptions, Semeiotic, as expressed with Betagraphic (hereafter *ß*, a diagrammatic version of relational first-order predicate calculus), is a formal system that provides a more precise means of dealing with the numerous relations of neurons and how they may (via the presence of activatable but latent variables) combine to produce "emergent" mind processes like thought. In this approach, descriptions are available for neuron interactions that display connective processes that are primarily two-place or dyadic in nature. However, other neural processes can also be described, especially those that are "emergent," which display additional connective relations that include three-place or triadic relations.

Note that Semeiotic is a general hypothesis about the relational nature of cognition, whereas *ß* is a formal tool used to explore the important relation-logical features of Semeiotic. We conclude with some examples of Semeiotic as a possible method for mapping neural activity onto the emergence of learning in a way that eliminates logical cul-de-sacs. Finally, Semeiotic as expressed in *ß* provides a visually efficient inference engine that could be useful in further modeling the emergent processes linking neural activity to mental phenomena.

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Part I
Prologue

> *They reason theoretically, without demonstrating experimentally, and errors are the result.* Michael Faraday[2] (1870, 178)

The distinguished neuroscientist Eric R. Kandel (2006) made the following proposal, which we heartily endorse:

Let us now pursue the "biology of mind."

In so doing, we propose that the application of scientific methodological principles formulated by Charles S. Peirce might well contribute worthwhile insights into the biology of mind and could do so primarily in two ways. First, the careful formalized use of Peirce's Semeiotic and his concept of "natural semeiosis" allows for increased clarity of such processes as habit formation or strengthening or diminishing of neural connections. These, and related phenomena, have been difficult to capture using only dyadic relational forms: for instance, whether one neuron "communicates" or "dialogues" with another in the true sense of those terms. Second, basing Semeiotic on Betagraphic (β)—a streamlined form of Peirce's graphical approach to first-order relational logic—can provide for enhanced descriptions of known neural processes. That approach will avoid falling back on inexact metaphors at key points in arguments (for instance the "binding problem") as one progresses toward discussions of cognitive phenomena.

In the years in which Peirce published his articles concerning the principles of cognition—1860–1900—brain and mind research was highlighted by two significant scholars: Santiago Ramón y Cajal (1894)—recipient of the 1906 Nobel Prize in Physiology or Medicine—and William James, author of *Principles of Psychology* (1890). These scientists were prominent in initiating two new scientific disciplines (neuroscience and modern psychology) that had substantive impact on contemporary biology of mind. During this period, Peirce had focused his scientific investigations on mind and brain activity by developing a methodological setting for merging the insights achieved by (1) biological studies concerning neural activities with (2) psychological studies concerning cognitive activity of mind. Prior to James and Cajal, by 1860 Peirce had begun to study such problems. His interest in human nature was broad, and he contributed notably to the study of what would become the neural basis of psychological phenomena such as sensa-

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[2] Faraday was complaining about a group of contemporary chemists, but his remarks could well describe the history of the study of mind, *until recently*.

tion, perception, and cognition. He was certainly no amateur in these fields, but was profoundly acquainted with the development of psychology and criticized its existing divisions of introspective, experimental, and anatomical psychology. He proposed a *physiological* psychology that should work well with the exploration of the brain and its connections. He considered psychological theories, derived from the study of the anatomy of the brain, to be of great value, as long as mind was considered as relational processes embodied in brain activity (Cadwallader 1974, 1975; Cadwallader and Cadwallader 1972).

The scholarly study of mind has a long history, and various proposals have been made to provide a solid link between brain science and mind. An issue naturally arises at this point, which we label as the ***Link Question***: *What method(s) will enable a transition from laboratory study of neural activity to a scientific understanding of the phenomena of mind, and conversely, how might a formalism of mind provide guidance for future experiments about neural activity?*

Here are some historically proposed answers to the *link question* which one may find in the extensive, centuries-old literature:

- Mind is an autonomous half of Mind/Body Dualism (Descartes).
- Body is nothing but Mind (Idealism).
- Mind is nothing but Body (Materialism).
- Mind is identical to Brain (Identity Thesis).
- Mind is behavior (Behaviorism).
- Mind is computation (Some Computer Scientists).
- The phenomena of Mind and the phenomena of Body are aspects of a common underlying reality (e.g., Some Quantum Physicists, and Peirce as well).

The *Link Question* remains implicit in Kandel's work. Yet, its presence may be observed in his use of some principal epistemic concepts of natural language—such as *communicate, interpret, learn, remember*—while discussing neural phenomena in a cognitive context. His recommended approach appears to be: If laboratory scientists will keep this range of epistemological notions in mind as they pursue neurobiology, eventually an accurate description and understanding of mind in laboratory terms, a "biology of mind," will develop. We regard this as an attractive and potentially fruitful hypothesis for a research program. While the use of such an approach as a starting place to describe the transition from laboratory studies of neural activity to a scientific understanding of mind seems inevitable, it comes at a cost: logical imprecision (for example, see Kandel 2006, chapter 6 "Conversation Between Nerve Cells"). We propose the use of Semeiotic as a strategy that can add increased precision to the pursuit of biology of mind, upon which Kandel and his neuroscience colleagues have embarked.

Peirce developed Semeiotic, in part, as an improved version of the epistemic and problem-solving features of natural language and natural reasoning, thus offering a careful terminology and method for the "mind" side of the "biology of mind"; it also has the advantage of housing a powerful account of inference—including inference types of (1) *Abduction* (guessing a hypothesis for testing), (2) *Deduction* (exploring the consequences of a hypothesis to design an experiment) and (3) *Induction* (experimental testing of hypotheses). That is, as a candidate for the "link," Semeiotic offers a more specific and evolved terminology for "natural language and reasoning," and it has the advantage of handling inference processes, for both simple and complex system interactions. We note that Semeiotic analysis can encompass a wide variety of inference types, from hypothesis development, to analogical inferences, to computation and algorithmic procedures, as well as non-algorithmic processes.

A foundational component of Semeiotic is the Logic of Relations (hereafter ***LR***), a now well-codified subject to which Peirce made major pioneering contributions (Peirce *Collected Papers*, volumes 2 and 3; also *ISP* 2011, 2015). The adaptation of ***LR*** in a diagrammatic or graphical format, as opposed to an algebraic notation, occupied a fair amount of Peirce's attention during his productive later years; he referred to this project as *Beta Existential Graphs*. The term "existential" in this usage referred to mathematical and logical analyses of relations as they exist in scientifically observable phenomena. He reasoned that the presentation of logical concepts and inferential procedures in visually rich implementation would provide the best means for study of formal logic, inasmuch as visualization supports complex understanding. Because the observable natural process of semeiosis displays distinctive relational components, one can, then, develop an account of Semeiotic based on ***LR***. It is especially encouraging to note that Peirce intended his development of Semeiotic to be a more precise set of tools for dealing with just those epistemological aspects of natural language and reasoning that play an essential role in Kandel's approach.

An important component of general ***LR*** is the first-order predicate calculus with identity. A recently developed improvement for presenting that component in the notational spirit of Peirce's "Beta Graphs" is "Betagraphic," or, for short, "***ß***." We apply ***ß*** as our formalism for using Semeiotic to link cognition and neuroscientific discoveries.

In Part II we review the part of ***ß*** that we shall use, and provide a summary introduction with a focus on describing neurons and their connections. In Part III of the paper, we use Semeiotic presented in ***ß*** to describe some aspects of triadicity in neuronal activity. In Part IV, we apply ***ß*** and Semeiotic to some detailed examples described by Kandel (2006).

Part II
Linking Betagraphic and Semeiotic to Neural Connections

Our task is to present Semeiotic principles and applications of them in a form expressible within ***LR***. As we have noted in our previous work (*ISP* 2011; 2015; see also Peirce 1902), ***ß*** is a diagrammatic form of the first-order part of ***LR*** with some added features that will be particularly useful in Semeiotic. Thus, ***ß*** provides a vehicle for describing semeioses (the processes studied within Semeiotic) *in situ*; for example, within the logical aspect of activities of neural systems. Although ***ß*** is basically just first-order predicate logic, it accommodates some additional features Peirce regarded as effective, especially as found in dealing with phenomena encountered in Semeiotic. Specifically, these features include *hooks*, *bonding*, *fundamental characteristics of triadic relations*, *nonreduction theorem*, and a body of background notions that he incorporated in his description of the conditions of assertion. We label these features as *Peirce's enhancements* of ***ß***.

In summary, our fundamental notion is that semeiosis, as a natural phenomenon and activity, can be well described using ***ß*** (as informed by Peirce's previous work in graphical logic). As our discussion unfolds we will also find that Peirce's generalized notion of habit (see Davenport 1977; West and Anderson 2016) will be quite useful.

*Section 1: A Brief Review of **ß***

For the benefit of readers who may not have prior knowledge of *ISP* 2015, we provide here a sketch of those of its features that are needed relative to the diagrams that will be encountered in the present paper. Letters $x_1, x_2, x_3, \ldots, y_1, y_2, y_3, \ldots, x_1, z_2, z_3, \ldots$ from the latter part of the English alphabet, denote (as is customary) ***variables***, ranging over whatever collection of entities we might be referencing in a specific situation. Letters $c_1, c_2, c_3, \ldots$ denote ***constants***, particular entities to be singled out in any such situation. ***Relations*** among variables and constants, in ***ß***, are either ***atomic***, meaning that they are either ***unary*** relations (i.e., ***sets*** of entities), ***binary*** relations (ordered pairs), or ***ternary*** relations (ordered triples); or they are ***molecular constructs***, meaning that they are formed from atomic relations by means of a ***bonding operation*** (introduced below).

The atomic relations are presented diagrammatically in the following way:

would be a typical form for a ***unary*** (***monadic***) relation. The ***spot***, •, represents the relation itself; the subscript i is just an index indicating that this is the i-th unary relation in a list; the horizontal line, called a ***hook***, is labelled by a variable x_j, that can range over the contents of •. The hook, labelled by this variable, signals that the relation is eligible for ***bonding*** with some other hook in some other relation; such bonding is allowed to occur (under appropriate contextual conditions) at any hook of another relation that also bears the label x_j. The graph:

would be a typical form for a ***binary*** (***dyadic***) relation on two variables. The remarks from (1) apply here in the same way. One might also have, say,

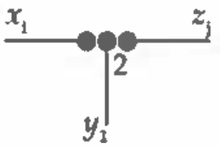
with one of the hooks occupied by a ***constant*** c_2. Hooks that have been supplied with a constant are "*closed*" and not eligible for bonding; they simply identify something that is fixed in the relation. The diagram:

would be a typical form for a ***ternary*** (***triadic***) relation; all of the remarks from (1) and (2) again apply.

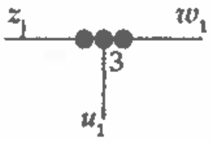
Note: In all the above simple diagrams, the number of "bullets" ("spots") indicates the *valency* (monadic, dyadic, or triadic) of the relation.

In the linear notation commonplace in formal logic contexts, (1), (2), and (3) would be written, respectively, as $R_i(x_j)$, $S_i(x_j,x_k)$, $T_i(x_i,y_k,z_j)$. We could certainly make equivalent use of that linear format; however, it is our experience that there is visual advantage in using the diagrammatic format, especially relative to the formation of "molecular bonds." We shall not make much explicit use of bonding in the present paper, but here is one simple example: suppose we are in a context wherein triads bond to form ***quaternary*** (***quadradic***) relations, perhaps according to some electrochemical principle of connection.

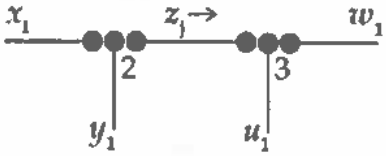
Consider that:



is eligible to bond, say, to



at the z_j-labelled hooks. We would indicate the completion of this operation by the following diagram:



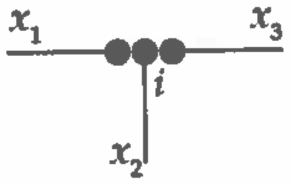
(The z_j on the connecting line is just a record of what presumably information-bearing label was the "bonding agent"; while the ⟶ indicates which triad "bonded onto the other one.")

Now, as to the way in which logical operations on relations are represented in ß. For the so-called *Boolean operations* of conjunction and negation, we follow exactly the practice originally established by Peirce: if $\mathbf{D}_1$ and $\mathbf{D}_2$ are logical diagrams that have already been formed, we indicate their *conjunction* ($\mathbf{D}_1$ and $\mathbf{D}_2$) by simply juxtaposing them: $\mathbf{D}_1\mathbf{D}_2$. The *negation* of, say, $\mathbf{D}_1$ is indicated by drawing an oval around it— this diagram:

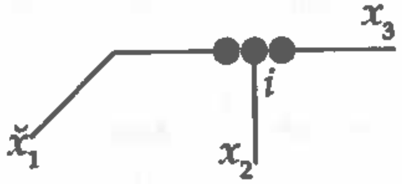
means *not* whatever $\mathbf{D}_1$ itself expresses. Then *logical implication* (often in textbooks referred to as "material implication") takes the following diagrammatic form, in the general case of "$\mathbf{D}_1$ implies $\mathbf{D}_2$":

This graph "says" *it is not the case that:* $\mathbf{D}_1$ *holds, but* $\mathbf{D}_2$ *does not hold*. Particular examples of this form will occur often in the present article.

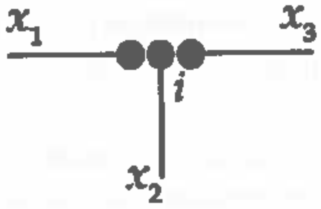
Now, a very brief word about quantification: Suppose we have, say, the triad



and we wish to indicate that for *every* x_1 in whatever the entire range of possible values is, we have this triad. This, in ß, is indicated by drawing a line to the x_1-bearing hook, at an angle to it, erasing x_1 from the hook, and labeling the newly-drawn line "$\check{x}_1$":



This says: "for *all* values of x_1, it is the case that



For an existential quantification (that is, "there is a ..."), we apply the same diagrammatic format, but with $\hat{x}_1$ in place of $\check{x}_1$; for instance, substituting $\hat{x}_1$ in the same triadic diagram just above.

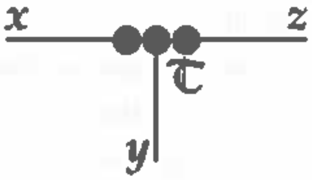
Quantifications will not play a role in the present paper; however, when needed elsewhere can be indicated in this way. Logical processes other than these basic types that might be employed will be explained when introduced. For some further, purely introductory, material regarding the ß approach, the reader might refer to *ISP* 2011; but with what has just been shown here, one should feel fully equipped to go ahead and read *ISP* 2015.

Finally, a terminological note: For the more complex diagrams that appear later in the paper, we use the term "ß-form" rather than just "ß." This is because, in order to save space and reduce the amount of labeling, we have (a) condensed diagrams into an abbreviated form and (b) taken advantage of some of the notational "enhancements" that are compatible with pure ß; however, we always retain a clear indication of where ß-molecular bonds occur, and label those bonds in such a way (number of "bullets" or "spots") as to indicate the valency (i.e., the number of input/output ports) at each bond.

Section 2: Weak Implication

As an enhancement of *ß*, we shall have occasion to use a procedure that we label *weak implication* (*WI*), which is *tentative* or *provisional* inference to a conclusion from premisses. A straightforward manifestation of *WI* is found in one basic line of reasoning common in laboratory work. Using a description adaptable to our later discussion of semeiosis, it sets up as follows.

If we employ $\mathfrak{T}$ as a label designating any arbitrary triadic relation, we may construct the figure:



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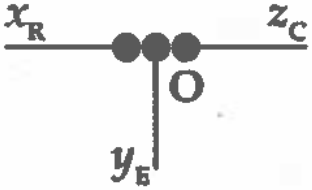
This reads "x, y, and z are in some unspecified triadic relation $\mathfrak{T}$." So we can describe a laboratory observation **O** (a triadic relation) as:



,

which reads, "'y_E' the Experimenter(s) observes 'z_C' (the Content of the observation) as a correct representation of 'x_R' (the Result of the experimental process being observed)."

The first run of this experiment can be represented as:

$$(\mathbf{T}\ \&\ \mathbf{D})_1 \longrightarrow \mathbf{O}_1 ,$$

where, (*i*) "⟶" means that activation on the left is *followed (in time) by* the investigator's observation on the right, (*ii*) D (Design) is the particular experimental design (the initial conditions of the experiment), and (*iii*) T (Theory) is the relevant previously established background knowledge of the investigator as a competent member of the scientific discipline at hand.

As the experiment is repeated, the investigator notices a new observation, $\mathbf{O'_1}$, namely: $(\mathbf{T \ \& \ D})_\mathbf{n}$ continues (in **n** number of runs) to be followed by $\mathbf{O'_1}$. This leads the investigator to a conjecture that

$$(\mathrm{T \ \& \ D})_n \text{ will routinely yield } \mathrm{O'}_n = \mathrm{O'}_1.$$

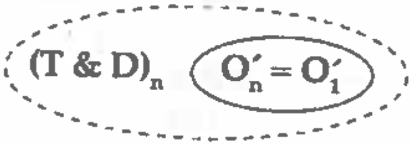
Note that a general operating principle of learning is that instances that occur together are gradually linked into a single relational unit.)

This new observation may be written as

$$(\mathrm{T \ \& \ D})_n \Vert \mathrm{W} \ \mathrm{O'}_n = \mathrm{O'}_1 ,$$

where "$\Vert$W" means "weakly implies" (*WI*). Here the experimenter is moving from (*i*) observing that a result **O** *follows after* **T & D** to (*ii*) an informed guess that **T & D** *might routinely result in* the observed **O**—that there may be a relation such that, if this particular **T & D**, then maybe this particular result **O** *will be* observed. This conjecture, resulting from such a process, we call *Type A weak implication* (WI_A), which in a neurological setting will be illustrated in Part IV.

Using a dashed oval, this can be put in the form of a *ß*-form diagram asserting a "weak implication," as follows:



Here, the outer oval appearing as dashed indicates that the implication—the inference relation between premisses and conclusion—is *weak* (*tentative, provisional, is a hypothesis that requires checking*— i.e., *WI*). When a scientist suspects a weak implication, a matter for further testing is acquired; in such a case, one does not acquire a finished "truth." If such a hypothesis is substantiated by the wider scientific community in repeated tests, the weak implication could resolve into an ordinary empirically strong implication.

As a caveat, we note that ordinary logical implication is of course *transitive*:

But transitivity does not hold logically for weak implication: the weakness is cumulative. However,

might in some cases be *experimentally* established.[3] In general, confirmation of a weak implication requires the support of experimental evidence for—or probabilistic considerations of—the likelihood of re-occurrence. Nevertheless, and this is important: if the *same* sequence of events, *with regularly the same outcome,* is repeated over and over, one anticipates that the strength of the initially weak implication will gradually (in some cases, perhaps, even rapidly) *increase.*

Note that although it is formulated in ß-style notation, this process of *WI* is by no means a *logical consequence* of ß; it is rather a procedural add-on or enhancement appropriate for various applied situations. It can be viewed as a formalization of at least a part of what Peirce meant by “habit formation.” But as we have noted above, after arriving at a weak implication (or “promising” hypothesis), an investigative community’s confidence in the implication may grow stronger—that is, “ ‖W “ may gradually transition to “ ‖” —as the successful, repeated, public trials accumulate. If, after further testing, the investigator and the relevant experimental community achieve the stronger results, the following may be written:

any instance of (T & D) ‖ O’ .

In addition to the above implicational sense of weak or tentative arguments, we could mention other types. For example, one might have a set of evidence that included observational premisses $P_1, \ldots, P_j$ connected by weak implication WI_A to a possible conclusion C. However, one or more of the observational premisses could be of low confidence such that something about the observation itself is not yet specific. Parallax error in visual judgments is a relevant example (e.g., an analog meter “needle” reading “registers” slightly differently from different viewing angles). Thus, we may say that we could have a weak implication in which one (or more) of the premisses is at issue, so that two kinds of operation would be needed: a test of WI_A, and a test of the currently vague observation(s), the “weak” premiss(es), constituting WI_B. Such an argument might look like this:

$$P_1, P_2\,(WI_B), P_3 \| WI_A\ \mathrm{C}\ .$$

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[3] Weak implication can be thought of probabilistically. If there is no reinforcement of the relation between *A* and *B* when *A* occurs, then repetition of *A* provides no increase in the likelihood of *B* as a result: if we have assigned a probability of $p < 1$ to getting *B* out of *A*, we should expect, absent reinforcement, to see that same value of *p* persist “in the long run,” just as in coin tossing. However, we are in general interested in cases in which there *is* a reinforcement factor at work; this can lead to habit-formation, as the strength of the relation AⒷ is gradually increased—that is, as the value of *p* increases. If *p* gets sufficiently close to 1, we may say we have a habit.

This states that the inference from premisses *P* to conclusion *C* is $\boldsymbol{WI_A}$ and that the second premiss is weak in the $\boldsymbol{WI_B}$ sense.

Section 3: 'Habit' Terminology

We have concluded that a terminology based upon careful use of the concept *Habit*—not just in the context of living systems (Smolin 2013)—could offer a more precise and integrated resource for the biologyofmind endeavor. Because it will be useful in later discussions, it is appropriate to review *habit* below.

While concepts of mind have been implicit in social and neurological sciences, the actual framework by which mind appears in neuro/biological systems has not been detailed. Now that research has made possible a renewed consideration of mind vis-à-vis biology, terminology will need adjustment to facilitate progress. The language to be developed must not neglect past empirical results, but should allow for the expanded findings and theorizing of researchers such as Kandel and others. Modifications will especially be needed on the side of mind phenomena. For example, one would not want to rely upon Descartes's conceptual scheme—unfortunately still permeating everyday language in western culture—because it postulates an uncrossable chasm between mind and biology.

We regard such a terminological adjustment as capable of accommodating findings of previous research, while leaving some openings for integration of additional findings that may emerge in future research; all this is in a context of providing a more precise unifying terminology. For instance, the often-blurred distinction between signaling and communicating can be clarified: communication entails signaling but not conversely. (Signaling is a two-part relation such as *stimulus/response*, while communicating is a three-part relation such as *sender/message/receiver.*) Consider the case of "neurotransmitters" (**NT**). Is an **NT** a transmitter or a message? There appear to be grounds for regarding **NT**s as messages from a sender (transmitter) to an appropriate receiver—if so, **NT**s might better be known as "neuromessages" (or "neurorepresentamens") that constitute one co-relate of a triadic relation: sender/message/receiver (or object/representamen/interpretant). To regard the situation as a dyadic relation—transmitter/receiver (stimulus/response)—could eliminate important features of the empirical events under study.

A. *Habit in general*: We shall understand *Habit* as an activity relation of a particular sort between two components or phenomena—here designated as *items*—such that the relation, described by the proposition "If *item one*, then *item two*," holds to some degree, as shown by experiment. The notion of *degree* can range over varying strengths of relationship, such as "a small degree of likelihood," to "will be the case regularly and reliably." We designate habits of the latter kind as *hard habits*, while those of various weaker degrees we describe as *soft habits*. Efficient causal relations, or "laws of nature" are examples of hard habits. A general property associated with this distinction, although not strictly so, is found in the typical usefulness of soft habits as hypotheses for further testing or exploration; whereas, hard habits are useful as foundations (premisses) in future research.

B. Forming Soft Habits: The simultaneous presentation of items in close temporal contiguity (as in classical conditioning) may activate neurons to become interconnected in ways describable within a Semeiotic framework using *ß*. We propose to re-designate this activity as *formation of a soft habit*, which is a transition from no connection between two items into a weak degree-of-habit relation, which might be followed by a process of additional strengthening of degree of habit. In expanded *ß* notation (where '__:=__' means '__*is defined as*__'; ' I ', ' J ' := *items*; '__][__' := '__*is observed as present with*__') we have:

I][J .

Here, there is no connecting habit, just two items in a field of observation. If a weak relationship is hypothesized between these items, this can be roughly symbolized by:

premiss 1: I][J;
premiss 2: O;
weak implication to:
$I\,R_w\,J$,

where R_w is a weak relation of as yet unspecified nature, and O is a previously derived experimental principle now hypothetically associated within this particular context. (Like weak inferences, weak relations suggest—but do not finally confirm—hypotheses suitable for further testing.) Given the above, we turn to a basic account of Semeiotic.

Section 4: Developing Semeiotic using ß

Peirce proposed that *semeiosis* commonly occurs in various natural processes. Below we display an extended quotation from one of his many essays concerning how natural semeiosis occurs, and how it is to be distinguished from other types of natural processes.[4] We will comment on his remarks to display our interpretation;

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[4] Peirce: *CP* 5.473 f. Our interpretation of these remarks is indicated through emphasis and added comments in square brackets.

also, we will interpolate some comments we regard as useful, including notice of some important terminological improvements, those features being indicated by `smaller sans serif typeface` within square brackets.

> The *action of a sign* `[also known as` ***`semeiosis`***`, which means the` ***`broad`*** `sense of the word` ***`sign`***`]` calls for a little closer attention. Let me remind you of the distinction… between dynamical, or dyadic, action; and intelligent, or triadic action.
>
> `[Peirce's dyadic action example:]` An event, A, may, by brute force, produce an event, B; and then the event, B, may in its turn produce `[in a brute manner]` a third event, C. The fact that the event, C, is about to be produced by B has no influence at all upon the production of B by A. It is impossible that it should, since the action of B in producing C is a contingent future event at the time B is produced. Such is dyadic action, which is so called because each step of it concerns a pair of objects.
>
> `[ANOTHER example of dynamic or dyadic action: A space rock strikes a satellite in Earth orbit (event A); the satellite goes out of orbit (event B); the satellite strikes an abandoned house in the Mojave Desert (event C). It is important for Peirce's example of dynamic action here that A does not ONLY materially imply B (and likewise the pair B/C), but that also event A, mechanically and unavoidably, produces event B independently of any intelligence or cognition (and likewise B/C).]`
>
> … `[Triadic action or semeiosis example number ONE:]` But now when a microscopist is in doubt whether a motion of an animalcule is guided by intelligence, of however low an order, the test he always used to apply when I went to school, and I suppose he does so still, is to ascertain whether event A, produces a second event, B, as a means to the production of a third event, C, or not. That is, he asks whether B will be produced if it will produce or is likely to produce C in its turn, but will not be produced if it will not produce C in its turn nor is likely to do so….
>
> `[Triadic action or semeiosis example number TWO:] [suppose]` … an officer of a squad or company of infantry gives the word of command, "Ground arms!" This order is, of course, a sign `[`***`Representamen`***`, the` ***`narrow`*** `sense of the word` ***`sign`***`]`. That thing which causes a sign `[`***`Representamen`***`]` as such is called the object `[`***`Object`***`]` (according to the usage of speech, the "real," but more accurately, the existent object) represented by the sign `[`***`Representamen`***`]`: the sign is determined[5] `[specified]` to some species of correspondence with that object. In the present case,

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[5] By *A determines B*, Peirce usually meant "*A* makes *B* more definite (or less vague, or more specific)," as opposed to "*A* is the efficient cause of *B*." For example, one might ask a friend, "Please determine the name of that red-coated gentleman across the street." Such *determination* would be a result of some further inquiry or study or investigation. See Peirce 1868.

the object the command represents is the will of the officer that the butts of the muskets be brought down to the ground. Nevertheless, the action of his will upon the sign [*Representamen*] is not simply dyadic; for if he thought the soldiers were deaf mutes, or did not know a word of English, or were raw recruits utterly undrilled, or were indisposed to obedience, his will probably would not produce the word of command.

[The *object* of this semeiosis, A, is the officer's will that the squad place arms on the ground; B is the spoken command "ground arms," which is the *representamen* (*sign* in the narrow sense); C is the squad's actual placement of their weapons on the ground]. The entire process is a *sign in the broad sense*, namely an instance of *semeiosis*. As we shall see below, this example of semeiosis is of the *Symbol* subtype.]

However, although this condition is most usually fulfilled, it is not essential to the action of a sign [*semeiosis*]. For the acceleration of the pulse is a probable symptom of fever and the rise of the mercury in an ordinary thermometer or the bending of the double strip of metal in a metallic thermometer is an indication, or, to use the technical term, is an *index*, of an increase of atmospheric temperature, which, nevertheless, acts upon it in a purely brute and dyadic way. In these cases, however, a mental representation [*Representamen*] of the index is produced, which mental representation is called the immediate object of the sign [*semeiosis*]; and this object does triadically produce the intended, or proper, effect of the sign strictly by means of another mental sign [*Representamen*]; and that this triadic character of the action is regarded as essential is shown by the fact that if the thermometer is dynamically connected with the heating and cooling apparatus, so as to check either effect, we do not, in ordinary parlance speak of there being any semeiosy [Peirce's more commonly preferred term is *semeiosis*],[6] or action of a sign, but, on the contrary, say that there is an "automatic regulation," an idea opposed, in our minds, to that of semeiosy [*semeiosis*]. For the proper significate outcome of a sign [*semeiosis*], I propose the name, the interpretant [*Interpretant*] of the sign [*representamen*].

[Dynamic relations (a species of dyadic relations) produce results in a matter of course, or blindly. Dynamic relations can be chained, but the result is still a dyadic dynamic relation (signalling is an example). A semeiosis relation, however, essentially involves a nonreducible three-way relation, *communication* or *dialogue* being examples.]

An important feature to be noted is that Semeiosis is a process involving relations. Peirce regarded a *relation* as a *fact* about some number of items.[7] For instance,

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[6] See Fisch 1986 on Peirce's General Theory of Signs; also *CP* 2.227 is quite helpful.

[7] There are, to be sure, other types of relations, e.g., various relations of importance in mathematical investigations. But for present purposes, we shall concentrate on Peirce's proposed description.

an *efficient causal relation* is a fact about two items, one being a cause and, if the relation holds, the second being the effect. So in this functioning dyadic relation, there are two corelated items, plus the additional reality of a dyadic relation among those two items.

A *promise relation* is a fact about three items: a promiser, the promised topic, and the promise recipient, to wit: Jack promised his sister that he would mow the lawn (promiser, recipient, topic). Note that in functioning triadic relations, there are three co-related items, plus the additional factual reality of a triadic relation among those items.)

In this discussion, *real* is understood to mean "the successful and reliable result of a properly conducted experiment." *Exist* is understood as "real items that can be manipulated as material." On this approach pioneered by Peirce, there can be non-existing reals: for instance, while one is not now slamming a car door on one's finger, it is a valuable and real piece of knowledge to know that to do so would result in a serious injury.

The role of *fact* in Peirce's account of relations is essential. He understood a fact as an accurate description of the proper outcome of a successful wellexecuted experiment that has been vetted by a scientific community. Given that such an experiment succeeds, an accurate statement describing the outcome constitutes a fact, which is now eligible to become a part of the background evidence for subsequent hypotheses and experiments. In effect, a relation often is an empirical summary of past dependable experimental results. Note also that a fact may be construed as a sentence properly describing a reality. This matter was thoroughly discussed by Peirce under the heading of *Abstraction* (Peirce 1997 [1903], 132 f.) or later *Hypostatic Abstraction*.

Semeiosis is not a particular relation such as "A is on top of B," or "C sold D to E"—rather, semeioses constitute *classes* of relational types which can be described using the logical tools of ***ℬ***. Initially, we notice that any instance of semeiosis must include a fact about three items. But, to further characterize the matter, the three items that might be found to be so related are themselves considered as instances of three different class types. The first class type, Peirce labeled as (*i*) the *Object* ***o*** of the semeiosis; the second (*ii*), he identified as the *Representamen* ***r***[8]; while the third (*iii*) was termed the *Interpretant* ***í***. Thus, in every semeiosis, there will be instances of each of these three class types: ***o***, ***r***, ***í***. Each of these three class types

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[8] We prefer *representamen* over *sign*, inasmuch as the latter can be ambiguous concerning whether reference is made to the item that represents an object, or whether reference is made to an entire triadic "sign" relation. We prefer *semeiosis* as a reference to "triadic sign relation."

is specified under the general heading of the *Content* of the relation. In a given semeiosis—which is basically a three-place, or triadic, relation type—its Content will describe some relational state of the following: a particular *Object Element*, a particular *Representamen Element*, and a particular *Interpretant Element*. Content often is compacted into a shorthand term, as in "Ike's promise"—where those words could summarize a particular triadic relation such as "Ike promised Betsy to wash the dishes."

What are the details of these three class types: Object, Representamen, Interpretant? Within the Content of a semeiosis, an **Object** is what the semeiosis is "about." In similar manner, the **Representamen** is a representation of the Object. And, the **Interpretant** is an interpreting function for the Representamen-Object relationship.

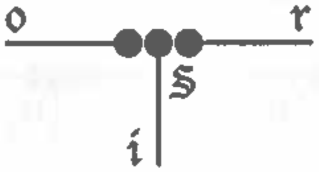
Section 5: Semeiosis in its Most General Form

Any instance of semeiosis ($\mathfrak{S}$) in its most indeterminate state is a member of the class: Triadic Relation Types ($\mathfrak{T}$).

The *Content* c of $\mathfrak{S}$ is specified as: an *Object* o represented by a *Representamen* r to an *Interpretant* (interpreting function) $\acute{\imath}$. Thus, an expression of the most general form of semeiosis would, in typical predicate logic linear form (the expression is presently unquantified), be written as:

$$\mathfrak{S}(o,\acute{\imath},r),$$

where $\mathfrak{S}$ is a relation of the triadic kind. In *ß* notation, this would appear as:

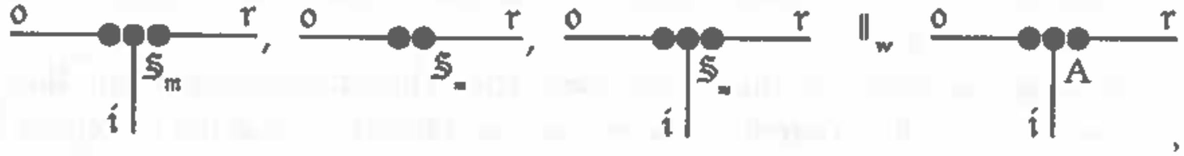


The content in the above case is merely named by $\mathfrak{S}$, which is barren other than specifying a triadic relation involving *some* object, *some* representamen, and *some* interpretant (that are as yet not further specified). Or, alternatively, the content in this case is *Semeiosis in its most general form*. All instances of semeiosis bear this structure as a minimum form.

Section 6: Partially Determined (Specified) Semeioses

A Partially Determined Semeiosis is one in which the content members o, $\acute{\imath}$, r of the root triadic relation $\mathfrak{S}$ are partially specified, but not yet fully determined (i.e., fully specified).

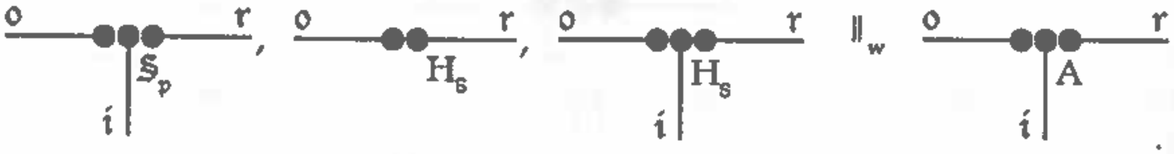
For example, an ***Icon*** semeiosis is a sub-type of the general triadic type $\mathfrak{S}$ such that, within the content of $\mathfrak{S}$ the *r* is in some particular similarity relation "S_{-}" to the *o*, and the *i* is "recognition of *that* (i.e., S_{-}) similarity relation as holding between *o* and *r*." Various types of similarity relations can be specified for icons in general.[9]



(where "A" means "Acceptance" and $\mathfrak{S}_m$ is a selected $\mathfrak{S}$).

An ***Index*** is a sub-type of the general $\mathfrak{S}$ such that in its content the *o* is in some fixed efficient causal relation "H_H"—a *hard habit*—to the *r* (as effect), and the *i* is "recognition of *that* (i.e., H_H) fixed causal relation as holding between *o* and *r*." (We will employ commas on the left of the weak implication sign because we wish our antecedent to be read as a sequence.) Expressing this in *ß*, we have:

A ***Symbol*** is a sub-type of the general $\mathfrak{S}$ such that, in its content the *o* is in some dyadic relation "H_S" (a *soft habit*) to the *r* (as supposed result), and the *i* is "recognition of *that* (i.e., H_S) relation as typically or possibly holding between *o* and *r*." Thus in *ß* form, we have:



Section 7: Fully Determined Semeioses

A Fully Determined Semeiosis is one in which all components of the content are completely specified; as we noted above, a term may be assigned to the *Content* or entire relational structure.

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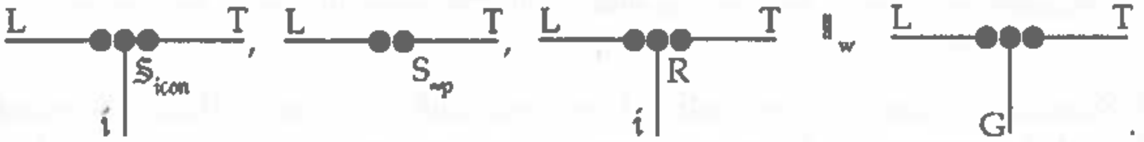
[9] Very generally, a *similarity relation* is a reflexive and symmetric relation (usually not transitive) on a given class of entities.

Additional expressions of other sub-categories of semeiosis were described by Peirce. Here we do not produce them in the interest of brevity, but recognize there are many more subtypes of semeiosis. Below is one example of an *Icon* case.

A *Photograph* (**P**) *of Luke* [*content* term]
is an *Icon*, a particular semeiosis wherein:

(*i*) a unique person, Luke (**L**), is the *o*,
(*ii*) an indicated item "this thing in my hand" (**T**), is the *r*, and
(*iii*) **R** is recognition through S_{-p} (which is a particular designated photographic similarity relation between **L** and **T**), and that the appropriate *í* in this specific case is the sentence **G** (**G** = *This thing in my hand is a photograph of Luke*).

So we could then write in *ß* (substituting the specifics S_{-p}, **L**, **P**, **R**, **T**):



In light of the preceding outline of Semeiotic, we offer the following:

Conjecture: *The general nature of semeiosis can be described by using ß; and the flow or process of semeioses can be modelled by inference relations within ß (or, in the case of weak implication, additional inference relations or enhancements compatible with ß). This strategy will also provide an improved terminology for the "mind" aspect of "biology/mind" relationships, thus minimizing errors arising from multiple possible meanings of unspecified natural language "mind" concepts. Moreover, the inferential processes of semeiosis can model both lower level and higher level neuronal processes in ways that allow transitions among those levels without introducing logical paradoxes or barriers to further understanding. An additional benefit of such a modeling technique is that it may offer parallelisms between Semeiotic (expressed in ß) and biology of mind phenomena that may suggest additional empirical studies or experiments. That is, new relations that might be derived in Semeiotic, can perhaps be found paralleled in biological settings, or vice versa.*

Part III
Triadicity and Neurons

As our discussion continues, we will need to deal with *potential* relations. As Pietarinen (2006, Chapter 4) observed, potentials are not formally represented in Peirce's Beta existential graphs, nor (we note) in *ß*, which, like Beta graphs, is a diagrammatic form of basic first-order relational logic. We will, nevertheless, supplement *ß* notation via the inclusion of a notational device referred to as "pot-hooks" (*potential hooks)* that is a compatible *enhancement* of *ß*. In the absence of a full introduction of a general logic of modal relations (covering the complete modal features such as necessity, possibility, and so forth), this enhancement of *ß* will suffice for present needs.

In Kandel (2014, 202 emphasis added) we find the following suggestive statement:

> …several results on habituation, sensitization, and classical conditioning led us irresistibly to think about how genetic and developmental processes interact with experience to determine the structure of mental activity. Genetic and developmental processes specify the connections among neurons—that is, which neurons form synaptic connections with which other neurons and when. But they do not specify the strength of those connections. Strength—the long-term effectiveness of synaptic connections—is regulated by experience. This view implies that the *potential* for many of an organism's behaviors is built into the brain and is to that extent under genetic and developmental control; however, a creature's environment and learning alter the effectiveness of the preexisting pathways, thereby leading to the expression of new patterns of behavior.

If Semeiosis, understood as a natural communication process, is described using *ß*, and if we understand neural activity as a natural semeiosis, then it should be possible to describe important aspects of neural activities by using *ß* in concert with suitable empirically based axiomatic extensions of *ß* arising from neuroscientific experiments. This method offers a proper balance between theoretical and experimental aspects, and provides a coherent formalism to specify the *communicational* structure of neural systems and mind phenomena, thereby side-stepping some of the pitfalls of Cartesian dualism and its associated concepts.

Moreover, using this approach will help clarify vague natural language terms currently used in biology of mind discussions. Kandel's mention, here and elsewhere, of such common epistemological concepts—*process, interaction, experience, determine* (likely in the sense of "becoming more definite"), *connection, potential, learning, communication, signaling*—suggests that the modeling system for these phenomena available in *ß* and Semeiotic might be fruitful in future neuroscience research. (For example, some neurons exhibit dyadic properties, as in reflexes like breathing, while others exhibit triadic properties as in higher-order cognition such as reasoning.)

Section 1: Pipes, Pothooks, and Triadic Necessity

As an aid toward visualizing the more formally stated descriptions in *ß*, we will introduce a useful entrance point for modeling principles and operating procedures of this complex process: a simple physical analogy we refer to as "***PIPES.***"

(One might imagine having access to a collection of small plastic pipe fittings from a home improvement shop.)

We suggest the rough informal idea of a ***PIPE*** as a “path,” in which there are connections and contents. No knowledge of the “inside” (connected content) of the “pipe” is posited—it could be electrical, chemical, volumetric, mechanical, whatever—at this point we are only interested in the bonding/connecting patterns within our model. We do this because we propose that such ***PIPE*** relationships can illustrate some characteristic relationships among neurons. But this is a heuristic device only, to be discarded as use of *ß* becomes more familiar within the neural context.

1. **Connection along a “stem.”**

A pipe might proceed for a length with no changes in its connectivity pattern as below:

Figure 1: A dyadic stem.

Here, a straight pipe (***STEM***) could be considered, from a connectional aspect, as a series of shorter pipes (***STEM SEGMENTS***) each of which is a Dyadic type (as is an unsegmented ***STEM***), which are serially connected in a bonded sequence (“**B**” will indicate a bonding connection has been made):

Figure 2: A series of dyadic stems bonded producing a dyadic stem.

Input/output, or direction-of-flow can be overlaid into this framework if needed.

2. **Blocked Pipe (CAP).**

This structure instantiates a cessation of whatever is an active connective element of the pipe (“]” indicates a cap):

Figure 3: A monadic cap or block.

This is of monadic relation type, and monads have two important structural features: (*i*) each has one hook (or connection point), and thus can be bonded (connected) to some other hook given the appropriate connection conditions relevant to the phenomena being studied; (*ii*) the hook in a monadic relation can be used to seal (as above)—this is "blockage," or "termination," or cessation of some relevant activity or cancellation of further connection *potential* along the path that is blocked.

3. **Branching.**

If a pipe-like structure has three connection locations, as in the case of a "fork" or "branching pipe," it is of Triadic relation type, which we name ***BRANCH***:

Figure 4: A locus of three connections at once, or triadic branch.

Section 2 : Pipe Collections

Hook positions within collections of the above basic pipe types may connect to other available hooks within the given collection. Here we give examples involving various possible combinations of collections of two pipe types.

Two Pipes with one Connection:

C1. Two ***BLOCKS***

Figure 5: Two blocked stems with one bond.

This shows a situation in which all hooks are occupied or closed (referred to as ***SATURATED HOOKS***).

C2. One ***BLOCK*** and one ***STEM***

Figure 6: Two stems, one blocked, and one bond.

This shows one open hook remaining, with one closed.

C3. One ***BLOCK*** and one ***BRANCH***

Figure 7: One stem blocked, one branch, and one bond.

This shows one closed hook pair with two hooks remaining open.

C4. Two ***STEMS***

Figure 8: Two stems and one bond.

This shows two closed hooks and two remaining open.

C5. One ***STEM*** and one ***BRANCH***

Figure 9: One stem, one branch, and one bond.

This shows two closed hooks and three remaining open. Here an arm of a branch is extended, yet the resulting figure retains three open connection points.

C6. Two or more ***BRANCHES***

Figure 10: Two branches, and one bond.

This shows two closed hooks and four remaining open.

C7. ***P-STEM***, ***POTHOOK***, and ***BRANCH GENERATION***

We now consider a process we call ***BRANCH GENERATION***. In this case, a ***STEM*** may develop a ***BRANCH***. However, within the rules of ***β*** a ***BRANCH*** cannot be generated from a collection containing only ***STEMS***, which includes the case of there being only one ***STEM*** as a ***BRANCH*** generation resource. We decide to explore the possibility of staying within the framework of ***β*** as we explore generation; thus we propose another type of pipe, designated as ***PSTEM***, which *appears* to be a ***STEM*** pipe, but which has the *potential* to open an additional hook site under particular conditions. (That there is such a potential in some cases is shown by prior laboratory experiments, such as Kandel 2006, 261 f.)

Figure 11: (a) Stem with one inactive pothook; (b) Stem with active pothook.

In the above figure scheme, the caret would point *in* ∧ if the pothook is inactive, and would point *out* ∨ if the pothook were active.

A ***P-STEM*** contains the potential for an additional connection site, not now actualized, which can become *actual* under appropriate conditions. Such a site we call a Potential Hook (***POTHOOK***). When a ***P-STEM*** activates, we call that process ***BRANCH GENERATION*** (***BGen***). In such a case, a pothook is actualized and becomes a third hook site that can then be open or closed. A ***STEM*** is a dyad, but note that a ***P-STEM is a triad***. Thus ***BGen*** cannot occur by employing only ***STEMS***. On the working hypothesis of following *ß* for our modeling activities, if one insists that only dyadic relations may be used in analysis, triads cannot be generated via bonding. Note: Here we are not tracing an instance in which a pre-existing genuine dyadic relation *becomes* (or *changes into*) a triadic ***P-STEM*** with an active or inactive pothook. We are instead proposing that *what at one present moment is construed as a dyad*, may in actuality already be a ***P-STEM*** with one of its three hooks currently inactive.

Thus, we propose a new relational form to be included among those that are essential to our approach—a *P-STEM* is a triad with two active common hooks, and one inactive pothook. Thus a *P-STEM* is a *virtual dyad*, but under particular conditions, its inactive third pothook can become active.

Adding the ***P-STEM*** form is a consequence of our decision to follow the lead of Peircean nonreduction theory (*ISP* 2011). On that approach, from a list of primitive relational forms comprising monads, dyads, *and* triads, we can generate relational structures of any adicity (quadrads, pentads, etc.). But, if one omits triadic relations, then one is limited only to chains of dyads, perhaps with some monadic closure events. The point is that in the case of a chain of only dyads there can be no branching, yet branching has been clearly observed in neuronal structures at least since the time of Cajal. Our proposal allows for structures that presently might be dyadic but which are, in reality, *virtual* dyads with a currently inactive pothook, which, under particular future conditions, could be activated as a branch.

Consider the following example based on our temporary piping analogy. A plumber buys a piece of pipe suitable for installation in a kitchen remodeling project. Based upon his prior understanding and experience, he believes a particular pipe (*apparently* a ***STEM***) will work normally (dyadically, as two water flow points) in his project. After installing, he turns on the water and the system works properly. As a test, he turns it off and then on again, and it continues to perform properly. He then remembers that a valve in the upstairs bath has not been opened, which he then opens. Surprisingly, the kitchen pipe springs a leak

(***BRANCH*** or triad, three water flow points). He then remembers that the upstairs shower is for high pressure. He then guesses that the kitchen pipe may have properties not appropriate for use in the overall installation. He re-examines the leaking kitchen pipe, and is surprised to find that it is a fusible type of pipe designed and manufactured to open a 5 mm aperture through a disguised thin wall *IF* a particular higher pressure occurs in the overall plumbing system. After this experience, the plumber realizes that the characteristics of the pipe he installed was not fully knowable from its outward appearance, but became better known through the experiment of applying higher pressure. The plumber suspects that a *new* phenomenon (*not part of* the plumber's initial state of knowledge) is manifest, and wishes to re-examine prior assumptions. The plumber returns to the supplier to request a free exchange of nonfusible pipe (a ***STEM***) to replace the installed fusible pipe that was a virtual dyad prior to application of pressure, but upon the experiment of pressurization showed to be a ***PSTEM***.[10]

Section 3: Exploring Emergence Possibilities

We begin with some definitions and special notations for diagrams that will prove useful as we provide examples of neuron-to-neuron interaction.

i. Hook types.

Common hook: a hook that is either open or closed, with no provision for potentiality; if open, it is eligible for *bonding*; if closed, it is either part of a bond, or else is labeled by a constant term meant to denote some specific entity.

Potential hook: This is the *pothook* just mentioned. Typically, a pothook (on a p-stem) will initially be in a *non-active* state not eligible for bonding, and will, in one of our ***ß***-style diagrams, bear the label “ρ.” It will, nevertheless, be *activatable*, thereby becoming an open, and hence bondable, hook, now labelled by “ρ_0.” But it may, subsequently, prior to any bonding, either remain permanently open, or be *de-activated* and revert to being labelled simply by “ρ.” If bonded, it will, in our representations, be given the new label “ρ_b.”

Activation and de-activation are described, in a given applied setting, by appropriate axiom schemes; typical examples of such axioms are provided in subsection *iii* below. (If a *common* hook is de-activated, it thereby becomes per-

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[10] By the way, we are not arguing that neurological events can be fully captured through study of PIPE events, but we do propose that PIPE structures are similar to neurological patterns of connection, thus providing a useful initial embodiment of our formal model.

manently closed, lacking the potential for re-activation that is in general present for a pothook. A pothook that has been de-activated will retain its eligibility for activation unless, as indicated in subsection *ii* below, the axioms in force for the setting under discussion dictate its permanent closure owing to the nature of a particular bond-breakage involving that pothook.)

ii. Bonding notation.

We employ the symbol "$\mathbf{B}$" to denote the bonding operation: if two ß-diagrams $\mathfrak{G}_1$ and $\mathfrak{G}_2$ have been bonded, $\mathfrak{G}_1$ to $\mathfrak{G}_2$, this is notated by "$\mathfrak{G}_1 \mathbf{B} \mathfrak{G}_2$". (Bonding is a not-necessarily-commutative procedure.) The details of the bonding are made apparent in the actual diagram that results. A hook that was *potential* when the bonding occurred may

either
become permanently closed and marked, diagrammatically, by the label "ρ_{pcl},"
or
become again an open pothook labelled by "ρ_o,"
or, finally,
it may emerge from the breakage as an inactive but activatable pothook bearing the label "ρ."

iii. Activation and De-activation of Hooks.

Peirce made the interesting proposal that pre-conscious perceptive processes are inferential in nature.[11] We can codify specific examples of this in ß notation, once we have provided suitable diagrammatic formulations of the notions of *activation* and *deactivation* of pothooks so as to accommodate notions of *growth*, *emergence*, and *pruning*.

In the simple case of a dyadic figure with one common hook and one pothook, the ß-diagram is just this:

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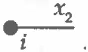
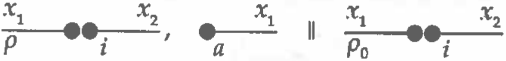
[11] Peirce's review of James's *Principles* presented a critique of the work from the standpoint of physics, psychology, mathematical logic, and the history of science. Part II of the review also discusses issues connected with "perception as unconscious inference," see: Peirce 1975 [1891].

Note: If we were just doing *pure predicate calculus*, in ß form,

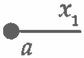
would always function simply as the monad



How would *activation* look here, in ß? As an *inferential procedure*, it would be:



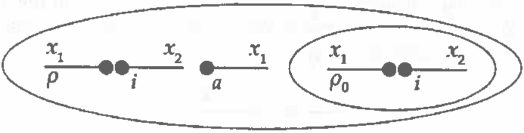
Next,



is a special notation meaning "activate the pothook labelled "x_1" in the i-th dyadic figure."

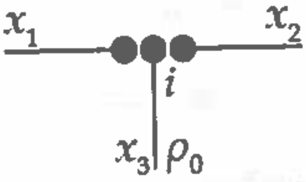
It is preferable for purely logical reasons to treat any activation scheme of this sort as being *general in some applied setting*. As an example, the relation

is present as a *special axiom* for that applied setting, rather than an inference procedure described in ß; in such a case, we would write it as:

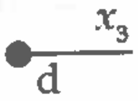


The activation procedure described above avoids adding to the inference rules, in the applied setting in question, and instead augments the formal axioms of the system by a suitable set of applied axioms (derived, presumably, from experimental considerations). This formula is now one of the *activation axioms* for whatever applied setting is being considered. Similarly, activation of one or more pothooks in a more complicated ß-molecule can be taken as general in some applied setting.

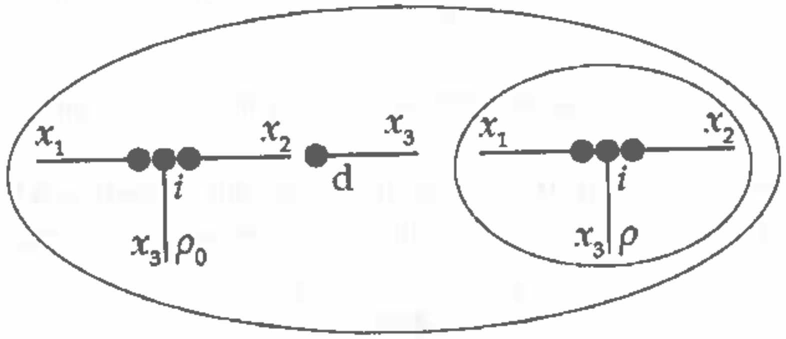
Representation of the *de-activation* of an open pothook is essentially the same as that for activation, with just a small relational change in the "de-activizer" piece of the diagram. Thus, to illustrate this time with the type of relation that is most distinctive of our approach, namely a *triad*; given:



with an open pothook at hook-position x_3, *de-activation* via a deactivator monad



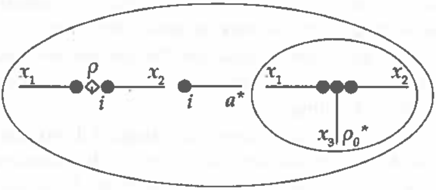
would be expressed thus:



and this diagram would function as an *axiom* in any applied setting in which the ρ_0 hook is to be deactivated *whenever* the remaining open hooks bear the labels x_1 and x_2 and the ρ_0 hook bears x_3.

Finally, we may consider the possibility of "emergence from the inside" or "branch growth," via the following *ß*-form notations. Given the "virtual dyad" below (its inactive pothook shown as "◊"):

in which only the hooks labeled x_1 and x_3 are currently open and present for observation. A third, potential hook, bearing x_2, while not evident, may be discovered by micro-inspection, or known to be potential as the result of prior experiment. In this way it can be viewed as a potential connection point or "bud." In this situation, activation may be regarded as "coming from the inside." To diagram a case of this type of "growth activation," we use the following notation:



Here the "." notation indicates that activation is occurring via the triggering of an internal growth potential. (Via bonding, we can obtain pipe-like configurations with multiple such "buds.")

A key feature of ***ß*** as a tool for analyzing relations and their interconnections is the fact that, on the approach used, it will not be possible to form all connections of any adicity using only dyadic and/or monadic relations. This is evident in the simple examples provided above by ***PIPES***: no collection of pipes that includes only monadic or dyadic connectivities can produce (using Bonding) any relation of triadic adicity.

Based on experimental observations, Kandel and other neuroscientists routinely describe neurons as "communicating" and "dialoguing" with each other. Given that communication and dialogue are more complex than simple two-way (dyadic) signaling (each being instead examples of triadic relations involving *speaker/message/hearer* functions) ***we propose, as a natural starting point for describing such cognitive-like interactions, that triadic relations are found at the neuronal level***. The existence of triadic relations at the level of neurons is an effective logical means (on the working hypothesis of Semeiotic/betagraphic) of capturing the rich connections between biology and mind. Therefore, in Part IV we present two examples from Kandel's discussion of such neuronal processes, looking specifically for triads and the logical and research benefits they might provide.

Part IV
Neuronal Applications

In this part we use the logical framework—***ß*** and Semeiotic—to add precision to the current neuroscience/mind nomenclature, imparting new potentialities to be evoked by the traditional terms used to describe complex neuron-to-neuron interactions. On occasions when a neuroscientist reports that neurons in an experiment are "communicating" with one another, Semeiotic allows for a fuller logical description of the phenomena through the inclusion of triadic relational resources. In the following, we will illustrate those factors to show how a method of analysis that allows for connective relations of any adicity/valency could facilitate further research into the interplay between the activities of neurons and their cognitive descriptions, thus perhaps easing the translation from one domain to the other.

In neuroscience research it is now clear that a full-bodied logic of relations is needed. At present Kandel and others use the casual, natural, somewhat vague, logic of relations available in everyday language which, while initially useful, is unfortunately inadequate and tends to be biased toward an exclusively dyadic perspective (such as physicalist or Cartesian theory) for understanding relational structures and interconnection resources. Our previous work shows that ***LR*** and Semeiotic are two different theoretical entities. Semeiotic, the study of communicational processes (semeioses), requires *some* ***LR***. If the ***LR*** of everyday life is employed, many capabilities available in a fuller ***LR*** will be lost. Following Peirce, we recommend, for research into the biology of mind, a study (Semeiotic) of semeioses (communicational processes) that employs the fuller ***LR*** (and other resources) of ***ß***. If this approach is taken, it might be possible to bypass the strange paradox that would require neuronal processes, taken as exclusively dyadic, to somehow result in triadic cognitive processes; from the logical perspective of ***ß***, the latter is simply not possible.

Before we begin our analysis of neuronal applications, we call attention to features and terminology for basic structures of a neuron. (See Banich and Compton 2011, 35.) All neurons consist of three primary parts, dendrite, cell body and axon. The dendritic tree, made up of individual dendrites, is the region that receives primary input from other neurons, while the cell body contains the nucleus and other resources necessary to promote neuron life. The axon and the axon hillock are important for the transmission of electrochemical impulses generated and propagated along the length of these tracts. Branches at the end of the axon contain bulbous terminals, which have vesicles filled with neurotransmitters. These neurotransmitters, which can be either inhibitory or excitatory, are released into the synaptic cleft (a small space between neurons), resulting in a connection between one neuron and another.

We are aware that "neurotransmitter" is standard terminology in neuroscience. However, we raise the issue whether, in light of the application of concepts such as "dialogue" or "communication," as analyzed in natural language or in Semeiotic, an argument might be produced supporting change of this term into one that captures notions like "neuromessage," or "neurorepresentamen." It appears that what are designated as neurotransmitters are "sent" from somewhere to be "received" somewhere, thus fitting the general structure of a semeiosis (presence of an *Object*, *Representamen*, *Interpretant*). We argue that if all neuronal processes are nothing more than dyadic signaling (*Signal* causes *Result*), then it does not make sense to apply communicational ideas and related concepts within "conversations between neurons."

Section 1: Neuronal examples in enhanced ß

With this basic framework in mind, we now consider two examples of mapping enhanced ß and Semeiotic onto a series of neuronal connections.

Example One. Our first example, presented by Kandel illustrates how a gill and siphon withdrawal reflex in the simple organism *Aplysia* can take place at the cellular level. As background, we cite the author's brief overview of Aplysia physiology (2016, at figure 4.3):

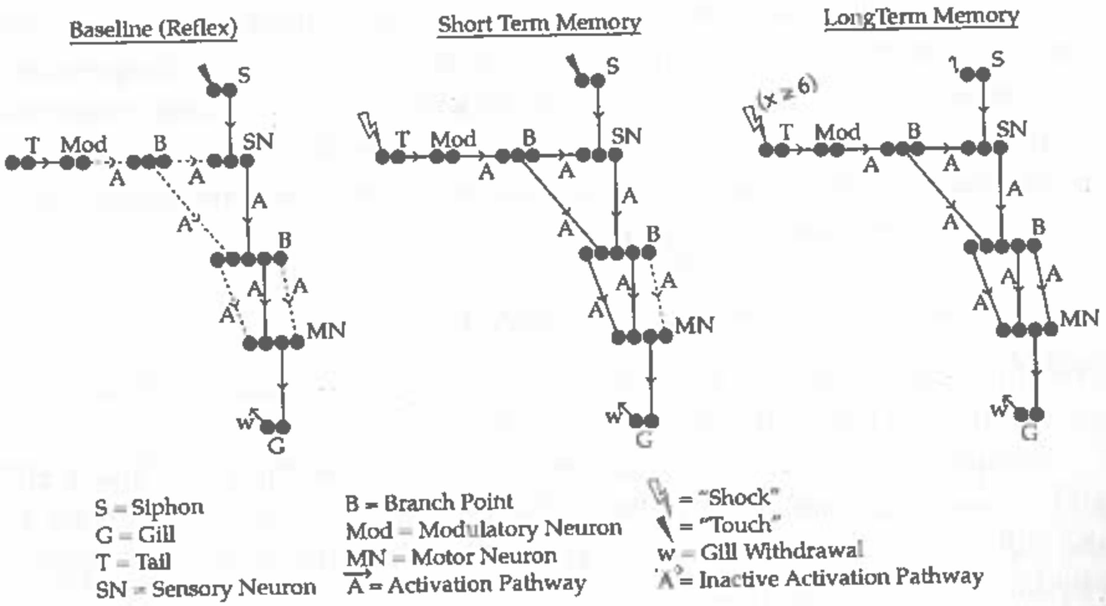
> *Aplysia*'s gill-withdrawal reflex can be modified by learning. A weak tactile stimulus to the siphon normally causes the gill to withdraw modestly (middle panel). A shock to the tail scares the animal so that the same weak stimulus to the siphon now produces a much more powerful withdrawal of the gill (right panel). The animal remembers the fear induced by the tail shock as a function of the number of training trials: one tail shock leads to a memory that lasts for minutes, whereas five tail shocks produce a memory that persists for days or weeks.

Kandel (2016, at figure 4.5) then presents a diagram and description supporting his hypothesis that learning and memory processes can apply to the above withdrawal reflex.

> Different mechanisms underlie short- and long-term memory storage. A single sensory neuron from the siphon skin connects to a motor neuron that innervates the gill. Short-term memory is produced by a single shock to the tail. This activates modulatory neurons (in blue) that cause a functional strengthening of the connections between the sensory and motor neurons. Long-term memory is produced by five repeated shocks to the tail. This activates the modulatory neurons more strongly and leads to the activation of CREB-1 genes and the growth of new synapses.

We offer a Beta-form diagram summarizing the connections in Kandel's figure 4.5.

Figure 12: Enhanced Beta-form diagram of Figure 4.5 (Kandel 2016).

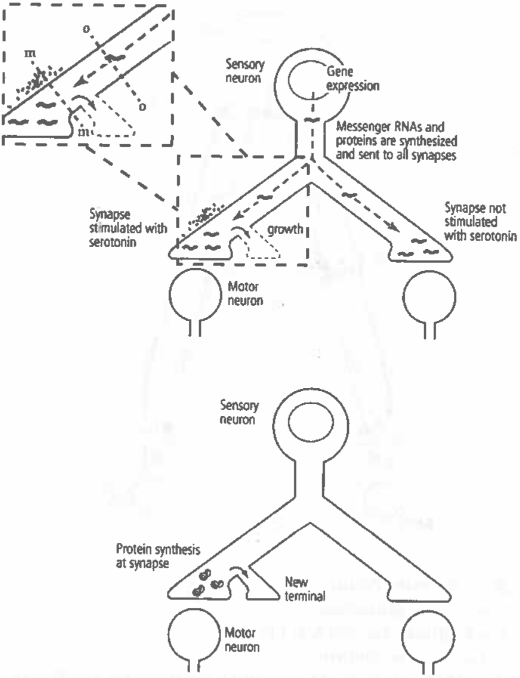


The above figure actually is partly enhanced and partly simplified; certain features of molecular bonding in β have been suppressed for the sake of clarity.

In this diagram we show activation pathways with arrows to indicate the direction of flow of events in time (top to bottom and left to right of page); note that the relations characterizing short-term and long-term memory require connectivities that are triadic and/or greater. Moreover, each junction point indicates the valency (that is, the number of input/output points) at that location. As illustrated above, modifications of the gill siphon reflex require neurons with at least triadic capability if they are to be accurately represented.

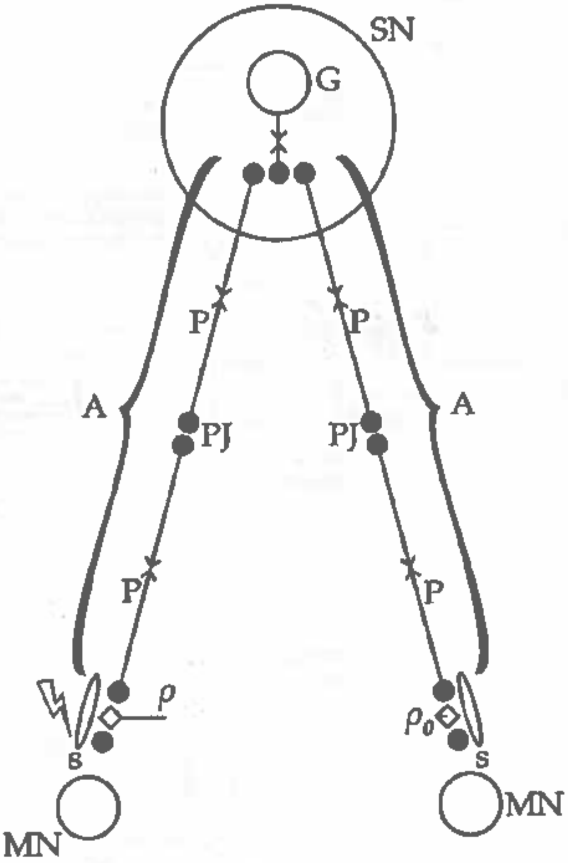
Example Two. Next we explore an example provided by Kandel (2006, 271) that involves a phenomenon that in our discussion has been labeled ***BRANCH GENERATION.*** Illustrated below, in Figure 13 is his diagram (with our modifications) of a model of long-term neuronal change.

Figure 13: Growth of new axons (after Kandel 2006, 271)



Some neuroscientists, when viewing this diagram, might perceive our first inset added to Kandel's figure as a dyadic ***STEM***, which only partially captures the connectivity observed in his actual experiments, while blurring the relational aspects of branch formation. The fact that branching occurs experimentally suggests a preexisting *potential* for additional connectivity that can be activated under specific neuronal conditions. Our interpretation of these findings suggests that the region of the neuron from which the new terminal grows, is not a dyadic ***STEM***, but is a triadic *virtual stem* with inactive pothooks—a ***P-STEM***. It is notable that, in some cases, when a pothook activates, it may carry with it additional virtual p-stems with their own pothooks currently inactive. Thus one might observe developing patterns that demonstrate how a series of p-stems can generate multiple "tree" branching forms.

Figure 14: Pothook activation.



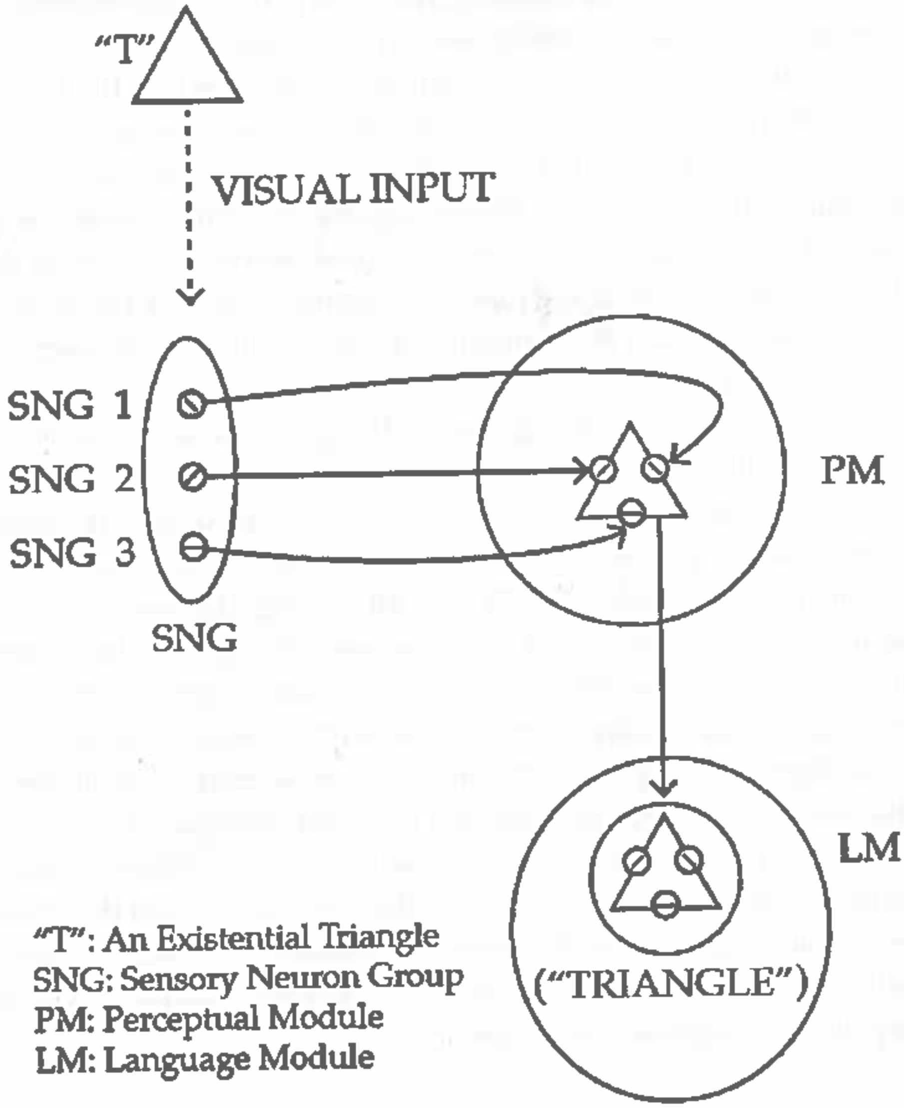
SN = Sensory Neuron
G = Gene Expression
P = Pathway for RNA & Proteins
SN = Sensory Neuron
↕ = RNA & Protein Flow with Allowance for Feedback
A = Axon
MN = Motor Neuron
⬯ = Synapse
s
ϟ = Seratonin Hit
ρ = Active Pothook ("Growth Bud")
ρ_0 = Inactive Pothook
PJ = Pipe Juncture*

**These may or may not be present, in various numbers; but if an axon is of sufficient length, it is plausible that such junctures occur.*

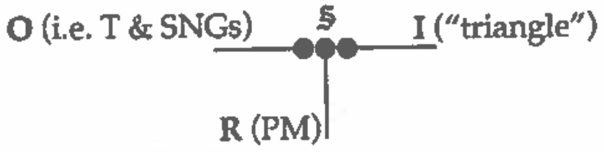
The biochemical conditions by which pothooks are formed and activated is a matter for empirical neuroscience research. The concept of *pstem/pothook* gives such formation and activation a representation that is amenable to logical manipulation, and provides a formalism for avoiding *ad hoc* explanations for processes not yet seen. Furthermore, the concept of pothook could serve as a guide for future research on the biology of mind. Such research may lead to discoveries about neuron connectivity not currently known, and not presently considered possible (but, that logically "could be"). For example, consider the discovery of dendritic to dendritic connections required for the phenomenon of back propagation as in parallel distributed models of cognition (see Chen, Mitgaard, Shepherd, 1997).

Example Three. In Figure 15 we illustrate how a visual presentation of a triangle could be translated into its verbal equivalent (the name "triangle") via neurons that are capable of triadic relations. In the left panel a visual stimulus of an existential triangle (T) is presented, sensory neurons activate in response to the component parts of the stimulus, in this case neurons sensitive to the right-leaning diagonal (SNG 2), the horizontal line (SNG 3), and left-leaning diagonal (SNG 1), fire in response to the visual presentation T (Hubel and Wiesel 1959). In the next stage of the process, a Perceptual Module (PM) relates these component lines to one another to represent a visual percept that takes the form of a triangle. In the last stage of the figure, a Language Module (LM) retrieves the verbal label of the entity that best fits the input received and the word "triangle" is formulated and produced. Note: There is at least one location in the figure where a neuron with triadic endowment is required to produce this translation from the visual input to the verbal label, namely in the perceptual module PM (which may contain several other neurons endowed with triadic features and may result in other ways of putting the SNG segments together).

Figure 15: Visual to verbal.



We note, moreover, that the overall process summarized in Figure 15 can be considered as a semeiosis wherein: the Object is the combined T and SNGs, PM constitutes a Representamen, and the verbal presentation "triangle" is the Interpretant. This overview could be expressed in the following Betagraph:



Notice that this figure can be analyzed further; as it stands it only shows that there is a semeiosis relation present, in contrast with an everyday language expression saying that these features are dyadically "communicating." Assignment of more detailed subtype specifications, such as Index or Symbol (see above) would require additional laboratory research.

Given our relational treatment in modified β form of the above three examples, it appears possible to overlay, onto these neuronal examples, an analysis of communication and dialogue provided by Semeiotic without introducing troublesome background Cartesian assumptions. Moreover, it does so without injecting a presupposed *exclusively* dynamic (dyadic) account from everyday language that is inadequate for an accurate expression and full understanding of triadic communicational phenomena or semeioses. Such a move opens an analytical pathway from neuronal activities to cognitive descriptions that avoids the hand-waving account that "emergence just *somehow* occurs" in the context of dyadic relations alone.

Section 2: Semeiosis in neuroscience

Having β-form diagrams such as those presented above, and given the knowledge that the communicational processes of semeiosis are triadic in kind and are presentable in β-form, it is now possible to trace out the details of "conversations and dialogues" that are triadic semeiosis processes among neurons. That is, some "conversations" between neurons may be indexical (or iconic, or symbolic) semeioses, whereas some such events may not be semeioses at all, but merely cause-and-effect *signals* (a dyadic process). If we apply semeiotic analyses to neuronal processes (with the aid of the logic of relations as presented in β) it might be possible to display the actual presence of various semeioses in both simple and complex neuronal contexts. This approach could provide experimenters with a valuable new tool for empirical study.

Toward such a goal, we offer the following suggestions.

1. As noted earlier, some *neurotransmitters* might well be understood to be *Representamens* originating from an *Object* directed toward an *Interpretant*, the whole process being a *semeiosis* (instead of a dyadic signal).
2. Soft habits formed via conditioning processes can become the basis needed for applying a Symbol-type semeiosis structure in particular neural activities (see discussion of Symbol semeioses above).
3. Iconic semeiosis processes could—through either their analogy or similarity aspects—add insightful tools for features under study; iconic processes might also be helpful in understanding similarities or analogies relating to the senses of sight, taste, smell, touch, and hearing (see prior Icon discussion).

4. Indexical semeioses are different from simple cause and effect events. An indexical semeiosis occurs when an Interpretant is applied to acquire a meaning for a particular causal event (see Index discussion).
5. Semeioses—in everyday speech, conversation or literature—and neuronal-level semeioses can differ in means of embodiment, but their common relational and semeiotical logical features provide a continuity between biology and mind that might overcome the difficulties with the Link Question noted in our introduction.

Part V
Conclusion

In this essay we have provided details of a logical framework that allows for some (but not all) neuron-to-neuron interactions to be triadic in nature, enabling neuroscience researchers to theorize and conceptualize neural interactions in logical ways above and beyond simple dyadic (stimulus-response) connections. As such, it provides for the likelihood that neurons (and the brain) are capable of representing experiences or events not only in the simple traditional stimulusresponse, or "signaling" format, but potentially to engage in interactions involving triadic relationships. These in turn allow for significantly more complex types of interactions—for example, neurons actually "communicating" in the full sense of the term—communication as in a triadic relation involving transmitting, messaging, receiving rather than just "signaling" one another as in a dyadic relation. This triadicity is important for the biology of mind because it sets the stage for experimental neuroscience to directly link simpler neuronal processes with neuronal processes in higher-order thinking, without invoking a *homunculus* or the need for any "spooky metaphysical" constructs. Perhaps what has been called the binding problem in neuroscience might be overcome in view of what appears to be availability of triadic relations in neuron-to-neuron processes. Perhaps the binding problem only arises when researchers limit themselves to only dyadic relational resources. The addition of the possibility of bonding between dyadic *and* triadic relations might be a path to address some aspects of general binding problems (both segregation and combination) that are usually expressed in terms of combining dyadic stimulus features in order to form an object representation (which, within the framework we propose, is a logical impossibility).

In light of the triadic nature of relationships found in some neurons, it should be possible for epigeneticists to conceptualize and test for whether very subtle yet complex aspects of human behavior might be directly represented in the structure of the genome. As a result of allowing for triadicity, one might find that genetic production of next generation basic-level neurons could reproduce genetic changes from the earlier survival experiences of one's ancestors (for example, food preferences, or taste in music or art). These in turn may manifest in a given individual's current thinking or behavior, even generations later. Interestingly, from a simple dyadic perspective, these characteristics or capabilities may appear "unexpectedly" and/or without apparent "cause." In reality, however, these subtle behavioral aspects could have evolved over time and have subsequently been coded as activatable gene sequences passed on from generation to generation. Such phenomena could be scientifically explained only if some neurons possess triadic relationship potentiality.

We acknowledge that there are numerous variations of neural bonding that are not dealt with in this paper, including: (1) Permanent or Temporary (as in how long the bond will last); (2) Near or Far (as in the proximity of the neurons necessary to create a bond); (3) Weak or Strong (as in terms of strength of the bond formed); (4) Specific or Non-Specific (as in two compatible hooks can connect, or can only form a bond between specific types of hooks); (5) High or Low Threshold (as in the amount of input required to form a bond); (6) Singular or Multiple (as in the number of opportunities that a hook can have to bond with another—a sort of hook "half-life" before they become permanently closed). However, in this discussion our focus has been upon the fundamentals of neuronal relations and connections, rather than how they eventuate in more complex forms. The above variations on bonding will eventually need to be addressed if a complete biology of mind is ever to emerge.

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