MTR 06B0000060

MITRE TECHNICAL REPORT

# A Multi Scale Definition of a System

**August 2006**

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| **Sponsor:** | MITRE | **Contract No.:** | |
| **Dept. No.:** | D410 | **Project No.:** | 51AAV018D1 |





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# ABSTRACT

The notion of a system, although central to system engineering, is very loosely defined. In order to understand and reach beyond the limits of “traditional” system engineering, an improved definition of a system is required. Such a definition has to be able to capture the multi scale aspect of systems; it has to capture the substantive, the structural and the dynamic aspects of systems; and it has to acknowledge the unavoidable entanglement of the subjectivity and objectivity in the human conceptualization of systems. Such a definition underpins the analytic and synthetic aspects of complex-system engineering and is presented in this paper.

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# 1.0 Introduction and Motivation

*The systems engineering perspective is based on systems thinking … a perspective that sharpens our awareness of wholes and how the parts within those wholes interrelate. A systems thinker knows how systems fit into the larger context of day-to-day life, how they behave, and how to manage them. Systems thinking recognizes circular causation, where a variable is both the cause and the effect of another and recognizes the primacy of interrelationships and non-linear and organic thinking — a way of thinking where the primacy of the whole is acknowledged.*

INCOSE; Systems Engineering Handbook version 3; June, 2006; section 2.2

The notion of a system[1] is central to system engineering. In fact, it is the *sine qua non* of system engineering. System engineering has been successfully applied to a wide range of systems. Increasingly, however, system engineering has been seen to be less effective when applied to such systems as the Health Care System, the Internal Revenue System, and a Missile Defense System. It has also been found to be ineffective when applied to the introduction of new capabilities into such systems (for example, the introduction of a net centric capability into the DOD). One of the reasons can be found in the definition of a system itself.[2]

The currently accepted definition of a system is no longer adequate. It is no longer sufficiently general, and too much is left implicit in its articulation. While the current definition *is* adequate for "traditional" systems, it is lacking when it is used as the foundation for the engineering of systems associated with the more recent and ambitious efforts.

It is impossible to fully conceptualize systems like a Missile Defense System. But "traditional" system engineering depends on completeness, and a system's traditional definition reinforces this expectation.

It is impossible to disjointly partition a system – like the Health Care System – from its environment. But the traditional definition is largely silent with respect to the environment of a system and thereby leaves the impression that a system can be disjointly partitioned from its environment and even considered separately.

These and other drawbacks in the currently accepted definition of a system have contributed to the disappointments now associated with system engineering's more recent and ambitious efforts. These drawbacks can be avoided with a revised definition of a system.

The most fundamental reason for the growing discrepancy between expectations and results is that we are increasingly attempting to tackle problems (with system engineering and its traditional definition of a system) that directly challenge our most basic

[1] There are many versions of the current definition of a system. For example, Eberhardt Rechtin, in the March 2006 issue of INSIGHT (the flagship publication of the International Council on Systems Engineering) defines a system as: "a collection of elements which, interrelated and working together, create useful results which no part of the elements can create separately." Another version is, "a set of parts that can be assembled and made to work together to accomplish some purpose."

[2] There are other reasons, and they are taken up in a separate paper referenced in the concluding section.

assumptions about how we think about problems, their solutions, and even reality itself. The problems and solutions amenable to "traditional" system engineering do not pose this challenge to conventional thinking.

It is not the purpose of this paper to trace this recent historical development or to assess the merits of the arguments that have been marshaled along the way. It is simply assumed here that the traditional "Newtonian" or fully deterministic and reductionist understanding of the Universe along with the traditional understanding of how we understand that Universe is giving way to an improved understanding that is reflected in this paper. However, the interested reader is invited to consider the reflections of Erwin Schrödinger and others in this regard.[3]

[3] Erwin Schrödinger, *Mind and Matter*, 1958, Cambridge University Press.
F. Heylighen, P. Cilliers and C. Gershenson, *Complexity and Philosophy*, 2006, arXiv.org pre-print.

## 2.0 Reality and Conceptualization of Reality

As Schrödinger and others have argued, reality and our conceptualizations of it (including systems) are inextricably intertwined or entangled. They can never be fully separated or isolated. It is not fruitful, however, to *start* with such an entanglement. Rather, it is better to first distinguish the various considerations that are impacted by this entanglement, and only later to genuflect to entanglement's inevitable influences.

For our purposes, we will first distinguish what we will call the "soup of objective reality" (or the soup of reality, or objective reality, or just reality) from the "subjective observers" (or just observers) of that reality. We are those observers. We think about reality, and in so doing form and use our "conceptualizations" of reality. Our conceptualizations (of reality) are distinct from reality itself. They are not the same. Of course, to the extent that our conceptualizations of reality are actually congruent with reality, then our courses of action (as engineers) can be successful. Regardless, these two notions (the soup of objective reality and our subjective conceptualizations of it) are distinct.[4]

Since we can no longer speak *directly* of thinking in terms of objective reality (we can only speak of thinking in terms of our subjective conceptualizations of it), we put ourselves at a bit of handicap. How can we speak of reality at all if this is the case? In order to surmount this difficulty, we will introduce a (strict) vocabulary to denote the *assumptions* that we will make about reality. These assumptions will seem reasonable, but it is important to remember that there is no direct way to test (never mind to prove) them. That is beyond our ability as subjective observers distinct from the soup of reality itself.

We will say that the soup of reality has both an **EXTENT** and a **RICHNESS**. These terms refer, respectively, to the immeasurable expanse of the soup of objective reality and to the uncountable details that might be found anywhere in that expanse. These two terms **EXTENT** and **RICHNESS** should not be construed as exclusively spatial. They are meant to span all and every aspect of objective reality. These two terms represent a start at a vocabulary to refer to objective reality without conceptualizing its content.

Another assumption about the soup of reality that we will make is that it is not undifferentiated – it is not endlessly homogeneous. There is both variation and likeness in reality that is a mixture of the random and the orderly. We will also assume that portions of the soup of objective reality can be distinguished. (Distinguished and differentiated are not *exactly* the same.[5])

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[4] In making this simple dichotomy between the soup of objective reality and the subjective observers of it, we are omitting an important consideration. Observers such as ourselves must first sense the soup of reality before it can be conceptualized. There is no reason to suppose that our sensing of the soup of objective reality is in any sense complete. In fact, just the opposite is true. And this partial availability of the soup of reality as the basis for our conceptualizations has important consequences. But we are going to ignore them in this paper. Another digression that we are going to avoid is the possibility of conceptualizations independent of the soup of objective reality. These are our imaginings. These, too, are important; but they are ignored in this paper.

[5] This same nuance of meaning as applied to our conceptualizations of reality is touched upon in section 9.0.

Lastly, we need to note one final assumption. We cannot know if we can conceptualize all of the **EXTENT** and **RICHNESS** of the soup of reality. This assumption applies, regardless of what is assumed about our ability to sense the soup of reality. In other words, even if we could sense everything that is the soup of reality, we are not capable of knowing if we have fully conceptualized all of the soup of reality. Although this is a plausible assumption, it can't be proven. However, it does align with our personal experiences. It reflects the fact that our brains are just a part of the soup of reality and so must be, in some sense, less than all of the soup of reality and conceptualizing everything then invites an endless recursion; and so on. In fact, we will go further below: all of our conceptualizations of the soup or reality (even taken together) are always partial.

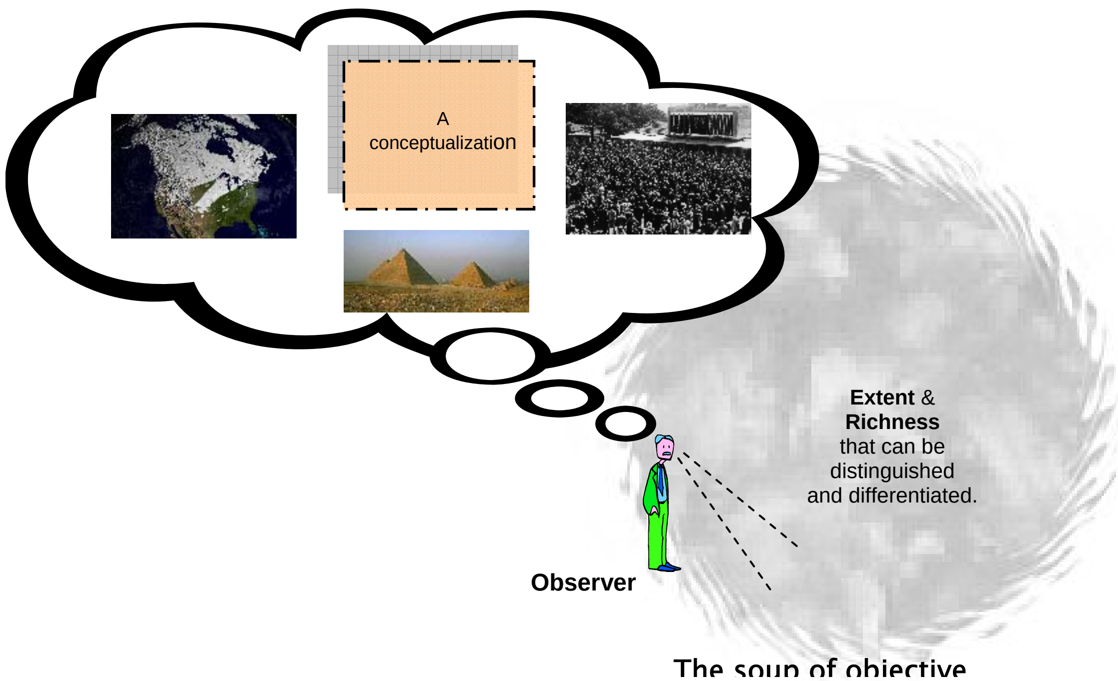


**Figure 1**

*The human brain functions to parse what can be sensed of reality into conceptualizations.* This conceptualizing functionality of the brain is a mixture of the voluntary and the involuntary. Below, we are going to discuss this functionality as the **MODALITIES** of conceptualization. This will be a discussion of *how* we think – or how we form conceptualizations. However, before we do that, we want to distinguish this functionality from the *consequences* of that functionality – which we will call the **CONTENT** of conceptualizations. This is *what* we think about.

A system is an example of *what* we think about. A system is a portion of our conceptualizations of reality. This is what we are going to define. Although it might seem almost too obvious to state at first, *what* we think about is heavily dependent on *how* our brains function. As a consequence, a definition of a system needs to take this dependency into account. Earlier definitions have slighted this dependency. As a result, we presently have definitions of a system insufficiently general and explicit enough to help us to grapple with the engineering of systems like a Missile Defense System.

So, to this point, we have deliberately distinguished:

(1) The Soup of objective reality (with **EXTENT** and **RICHNESS**).
(2) *How* we conceptualize (the **MODALITIES** of conceptualization).
(3) *What* we conceptualize (the **CONTENT** of conceptualizations).

# 3.0 Conceptualizations, Patterns and Systems

Before we can discuss the **MODALITIES** of conceptualization, we need to establish three attributes of any conceptualization. The first two are the **FIELD OF VIEW** of a conceptualization and the **RESOLUTION** of a conceptualization (FOV and RES). And we want to begin to introduce a vocabulary to discuss the third attribute of any conceptualization, its **CONTENT** (or **INFORMATION CONTENT**).

The FOV of a conceptualization is a measure of the expanse of a conceptualization. As was true for the **EXTENT** of the soup of reality, the FOV should not be construed in a strictly spatial sense either. The FOV is a measure of the inclusiveness of a conceptualization. See Figure 2.[6]

RES is a measure of the degree to which portions of a conceptualization *can be* distinguished. It should not be confused with what actually *is* distinguished. What is distinguished are portions of the **CONTENT** of a conceptualization.

**PATTERNS** are the entire **CONTENT** of any and every human conceptualization of reality. (There is nothing else in a conceptualization regardless of FOV and RES.) And a system, S, is *a portion of* the patterns that make up one or more conceptualizations. This last statement is the start of a new (revised) definition of a system.

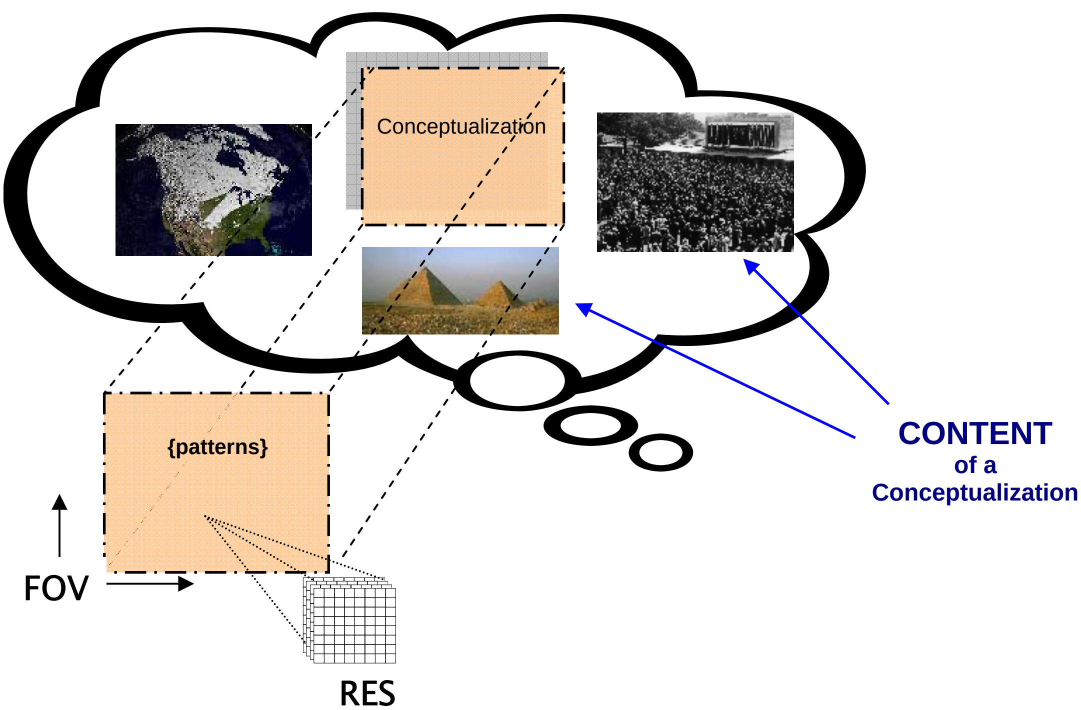


**Figure 2**

[6] The images in this figure, and the others like it in this paper, are meant to be suggestive of conceptualizations. It is literally impossible to draw pictures of conceptualizations. However, images can be quite suggestive and readers are invited to turn their attention to the conceptualizations that these images induce.

The **PATTERNS** *of all possible human conceptualizations of reality* can be designated as a set, $\{\text{pattern}_c\}$, where $\text{pattern}_c$ is used to distinguish an individual **PATTERN**; and $c \in \mathbf{C}$, where **C** is an index set that enumerates all of the **PATTERNS** in all humanly possible conceptualizations of reality.

Since a system is only a portion of such **PATTERNS**, a way is needed to designate those **PATTERNS** that belong to the system. The most general way to do that involves what is termed a **HOLON**. This term was introduced by Arthur Koestler in 1976.[7] A **HOLON** (H) is a <u>whole</u> (with parts or portions) that is itself <u>a part of</u> (or a portion of) a more expansive whole. The label **HOLON** is just a term for this <u>duality</u>. This label can be understood to designate what it is that provides cohesion to a system and that distinguishes the system from the rest of the **CONTENT** of all humanly possible conceptualizations. By common convention, the "left over" portion of conceptualizations is usually termed the environment of (or the context for) a system. The introduction of H in the definition makes the role of the environment explicit in defining any system. This is usually omitted in conventional definitions.

$S \equiv \{\text{pattern}_c\}; H.$

Human beings can only conceptualize one **SCALE** at a time. This is explained below. For the moment, it is simply stipulated. What is conceptualized of a system at any one **SCALE** $\nu$, $S^\nu$, is all or a portion of S. All of the **PATTERNS** in a conceptualization at the given **SCALE** $\nu$ can be designated $\{\text{pattern}_\kappa\}$ where $\kappa \in \mathbf{K}$; and $\mathbf{K}$ is the index set that enumerates the **PATTERNS** available in the conceptualization at this **SCALE** $\nu$; $H^\nu$ is the **HOLON** at this **SCALE**.

$S^\nu \equiv \{\text{pattern}_\kappa\}; H^\nu$ [8]

The patterns available in a conceptualization at any one **SCALE** can be augmented by increasing FOV and/or RES:

$\{\text{pattern}_\kappa\} \subseteq \{\text{pattern}_{\kappa'}\}$ where $\kappa' \in \mathbf{K}'$; and $\mathbf{K}'$ is the index set that enumerates the **PATTERNS** available in the conceptualization with increased FOV or RES.

Not all of the **PATTERNS** that might belong to S may be available at a single **SCALE** such as $\nu$, regardless of FOV and RES:

$\{\text{pattern}_{\kappa'}\} \subset \{\text{pattern}_c\}$ and there can be at least one **PATTERN** in $\{\text{pattern}_c\}$ selected by H that is not in $\{\text{pattern}_{\kappa'}\}$. In this case, S cannot be completely conceptualized at one **SCALE**. And so $S^\nu$ is an *approximation* of S.

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[7] Koestler, Arthur; *The Ghost in the Machine*; Random House; 1976

[8] Once the **MODALITIES** of conceptualization are introduced, we might want to understand **HOLON** as the operation of the Identification **MODALITY**. It could then be considered a conceptualization operator applied to the patterns of a conceptualization. Given such an understanding, this formula might be more aptly written as $S^\nu \equiv H^\nu(\{\text{pattern}_\kappa\})$. However, since S cannot in general be fully conceptualized at one **SCALE**, and the notion of the **HOLON** must remain as part of the definition, the notation shown in the body of the text is used.

A system can be conceptualized at more than one **SCALE**, however. At each such **SCALE** of conceptualization a system is approximated by the **PATTERNS** of S that are available at that **SCALE**, *and* that comply with the system's **HOLON** at that scale.

As we will see, it is not generally possible to conceptualize combinations of conceptualizations at different **SCALES** together. *So multiple **SCALES** of conceptualization may be required* in order to conceptualize the relevant **PATTERNS** of S.

The foregoing can be summarized with the following (new and revised) definition of a system.[9]

$$\mathbf{S \equiv \{pattern_c\};\ H}$$
$$\text{----------------}$$
$$\mathbf{S^{\mu} \equiv \{pattern_{\varphi}\};\ H^{\mu}}$$
$$\vdots \qquad\qquad \vdots$$
$$\mathbf{S^{\nu} \equiv \{pattern_{\kappa}\};\ H^{\nu}}$$

If exactly one **SCALE** of conceptualization is needed to think about all of the pertinent **PATTERNS** of S, then the result amounts to an improved version of today's conventional definition of a system. The improvement is an explicit appreciation of the role of the system's environment in defining a system. In this case, $S^{\mu}$ is not simply an approximation of S; it is exactly S.

If more than one **SCALE** of conceptualization is needed to think about all of the pertinent **PATTERNS**, then the definition becomes a multi **SCALE** definition of a system. As will be discussed in much more detail below, what is crucial to appreciate is that the **PATTERNS** available at any one **SCALE** of conceptualization (say $\mu$) are neither contained in or contain the **PATTERNS** at another **SCALE** of conceptualization (say $\nu$).

$\{pattern_{\varphi}\} \not\subset \{pattern_{\kappa}\}$
$\{pattern_{\kappa}\} \not\subset \{pattern_{\varphi}\}$

where $\kappa \in K$ and $\varphi \in \vartheta$; and K and $\vartheta$ are the index sets enumerating the patterns at the two different scales of conceptualization. The **PATTERNS** at the two **SCALES** may overlap, however.

So a system is a specific subset of all possible **PATTERNS**, the remaining being the system's environment. This collection of **PATTERNS** can be understood to express the structure and the dynamics as well as the substance of the system. In many cases, not all of the **PATTERNS** of the system can be simultaneously conceptualized. In such cases and in order to comprehend more of the **PATTERNS** of the system, multiple **SCALES** of conceptualization must be used.

It should also be noted that it is always possible to conceptualize arbitrary portions of a system at any particular **SCALE**. In doing so, the **HOLON** attribute of the system at that scale is omitted and the designation of the **PATTERNS** that are considered is accomplished by other means. The absence of the **HOLON** attribute means that any distinction between

[9] An elaborated version of this definition is available in figure 17.

the portion of the system being conceptualized and the environment of the system is now arbitrary rather than being a feature of the conceptualization of the system. It is possible in many such cases to substitute a new **HOLON** for the **HOLON** omitted. In such cases, the *portion* of the system conceptualized can then be treated as a system in its own right. In such cases, terms like subsystem are used to refer to the portion of the original system that is now treated as a system itself. However there is no guarantee that the two **HOLONS** agree with respect to the distinction between the original system and its environment.

A number of authors have identified **PATTERNS** (configurations of similarities and differences) as one of the most fundamental of conceptual notions.[10] We agree. Similarities and differences are extremely difficult to define in terms of more basic notions; and they are either explicit or implicit in almost all other notions.

**PATTERNS** make up the whole of the **CONTENT** of any one human conceptualization of reality. **PATTERNS** are the configurations of things that are similar or different in such a conceptualization. We might want to call the most basic and irreducible of such things in a conceptualization the “quanta” of patterns or the “quanta” of conceptualizations. We have chosen, instead, to refer to such “quanta” with more specific terms such as **PROPERTIES** and **RELATIONSHIPS**. The following section introduces these more specific terms that can be used to discuss the content of **PATTERNS** and the entire **CONTENT** of conceptualizations.

When **PATTERNS** are discussed, it is sometimes convention to stipulate (or just to assume) that there is also some sort of regularity in the configurations of similarities and differences that are recognized. When this is the case, the notion of a “random” **PATTERN** becomes an oxymoron. We do not exactly adopt this convention, however. Instead, we say that if a **PATTERN** contains no information for us, then it is a random **PATTERN**.[11] A conceptualization that is entirely a random **PATTERN** contains no information about anything – including the soup of reality if that is what is being conceptualized. Using the terms that we will introduce, such a conceptualization would have no **PROPERTIES** or **RELATIONSHIPS** that we can recognize.

[10] W. Ross Ashby said “The most fundamental concept in cybernetics is that of ‘difference,’ either that two things are recognizably different or that one thing has changed with time.” [*Introduction to Cybernetics*, Wiley, 1961] Gerald M. Weinberg said “Difference is the most fundamental concept in cybernetics – and in general systems thinking as well. We must never forget that it is also the most *difficult* concept…” [*An Introduction to General Systems Thinking*, Dorset House, 1975] And so on. We would add that the notion of distinguishing things (whether similar or different) is equally fundamental.

[11] It is also worth noting that some authors equivalence random and stochastic. We do not. Stochastic processes or stochastic patterns or stochastic functions *do* carry information.

# 4.0 Content of Conceptualizations Elaborated

To discuss the **CONTENT** of a conceptualization, we begin by considering the example in Figure 2 of the **CONTENT** of a conceptualization that includes the pyramids. Each pyramid is a portion of the conceptualization. Each pyramid is also an example of what we will call an **OBJECT** in the conceptualization. If the RES of a conceptualization is sufficient, we are able to distinguish and pick out blocks in the pyramid. Blocks are more **OBJECTS** in this conceptualization. And we can note that a pyramid is some sort of **AGGREGATION** of the blocks.

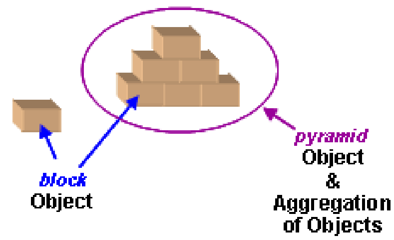


**Figure 3**

**OBJECTS** have what we will call **PROPERTIES**. For example, the blocks in the example can each have a **PROPERTY** such as color. And each block can have another **PROPERTY** such as location. And so on. **OBJECTS** are **AGGREGATIONS** of such **PROPERTIES**.

These three terms (**OBJECT**, **PROPERTY**, and **AGGREGATION**) refer to portions of the **CONTENT** of a conceptualization. They are **PATTERNS**. They will be more formally defined in a separate section below. However, we continue with their informal introduction here so that the reader will be able to develop an initial appreciation for the connections between the **MODALITIES** and the **CONTENT** of conceptualizations as well as for what **PATTERNS** are.

**PROPERTIES** are also **AGGREGATIONS**. They are **AGGREGATIONS** of what we will call **P-VALUES** (or just **VALUES**). The blocks mentioned above have the **PROPERTY** of color. What we mean by a **PROPERTY** is a collection of **VALUES** such as {blue, green, tan, red, yellow, black …}. Other **PROPERTIES** of a block might be its shape or its location, each with its respective aggregation of **P-VALUES**. However, these **AGGREGATIONS** are slightly different than the **AGGREGATIONS** that we have called **OBJECTS**.

A **PROPERTY** is not simply an **AGGREGATION** of **P-VALUES**. One of its **P-VALUES** is always distinguished from all of the others in the **AGGREGATION**. For example, here we have distinguished the **P-VALUE** of tan by underlining it. While the **PROPERTY** of color of the **OBJECT** block is the **AGGREGATION** of **P-VALUES**, { }, the **P-VALUE** that applies in the conceptualization is the **P-VALUE** of tan. While the **PROPERTY** of the block *could be* blue, it isn't; it's tan. We conventionally understand a **PROPERTY** as exhibiting both of these traits. A **PROPERTY** is both an **AGGREGATION** of **VALUES** and a particular **VALUE** selection from the **AGGREGATION**. Both traits are included in our formal definition of **PROPERTY** – and eventually of a system – below.

It is also important to note that **P-VALUES** are specific to their **PROPERTIES**. For example the **P-VALUE** of spherical does not belong to the **PROPERTY** of color. (It could belong to another **PROPERTY** such as shape.) In other words there is an affinity among the members of an **AGGREGATION** that we have called a **PROPERTY** as well as a selection among those members. Rather than simply defining a **PROPERTY** as another example of an **AGGREGATION** (which it is), we will be defining it as an affinity group with selection.

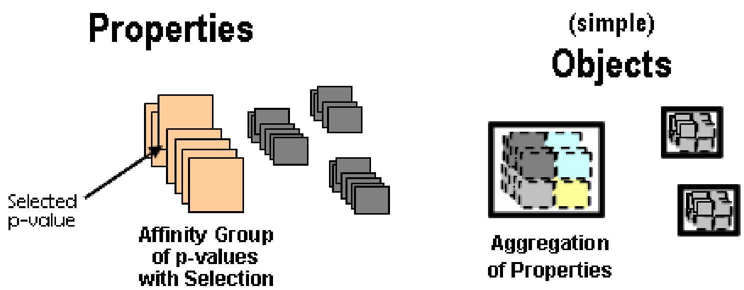


**Figure 4**

As we will state below, this careful treatment of a **PROPERTY** (as an affinity group with selection) is coupled to our understanding of the **MODALITIES** of conceptualization. Our treatment for a **PROPERTY** does not apply to all **AGGREGATIONS** – in particular it doesn't apply to what we have called **OBJECTS**. **OBJECTS** and **PROPERTIES** are different sorts of **AGGREGATIONS**. There is no selection among the **PROPERTIES** that are the **AGGREGATIONS** that we have termed **OBJECTS**, for example. These differences are due to the different **MODALITIES** of conceptualization that dominate their respective formation.

There is one more important notion that we need to introduce before we turn to the **MODALITIES** of conceptualization. In order to appreciate this notion, we consider again the **OBJECT** of a pyramid in the above example of a conceptualization. It is an **AGGREGATION** of blocks (which are other **OBJECTS** in the same conceptualization). We juxtapose the pyramid with another **OBJECT** that we will call a heap (as shown in Figure 5).


**Figure 5**

Both the pyramid and the heap are **AGGREGATIONS** of blocks. Blocks are **OBJECTS**, and they have **PROPERTIES** (as do the pyramid and the heap; *all* objects have properties – they are aggregations of properties). All of the blocks (in both cases) have a **PROPERTY** of location, for example. In the case of the pyramid, the location of a block constrains the locations of other blocks. This is not the case for the heap. In the case of the pyramid, knowing the location of a block allows us to figure out the location of other blocks. This is because there is a regularity in the case of the pyramid that is absent in the case of the heap. In the case of the heap, the locations of the blocks are independent. Knowing the location of a block provides no insight into the location (or even the existence) of other blocks. In the case of the pyramid, the locations of the blocks are not independent – they are interdependent. This regularity or this interdependence is a portion of the conceptualization of the pyramid *that is not present* in the case of the conceptualization of the heap. We call these portions of conceptualizations **RELATIONSHIPS**. O**BJECTS** can be **AGGREGATIONS** not just of **PROPERTIES** but of both **PROPERTIES** and **RELATIONSHIPS**.

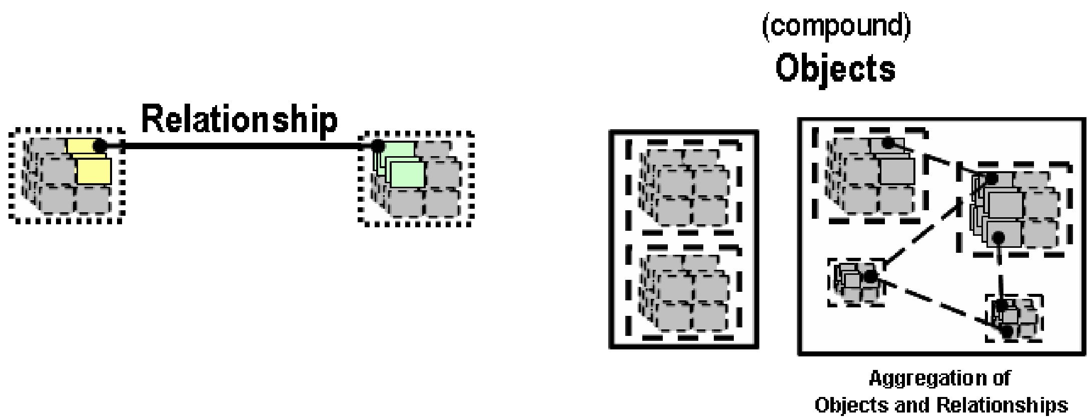


**Figure 6**

# 5.0 Modalities of Conceptualization

We have singled out what we call the six **MODALITIES** of conceptualization. These are meant to label six expressions of the functionality of the human brain without attempting any neurological (or other) explanation for this functionality.[12]

The first of these **MODALITIES** establishes a correspondence between a given conceptualization and a portion of the soup of reality. We call it the **FOCUS OF ATTENTION** (or just **FOCUS**). It amounts to what we, as observers, are trying to think about.

This **FOCUS**-selected portion of the soup of reality involves some portion of the **EXTENT** of reality and some portion of the **RICHNESS** of reality. The second of the **MODALITIES** of conceptualization establishes a correspondence between the **FOCUS**-selected portion of the **EXTENT** of reality and a FOV of the conceptualization. The third of the **MODALITIES** establishes a correspondence between the **FOCUS**-selected portion of the **RICHNESS** of reality and a RES of a conceptualization. These **MODALITIES** also select the FOV and RES that are employed to establish these correspondences. Figure 7 is meant to illustrate this.

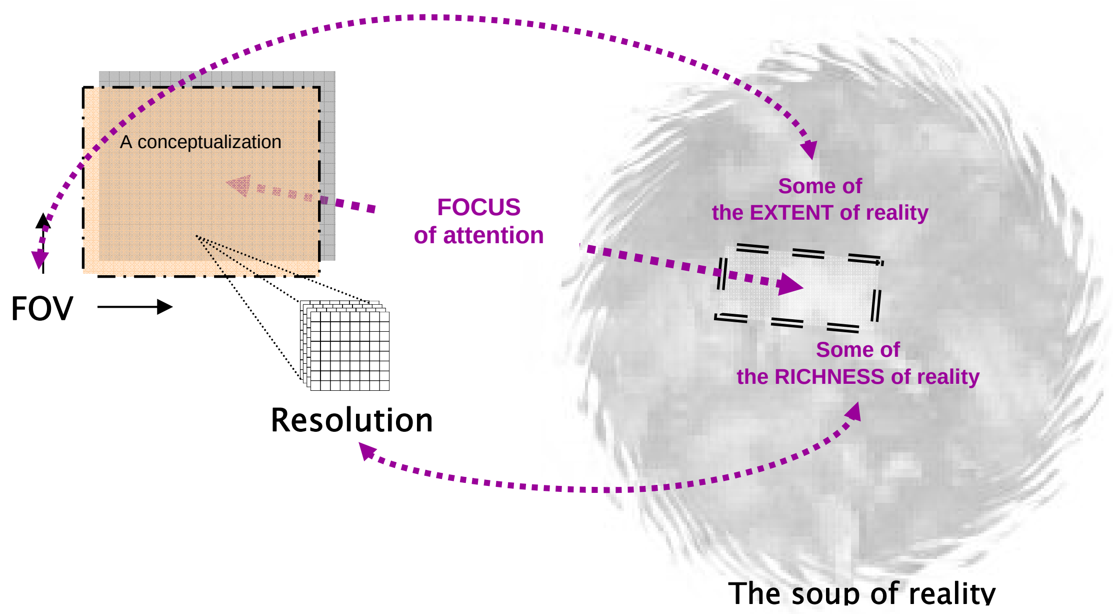


**Figure 7**

The fourth **MODALITY** we call **IDENTIFICATION**. This is the functionality of the human brain responsible for picking out and possibly aggregating (as well as labeling) portions of a conceptualization. *What* is picked out we have called **PROPERTIES**, **RELATIONSHIPS** and **OBJECTS**. These are some (or all) of the **PATTERNS** of any conceptualization. Systems at any one **SCALE** of conceptualization are very extensive and inclusive **OBJECTS** whose **IDENTIFICATION** can be understood as a **HOLON** at this **SCALE**.

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[12] It is our opinion that this functionality is itself rooted in what we conventionally call "memory." It is not the purpose of this paper to pursue this dependency. However, certain of the **MODALITIES** that we identify clearly bear the signature of this dependency (such as that of Frames of Reference).

The fifth **MODALITY** we call **FRAMES OF REFERENCE (**FORs**)**. This is the functionality of the human brain that is responsible for inducing the affinity group **AGGREGATION** *and* selection of **P-VALUES** that we have called **PROPERTIES**. A particular FOR, the so called temporal FOR, merits special attention. It will be discussed in more detail below. This particular FOR is responsible for what we understand as the **PATTERNS** in a conceptualization that we think of as the dynamics (or the functionality, or the behavior) of any system. It is these **PATTERNS** that we conventionally understand as changes, for example the changes in the selections of the **P-VALUES** of the **PROPERTIES** (of **OBJECTS**) that we conventionally call location or position when we think of something moving. These changes are also aggregated as affinity groups and accompanied by selection in our conceptualizations.

The last **MODALITY** is the functionality of the human brain that is responsible for what we call changing **SCALE**. Although it can be understood (and explained) completely in terms of the other five **MODALITIES**, there are restrictions in its application and therefore merits a separate discussion (next).

These six **MODALITIES** (**FOCUS**; the correspondence between **EXTENT** and FOV; the correspondence between **RICHNESS** and RES; **IDENTIFICATION**; **FRAMES OF REFERENCE**; and changing **SCALE**) operate either consciously or unconsciously. We will not pursue this distinction.

## 6.0 Scale and Changing Scale

Given a particular **FOCUS** and the fact that the human brain has a bounded capacity to its functionality (whatever that bound might be) there is the clear implication that there are conceptualizations of the soup of reality that we cannot form. More specifically, there are combinations of FOV and RES that we cannot use which limits, in turn, how much of the **EXTENT** and the **RICHNESS** of the soup or reality that we can conceptualize at once. This is represented in Figure 8.[13]

All of the possible combinations of FOV and RES can be thought of as a space of points {FOV, RES}. Individual combinations can be denoted as points <FOV, RES>. What we are saying is that there are points in this space that are not available to us as human observers of the soup of objective reality. These *impossible* combinations would notionally correspond to portions of the **EXTENT** and **RICHNESS** of the soup of reality just as those points that *are* available to us actually do correspond to a portion of the soup of reality. These impossible combinations we call conceptualizations beyond human comprehension.

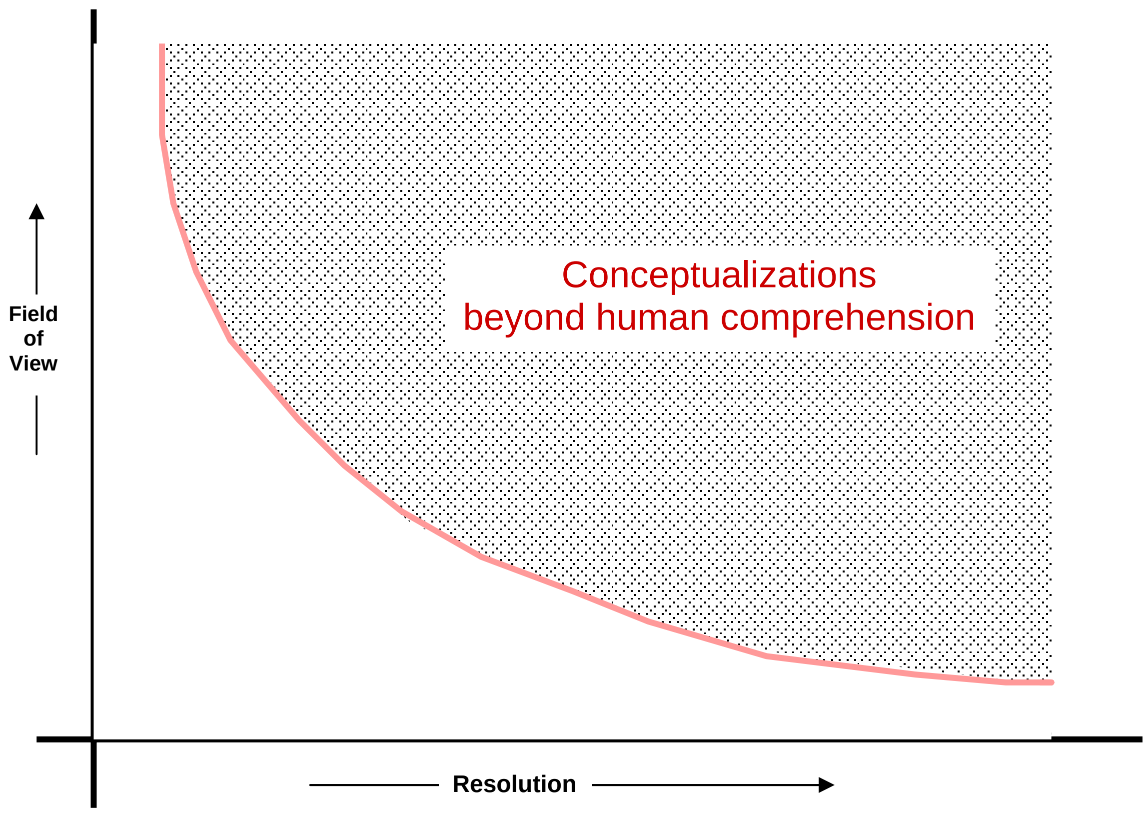


**Figure 8**

[13] This implication is not exactly the same as the assumption above that we cannot know if all of the soup of reality has been (or could be) conceptualized. As will be discussed below, changing **SCALE** is a way to partially compensate for the limitation to conceptualization being discussed. Nonetheless, even when this compensation mechanism is employed, it is still impossible to know if all portions of the soup of reality have been conceptualized.

In a moment we will look at how our brains operate to allow us to compensate – partially – for this limitation to our power to conceptualize. But first it is necessary to establish a baseline for how the basic **MODALITIES** of conceptualization can operate.

Figure 9 is meant to illustrate one facet of this phenomenon. We can increase or decrease the FOV of a conceptualization. Again, this can happen consciously or unconsciously. In Figure 9, we are suggesting an increase in FOV.

As we increase our FOV, there are clearly more **PATTERNS** to think about. **PATTERNS** are the configurations of similarities and differences that we recognize in a conceptualization. It should be obvious, however, that we cannot – as human beings – indefinitely increase the FOV of our conceptualizations. And we certainly cannot indefinitely increase FOV without impacting the RES of a conceptualization.

We can increase the **INFORMATION CONTENT** of our conceptualizations in another way. We can increase **RESOLUTION** (RES). We can do so in two ways (at least).

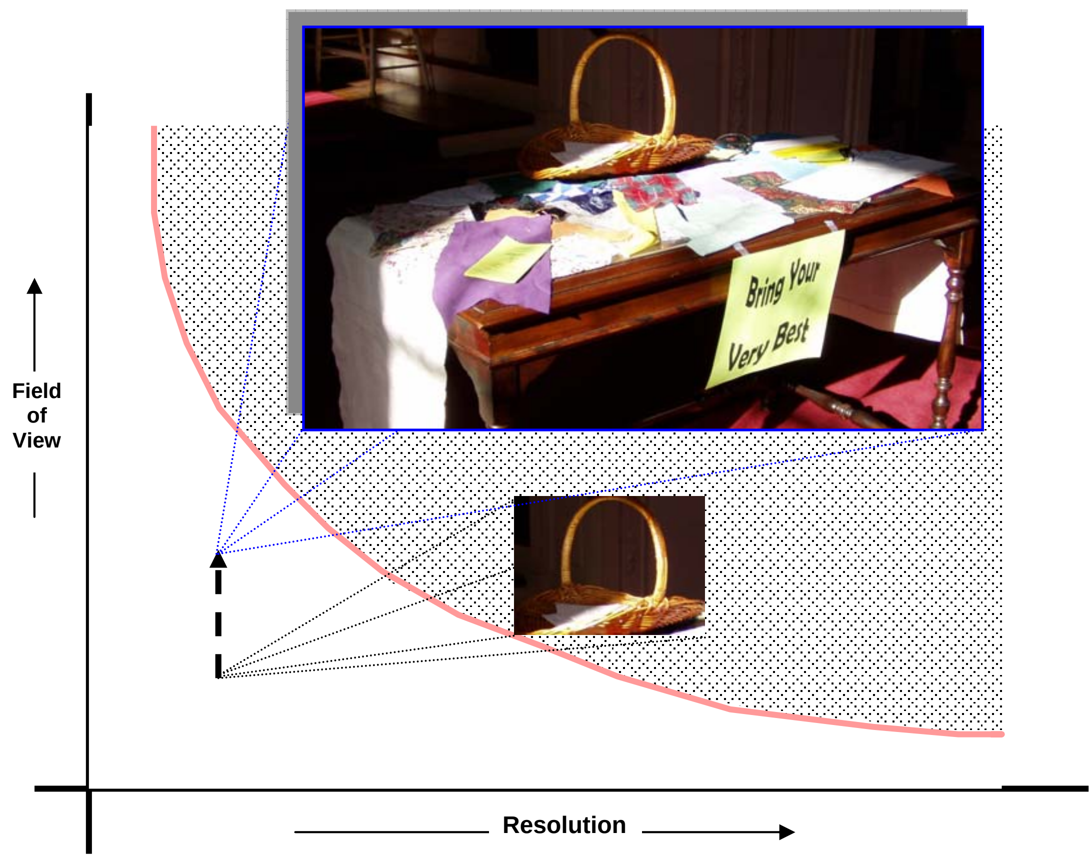


**Figure 9**

As noted above, RES is what permits distinguishing portions of any conceptualization (the "quanta" of **PATTERNS**) and recognizing their similarities and differences. Changing RES alters what *can be* distinguished. In particular, increasing RES does not automatically mean that more will actually be distinguished. That depends on what is being conceptualized. (And that depends, in turn, on the **FOCUS** of attention.)

One way to understand this is to imagine that RES is determined by an array of cellular automata in the FOV.[14] The total quantity of such automata working to build the conceptualization is then determined by their density in the FOV. Changing the density of such automata is one of the two ways to alter RES. In Figure 10, this is suggested in the change of RES from 1 to 2. As the density of the automata is increased, it becomes possible to better discern the similarities and differences of the **PATTERNS** that constitute the **CONTENT** of a conceptualization. The conceptualization contains more information.

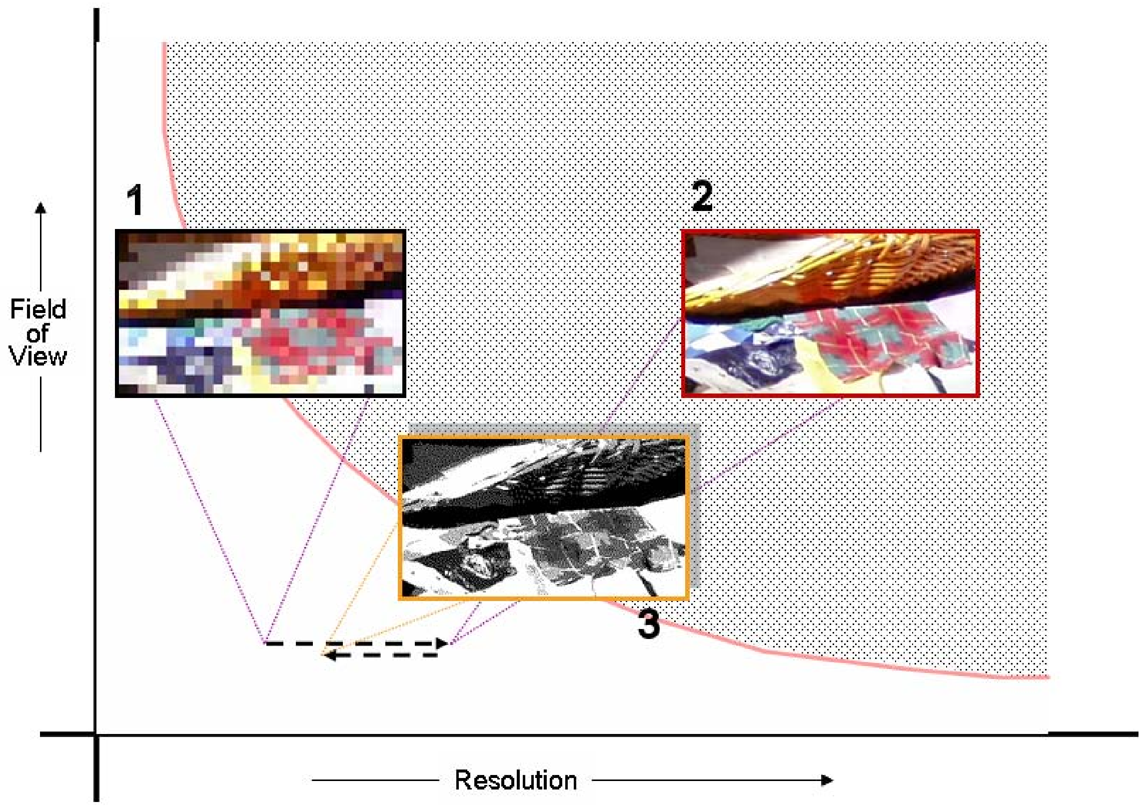


**Figure 10**

The other way to change RES involves altering the number of states available to each of the automata. (In doing so, keep the automata "programs" responsible for state changes invisible. Just the set of states of the automata is used to understand how the conceptualization is formed.) In the Figure 10, this is suggested by the change of RES from 2 to 3. As the possible states available to the automata are decreased, the **PATTERNS** that can be discerned convey less information despite the density of the automata remaining the same.

These two methods can work in combination in altering the RES of a conceptualization.

Changes to FOV and to RES can work in combination to alter the **PATTERNS** that are available in a conceptualization (yielding the conceptualization's **INFORMATION CONTENT**). Figure 11 is meant to illustrate a difficulty encountered by the human brain as

[14] An excellent discussion of automata can be found in Marvin L. Minsky's book, *Computation: Finite and Infinite Machines*, Prentice-Hall, 1967.

it attempts to expand FOV to acquire more **PATTERNS**. At some point, RES must be lowered. This is a consequence of the aforementioned limitation of the points <FOV, RES> actually available to us in the {FOV, RES} space. In terms of RES automata, this means that either or both the density of the RES automata and the number of states available to each RES automaton is reduced.

In Figure 11 we contrast a small portion of two conceptualizations of the same portion of the soup of reality but with differing FOV and RES. The “quanta” available in the portion of the “high RES low FOV” conceptualization (shown on the left) form at least two **PATTERNS**. One **PATTERN** we might think of as the relative proportions of four different shades captured by a 5x5 array of the RES automata. The other **PATTERN** in the same small portion of the same conceptualization we might call the letter “L.”

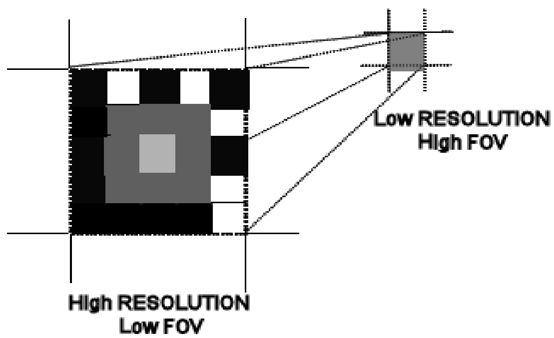


**Figure 11**

On the right is shown what is captured by a single RES automaton in the “low RES high FOV” conceptualization. It is some “average” of the four shades in the first conceptualization. This preserves the relative proportions of the four different shades in the first conceptualization, but the information associated with the letter “L” is lost. Figure 12 is also meant to be suggestive of this phenomenon, showing three distinct conceptualizations. In this case, as FOV and RES is altered, the **PATTERNS** available in the different conceptualizations (their **INFORMATION CONTENT**) changes. New **PATTERNS** are acquired, but others are lost.

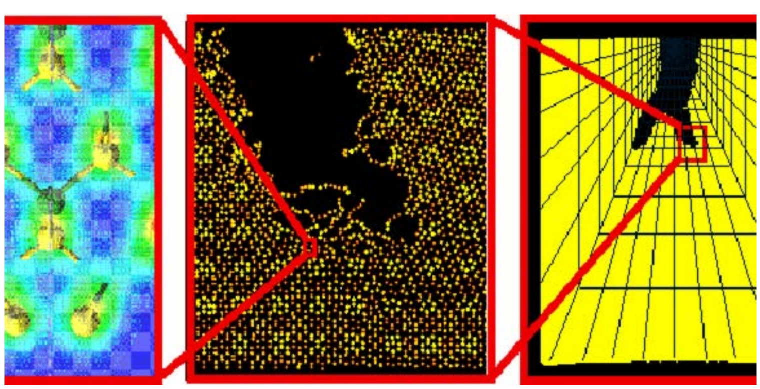

**Figure 12**

We call this a change of **SCALE**. It has been induced by a change in **FOCUS**. In changing FOV and RES, the human brain also had to make a choice of which **PATTERN(S)** to preserve (or to emphasize) in the new conceptualization with the altered FOV and RES. We call the functionality of the brain that accounts for this reselection, emphasizing and deemphasizing of **PATTERNS** the **MODALITY** of **SCALE**.

There are many ways in which **PATTERNS** can be added, removed, or reconfigured in conceptualizations. The purpose here is not to catalog them. The human brain cannot increase without bound the **INFORMATION CONTENT** of its conceptualizations. At some point, already available **PATTERNS** must be dropped or reconfigured to permit the addition of new **PATTERNS**. At such points there is a change of **SCALE**. As was noted earlier,

$\{pattern_{\varphi}\} \not\subset \{pattern_{\kappa}\}$
$\{pattern_{\kappa}\} \not\subset \{pattern_{\varphi}\}$

Of course, if changes to FOV and RES do not force such a dilemma for the human brain, then no change of **FOCUS** is necessary. But other considerations may still force a change of **FOCUS** and therefore a change of **SCALE** as we shall presently illustrate.

What is important to grasp is that when changes of **SCALE** do occur some **PATTERNS** will be lost even as others are added or preserved in a new conceptualization. This is important because all that we can think about is contained in a conceptualization. We can no longer think about the **PATTERNS** that have been lost (without returning to a previous conceptualization that contains the **PATTERNS** that have been lost).

Figure 13 is meant to further illustrate this phenomenon. In this figure the two images are suggestive of two conceptualizations. The first is meant to be a conceptualization with sufficient FOV to encompass an entire molecular cloud.[15] The cloud is an **OBJECT**. The cloud has **PROPERTIES** such as volume, temperature and pressure as well as position. (The **VALUES** that comprise these properties are induced by **FRAMES OF REFERENCE**. However, the granularity or the precision of these values are governed by the FOV and the RES of this conceptualization.) It is these **PROPERTIES**, the **RELATIONSHIPS** among them, and their **AGGREGATIONS** that are the **PATTERNS** that we treat as the **INFORMATION CONTENT** of this conceptualization.

The second image in Figure 13 is meant to be suggestive of a second conceptualization of the same portion of the soup of reality as the first, but at a very different FOV and RES. This second image also involves a new **FOCUS** (and hence is at a different **SCALE**). What is important to keep in mind as we consider these two conceptualizations based on the same portion of the soup of reality is that we can conceptualize (and therefore think about) one or the other, but not both simultaneously.

[15] This is the Horse Head nebula in the Orion constellation.

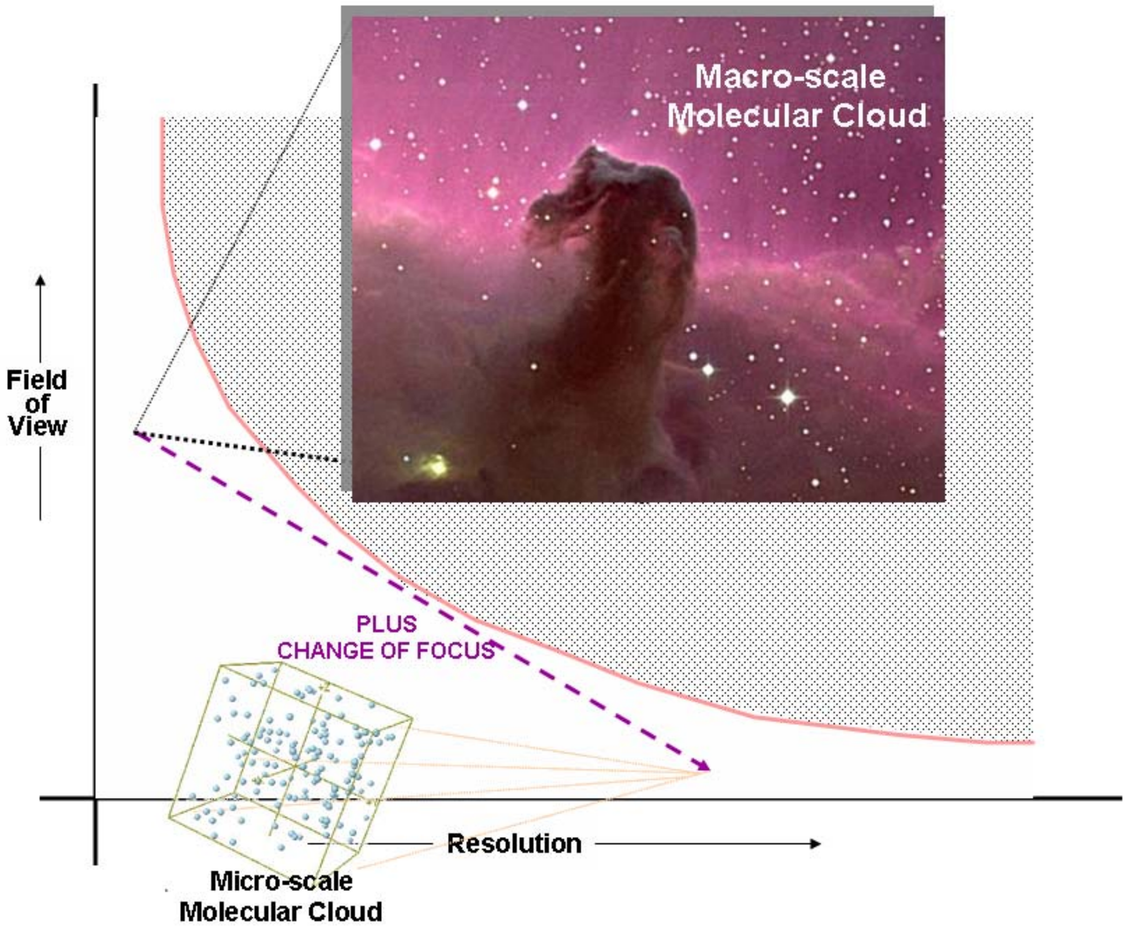


**Figure 13**

The conceptualization at the second scale (what we've termed the micro-scale conceptualization in the figure) also involves **OBJECTS**. They are molecules. And these **OBJECTS** have **PROPERTIES** such as location and velocity. We can call these **PROPERTIES** (and the **RELATIONSHIPS** among them) the kinematics of the molecules. It is these **PROPERTIES**, the **RELATIONSHIPS** among them, their **AGGREGATIONS,** and their changes that are the **PATTERNS** that we treat as the **CONTENT** of this second conceptualization.

It is now well understood that the **INFORMATION CONTENT** in the micro scale conceptualization cannot fully account for the **PROPERTIES** (and the **RELATIONSHIPS** among them) that are available in the first conceptualization's **OBJECT** of the cloud. What is not as easily accepted is why. The reason lies in the fact that we are unable to conceptualize "broadly and finely enough" so as to include all of the **PROPERTIES** and **RELATIONSHIPS** (readily available in the two separate conceptualizations) in a *single* conceptualization. We simply cannot think about the fuller set of **PATTERNS** available in both conceptualizations. We simply cannot think about how all of these **PROPERTIES** and **RELATIONSHIPS** can be combined or related to one another.

That does not mean that we can't know generally that such **RELATIONSHIPS** or combinations must exist. We simply can't think about all of this together. The scientific and engineering community has given a label to this phenomenon. It is said that the

**PROPERTIES** and **RELATIONSHIPS** of the **OBJECT** cloud (in this case) are emergent relative to the **PROPERTIES** and **RELATIONSHIPS** of the molecules. (Equivalently, the **PATTERNS** that comprise the first conceptualization are emergent relative to the **PATTERNS** of the second.)

What we will do in the next section is to provide a way to think about what actually happens in such cases of emergence. We will provide a way to think about what happens when multiple conceptualizations are needed to understand a particular system – so that it can become an engineering solution to a real world problem.

However, before we do that, it is important to appreciate that this re**FOCUS**ing or change of **SCALE** from one conceptualization to another is not always tied to changes in either FOV or RES (or both). It can happen independently of such changes. It can happen when the brain must deal with two sets of **PATTERNS** drawn in the same "quanta" that comprise those **PATTERNS**. (Recall that such "quanta" are irreducible in any given conceptualization, the configuration of their similarities and differences constitute **PATTERNS**, and that we have chosen to call these "quanta" **PROPERTIES**, **RELATIONSHIPS** and their **AGGREGATIONS**.)

Figure 14 is frequently termed an "optical illusion." There is nothing illusory about it however. What it serves to illustrate is what happens when our brains are confronted with the seeming relevance of two sets of **PATTERNS**. It can only conceptualize one set of **PATTERNS** or the other because the "quanta" in which those **PATTERNS** are rendered are irreducible. Changes in RES or in FOV are irrelevant. As you reflect on this image, you will eventually recognize both an Eskimo and an Indian Head. Both are present, but your brain can only **FOCUS** on one or the other. It can, however, toggle between them, and does so. This is an example of a change in **SCALE** without a change in FOV or RES.

Admittedly, it is not *absolutely* impossible to maintain both conceptualizations in such a simple case as suggested by this optical illusion. That is because it is so simple. As conceptualizations become more densely packed with **INFORMATION CONTENT** (**PROPERTIES**, **RELATIONSHIPS**, and their **AGGREGATIONS**) it actually does become impossible. Our brains have to make a choice for one **FOCUS OF ATTENTION** or another. And still, we can continue to toggle between them. This re**FOCUS**ing is how our brains partially compensate for the seeming limits to our powers of conceptualization due to their bounded capacity.

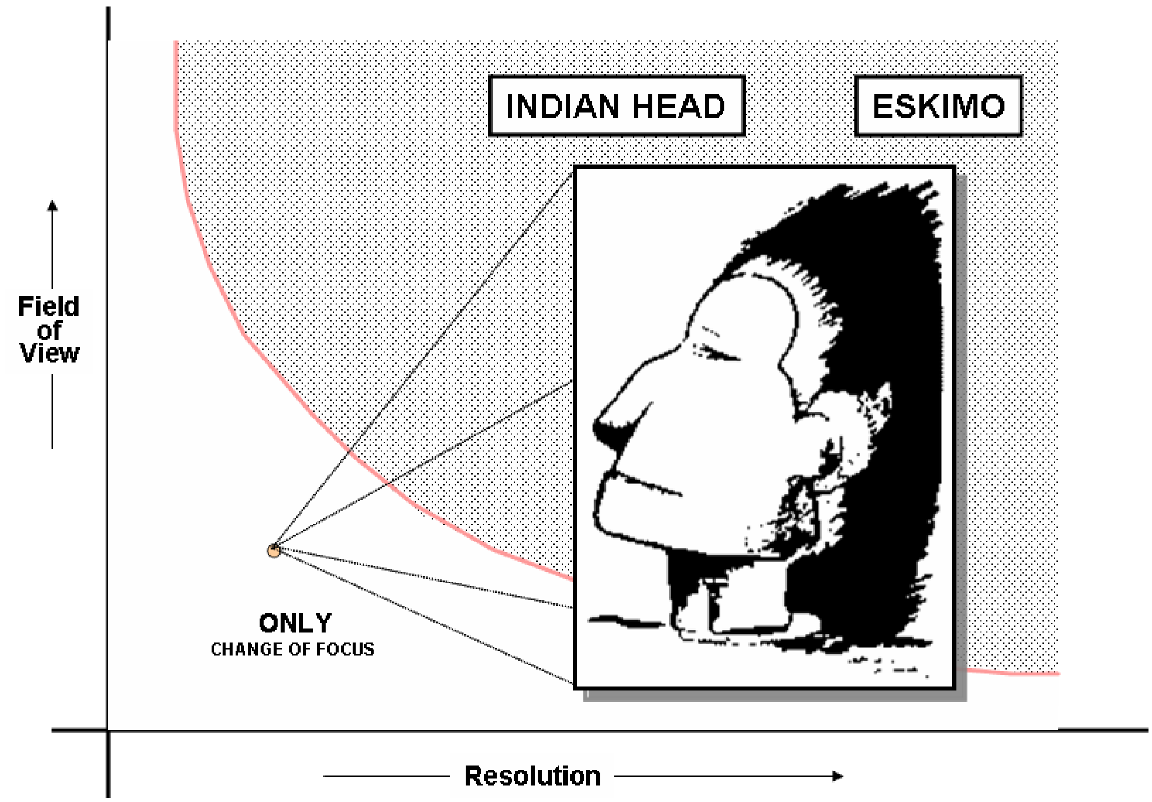


**Figure 14**

The term emergence is not normally associated with this form of change in **SCALE**. The term emergence is usually reserved for changes in **SCALE** that are accompanied by changes in FOV and RES.

This is an important **MODALITY** of our brains. Unfortunately, it has not been adequately accounted for in terms of how we think about systems. The time has come to do so.

It is also very important to appreciate just how automatic that this ability to change **SCALE** is when used by our brains to cope with the task of conceptualizing beyond its straightforward capacity. And how difficult it is to notice its operation. It is very difficult to recognize what has "gone missing" in new conceptualizations at a different **SCALE**. And even more importantly we can no longer think about what is missing as long as we maintain the conceptualization in which such **PATTERNS** are not present.

# 7.0 Properties, Objects, and Relationships

## *7.1 Properties*

In the above discussion, we have indicated that **PROPERTIES** are **AGGREGATIONS** of **P-VALUES** along with a selection among those **P-VALUES**. This can be denoted as follows where P denotes a **PROPERTY**, the $V_i$ denote **P-VALUES**, and the underlined **P-VALUE** is selected.

$P \equiv \{ V_1, V_2, V_3, \ldots \underline{V}_n, V_{n+1}, \ldots \}$

Clearly P is an **AGGREGATION**. An **AGGREGATION** (or a set) is just a *collection* that can lose (or change) its *identity* in our conceptualizations whether or not we can conceptualize changes to its membership. A **PROPERTY** is an **AGGREGATION** of **P-VALUES**. It is not, however, an arbitrary **AGGREGATION**. This type of **AGGREGATION** is a consequence of the **MODALITY** of conceptualization that we have labeled **FRAMES OF REFERENCE**. A **PROPERTY** is an **AGGREGATION** of **P-VALUES** with some affinity *and* a selection among those **P-VALUES**. We call this sort of **AGGREGATION** an affinity group. All affinity groups are **AGGREGATIONS**, but not all **AGGREGATIONS** are affinity groups.

Quite clearly, our brains also collect together **PROPERTIES** in forming conceptualizations. Its doing so is so intuitive and straightforward that it is hard to explicitly recognize that it is happening. We used this fact above to open the discussion. We gave the label of **OBJECTS** to such **AGGREGATIONS**. We used the **OBJECTS** labeled as blocks as an example. We noted that the **PROPERTIES** of color and of location were aggregated as blocks in the example. Each block had these properties in our example conceptualization. (The blocks could have had other **PROPERTIES** as well.)

In *most* conceptualizations, **PROPERTIES** do not float freely. They are aggregated as **OBJECTS** in our conceptualizations. We always understand them as the **PROPERTIES** *of* something.[16] This is a consequence of the **MODALITY** that we have labeled **IDENTIFICATION**. (This **MODALITY** is that portion of the brain's functionality that isolates *anything* in our conceptualizations as well as contributing to their **AGGREGATIONS**.) Since **PROPERTIES** can never float freely (be independently **IDENTIFIED**) in our conceptualizations (they are always aggregated), it is not appropriate to use them as the most basic "building blocks" for our conceptualizations of systems and we don't.[17] Instead, we will use **OBJECTS** in this role. However, **OBJECTS** are not irreducible in our conceptualizations, as we have just noted.

This is a seeming oddity – an **OBJECT** is *not* irreducible, but it is nonetheless a most basic fraction of any single conceptualization. As we will see, this can be used to help us to understand what happens when we change the **SCALE** of our conceptualizations. And we will do so.

[16] We can, of course, conceptualize *individual* properties. Since, however, we are interested in understanding how we conceptualize systems this exception is omitted in the discussion.
[17] To do otherwise would be much like insisting that since atoms can be resolved into electrons, protons, and so forth, that chemistry should be expressed in terms of such elemental particles.

But first we need to be a bit more precise by what we mean by an **OBJECT**. Another *label* for an object is an “element.” We will use the letter E to denote a simple **OBJECT**. A simple object is an **AGGREGATION** of **PROPERTIES**, $P_i$.

$E \equiv \{ P_i \}$ where $i \in I$ and I is an index set that enumerates the properties that belong to E.

In the simplest of conceptualizations, an **OBJECT** can be an **AGGREGATION** of just a single **PROPERTY**. We will just note here, as others have, that there is an important difference between an **AGGREGATION** of one member item and that one member item itself. We do not conceptualize them equivalently.[18]

## 7.2 Relationships

As we noted above, the **P-VALUES** of the **PROPERTIES** of **OBJECTS** in certain conceptualizations need not be independent. We used as an example the blocks in a pyramid and the blocks in a heap to make this distinction between independence and interdependence. It is now time to make this distinction more precise.

When we speak of a “relationship” of any kind what we are saying is that it is possible to infer or to deduce knowledge about one thing based on a knowledge of other things. Said another way, our conceptualization of one thing must be consistent with our conceptualization of another thing *if* there is a “relationship” between the two things. (And, course, this extends to multiple things.) This consistency means that the things involved are not independent. They are interdependent in some fashion.

We will say that there is a **RELATIONSHIP** among the **PROPERTIES** of **OBJECTS** if the **P-VALUES** of the various **PROPERTIES** in a conceptualization are not independent. Their **P-VALUES** are *not* free to be selected without regard to the selections associated with other **PROPERTIES**. These **RELATIONSHIPS** – if they are present – are as much a part of a conceptualization as are the **OBJECTS** of a conceptualization. A **RELATIONSHIP** (REL) can be represented as shown in Figure 15, where several **PROPERTIES** ($P_1$ through $P_z$) have their respective **P-VALUES** connected to one another.

Not all of the **PROPERTIES** involved are explicitly shown. (This is suggested by the ellipses and dotted circles.) What this figure is meant to convey is that if the **P-VALUE** $V_1$ of **PROPERTY** $P_1$ is selected, then the **P-VALUES** of the other **PROPERTIES** in the same expression of the **RELATIONSHIP** are also selected; if either **P-VALUE** $V_4$ or $V_5$ of **PROPERTY** $P_1$ is selected, then the **P-VALUES** of the other **PROPERTIES** in the expression are also selected; and so on.

The can be condensed into:

$REL \equiv \{ exp_j \}$

[18] Alfred N. Whitehead and others have explored this difference extensively in their writings. It is at the root of most so called paradoxes such as Russell’s Paradox or the Sorites Paradox. Such paradoxes are essentially parlor tricks using multiple **SCALES** of conceptualization.

where $\exp_j$ denotes a single expression of the **RELATIONSHIP** and $j \in J$ where J is an index set that enumerates all of the expressions in the **RELATIONSHIP**. An expression captures the interdependencies in the selections of **P-VALUES** of multiple **PROPERTIES**.

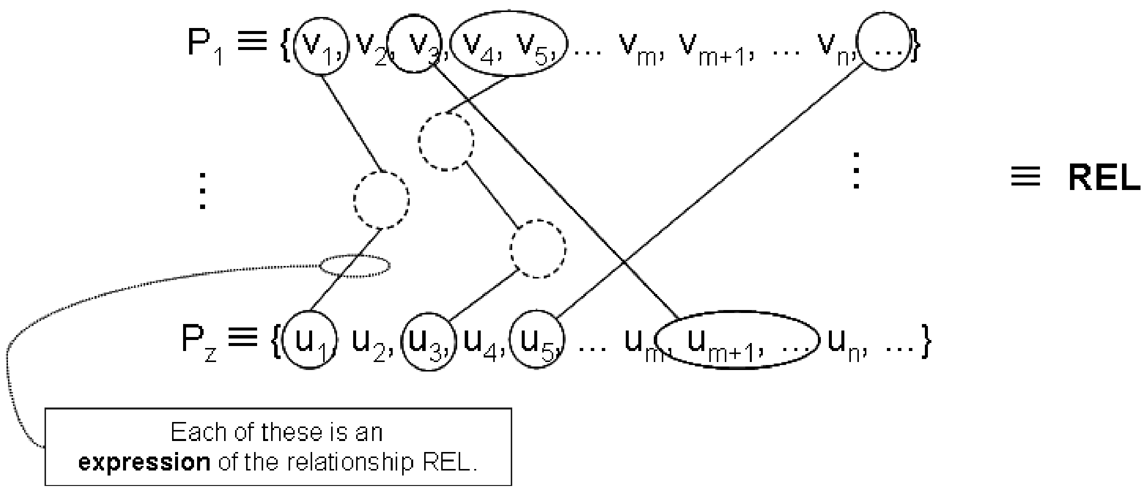


**Figure 15**

For those so inclined, an entire **RELATIONSHIP** can be considered to be a sparse Reed (or combinatoric) network with **P-VALUES** as its nodes, and expressions as its links. The links in a Reed network are *not* directional (either unidirectional or bidirectional) as they usually are in both Sarnoff and Metcalf networks. Links in Sarnoff and Metcalf networks are usually used to model flows; and directionality is essential. Links in Reed networks are non-directional or associational. Many nodes can be associated by a *single* link (and many links can involve a single node).[19] Almost all functions in mathematics are special cases of **RELATIONSHIPS**.

## *7.3 Objects*

Rather than distinguishing simple and compound **PROPERTIES** (and **RELATIONSHIPS**), we believe it is more appropriate to distinguish between simple and compound **OBJECTS**. We have already suggested a definition for a simple **OBJECT**, above. However, we will now state explicitly that a simple **OBJECT** involves no **RELATIONSHIPS** among its **PROPERTIES**, per se. In other words, a simple **OBJECT** is exactly and only an **AGGREGATION** of **PROPERTIES;** and those **PROPERTIES** are independent of one another other than to belong to the same simple **OBJECT AGGREGATION**. That they *are* aggregated in a conceptualization is a consequence of the **MODALITY** of **IDENTIFICATION**.

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[19] Although it well beyond the scope of this paper, we believe that **RELATIONSHIPS** reflect a deep neurological structure of the human brain. The human brain is a network of neurons, but it is fundamentally a Reed network, and not a Metcalf network as frequently assumed. Most importantly, its connectivity (in terms of the number of possible links) in bounded by $2^n$, where n is the number of nodes or neurons. Connectivity is the primary determinant of network capacity. In actuality, the capacity of the human brain is much less, since associations are spatially and temporally constrained. Associations made in the neurological network of the brain need to be essentially simultaneous. (Said another way, the maximum span of associations – Reed links – determines what we understand as simultaneity.)

A compound **OBJECT** is an **AGGREGATION** of simple **OBJECTS**, **RELATIONSHIPS**, and possibly other compound **OBJECTS**. A compound **OBJECT** can be decomposed completely and exactly according to the rules of reductionism.[20] This remains true even if increased **RESOLUTION** is employed to add precision to or to reveal new composite portions of the **OBJECT** *so long as there is no change of* **SCALE**.

This last restriction is crucial and is a primary reason for why this paper has been written. When the human brain employs a change of **SCALE**, different **OBJECTS** are formed in the new conceptualization that can involve the addition, deletion, and (most importantly) the re-**AGGREGATION** of portions of **OBJECTS** relative to the those in a previous conceptualization. This is equivalent to saying that different **PATTERNS** are available in the new conceptualization relative to a previous conceptualization exclusive of simple addition or subtraction. In other words, the **OBJECTS** (simple and compound) of a conceptualization at one **SCALE** are not the **OBJECTS** (simple and compound) at another **SCALE** of conceptualization. Reductionism cannot apply. And we cannot figure out (think about) how the **OBJECTS** at one **SCALE** correspond to those at another **SCALE**. In particular we cannot assume that we can always decompose an **OBJECT** at one **SCALE** into **OBJECTS** at other **SCALES** in a manner consistent with reductionism. We can, of course, note the seeming overlaps, and this is the root of the notion of emergence.

A new definition of a system must account for this phenomenon since many of the systems that we are now attempting to engineer require conceptualizations at multiple **SCALES** and it must be apparent when and when not the rules of reductionism apply. The latter is important since reductionism is an important predicate for "traditional" system engineering.

We also need to highlight another distinction between **OBJECTS** and **PROPERTIES**. A **PROPERTY** is an affinity group with selection from among the members of the affinity group that is essentially *invariant* across multiple conceptualizations. **OBJECTS** are **AGGREGATIONS** that are *specific* to individual conceptualizations.[21]

[20] **"Reductionism."** *Encyclopædia Britannica* from Encyclopædia Britannica 2006 Ultimate Reference Suite DVD. Or see the paper *Complexity and Philosophy* referenced at note 3.

[21] The invariance and specificity referenced here are "soft" since both are rooted in memory and memory involves accumulations that we associate with learning. For example, we can learn about additional **p-VALUES** that compose the affinity group of a **PROPERTY**; and we can recognize the same **OBJECT** in many different conceptualizations.

## 7.4 Holons

In his 1976 book, *The Ghost in the Machine*, Arthur Koestler, gave this label (the **HOLON**) to a notion already familiar to many: that something can be conceptualized as a *whole* even while being conceptualized as *part of* something more extensive in the conceptualization. He went beyond this, relying on assumptions about decomposition and hierarchical organization. We do not need to do so here.

In the terminology that we have developed in this paper, a **HOLON** is a consequence of the operation of the **MODALITY** of **IDENTIFICATION**. What matters is that a system must *always* be a **HOLON**. In particular, a **HOLON** is always a part of a more expansive conceptualization, and this applies to a system. A system is *always* a part of a conceptualization.

By common convention, we distinguish a system from its environment (or its context). The environment is that portion of a conceptualization that is not the system.

Although it may seem trivial and almost too obvious to mention at first, this aspect of any system is important. It is *impossible* to conceptualize a system without at the same time conceptualizing at least some portion of its environment.[22] The importance of this notion becomes more apparent when we consider how a system and its environment are parsed by our brains in conceptualizations at *multiple* **SCALES**. A definition of a system must account for this treatment.

[22] We could discuss this in a variety of ways. For example, if we cannot conceptualize a system as being a part of something larger, then it lacks a necessary cohesion in our conceptualization of it. And our **MODALITY** of **IDENTIFICATION** refuses to give the system a distinctiveness in our conceptualization. As the saying goes, if all that we see are trees, we cannot see the forest. The forest must adjoin something that is not forest.

## 8.0 Frames of Reference (FORs)

**FRAMES OF REFERENCE** are a **MODALITY** of conceptualization. FORs induce affinity groups of **P-VALUES**. Assembling such **AGGREGATIONS** based on affinities is a portion of the FOR **MODALITY**. In this respect FORs utilize information from prior conceptualizations. [23] The FOR **MODALITY** does something else as well. It emphasizes pertinent **P-VALUES** in a conceptualization. (Above, we had said that **P-VALUES** in **PROPERTY AGGREGATIONS** are selected not just aggregated. That is what we are discussing here.)

Selected (or emphasized or pertinent) **P-VALUES** for a **PROPERTY** can change in a conceptualization. And there can be **PATTERNS** in such changes. [24] We can think of such **PATTERNS** as a *sequence* of **P-VALUES** in the individual **PROPERTIES**, *and* the alignment of such sequences across all **PROPERTIES**. This sequencing and alignment across all **PROPERTIES** is the *temporal* **FRAME OF REFERENCE**. It is another sort of affinity with selection that the human brain can accomplish. It is, however, central if we wish to discuss the functionality (or the behavior or the dynamics) of systems. A temporal FOR applies to an entire conceptualization. (It is specific to a **SCALE** to be more precise.)

We can capture its influence as follows

$$P^t \equiv [V_a\ V_b\ V_c \ldots V_d \ldots V_e\ \underline{V}_f \ldots]$$

where t designates the temporal FOR; P is a **PROPERTY**; [ … ] designates a sequence;

$V_a$, $V_b$, etc. are drawn from $\{V_i\}$; and the underlined **P-VALUE** is the selected **P-VALUE –** the *currently* selected **P-VALUE** in the temporal FOR.

If a temporal FOR is included in a description of a conceptualization, then a simple **OBJECT** can be described as

$$E^t \equiv \{P^t_i\}$$

The impact of FORs on **RELATIONSHIPS** is more subtle. Not only can we recognize interdependencies among the **P-VALUES** of different **PROPERTIES** (as discussed above), we can also recognize that there are lags in such interdependencies, and that there are similarities and differences in such lags. These lags form **PATTERNS**. The **P-VALUES** that are interdependent are not all selected together but there is a **PATTERN** in their selection. Using the above, we can describe how a temporal FOR influences a **RELATIONSHIP**, designated as $REL^t$. This is shown in Figure 16.

[23] Whether these prior conceptualizations are entirely individual experience based or partially given to us (genetically, or however) is not the issue here. As we noted earlier, we believe that FORs are signatures of the brain's memory capability, capacity, and accumulation.

[24] We are not discussing **RELATIONSHIPS** here. **RELATIONSHIPS** pertain to recognized interdependencies among **P-VALUES** across *different* **PROPERTIES**. **RELATIONSHIPS** in the context of a temporal FOR are discussed below.

Again, the temporal FOR induces both a sequencing of **P-VALUES** in **PROPERTIES** and the alignment of such sequences. The interdependencies captured by **RELATIONSHIPS** overlay this alignment. All of this contributes to **PATTERNS** that we can recognize as the **CONTENT** of conceptualizations.

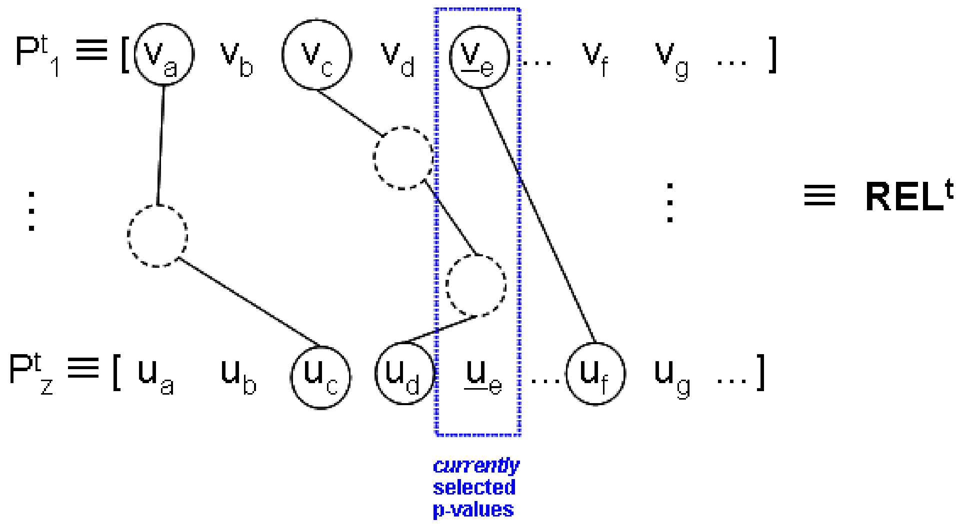


**Figure 16**

## 9.0 A New (Revised) Definition of a System

An increasing number of the systems of interest to practitioners of system engineering require conceptualizations at multiple **SCALES**. At the same time, we cannot generally hold or think about conceptualizations at multiple **SCALES** at once – and this applies to the systems that are parts of such conceptualizations. Current definitions of systems do not address this – and are actually suggestive that this is without consequence by virtue of its omission in such definitions. But there *are* consequences. We will examine a few of those consequences, but first we must look at a new and revised definition of a system to do that conveniently.

As befits a first attempt at a more generalized and more explicit revised definition of a system, there are several parts to it. First we will state all of the parts, and then we will cycle through them, noting some of the important consequences as we go.

$$\mathcal{S} \equiv \{ P_m ; REL_n \}_{\mathbf{M,N}} ; H$$

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$$\mathcal{S}^{\mu} \in \{S^{\mu}\},\ S^{\mu} \equiv \{ E_i ; REL_j \}_{\mathbf{I}^{\mu},\mathbf{J}^{\mu}} ; H^{\mu}$$

$$\vdots$$

$$\mathcal{S}^{\nu} \in \{S^{\mu}\},\ S^{\nu} \equiv \{ E_i ; REL_j \}_{\mathbf{I}^{\nu},\mathbf{J}^{\nu}} ; H^{\nu}$$

- A system, $\mathcal{S}$, is an collection { } of parts (Properties and Relationships) that:
  - 1. Is approximated by conceptualizations at one or more scales $\mu$ through $\nu$ denoted as $\mathcal{S}^{\mu}$, etc.;
  - 2. Is always conceptualized as a Holon $H^{\mu}$ at each scale at which the system is conceptualized ($H^{\mu}$, $H^{\nu}$, etc.);
  - 3. Is always conceptualized at each scale as Objects ($E_i$) and Relationships ($REL_j$).
- For $\mathcal{S}$,
  - $P_m$ denotes a Property and $REL_n$ denotes a Relationship; $m \in M$ and $n \in N$ where M and N are index sets enumerating all Properties and Relationships in all possible conceptualizations;
  - H denotes the Holon that explicitly distinguishes the parts of the system from the parts of its environment and that explicitly provides the cohesion of its parts as a whole.
- For each scale specific approximation, $\mathcal{S}^{\mu}$,
  - The relevant modalities of Focus, FOV, RES, and FORs are explicitly noted.
  - $S^{\mu}$ denotes all the time invariant parts of the scale specific approximation; time invariant means without recourse to temporal FOR;
    - The text discusses the impact of a temporal FOR on this definition.
  - $E_i$ denotes a simple Object and $REL_j$ denotes a Relationship; $i \in I^{\mu}$ and $j \in J^{\mu}$ where $I^{\mu}$ and $J^{\mu}$ are index sets enumerating all of the simple Objects and Relationships available at scale $\mu$;
  - Simple Objects and Relationships can be aggregated as compound Objects consistent with reductionism and determinism.

**Figure 17**

A system, $\mathcal{S}$, is a collection of **PROPERTIES** and **RELATIONSHIPS** that is both a whole and a part of a more expansive whole. This duality is essential and is termed a **HOLON**. (The latter is captured by the non superscripted H in the first formula.) A system must be a **HOLON**. (If something is not a **HOLON**, then it can't be a system.) To say that a system is a **HOLON** means that there is a cohesion to its parts that allows its treatment as a whole; and that whole is itself just a part of "something more." By convention, that which is not the system in this “something more” is a called the system’s environment. This distinguishing of the system from its environment can also be termed the system’s identity.

In general, we *cannot* conceptualize a system defined in this way. There are two fundamental reasons (at least) for this, and the definition reflects both. First we can only conceptualize at specific **SCALES**. We cannot conceptualize with combinations of conceptualizations at multiple **SCALES**. Second, we do not conceptualize **PROPERTIES** separately when they are portions of systems. Properties are always “of” something. At any **SCALE** of conceptualization, **PROPERTIES** are *always* **AGGREGATED** (at least) as what we have termed here simple **OBJECTS**.[25]

A system can only be conceptualized at individual **SCALES.** One of those **SCALES** is designated $\mu$ and the **SCALE** specific approximation of that system is designated $S^{\mu}$. There can be more than one such conceptualization of the *same* system. These are designated in the definition by the ellipse and the “final” **SCALE**, $\nu$, of conceptualization with its **SCALE** specific approximation of the system, $S^{\nu}$.

The system at any **SCALE** of conceptualization is an *approximation* of the system. The word approximation is not used here as it might be used in saying that 3.14 is an approximation of pi ($\pi$). Approximation is used here in the sense of loose congruence and partial inclusiveness. A **SCALE** specific conceptualization of a system is partial if there are **PATTERNS** pertinent to an observer’s interest in a system that are only available at other **SCALES**. (Patterns are simple **OBJECTS**, **RELATIONSHIPS**, and their **AGGREGATIONS** with or without a temporal FOR.)

A **SCALE** specific conceptualization of a system is not an “abstraction” of the system, although this might be a tempting idea at first. Abstracting means leaving things out with the understanding that what is left out can always be reinserted. What are “left out” of a **SCALE** specific conceptualization of a system are patterns that might be available at other **SCALES**. Such patterns cannot be returned to a **SCALE** specific approximation of a system, regardless of RES or FOV. The “missing” **CONTENT** has no place in the conceptualization. It is never available to begin with. A **SCALE** specific approximation of a system can, however, be abstracted. And such abstraction complies with the laws of reductionism (and determinism, if a temporal FOR is employed).

The system as at a specific **SCALE** must always be a **HOLON**, but it is a **HOLON** at its specific **SCALE**. This is designated by a superscripted H in the formulas. At each **SCALE** (because of the applicability of reductionism) the **SCALE** specific approximation of the system can be disjointly partitioned from its environment. That means that the whole of the system (as a **HOLON**) has a well defined boundary with its environment.

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[25] Another term for a **PROPERTY** that more closely links it with the **OBJECTS** of which they are **AGGREGATIONS** is the term “a degree of freedom.” A degree of freedom is always “of” something (just as we have said is the case for **PROPERTIES**). A simple **OBJECT** can perhaps be better understood by some as the **AGGREGATION** of some number of degrees of freedom that are independent of one another – there are no **RELATIONSHIPS** among the degrees of freedom other than to belong to the **AGGREGATION** that we have termed a simple **OBJECT**.

To say that a boundary disjointly partitions the approximation of a system from its environment means that simple **OBJECTS** in the conceptualization belong either to the **SCALE** specific approximation of the system *or* to its environment – but never to both.

Given this understanding, inputs and outputs of the **SCALE** specific approximation of the system can be unambiguously associated with **RELATIONSHIPS** that involve **PROPERTIES** at least some of which belong to the environment *and* some to the system. (A **PROPERTY** belongs to the system or to the environment if the **OBJECT** of which it is a **PROPERTY** belongs to the system or to the environment.) If a **SCALE** specific approximation of a system has no inputs or outputs, it is termed closed at a specific **SCALE**; otherwise it is open. Even if a system is closed, it must still be a **HOLON**. Otherwise, it is not conceptualized as a system.

Such a boundary, however, will appear inappropriate or even non existent at other **SCALES** of conceptualization. This is because **OBJECTS** (as aggregations of **PROPERTIES** and possibly **RELATIONSHIPS**) can be **AGGREGATED** differently at different **SCALES**. This is true even if the *same* **PROPERTIES** are aggregated at a new **SCALE** – but this extreme case is rare since changes of **SCALE** almost always reveal new **PROPERTIES** (and **RELATIONSHIPS**) and delete others. As a consequence, the **OBJECTS** that were the basis of the boundary at a first **SCALE** are no longer apparent at a second **SCALE**, or they are in conflict with the **HOLON** nature of the system at the second **SCALE**. In other words, systems that require multiple **SCALES** of conceptualization in order to be properly understood also have ambiguous or shifting boundaries relative to their environment at multiple **SCALES**. This is a direct consequence of our new (revised) definition of a system and should no longer seem mysterious or troubling. But it can't be ignored either.

Regardless of the number of **SCALES** used to conceptualize a system, it can never be known if the system has been completely conceptualized. This may seem frustrating at first, but it aligns with the assumption made at the outset that it can never be known if the soup of reality has been completely conceptualized. But it is also a consequence of changing **SCALES** (one of the **MODALITIES** of conceptualization). Changing **SCALES** adds, deletes, and reconfigures **PATTERNS** that are the **CONTENT** of conceptualizations but there is no way to know or to learn that all **PATTERNS** have been conceptualized at one or more **SCALES**. Completeness is not possible. Using multiple **SCALES** of conceptualization can be understood, however, as a way of asymptotically approaching such completeness.

Completeness *does* apply to a **SCALE** specific conceptualization of a system. Completeness and reductionism (and determinism) are important predicates for all of the methods that are "traditional" system engineering. As a consequence, if "traditional" system engineering is to be used, it is important to limit its application to only those systems that can be adequately conceptualized at a single **SCALE** (with one or more FOVs and RESs as necessary).

The definition of a system provided above is not directly cast in a fashion that requires that temporal **FRAMES OF REFERENCE** be made explicit. They are important nonetheless and should be appended to the above definition at those **SCALES** for which it is appropriate (useful) to do so. This is when the system's behavior is important.

However, before we consider the role of temporal **FRAMES OF REFERENCE**, one final aspect of the above definition must be addressed. At each **SCALE** at which a system is conceptualized it is characterized in the above definition as a member of a set whose members are themselves collections of simple **OBJECTS** and **RELATIONSHIPS** bound together as a **HOLON**. This is done without regard to the impact of any temporal **FRAME OF REFERENCE**.

Systems can be characterized as having substance, structure, and behavior. (Behavior can also be termed functionality or dynamics.) Temporal **FRAMES OF REFERENCE** are useful in understanding the behavior of a system. The *substance* of a system can be understood as the **OBJECTS** of the system conceptualized at one or more **SCALES**. As **SCALE** is changed, what is thought of as the substance of the system is likely to change for the reasons already discussed: **OBJECTS** are aggregated differently at different **SCALES**. This should be evident in the example above of the Horse Head nebula.

The *structure* of a system can be understood as the **RELATIONSHIPS** of the system conceptualized at one or more **SCALES**.[26] **RELATIONSHIPS** can seem to change, as well, from **SCALE** to **SCALE**, especially as they are aggregated as portions of compound **OBJECTS**.

When a system is conceptualized at a given **SCALE**, without regard to its behavior, what is emphasized is its substance and structure at that **SCALE**. Because completeness and reductionism apply (as noted above), it is possible to conceptualize systems at a given **SCALE** that are absolutely identical (cannot be *differentiated* even though they can be *distinguished*). This is a frequently occurring phenomenon in the practice of "traditional" system engineering. Many copies of the "same" system can be realized. This is a predicate for "mass production." Such systems can only be differentiated once a temporal **FRAME OF REFERENCE** is explicitly employed – in order to make behavior a portion of the conceptualization of the systems. For example, we may all be using the same kind of watch, but they can tell different times. They are all substantively and structurally the same, but they can be behaving differently. Admittedly, their behavior is constrained by their **RELATIONSHIPS** (which can be, in the ideal, exactly the same), but even in the ideal, the watches can still tell time differently. We can reset ours, but you don't reset yours, for example. This "absolute" congruence among many instances of the same system "template" has become the basis for many essential "best practices" in "traditional" system engineering such as "configuration control." Configuration control has been successfully applied to the substance and the structure of systems, but not to their behavior. That is because systems (even at the same **SCALE** of conceptualization) are all potentially unique if their dynamics are explicitly considered.[27]

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[26] The substance of a system can also be thought of as its "tangible" aspects. And **RELATIONSHIPS** and the time varying aspects of both **OBJECTS** and **RELATIONSHIPS** that are induced by a temporal **FRAME OF REFERENCE** can be understood to constitute the "intangible" aspects of a system. However, it is important to keep in mind that we can conceptualize systems that are completely intangible as we normally use that term (without substance, or can't be touched). Our powers to conceptualize proceed in exactly the way as discussed in this paper in such situations. Portions of the conceptualization are aggregated as **OBJECTS** and portions are treated as **RELATIONSHIPS.** A system of bidding in the game of Bridge can be used to illustrate this.

[27] This difficulty is compounded when **PATTERNS** only available at *other* **SCALES** of conceptualization bear on a problem of interest to the system engineer but are treated as incidental or beyond the "span of control" of the traditional system engineer. Such **PATTERNS** cannot be included in or accounted for in the chosen **SCALE** specific approximation of the system regardless of whether or not behavior is considered.

The above definition of a system captures this aspect of the influence of our **MODALITIES** of conceptualization by noting that at any given **SCALE** system approximations are identical members of the same set as long as behavior is not explicitly considered. We can realize as many systems as we want that are identical when approximated at a given **SCALE** of conceptualization, exclusive of a temporal **FRAME OF REFERENCE**.

In order to explicitly incorporate a temporal **FRAME OF REFERENCE**, two changes to the above definition are necessary. The first change involves substituting $E^t_i$ for $E_i$ and $REL^t_j$ for $REL_j$ in the **SCALE** specific approximations of a system. The second involves rewriting appropriate **SCALE** specific approximations of the system as follows:

$$s^{\mu} = \mathcal{S}^{\mu} \equiv \left\{ E^{t}_{i} ; REL^{t}_{j} \right\}_{I^{\mu}, J^{\mu}} ; H^{\mu}$$

Again, it is important to emphasize that a temporal **FRAME OF REFERENCE** applies to an entire conceptualization. Each system (although perhaps identical in terms of substance and structure) can still be distinguished *and* differentiated according to its behavior.

## 10.0 Recognizing Changes in Scale

The above revised definition of a system explicitly introduces the notion of **SCALE** into a definition of a system. This sets it apart from all earlier definitions. But **SCALE** is a difficult notion to understand – never mind to accept. **SCALE** is not so much an aspect of any given conceptualization as it is an aspect of multiple conceptualizations. But we do not conceptualize at multiple **SCALES** at once. We can only conceptualize one **SCALE** at a time. So **SCALE** is a hard notion to grasp. How can we recognize when our conceptualizations involve a change in **SCALE**?

The fact that our conceptualizations of reality are somehow incomplete is an awkward fact. After all, we can think about *everything* in our conceptualizations. What else is there? In fact, much of contemporary science and engineering is predicated on the implicit *absence* of this awkward fact (that our conceptualizations are incomplete). In a word, this awkward fact is largely ignored. The exclusion of this awkward fact is the predicate for "obvious" notions like completeness; first order logic and its derivatives; reductionism; determinism; and so forth. Following this strategy of omission has proven to be very useful, and it therefore has been judged as successful. Further success, however, now requires that this awkward fact be confronted head on.

In order to gain some appreciation of this awkward fact, the following is offered.

(a) A Proposition, P, is true for any and every X.
(b) A Proposition, P, is true for all X.

Are statements of the sort (a) and (b) *always* exactly equivalent?

If a bag of marbles is considered, and any and every marble is blue, it is also true that all of the marbles are blue. "All marbles are blue," and "any and every marble is blue" say the same thing. Statements of the sort (a) and (b) are seen as equivalent in such a case. And it is possible to get from one to the other using conventional, first order, logic.

The planet earth can be treated as essentially flat (and corrugated if desired) at any and every place. So it is logically and empirically true that all places on the earth are flat. But it is also true that all of the earth cannot be treated as flat. The whole earth is spherical. Statements of the sort (a) and (b) are no longer seen as equivalent in this case because "all" can be understood *differently* depending on which of two conceptual models is used. Experience (observation, accumulated knowledge, successful courses of action, and so on), and not just logic, confirm the utility of *both* conceptualizations.

"All" can have a meaning as both "aggregated but undifferentiated," and "an aggregation of individual members." When "all" is of significance in a way that is beyond that revealed by every member individually, even in combinations, multiple **SCALES** are involved. As the adage goes, the whole is then greater than the sum of its parts. What makes the whole "greater" than the sum of its parts is the acceptance of a reality associated with the whole but at **SCALES** other than that which make the parts available for conceptualization (differentiated and distinguished, and so **IDENTIFIED**).

A large number of molecules collectively exert a pressure in a volume, but no individual molecule does so. The population of molecules *is and are* functioning at two different **SCALES** as far as human conceptualization is concerned. **PROPERTIES** (or "degrees of freedom") like pressure and temperature are associated with the all of the molecules but *only* as an aggregated but undifferentiated whole. Such **PROPERTIES** are not available at a **SCALE** of conceptualization which makes available individual molecules and their kinematics. For example, molecules do not have the **PROPERTY** of pressure, either individually or in any specific combinations.

Multiple **SCALES** of conceptualization are used (by our brains) in order to capture more of the **EXTENT** and **RICHNESS** of reality than might otherwise be thought to be available because of the limited number of points available in {FOV, RES} for human conceptualization. Multiple **SCALES** of conceptualization allow for a piecewise approach to completeness in conceptualizing reality, but it can never be known that completeness has been achieved.

The human brain functions to emphasize one **SCALE** at a time in its conceptualizations. Although **SCALES** are obviously related, they are not related in the same way as aspects revealed at any one **SCALE** are related to one another. (The **PATTERNS** that might be understood to capture this relatedness can't be conceptualized, except perhaps partially in the related conceptualizations. Some or all of such **PATTERNS** are missing in these related conceptualizations.) Conceptualizations are the canvases for all human thought. And it is very difficult if not impossible to stand, as it were, between these canvases as one might stand before any one of them. *Definitions of a system have to account for this phenomenon.*

As suggested by the above, the treatment of what we recognize as populations is a very important tell tale for changes in **SCALE**. If we treat a population in terms of its members (even in combinations if the members remain distinct), we do so at one **SCALE** of conceptualization. The members (and their combinations) are individual **OBJECTS**. If we treat that same population in the aggregate as a single **OBJECT** and that **OBJECT** involves **PROPERTIES** that are not the **PROPERTIES** of its members (at the first **SCALE**), then we are conceptualizing at another **SCALE**.

A spherical ball in my hand can be conceptualized as a single simple **OBJECT**. And if we want, we can conceptualize it as a compound **OBJECT** of two simpler objects at the same **SCALE**: hemispheres. There is at least one **RELATIONSHIP** between the hemispheres that allows us to conceptualize the two simpler **OBJECTS** *and* the **RELATIONSHIP** as the single compound **OBJECT** of a spherical ball. This process of decomposition can be continued (but not forever) at this **SCALE** of conceptualization. (This is a consequence of the bounded capacity of the human brain discussed above.)

We can also conceptualize the "ball" as an aggregation of some type of molecules – let's say plastic ones. These molecules are the **OBJECTS** at another **SCALE** of conceptualization of the same "ball." Plastic molecules are not spherical – or any fraction of spherical. They do not have the **PROPERTY** of which this is a **P-VALUE**. And there is no combination of such individual molecules (including the **RELATIONSHIPS** that we can find among the individual molecules) that is this **PROPERTY**. It is only we when aggregate all of the molecules as a single **OBJECT** that we can include in its **AGGREGATION** (as a single **OBJECT) PROPERTIES** such as shape (of which spherical is one **P-VALUE**).

When we consider a spherical ball in this way, we are conceptualizing a portion of the soup of reality at two different **SCALES**. If we choose to label both as balls, then we are mixing information gleaned from two distinct **SCALES** of conceptualization. There is nothing in the molecular **SCALE** conceptualization that corresponds to the spherical nature of the ball at the first **SCALE** consistent with reductionism. There is at least one **PROPERTY** gleaned from the soup of reality that is available to us at one **SCALE** that is not available to us at another. And in this case, if we consider the molecules as members of a population, then once again the treatment of populations is a powerful tell tale for a change in the **SCALE** of conceptualization.

Statistics and statistical mechanics are ways to hunt for **PROPERTIES** at “higher” **SCALES** of conceptualization when dealing with the members of populations. It is beyond the scope of this paper to pursue this point. This paper is intended primarily to incorporate the notion of **SCALE** into an engineering definition of a system.

**SCALES** of conceptualization are not hierarchically organized. Hierarchy is closely related to reductionist decomposition. There is no way to infer or to deduce what *must* be available in a conceptualization at other **SCALES**. However, as we have been discussing, it should be apparent that more information about the soup of reality is likely to be available at multiple **SCALES** of conceptualization. This can be captured in a metaphor of a “ladder” of **SCALES** of conceptualization on which each rung is a different **SCALE** of conceptualization. We can have a sense of “up” and “down” on such a ladder (leading to names such as micro and macro for nearby **SCALES** or rungs on that ladder as we did above), but we cannot actually know what is on each rung unless we visit it. And there is certainly no way to deduce what is on another rung based on what we can conceptualize directly on a given rung. However, we can infer the presence of such information at another **SCALE** of conceptualization; we usually label this as emergence.

## 11.0 Concluding Remarks

We began by noting that the systems increasingly of interest to system engineers today are ones that cannot be fully conceptualized and that cannot be unambiguously separated from their environments (such as a Missile Defense System). Hopefully we have provided a definition of a system that is consistent with such observations (as well as with others that we have mentioned along the way).

There is no engineering need, however, to render any system exactly as a system is defined above. What is important is to recognize how the **MODALITIES** of conceptualization influence what we recognize as the **INFORMATION CONTENT** of our conceptualizations. A system should be conceptualized at as many **SCALES** as necessary to deal with the pertinent **PATTERNS** of a problem and its solution. Efforts should no longer be made to attempt to render such systems in our thinking (or in models of our thinking) at a single **SCALE** (even with multiple FOVs and RESs) in the vain attempt to bring the tools of reductionism, determinism, and completeness to bear on the entire problem. At the same time, such systems need not be resolved in any greater detail than is necessary at any particular **SCALE** in order to deal with the **PATTERNS** that are pertinent and available at each such **SCALE**.

In a subsequent paper (to be published in early January of 2007) this definition of a system will be placed into the larger context of what is termed complex-system engineering. It will be proposed in that paper that complex-system engineering is a second branch of general system engineering (alongside what is now recognized as "traditional" system engineering). This second branch of general system engineering is grounded in the same foundational predicates as is "traditional" system engineering but eschews the methods appropriate for the engineering of "traditional" systems in favor of those appropriate to systems that cannot be fully conceptualized at a single **SCALE**. These alternate methods are termed the regimen of complex-system engineering. Rather than vainly attempting to specify, build, deliver, and then operate and finally retire systems, the methods of the regimen serve to focus and accelerate the processes of natural evolution that shape the continuous and overlapping operation and development of such systems as conceptualized at multiple **SCALES**.