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General Systems Theory

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General Systems Theory Background Summary

In the 1920's, Ludwig von Bertalanffy envisioned a *General Systems Theory*[1]. As a biologist, von Bertalanffy was concerned with behavioral and intentional systems. He clearly stated the mathematical foundations of his theory in his report "The History and Status of General Systems Theory"[2]:

> The goal obviously is to develop general systems theory in mathematical terms – a logico-mathematical field – because mathematics is the exact language permitting rigorous deductions and confirmation (or refusal) of theory.

In the 1960's, there were two major independent efforts made relating to developments in General Systems Theory. One was by the engineer and mathematician Mihajlo D. Mesarović, and the other was by the philosopher Elizabeth Steiner and the historian and mathematician George S. Maccia. The developments by Mesarović were more restrictive and in line with traditional developments of engineering models simulating various intentional systems, while the developments by Steiner and Maccia were more comprehensive and provided the first formalization of a *Scientific Education Theory* derived from *General Systems Theory*.

Mesarović's work, however, did lead to critical developments in mathematical models of General Systems; however, such characterizations were restricted to systems represented by a single relation.[3] A true mathematical analysis of *General Systems Theory* requires the ability to recognize multiple relations for one system. It would be another 30 years before that would be accomplished.

Also in the 1960's, Steiner and Maccia published their comprehensive treatment of *General Systems Theory* in developing a devising model for educational theory, the *SIGGS Theory Model*. This work was published in 1966, *Development of Educational Theory Derived from Three Educational Theory Models*.[4] This work was the first development of a **scientific or empirical education theory**. *A-GSBT* (subsequently changed to *ATIS*) is an extension of this work by Steiner and Maccia.

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[1] For Internet references, consider: http://panarchy.org/vonbertalanffy/systems.1968.html, http://www.nwlink.com/~donclark/history_isd/bertalanffy.html, http://en.wikipedia.org/wiki/Ludwig_von_Bertalanffy, http://www.mind-development.eu/systems.html, http://www.isnature.org/Events/2009/Summer/r/Bertalanffy1950-GST_Outline_SELECT.pdf.

[2] Bertalanffy, Ludwig von (1972), "The History and Status of General Systems Theory", *Trends in General Systems Theory*, G.J. Klir (ed.).

[3] Mesarović, Mihajlo D. (1972), "A Mathematical Theory of General Systems," *Trends in General Systems Theory*, G.J. Klir (ed.).

[4] Maccia, Elizabeth Steiner, and George S. Maccia (1966), *Development of Educational Theory Derived from Three Educational Theory Models*, The Ohio State University Research Foundation, Columbus, Ohio.

In the 1980's, Theodore W. Frick extended the *SIGGS Theory Model* by classifying the SIGGS properties into three categories: *Basic*, *Structural* and *Dynamic*.[5]

The recognition of the SIGGS categories by Frick led Thompson, in the 1990's, to recognize that the *Structural Properties* define the topology of a system. Developed properly as a mathematical theory, SIGGS could now be developed in a manner that could utilize the power of mathematics in educational theorizing.

But, there was still one problem that had to be overcome in order to treat SIGGS or any *General Systems Theory* mathematically—how to treat multiple relations in a system mathematically? It was as a result of Mesarović's work that Yi Lin extended the mathematical model so that multiple relations could be considered with respect to a single system[6].

This critical advancement by Lin in 1999 made it possible for Thompson to develop *ATIS* as an extension of SIGGS in a manner that the multiple relations of a system can be made mathematically precise. This advancement makes it possible to realistically recommend that *ATIS* can be used as a logical basis for intentional system models. In particular, the work of Frick has extended the *SIGGS Theory* in such a manner that his *SimEd* model for education can be founded on the *ATIS* theoretical base (an axiomatic logico-mathematical base), thus eliminating the need to rely on scenario-based models, as Mesarović and others have had to do.

[5] Since this report is intended for both those who are very familiar with axiomatic theories and those who are not, in order to facilitate the understanding of those who are not, there will be numerous hyperlinks to other sources that define or discuss various terms used in this report.

[6] Lin, Yi (1999), *General Systems Theory: A Mathematical Approach*, Kluwer Academic/Plenum Publishers, NY.

Critical Developments for a Logico-Mathematical Theory

In 1964, M.D. Mesarović, in "Foundations for a General Systems Theory," recognized two distinct approaches to the representation of a system: The "***terminal approach***," and the "***goal-seeking approach***." The ***terminal approach*** is the conventional representation of system as an entity that looks at a system from the outside and defines it in terms of subset mappings, as is done in physics, chemistry, engineering, etc. While, as Mesarović notes, such systems could be defined as *goal-seeking systems*, such representation would be meaningless, artificial or trivial.

Due to the strong bias toward empirical theories designed from the *terminal approach*, and physics, in particular being the paradigm for empirical theory development, the development of intentional system theories based on a *goal-seeking approach* is much less understood, if recognized at all.

The ***goal-seeking approach*** **incorporates an invariant base** that defines the system's goals. Further, the *affect relations* of the system **are defined so that they are related to the attainment of the system's goals**. **Such a system description results in the ability to predict the system's behavior**. That is, by defining an axiomatic description of a system, the means are then available to predict the system behavior—its end-target or predictive outcomes—under conditions that are different from its previous behaviors.

An axiomatic-based system description is critical for an intentional, behaviorally-predictive system. Predictions derived therefrom are not dependent on the result of previous behaviors, experiments or outcomes. **Predictions are dependent on a parametric analysis of an existing system state.[7]** A sequence of previous system states can define a dispositional system behavior, but are used, not as a definitive guideline for predicting future behavior, but as part of a comprehensive analysis of the existing system state.

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[7] A *parametric analysis* is an analysis of relationships between system components. A *nonparametric analysis* is an analysis of relationships between descriptive; that is, non-specific, and inferred relationships that a researcher may propose in the process of identifying system components in a *rough set*. *Classical sets* contain elements (components) that are well-defined, and elements can be specifically determined as to whether or not they belong to the sets. *Fuzzy sets* contain elements (components) that are not well-defined or are vaguely defined so that it is indeterminate which elements (components) belong to the sets although other elements (components) may be well-defined as in *classical sets*. *Rough sets* are defined by topological approximations, which include elements (components) that are well-defined as in *classical sets*, and elements (components) that may or may not be in the set. These potentially *rough set* components are not *fuzzy set* elements (components) since they are not vaguely defined, they are just unknown concerning the set property.

Statistical analyses rely on past performance to predict future **group** behavior. ***Statistical analyses can never be individually predictive***.

Axiomatic analyses rely on the internal structure of the system to determine its current goal-seeking behavior. Thompson emphasizes the critical nature of this observation—**predictions made with respect to intentional, behavioral systems are obtained as the result of the system structure at a given time**. The **structure** determines not only what is possible, but also the **intent** of the system as determined by its goal-seeking parameters.

It is recognized that the behavior of goal-seeking systems are much more complex than the behavior of terminal systems. However, systems can and do function in spite of their complexity. The problem, then, is to analyze the system in terms of its internal functioning structure, rather than by attempting to analyze each component of that structure. Components are considered in their relatedness to other components and how that relatedness helps to define the system structure. They are not considered in such minute detail that the structure; that is, the intent and behavior of the system is obscured.

While there are many disciplines pursuing the study of *General Systems Theory* (GST), none have gotten at the promise of providing a comprehensive intentional, behavioral theory envisioned by von Bertalanffy. These disciplines include *cybernetics*, *dynamic systems theory*, *control theory*, *information theory*, *set theory*, *graph theory*, *network theory*, *game theory*, *decision theory*, *chaos theory*, *complex adaptive systems theory*, among others. Each has helped to answer questions within their defined areas of study, but none are behaviorally predictive.

C. Francois of the International Society for the Systems Sciences (ISSS) has addressed the unresolved problem of predictability within the behavioral sciences during a seminar on systemic inquiry and integration. He asserts that the reason the disciplines to date are not behaviorally predictive is that they fail to address one of the more important unresolved problems of GST—how to develop a system theory that describes multiple and shifting interrelations and interactions between numerous elements at various levels of complexity of a system.

To describe the complexity of a system cited by C. Francois, it is asserted that no piecemeal approach can lead to a good understanding of the structure and dynamics of the complex wholes. What ISSS claims is needed is a set of concepts and models that can be used to understand relationships and moreover, simultaneous, transient and shifting relationships. Their approach to the problem, however, is inadequate. Their approach is:

> We must collect all synergetic concepts and models. We must integrate them in multiple cross ways. We should construct sets of any number of them and use these specific tools to resolve or at least better manage unresolved complex problems. ["Target Paper" by C. Francois, ISSS.]

Such an approach by the ISSS is doomed to failure from the outset. Existing concepts and models, due to their targeted specific objectives are inconsistent when combined. Further, integrating models that address specific subsystems do not thereby describe the entire system when combined—the whole is not simply an accumulation of its components, a basic tenant of *General Systems Theory* itself.

What must be developed is a comprehensive and consistent theory describing intentional (behavioral) systems. That is the focus of this research—to develop *ATIS* that is expressed by a rigorous definition of system, a comprehensive listing of axioms and a logico-mathematical derivation of its implications (theorems/hypotheses)—that is, its predictive results. This research will develop an axiomatic theory that uses the *Predicate Calculus*, *Mathematical Topology*, and *APT*[8] to analyze complex system relations.

Predictive results are possible due to the evaluations of the total interactions and connectedness of the different system components, rather than an analysis of each type of system relation individually. A further clarification is found by distinguishing *General Systems Theory* from *Cybernetics*. *Cybernetics* focuses on the **function** of a system; that is, how a system controls its actions via feedback mechanisms, how it communicates with other systems or with its own system components.

General Systems Theory, on the other hand, focuses on the **structure** of a system; that is, how a system changes as a result of structural modifications resulting from changing component relations, receiving input, emitting output, changing environmental relations, etc. Hence, the resulting predictability targeted by this research arises as a result of evaluating a system's structural changes in terms of known theoretical outcomes. Structural changes that result from specific system modifications are predictable by *Axiomatic Theory of Intentional Systems (ATIS)* in the same manner as physics predicts the behavior of the physical universe as founded on the appropriate theory of physics.

An additional concern of *Complexity Theory* must be addressed. "*Complexity Theory is the study of emergent order in what are otherwise very disorderly systems*."[9]

> In a sense, complex systems innovate by producing spontaneous, systemic bouts of novelty out of which new patterns of behavior emerge. Patterns, which enhance a system's ability to adapt successfully to its environment, are stabilized and repeated; those that do not are rejected in favor of radically new ones, almost as if a cosmic game of trial-and-error were being played.[10]

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[8] See Theodore W. Frick's reports at: http://educology.indiana.edu/Frick/index.html, and the reports listed under "Pattern Analysis".

[9] McElroy, M.W. (2000), "Integrating Complexity Theory, Knowledge Management and Organizational Learning," *Journal of Knowledge Management*, V.4, No.3, 2000, p. 196.

[10] *Ibid.*

Such a problem in *Complexity Theory* is what C.S. Peirce described as a tychistic event due to chance spontaneity within a system exhibiting synechistic (continuity) characteristics. The process of evolution is one such example of the tychistic-synechistic mechanism. However, with *ATIS* there is no mystery about such processes. Any tychistic event arises as system input, whether that is the result of genetic change or the intellectual contribution of an individual initiating a new social order.

There is no mystery when systems are properly analyzed. Air Force Colonel Warden 3rd recognizes the value of a system properly analyzed when he rightly asserts:

> "***Terrorists are quite vulnerable when a proper analysis of a terrorist's network system is made***."[11]

The same is true of *Complex Systems* or *General Systems*.

A Purposeful Existence and Operation Implies Predictability

A close examination of systems reveals that the interaction of system elements acts as if they were simple units that can be described by a set of a few variables. Their vast internal complexity is not directly manifested in their interactions.

> "This property of behavioral systems is not accidental: If we were to allow the elements to reflect all their internal complexity in the interactions, then the system as a whole would most probably not be able to display any stable and predictable behavior." A purposeful existence and operation implies predictability.[12]

Intentional systems are predictive by the very fact that they are *intentional*, and are the focus of this research. Further, that predictability is not out of reach when an analysis is made of the system structure; as opposed to a detailed analysis of system components from which an attempt is made to infer system behavior. *ATIS* does not provide a "causal analysis" for predictability. Past events provide a basis for determining the dispositional behavior of the system, but they do not predict future behavior. Behavior predictability is determined by system structure and not prior states. Prior states determine system dispositional behavior that defines the invariant initial system structure, but not causality nor predictability.

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[11] Warden III, Colonel John A. (1988), "The Enemy as a System," *Air and Space Power Chronicles*, National Defense University Press Publication, 13 pages.

[12] Mikhailov, A. S. (1990), *Foundations of Synergetics, I: Distributed Active Systems*, Springer-Verlag, Berlin, p. 2.

A problem confronted by General System Theorists[13] is that of accounting for multiple types of relations in a system. As noted above, Y. Lin, in "A Model of General Systems" establishes that a *General Systems Theory* can be developed that defines more than one relation between the objects of the system.

Frequently a general system, (V,S), is defined with respect to one type of relation as Mesarović has done:

$$S \subset \Pi\{V_i | i \in I\}.$$

Now, pursuant to Lin, assume that the set V has two relations defined by f and γ. Then, the system $(V,\{f,\gamma\})$ is not a Mesarović system because the set $\{f,\gamma\}$ cannot be written in a uniform relation symbol without changing the object set V.

In general, intentional systems will be of the form: $(V, \cup_{i=1\ldots n} R_i)$; where $i \neq j$ implies that $R_i \neq R_j$, and represents the number of different relations defined on V. These are the types of systems that concern theories to be developed from *ATIS*.

Intentional Systems Theory

The *Steiner and Maccia Theory* (formerly, *Maccia and Maccia Theory*) of 1966 has led to the development of a true scientific intentional systems (behavioral) theory. Prior to this development, intentional systems theories had been founded upon philosophical perspectives, a theoretical perspective from another science, the results of limited empirical research, hypotheses restricting the theory to a specific behavioral area, or an agenda, whether religious, political, or personal. Although they may purport to be scientific theories, they have not been well developed as scientific theories and none are comprehensive as an intentional systems theory.

The theory model developed by Steiner and Maccia is the *SIGGS Theory Model*. *SIGGS* is an acronym for the theories that were used to develop the theory model. Those theories are: ***S**et Theory*, ***I**nformation Theory*, ***G**raph Theory*, and ***G**eneral **S**ystems Theory*.

> From this theory model the educational theory is retroduced. To be retroduced means that content is added to the theory model to form the educational theory.[14]

[13] Such theorists as: Ludwig von Bertalanffy, Talcott Parsons, Niklas Luhmann, Béla Heinrich Bánáthy, Howard Thomas Odum, Eugene Pleasants Odum, Peter Michael Senge, Richard A. Swanson, and Debora Hammond.

[14] Maccia, p. 117.

The purpose of the current research is to develop an *Axiomatic Theory of Intentional Systems*, *ATIS*. Such theory will be developed as a model that can be applied to a variety of intentional systems. In particular, it is intended that *ATIS* will be used as the logical basis for *SimEd*. In particular, *ATIS* provides an *Options Set*, the *ATIS Option Set*,[15] which can be used to develop an open-ended number of intentional system theories.

The intent of *SIGGS*, as stated in the *SIGGS Final Report* is:

> "to set forth hypotheses [axioms] about human behavior and other factors involved in behavior irrespective of selected outcomes."[16]

The *1966 Final Report* presented the hypotheses of the *Behavioral Theory*. While *SIGGS Theory* has been available since 1966, there has been little development of the theory since that time (with the exception of the work by Frick and Thompson), and it has received little attention as a prospective model for behavior theory development. The reason for this lack of attention has been recognized by Kira S. King and Theodore W. Frick in their article "Transforming Education: Case Studies in Systems Thinking."[17] Therein they state:

> Unfortunately, since SIGGS is written in highly complex mathematical language, it has received little attention since its creation.

A further reason is that SIGGS and *ATIS* are axiomatic theories, whereas current emphasis for practically all research is on statistical analyses; e.g., data mining technologies, and similar research.

The present work will do nothing to further resolve the problem of relying on a logico-mathematical theory. The present work is designed; in particular, to provide an extensive formalization of the theory, and to, in fact, extend the mathematical rigor of the theory. It will build on Steiner and Maccia's 1966 work and the extension of that work by Frick. Further, Frick's development of *APT* will be integrated into this extended theory as a tool for evaluating specific dynamic applications of the theory.

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[15] An implementation of the *ATIS Option Set* has five steps: (1) Identify the problem-statement that defines the components of the empirical system, (2) Identify the affect relations of the target system, (3) Analyze the affect relations to determine relevant properties, (4) The relevant properties identify the related axioms, and (5) From the related axioms, derive the theory-predicted outcomes, the theorems/hypotheses. (P. 10 on the referenced site.)

[16] Maccia, p. 118.

[17] King, Kira S. and Theodore W. Frick (2000), "Transforming Education: Case Studies in Systems Thinking," *ed: Education at a Distance*, September, Vol. 14, No. 9.

In order to accomplish the integration of *APT* as a tool for *ATIS* analyses, *APT* as defined by Frick will be modified to read as follows:

> *APT is a method for gathering information about observable phenomena of an individual system such that temporal patterns of events can be used as* ***constants*** *in [ATIS] to* ***predict*** *individual behavior and outcomes.*

Returning now to the *SIGGS Theory Model*, hypotheses were developed from the **education** content given the theory model by the assigned properties. Frick subsequently classified those properties into ***Basic***, ***Dynamic*** and ***Structural Properties***. It is this classification that has led to the current research.

The properties defined by Frick are as follows:

Basic Properties are those properties that are descriptive of a system.
Structural Properties are those properties that show how system components are connected or related to each other.
Dynamic Properties are those properties that describe patterns in time as change occurs within or between a system and its negasystem.

Upon review of the work done by Frick, Thompson recognized that the ***Structural Properties*** represented the ***behavioral topology***. It was recognized that such a topology would bring the power of mathematics to the behavioral sciences as it has to other scientific theories. Such power is needed if behavioral theory is to join the ranks of the other empirical sciences.