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SPT II.: HOW TO FIND & MAP LINKAGE PROPOSITIONS FOR A GTS FROM THE NATURAL SCIENCES LITERATURE

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ABSTRACT

This paper continues a series that further develops the Systems Processes Theory (SPT) – as a candidate general theory of systems (GTS) that is tightly coupled to the experimental results of the several natural sciences and a half-century of systems research in an attempt to produce a true "science" of systems. This paper focuses on the discovery and documentation of mutual, causal "influences" between 55 systems processes (SPs) that were critically selected in a previous paper (Friendshuh & Troncale, 2012). We call these mutual, non-linear, causal influences, or other impacts or relations, Linkage Propositions (LPs). LPs create a "net" of interacting systems processes that we claim explains, "how many systems work" in a more detailed and experimentally verified manner than many previous systems theories. This paper begins by defining LPs and suggests criteria for determining what is and is not an LP. It continues with 30 case studies of finding possible LPs in the peer-reviewed literature of the natural sciences from quantum physics to astronomy to chemistry to geology to biology to ecology to network theory, even to human systems. We emphasize the steps that could be used by any informed investigator to find their own LPs between systems processes in personal scans of the available scientific literature. The paper continues by comparing several available computer tools that could be used to graphically portray the SP-LP network. Each is evaluated for usability, simplicity, and breadth of applicability. The tools are compared by applying them to making an overview map of the defining characteristics of Linkage Propositions. Then one of them, CMAP, is used to show how the new LPs suggested in this paper can be graphically related to previous CMAPs of the SPT. The paper closes with an image of future work that would further contribute to building, testing, and applying the SPT to complex systems of systems problems facing humanity today.

Keywords: systems processes theory; SPT; linkage propositions; natural systems science; science of systems; concept mapping; CMAP; networks

Capsule Outline:

- Why Linkage Propositions (LPs)? – The Need They Fulfill – LP Functions in A GTS
- *Table One: Minimal Set of 55 Systems-Level Processes for the SPT*
- What is a Linkage Proposition (LP)? Criteria for LPs
- How to Identify Linkage Propositions in the Natural Science Literatures
- Case Study: New Linkage Propositions from the Natural Sciences: Example Applications
- *Table Two: 30 New Linkage Propositions from the Natural Science Literature*
    - ✓ 17 New LPs Connecting SPs from the Physical Sciences
    - ✓ 10 New LPs Connecting SPs from the Life Sciences
    - ✓ 4 New LPs Connecting SPs from the Human and Symbolic Sciences
    - ✓ 3 New LPs Connecting SPs from Transdisciplinary Lit

- ✓ *Figure One: Network Graphic of Original LPs on SPs*
- Initial Comparison of Simple Mapping Tools for Graphing SPT
- Examples of Initial SPT-CMAPs: Uses for CMAPs
  - ✓ *Figures Two to Four: CMAPs of SP Categories & New LP Case Studies*
  - ✓ Networks of LP CMAPs Explain How Systems Work at New Depth
  - ✓ Use of CMAPs in Learning and Teaching – Advantages and Limits
- Future Work and Conclusions

Why Linkage Propositions – The Need They Fulfill – LP Functions in A GTS

The earliest workers on a general theory of systems (hereafter GTS) were delighted and apparently fulfilled to recognize the first individual isomorphic patterns across a range of different and independent disciplines. To them, this was already sufficient evidence that a more universal description of systemness was possible and desirable. This recognition of isomorphic (similarities) was already an advance beyond pure reductionism and the stovepipe mentality of ever-increasing specialty and decreasing span of inquiry. We must remember that this occurred in the 50's, a time of rigid disciplinarity. We can tell you from our own experiences it was a time of considerable skepticism about anything interdisciplinary much less the level of transdisciplinarity required for a GTS. Much has changed since then.

Yet even today's increasing acceptance and success of interdisciplinary centers and institutes has not resulted in synthesis, integration, and unification beyond the isomorphies. That is the subject of this paper. Linkage Propositions are a meta-level of abstraction and a higher level of synthesis, integration, and unification beyond the mere recognition of isomorphies in the 50's. Even at that time, one of the early founders of general approaches, called for going beyond citing isomorphic patterns to devising systems of them (Ackoff, 1971). His criticism was ignored. Focused on business and management systems, he also did not follow up on the critically needed advance he described. This may be partly due to the singular focus on social systems that necessarily limited the otherwise seminal contributions of Ackoff, Churchman, Mitroff, Warfield (2006), Checkland (1993) and Jackson. Even those focused more on the living and physical sciences, such as Miller and Odum, did not clearly base their GTS's on meta-level descriptions of influence across numerous isomorphies. Odum (1983) did use more SPs than most, but still used conventional measures of energy influence to connect them. Miller (1978) did suggest many cross-disciplinary hypotheses but these are quite different from the suggested linkage propositions (as explained in Troncale, 2006). Further, none of these workers clearly identified anywhere near as large and diverse a number of isomorphies for highlighting mutual influences as does SPT.

Systems Processes Theory, contends that recognition and understanding of the isomorphies common across systems is just the first step to achieving an adequate and useful description of how systems work. In SPT the isomorphies are as much as possible expressed as "processes" so that they can be explored for validation/verification using the tools of the natural sciences as well as tested for applicability to the social sciences and human problems. Even when some of the SPs are described as isomorphic "structures" or "patterns" (as in fractals or symmetry or hierarchies or networks), they are listed as "hierarchy-forming processes" or fractal-forming processes. The lowest level components of the SPT are these numerous "systems-level" processes. Table One (from Friendshuh and Troncale, 2012) is our current working list of 54 key systems processes or patterns (isomorphies) that remain after rigorously eliminating the "noise" of many non-dynamic human terms often included in lists of systems concepts.

The necessary and critical next step, the one heretofore not taken, is elucidation, documentation, testing, validation, and teaching of the specific ways systems-level processes influence or relate to each other. This is a proposed isomorphic description beyond the isomorphic processes themselves. But it is this dynamic level of description that we argue will give us insight into how systems work and that we propose will finally yield a testable general theory of systems (GTS) or thereby a true "science" of systems.

Table One: Minimal Set of 54 Systems-Level Processes for the SPT

1. Adaptation Processes	28. Input Processes
2. Allometry, Systems-Level	29. Limits as a Process
3. Allopoiesis	30. Integration, Synthesis as a Process
4. Binding Processes	31. Metacrescence as a Process
5. Boundary-Forming Processes & Conditions	32. Network-Forming Processes
6. Causality Processes (linear vs. non-)	33. Neutralization Processes
7. Chaotic Processes	34. Non-Equilibrium Thermodynamics
8. Competitive Processes	35. Origins Processes
9. Constraint Fields & Analysis	36. Output Processes
10. Cyclical/Oscillation/Hypercycle Processes	37. Phases, Stages as Processes
11. Decay, Autolytic & Senescent Processes	38. Power Law Processes
12. Development Patterns & Laws	39. Quantum Processes
13. Duality/Complementarity/Counterparity	40. Recursive Processes
14. Dysergy as a Process	41. Redundancy Processes
15. Emergence Processes	42. Replication Processes
16. Entropy, General (as a process)	43. Self-Criticality/Catastrophe Proc's
17. Equilibrium & Steady State Processes	44. Self-Organization/Autopoiesis Proc
18. Evolutionary Processes	45. Spin Processes
19. Exaptation, Cooption Processes	46. Storage-Forming Processes
20. Feedback Processes	47. Structure-Forming Processes
21. Field Processess & Potentials	48. Symmetry-Forming Processes
22. Flow Processes	49. Synergy/Synchrony/Coop Process's
23. Fractal-Forming Processes	50. Thermodynamic Processes
24. Systems-Level Function (Purpose) as a Process	51. Variation Processes
25. Growth Processes, Patterns & Laws	52. Maximality Processes
26. Hierarchy-Forming Processes	53. Minimization Proccesses
27. Information-Based Processes	54. Amplifiers as a Process

What is a Linkage Proposition (LP)? Criteria for LPs

The definition of LPs begins with the key question: "what would be a minimal description of influence, causation, or dynamics between any two isomorphic systems processes as listed? We contend that the simplest case would be a dyad statement as shown in the first paper to suggest the concept of Linkage Proposition (Troncale, 1978). A dyad statement consists of two specific systems processes joined by a logic operator describing the mutual or directional influence, causation, relation, or dynamic between them. We have encountered more complex cases where a triad of SPs or more are needed to fulfill a recognized and internally coherent influence. The operator may describe a relation that is unidirectional, forward or backward, or mutual in both directions. The “operators” or description of the connections were observed to fall into just a few “association classes” in the original formulation (also described in Troncale, 1978).

We selected the name for LPs carefully. “Linkage” refers to the operator because it proposes a very specific influence of one SP on another so ties them together. We only allow an LP operator when it has been observed in detail in a specific, manifest system using experimental or simulation methods. But the working suggestion in SPT is that it may therefore be true of many systems, just as the isomorphy has been proven true of many systems (see Troncale, 2012). To remind all workers who use SPT that this is a conditional assignment, we chose the word “Proposition.” The long-term task of the SPT community then is to determine how wide the applicability of each proposed dyad LP is by examining that relation in many diverse systems types, at markedly different origin times, with different origin mechanics, studied by different disciplines at different scales of natural systems. LPs may be facts for the specific systems in which they have already been observed as noted in the documentation of those suggested in this paper from the natural sciences literature. But the range of validity of that specific LP awaits confirmation and documentation from many other natural systems. With this feature, SPT has a built-in modesty of claim and a stimulus for much future work to determine as much as possible the range of systems that a particular one, or particular subset of LPs, could be applied.

We insist on keeping the LP as a “unitary” description of an influence. When many dyads are assembled together because of their use of the same limited list of SPs, much more complex “architectures” (sometimes called “motifs” or “subgraphs”) occur. When many LPs are placed in the same logical diagram as shown later in this paper, a “network” of many specific interactions emerges. SPT would claim that this resulting network is a graphic that represents the highest-level abstraction of interrelations demonstrated for many of the most mature and sustainable systems in nature and sometimes in human systems. It is a very detailed and dynamic picture of how systems work. Its detail also enables spin-offs like a highly developed taxonomy of systems dysfunctions, or as we call them, Systems Pathologies (Troncale, 2011).

It is important to note that in SPT, the LPs are all considered to be as “isomorphic” as the connected systems processes. We suggest that they are the minimal state of resources needed in trillions of tries that achieves the maximal state of sustainability for a system. It is also important to note that SPT considers ALL the systems processes to be necessary to achieve sufficing, not optimal sustainability of a system with a minimum of resources. As such, the more detailed the set of LPs a designer is aware of, the more mature the systems they design could become. It represents the advance that SPT makes over many alternative general theories of systems.

Criteria for identifying and judging the systems processes are described in Friendshuh & Troncale, 2012. We are just beginning to formulate criteria for all other segments of the SPT. Criteria for identifying LPs might include: (i) describes a pleiotropic or pleioetiologic cause and effect between two SPs; (ii) or a taxonomic relation; (iii) or one of the other classes of operators; (iv) empirically demonstrated in many or initially at least one manifest phenomenon; (v) its recognition explains the dynamics of the resulting system or phenomenon. We seek more. Some in the GTS or systems thinking community have objected that making specific LPs is the wrong direction for systems synthesis. They see it as reductionism. But LPs have exactly the opposite function. They make unitary universal statements of isomorphy. Without the specificity and explicit nature of these statements, there will never be an ability to test or validate systems patterns nor will there be a pathway to application of systems knowledge except in the most naive and abstract manner -- exactly the criticism of those who criticize the overall systems movement to date.

How to Identify Linkage Propositions in the Natural Science Literatures

While SPs and LPs have long been proposed, we have not yet explained how any worker could formulate them on their own or what the sources might be for new LPs. As a test of concept, we used two interdisciplinary journals. Our selections, *Science* and *Nature* are the most widely read and respected science journals extant (Impact Factors of 31.027 and 38.597 for 2012). They have the advantages of high rigor, coverage of all the natural sciences, and weekly publication. Scientists who want the maximum dissemination of their work publish in these journals. In fact, there is a joke that the (*Proceedings of the (U.S) National Academy of Sciences*), acroynm *PNAS,* means "papers not accepted by *Science.*" Most of the new LPs cited here are from these sources. But any reputable, peer-reviewed science journal could be a source of new LPs.

The process of finding LPs is greatly enhanced by the availability of the list of SPs (Table One). A good place to look for citation of systems processes is in the abstract for each publication. If it is mentioned in the abstract, it is likely to be one of the key foci for the research. Look for the presence of at least two systems processes and some finding of influence of one on the other. Any case meeting these two criteria is a good possible source of an LP in one particular instance.

It is important to note that this does not mean that the paper be on "systems" research itself. Every natural system has evolved to be a system of systems, or a hierarchy of systems with sub- and super-systems ramifications. Thus deep research on a particular phenomenon in science is simultaneously research on a particular manifestation or instantiation of "systemness" even if it is not primarily interpreted as such. That the paper describes one particular linear causality can be ignored. Once the unit influence is captured in an LP statement, and that single LP is joined with many others in a network, the non-linear aspects of causality (Troncale, 2011) become apparent and traceable. That is one of the unique contributions of SPT. Using reductionist science and so the proven conventional tools of science to reveal isomorphic relations for both SPs & LPs, one achieves more traction for the claim of the possibility of a "science" of systems.

Case Study: Finding New Linkage Propositions from the Natural Sciences

We now cite some examples of the above procedure. Note the importance of documenting each example by connecting it to peer-reviewed articles already accepted by one of the natural science communities. We call this the "case study" approach long used in law and business schools. A case study is an in-depth study of a specific instance whereby knowledge is gained from understanding its complex interactions as representative of the wider set of instances for that class of phenomena. By the deep study (analysis) and comparison of several case studies, one can achieve synthesis or integration. In each case below, the SPs found are cited, their dynamic interrelation specified, and the conventional discipline of source cited to show how even reductionist-oriented science literature can be used to better understand systemness in general. We are also building at-a-glance spreadsheets that summarize how many LPs we have found for each SP pairing and how many are documented by references from the natural science literature versus how many we have formulated from direct observations of the systems science literature.

Table Two shows 30 new LPs from 10 natural sciences. It is organized in the format we would like to use in all future LP catalogues but that was not used for the "old" list of the initial 175 LPs (Troncale, 1978). The [SP1 "operator" SP2] syntax of any one suggested LP is followed by the natural science it was experimentally observed in, the specific phenomenon it was observed in, and the reference citation of the publication describing the experiment. In the spreadsheet database on each LP there are also columns for each LP containing information on "direct quote," "explaining the inference or abstraction levels for that LP," "questions arising on this LP," "range of validity to-date for that LP," and "pathologies observed for this LP" where known. There is no particular order to the sequence shown here; it is in the order of identification and so random. There is a over representation from the Cycles and Cycling SP, including its putative discinyms (Troncale, 2007) Oscillations, Spin, and Waves because the SPT modeling teams asked the SP team to develop one SP in more detail as a "test" of the 26 categories of information planned for each SP. LPs are just one of these 26 categories of information.

TABLE TWO: Thirty recent candidate LPs suggested from the natural sciences literature

SP1	OPERATOR	SP2	SCIENCE	PHENOMENON	Reference
spin (cycling) in fields	**is a partial cause of**	**phase transition**	physics	quantum particles and spin-orbit coupled bose-einstein condensates	Lin et. al., (2011) *Nature* 471:83
cycling in networks	**are a partial cause of**	**chaos attractors**	biology	rat brain theta cycles in hippocampus	Jezek et. al. (2011) *Nature* 478: 246
feedback loops	**are a partial cause of**	**cycles**	biochemistry	effect of oxidation reduction cycles of peroxiredoxins on circadian rhythms	Edgar et. al. (2012) *Nature* 485: 459
cycling	**is a partial cause of**	**dynamic equilibrium homeostasis**	biology	effect of oxidation reduction cycles of peroxiredoxins on circadian rhythms	Edgar et. al. (2012) *Nature* 485: 459
positive feedback	**is a partial cause of**	**cycle synchrony**	biology	100's of genes & proteins coordinated for cell division cycle	Santos & Ferrell(2008) *Nature* 454:288

fields	**are a partial cause of**	**cycles**	geology	magnetic field effects on earth core dynamics	Holme, R. (2009) *Nature* 458:652
osc-illations	**are a partial cause of**	**phase-locking**	biology	human brain theta cycles and memory formation	Rutishauser et. al. (2010)*Nature* 464:903
flows (shearing)	**are a partial cause of**	**waves**	astronomy	effect of massive star formationon gas nebula in Orion	Berne et. al. (2011) *Nature* 466: 947
waves	**are a partial cause of**	**chaos**	astronomy	as above; due to increasing Kelvin-Hemholtz instabilities	Bally, J. (2011) *Nature* 466 :928
symmetry	**inhibits**	**oscillation coherence**	chemistry	electron leaving a symmetric dihydrogen before dissociation	*Nature* Martin et. al. (2007) 315:629 and Sanov :610
oscillation coherence	**is a partial cause of**	**symmetry breaking or asymmetry**	chemistry	electron leaving a symmetric dihydrogen before dissociation	*Nature* Martin et. al. (2007) 315:629 and Sanov :610
hierarchy structure	**is a partial cause of**	**recursion**	psychology	syntactic pattern learning in songbirds & human language	Gentner et. al. (2006) *Nature* 440: 1204
feedback	**is a partial cause of**	**cycles**	biology biochemistry	transcriptional regulators explain Arabidopsis circadian clock	Paz et. al.(2009) *Science* 323: 1481
feedback	**is a partial cause of**	**cycles**	biology biochemistry	sychrony with light dark cycle thru NAMPT-based NAD^+ biosynthesis	Ramsey et. al. (2009) *Science* 324: 651
feedback	**is a partial cause of**	**cycles**	biology biochemistry	CLOCK-SIRT1 light dark control of NAD^+salvage pathway	Nakahata et. al. (2009) *Science* 324: 654
decay processes	**are a partial cause of**	**cycling**	geolgy biology ecology	plant litter decay in semi-arid ecosystem	Austin & Vivanco ('06) *Nature* 442: 555
flows	**are a partial cause of**	**cycles**	astronomy	meridional plasma flow causes portion of sunspot cycle	Nandy et. al. (2011) *Nature* 471: 80

flows	**are a partial cause of**	**cycles**	geology	global water cycles	Thornalley et. al. (2011) *Science* 331: 202
cycle-format	**simplifies, improves efficiency**	**networks**	computer & information science	human subject experiments in color problelm solving	Kearns et. al. (2006) *Science* 313: 824
auto-catalysis	**increases stability of**	**oscillation**	mathematics modeling	modeling of glycolytic oscillaitons	Chandra et. al. (2011) *Science* 333: 187
symmetry	**is a partial cause of**	**fields**	astronomy	protogalactic magnetic fields & laser shock waves	Gregori et. al. (2012) *Nature* 481: 480
phase/state	**is a partial cause of**	**hierarchies**	geology	FeO phases and hierarchical stratification earth core	Ozawa et. al. (2011) *Science* 334: 792
feedback	**is a partial cause of**	**duality**	biology	antagonistic motor circuits in development	Tripodi et. al. (2011) *Nature* 479: 61
fields	**influence**	**flows**	astronomy	sunspot dark downward flows by strong magnetic fields	Scharmer et. al. (2011) *Science* 333: 316
couplled feedback	**is a partial cause of**	**equifinality**	biology	BMP signal pathway + and - feedback yields constant phenotpe	Paulsen et. al. (2011) *PNAS* 108: 10202
coupled feedback	**is a partial cause of**	**states**	biology	gene regulatory circuit and cell differentiation	Suel et. al. (2006) *Nature* 440: 545
fields	**are a partial cause of**	**symmetry breaks**	physics	higgs fields	
boundary	**is a partial cause of**	**storage-info**	biology	deduced from Salthe explanation + black holes	Salthe, S. *Evolving Hierarchical Systems*, 96-8

symmetry breaks	**are a partial cause of**	**flows**	trans-disciplinary	observed	*T. Collected Papers*
hierarchy	**is key organizer of**	**networks**	trans-disciplinary	math analysis across several phenomenon diff't disciplines	Clauset et. al. (2008) *Nature* 453: 98
binding linkage	**is a partial cause of**	**fields**	trans-disciplinary	observed, original	

The LPs in Table Two dynamically bind together, connect, or explain influences across 23 SPs including cycles & cycling (12 LPs); phases/states (3 LPs); networks (3 LPs); chaos (2 LPs); feedbacks (8 LPs); fields (5 LPs); oscillations (4 LPs); flows (5 LPs); waves (2 LPs); symmetry (2 LPs); symmetry-breaking (3 LPs); hierarchy (3 LPs); and 1 LP each for spin; equilibrium; synchrony; recursion; decay; autocatalysis; duality; equifinality; boundary; storage; and binding. Recall that the SPT tentatively combines cycles, spin, oscillations, waves, and recursions as discinyms of each other. This would constitute a cluster of 20 LPs on its own.

The articles cited above range only over a 6-year period from 2006 to 2012, as follows (2006, 4 hits) (2007, 2 hits) (2008, 2 hits) (2009, 4 hits) (2010, 1 hit) (2011, 11 hits) (2012, 2 hits). There is no particular pattern to this as journals were sampled on a random basis. Only three journals are represented with *Science* yielding 8 articles, *Nature* yielding 17 articles and *PNAS* yielding 1. This is a very limited sample of the natural sciences literature and we expect "crowd sourcing" of this SPT part of the project will result in many more instantiations of each LP above, or many new LPs, or falsification of the above by counter results or finding they are limited to only that phenomena and so are not isomorphic. We already have 60 similar, additional suspected-LP reprints on file yet to be analyzed and searched for suspected LPs.

The range of ten sciences successfully yielding LPs in this initial use of the suggested protocol indicates its efficacy. This breadth also supports the claim that the systems processes and patterns as well as their connecting linkage propositions of the SPT are potentially isomorphic. By isomorphic we mean retaining essential identifying features and functions across otherwise separated conventional Disciplines, Domains, Tools and scales. So they are DDT's-independent. Numbers listed below do not agree exactly with the 30 cited in the title because some examples in biochemistry could be counted in the biology or chemistry categories, and some that were interdisciplinary could be double counted. Biogeochemical cycles, for example, could represent any of three sciences. Isomorphy suggests even categorizing a particular LP by one science is for conventional purposes and to better follow the documentation. It is not fundamental to a GTS.

17 New LPs Connecting SPs from the Physical Science Peer-Reviewed Literature

Astronomy articles generated 5 LPs, physics articles generated 2 LPs, chemistry-biochemistry articles generated 6 LPs, and geology articles produced 4 LPs. So a domain that is often not represented at all in candidate general theories of systems, the physical sciences, was responsible for contributing the most suggested LPs. The physical sciences contributed an impressive variety of phenomena in this sample ranging across quantum particles, peroxiredoxin oxidation-reduction cycles, earth core dynamics, massive star formation, Kelvin-Hemholtz instabilities, dihydrogen dissociation, plasma flow in sunspots, NAD^+ (nicotinamide adenine dinucleotide) synthesis, global water cycles, laser shock waves, SIRT1 control of NAD, protogalactic magnetic fields, earth core stratification, sunspot magnetics, and Higgs fields.

10 New LPs Connecting SPs from the Life Science Peer-Reviewed Literature

Biology articles generated 9 LPs and ecology articles generated 1 LP. We expect that ecology will contribute many more when its specialized journals are studied because it is a systems-based science. Ecology could have been collapsed into biology as a category, but since biology contains so many scalar levels, from the molecular up to world wide, we decided to represent its range by subcategories. Eventually we will recognize all of its scalar levels in such charts. There is an impressive variety of phenomena in this biological sample ranging across rat brain theta cycles of the hypothalamus, circadian rhythms, cell division cycle control of hundreds of genes & proteins, human brain memory formation, *Arabidopsis* transcriptional regulators, plant litter decay, antagonistic motor circuits, signal pathways for constant phenotypes, and gene control circuits in cell differentiation.

4 New LPs Connecting SPs from the Human & Symbolic Science Peer-Reviewed Literature

Mathematics proceeds by proofs and manipulation/extension of valid procedures rather than by experiments on natural events. So we combine mathematical approaches with those of computer science and human social systems research under the category “symbolic.” Pure math articles generated 2 LPs and computer or information science generated 1 LP. We expect these categories to yield many more LPs in future studies. The phenomena represented in this sample range across comparison of learning between human language and songbirds, human patterns in color problem solving, and computer mathematical modeling of glycolytic oscillations.

3 New LPs Connecting SPs from the Transdisciplinary Peer-Reviewed Literature

Some of the above (3 LPs) are from studies that are most properly termed “across disciplines” not within one discipline because they study systems-based phenomena such as those represented by networks. Often network studies compare across both biological (both physiological and ecological) and social networks using mathematics. We expect that the future will see a multiplication of this class of studies because someday the individual systems processes (SPs) will each have extensive literatures of their own that are not solely disciplinary-based.

The above initial analysis gives some indication of the diversity of LP sources and instantiations in real systems that can be derived from searching the natural sciences literature. But it is beyond the scope of this introductory paper to explain the observations, understanding, and insights into how systems work resulting from each of these 30 LPs. The next step would be providing at least a page of explanation for each suggested LP. Initial examination already suggests that these explanations will delve more deeply into how systems work than heretofore possible. These elaborations will be the subject of workbooks devoted to that task.

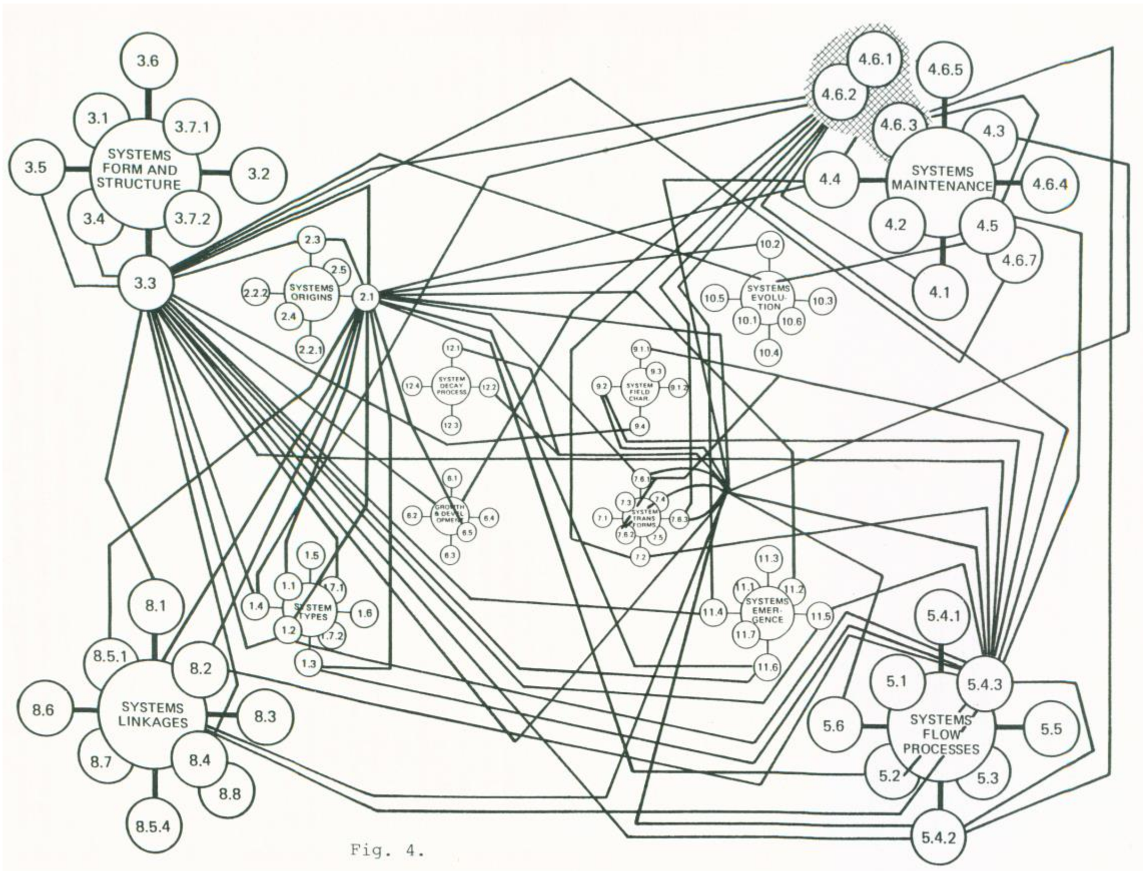

Figure One: Lines showing original LPs between SPs (from (1978) not LPs of Table Two)

Even with this limited set of LPs an observer can see that: (i) mapping of all the LPs on SPs would produce a very complex network of the type seen frequently in the current literature on real networks; (ii) this system of systems processes network has within it “circuits” and/or chains or pathways of causality (as in “flows are a partial cause of waves are a partial cause of chaos”); (iii) there is initial evidence of isomorphic LPs across disciplines (e.g. two LPs in Table Two state that “flows are a partial cause of cycles” from as distinct domains as sunspot cycles in astronomy and global water cycles in geology); (iv) appearance of novel or unexpected influences (such as “symmetry is a partial cause of fields” or “symmetry breaks are a partial cause of flows”; and (v) there is clear evidence for currently unrecognized pleioetiology, meaning multiple causes that yield a singular effect (LT neologism). When the SPT is more developed, this could help us understand the feature of non-linearity in complex systems.

Representing Knowledge with Graphics

As noted above, a linkage proposition is a relationship between two systems processes. “A dyad statement consists of two specific systems processes joined by a logic operator describing the mutual or directional influence, causation, relation, or dynamic between them.” This statement implies a direction and a qualifying element in the relation. From the preceding lists it can be seen that each SP has several LPs linking it to other SPs. The result is a network of linkages.

While this can be represented in text as the previous tables illustrate, a graphical representation has several advantages.

Perception of systems and other complex structures is facilitated by a variety of knowledge representations. For example, systems representations typically have three components and can include text, visual, and relational views (McNamara, xxxx). One example of three part descriptions comes from pattern languages (Alexander, xxxx). A design pattern consists of a situation description, a representation of the conflicting forces in that situation, and an image of a possible solution. Pattern languages are sets of these patterns linked together to represent an area of design. They have been implemented in architecture (Alexander, xxxx), programming languages (Schmidt, xxxx), and communications along with many other areas. A design would typically utilize several patterns representing different aspects, and the patterns could be across multiple levels of hierarchy.

While the idea of a pattern language of LPs and SPT is appealing, the current state of identification and description indicates that exploration of this will be future work.

Pattern languages are often created and maintained as open source repositories of design solutions. By being publicized and critiqued, the pattern descriptions evolve and improve.
An alternate graphical representation would be a cognitive map. “Cognitive maps (also known as mental maps, mind maps, cognitive models, or mental models) are a type of mental processing composed of a series of psychological transformations by which an individual can acquire, code, store, recall, and decode information about the relative locations and attributes of phenomena in their everyday or metaphorical spatial environment” (Wikipedia). Although the implication from this description is that the representation is based on human cognition and recognition of knowledge, an examination of examples from an image search via google reveals many examples that are similar to the goals of LP representation. Note that a mind map is an example of a cognitive map.

A third representation would be a conceptual map. “A concept map is a diagram showing the relationships among concepts. It is a graphical tool for organizing and representing knowledge. Concepts, usually represented as boxes or circles, are connected with labeled arrows ... The relationship between concepts can be articulated in linking phrases such as "gives rise to", "results in", "is required by," or "contributes to” (see). This is very close to the desired representations for LP operators, developed independently. What is required: developing a standard language of relations and finding a common representation tool. (Wikipedia)

Another approach to knowledge representation is as a semantic network. “A semantic network, or frame network, is a network which represents semantic relations between concepts. This is often used as a form of knowledge representation. It is a directed or undirected graph consisting of vertices, which represent concepts, and edges.[1]” (Wikipedia). Semantic networks are often used to represent knowledge in artificial intelligence systems. It has been said that semantic networks most easily represent taxonomic hierarchies. Other representations: it is possible that work on languages to support the semantic web will be useful. UML and SysML should be explored to determine if the LP <> SoSP framework can be represented in them.

Identifying Computer Tools for Mapping the SPT-SP-LP Network

There are a variety of open source modeling tools for UML identified here:
http://en.wikipedia.org/wiki/List_of_Unified_Modeling_Language_tools
This site lists three open source SysML modeling tools:
http://www.sysmltools.com/open-source-sysml-tools/
A large list of concept and mind mapping tools:
http://en.wikipedia.org/wiki/List_of_concept-_and_mind-mapping_software
Some resources for semantic modeling can be found at:
http://web.missouri.edu/jonassend/courses/mindtool/SemanticSoftware.html

Comparison of Mapping Tools for Efficacy at Graphing SPT

In the short term we have used simpler mapping software to illustrate the high connectivity of the SPT. Here we briefly compare three such tools using the results of Hanson & Delcambre, 2005. GetSmart is an open source program in the Java environment, while CMAP and SMART-Ideas are commercial tools. Hanson & Delcambre provide convenient comparison charts for twenty features juxtaposing whether or not each tool supports that feature. Compared features are colors, shapes, background images, shadows, borders, text alignment, directed arrows, undirected arrows, labeled nodes, unlabelled nodes, attachments, patterns, multilevel, autolayout, quick connect, shared repositories, access, viewing, editing, searching, and export capabilities. Nine of these features were supported by GetSmart, fifteen by CMAP, and seventeen by SMART Ideas with the latter having some extended capability in two of the supported features.

After exploration and testing of various representations, the following criteria for a mapping tool were established:

- Freely available
- Links can show directionality
- Links can have descriptors
- Ease of use, minimal time to first map creation

Overall, we decided to use CMAP for its combination of convenience, team familiarity and past experience, and mid-range number of supported features. It can be found at: http://cmap.ihmc.us/

This section is also a plea to those who might read this article. We hope readers will suggest to the corresponding author additional available alternatives from their experience.

Examples of Initial SPT-CMAPs: Uses for CMAPs

Figures 2 to 4 show some early versions of CMAPs constructed by co-author Curt McNamara from both earlier components of the Systems Processes Theory and from Table Two above; the new Linkage Propositions from the Natural Science literature. Using this tool, these maps are very easy and quick to build, modify, and manipulate.

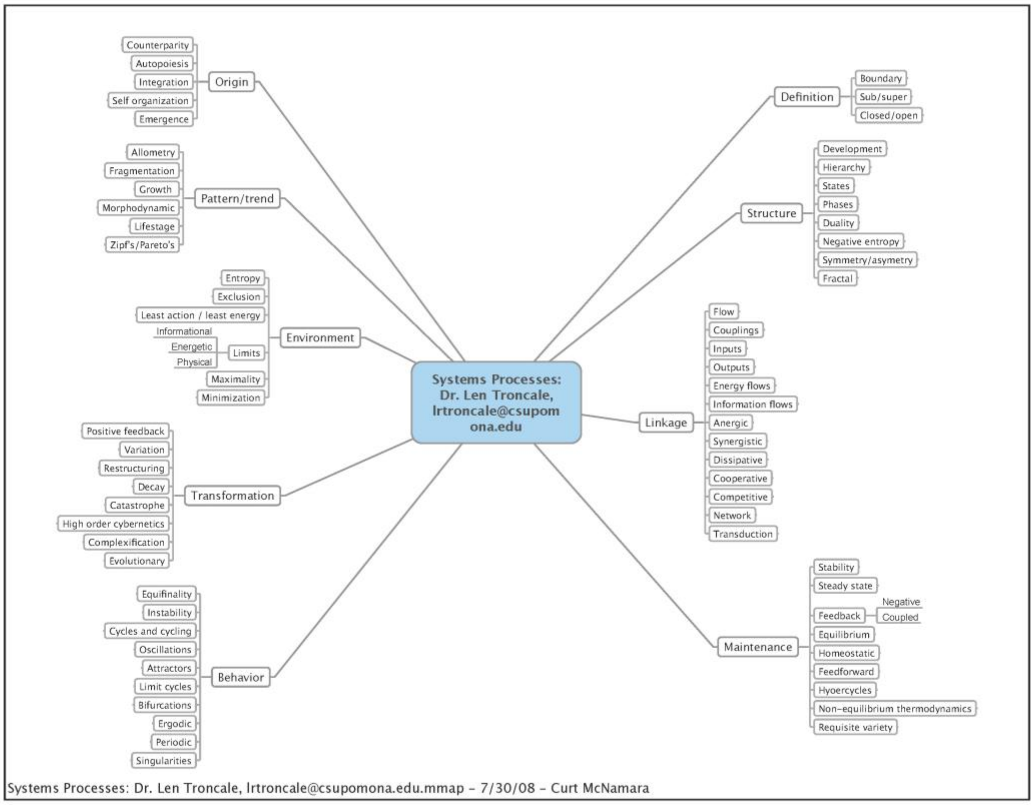

Figure 2: Seventy early Systems Processes CMAPped into Nine Primary Systems Functions

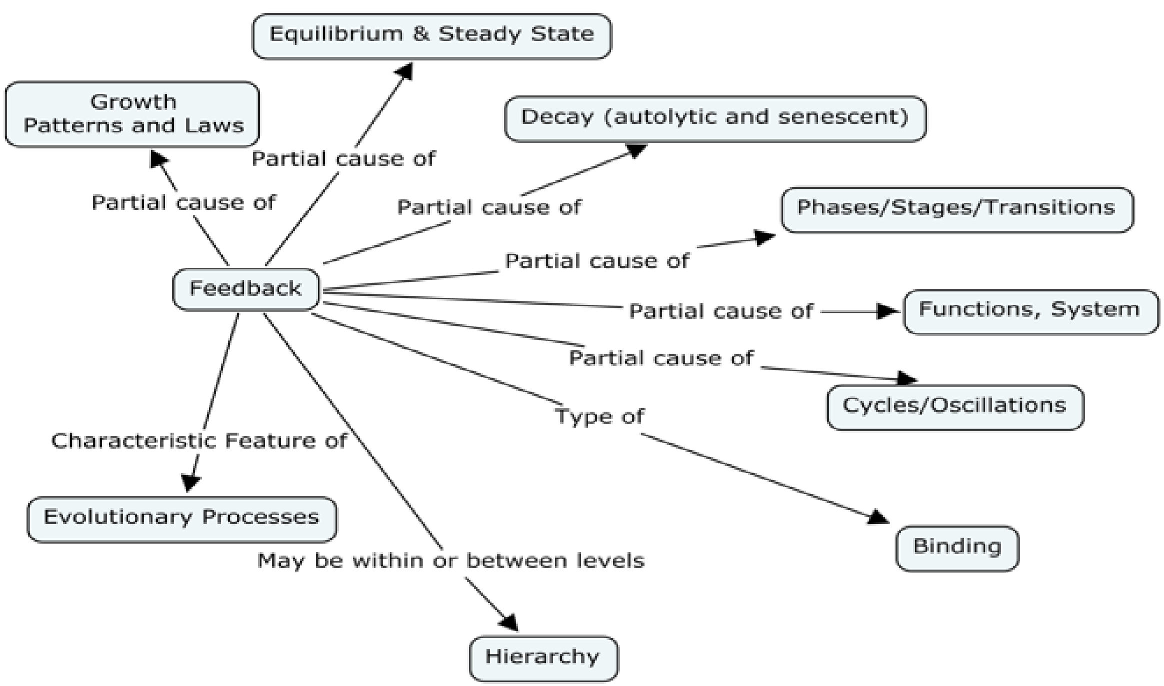

Figure 3: CMAP of 9 LPs between Feedback and 9 Systems Processes + LP operators.

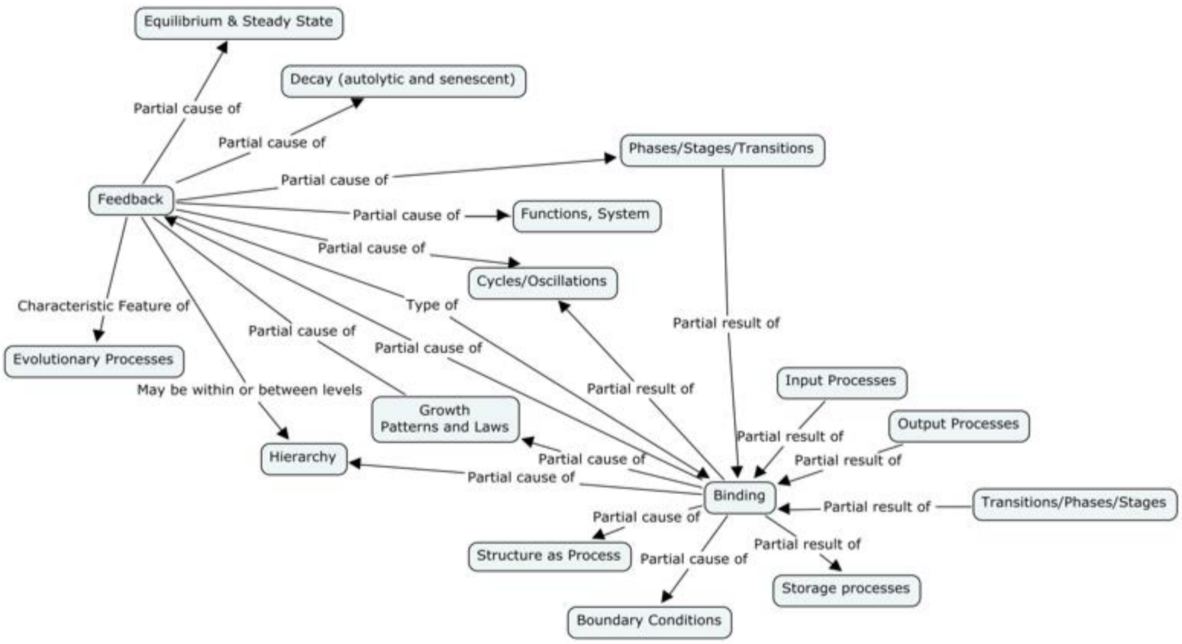

Figure 4: CMAP resulting from adding a cluster of 12 Linkage Propositions on Binding/Interaction as a Systems Process to the Feedback Cluster shown in Fig. 3. Notice that two LPs are responsible for tying the two clusters together.

Some of the advantages of use of CMAPing for applications of this candidate general theory of systems are described here.

Networks of LP CMAPs Explain How Systems Work at New Depth but At-A-Glance

Given its identification, inclusion, and dynamics of >50 isomorphies (systems processes) and hundreds of specific Linkage Propositions, SPT enables description of how systems work and don't work (pathologies) in much greater depth than other candidate systems theories. Yet that same depth and detail challenges ease of communication and use of the theory. Some might even suggest that the theory is as complex as the systems it describes. We would argue that they are not measuring its complexity relative to the complexity of the vast numbers of manifest natural and social systems that it models. It may be complex; but it is one model representing all; each of which is very complex in itself. As complex as 50 isomorphies may seem at first to the uninitiated, each individually integrates a multitude of specific instantiations of the abstract process. This should be recognized and counted as simplification, not complexification.

Still, tools are needed to further simplify and render the SPT easier to learn and apply. We advocate the "at-a-glance" feature of the CMAPs shown here and many more to come. Being able to "see" many relationships at one time in one format tames the detail of networks of many interconnected processes. Similar mappings are used for teaching the complexities of modern genetics, of advanced molecular biology, of details of metabolite interactions in cell physiology, of social interactions and often are even incorporated as exercises in introductory textbooks.

Use of CMAPs in Learning and Teaching: Advantages and Limits

CMAPs have been widely used of late in courses in the biological sciences to motivate and enable student involvement. The students construct the CMAPs for a phenomenon, say DNA replication, or control of RNA synthesis, or photosynthesis from simple lists of steps and dependencies. By moving from overview mappings, to more and more detailed mappings, this encourages students to add stepwise detail. Classroom interactions wherein instructors build more complex maps while interacting with students in discussion adds a groupwork and social dimension to the mappings. Comparison of alternative maps by different students or of initial student maps with maps built by experts encourages improvement and verification.

However, this project envisions CMAPs as just one approach to simplifying and enabling learning of SPT. It has important limitations. CMAPs are not models or simulations that have inherent dynamics and mathematical representations. They are not usually connected to the very detailed documentation required in the SPT. They are not point-to-point interactive such that users can fly through the network and stop at particular points. They are not malleable as a network is when associated with a relational database that allows selection of subsets of maps. We see them as a first, convenient, simple and widely available step in a much longer development cycle.

Future Work and Conclusions: Other Projects Applying Mapping Tools for Graphing SPT

Given the complexity of the network of LPs on SPs as indicated in Figure One, there would be great utility to adoption of software that builds such a map automatically from a listing like Table Two and rebuilds it automatically when LPs are added or subtracted. This mapping should also allow for easy access to documentation in context. Such a tool would enhance attempts to model the SPT. At present, in addition to the simple CMAPs in this article, we have seven ongoing efforts to explore the SPT using the following software or tool approaches:

- UML-Based SysML Systems Processes implementation (Tom Marzolf)
- S*Framework implementation (Bill Schindel, Tom Marzolf, Gary Smith)
- IPA implementation (Integrative Propositional Analysis) (Steve Wallis)
- Alloy Analyzer implementation (Kristen Giammarco)
- Systems Processes in C^{++} Source Code (Luke Friendshuh)
- Virtual Systems Research implementation [like artificial life] (Friendshuh & Troncale)
- Prolog Expert System AI implementation (Len Troncale)

One very useful project for future SPT mapping would be providing easy to access and exact details and documention on the RANGE of VALIDITY for any one proposed Systems Process or Linkage Proposition. This is a vital step for verification and testing of the SPT. Another would be tying any one LP to its evidence-based functionality in different contexts. As data is identified and collected for the 26 categories of information on each Systems Process, it is being added to a relational database to support both of these important features. This future work would provide ready to use tools and useful guidelines for systems designers, systems engineers, and experts on sustainability. It might also provide more accurate guidelines for new specialists who attempt to cure the wide range of systems pathologies we now face.

References:

Ackoff, R.L. (1971) "Towards a System of Systems Concepts," *Management Science*, 17(11): 661-671.

Alexander, C. (1977) *A Pattern Language*, Oxford University Press, New York, NY.

Alexander, C. (1979) *A Timeless Way of Building*, Oxford University Press, New York, NY.

Checkland, P. (1993) *Systems Thinking, Systems Practice: 30 Year Retrospective*. John Wiley & Sons, N.Y., 330 pp.

Churchman, C.W. (1968) *The Systems Approach*. Delacorte Press, NY.

Friendshuh, L. & L. Troncale (2012) "SPT I.: "Identifying Fundamental Systems Processes for a General Theory of Systems (GTS)," in Proceedings of the 56th Annual Conference, Int'l Society for the Systems Sciences (ISSS), July 15-20, San Jose State Univ. (electronic proceedings: Go to http://journals.isss.org/index.php/proceedings56th), 23 pp.

Hanson & Delcambre, (2005) "A Survey of Current Mapping Tools," Course Internet Notes. Available from **Author:** Eric Hanson, elh@cs.pdx.edu **Instructor:** Lois Delcambre, lmd@cs.pdx.edu

McNamara, C. (2009) "Systems Thinking" in Jedlicka (Ed.), *Sustainable Graphic Design*, John Wiley, New York.

Miller, J.G. (1978) *Living Systems*. McGraw-Hill, N.Y., 1,102 pp.

Odum, H. (1983) *Systems Ecology*. Wiley Interscience, John Wiley & Sons, N.Y., 644 pp.

Schmidt, D.C. (2012) Associate Chair of Computer Science and Engineering, Vanderbilt University, Institute for Software Integrated Systems (ISIS). Go to http://www.dre.vanderbilt.edu/~schmidt/

Troncale, L (1978), "Linkage Propositions Between Fifty Principal Systems Concepts," in *Applied General Systems Research: Recent Developments and Trends : N.A.T.O. Conference Series II. Systems Science* (G. J. Klir, Ed.) Plenum Press, N.Y., pp. 29-52.

Troncale, L. (2006), "Towards A Science of Systems" *Systems Research and Behavioral Science*, Special Issue on J.G. Miller, Founding Editor (G.A. Swanson, Ed.) 23(3): 301-321.

Troncale, L. (2007) "Pre-requisites, Discinyms, Discriminations & Mutuality in the SPT. (poster showing 26 discinyms for 6 SPs) at 51st Annual ISSS Conf., Japan, Tokyo Institute of Technology (available from corresponding author).

Troncale, L. (2011) "Would A Rigorous Knowledge Base in Systems Pathology Add Significantly to the SE Portfolio," *CSER'11 Proceedings*, Conference on Systems Engineering Research, April 14-16, Redondo Beach, Ca., 11 pp. (electronic proceedings)

Troncale, L. (2011) "Types of Non-Linear Causalities," Powerpoint presentation of 38 slides, Annual Conference of the Int'l Society for the Systems Sciences (ISSS), July 17-22, Hull University, England (available from corresponding author)

Troncale, L. (2012) "SPT V: Proving Isomorphy by 52 Case Studies: Testing for Cycles and Cycling Across Disciplines, Domains, and Scales" in Proceedings of the 56th Annual Conference, Int'l Society for the Systems Sciences (ISSS), July 15-20, San Jose State Univ. (e-proceedings: Go to: http://journals.isss.org/index.php/proceedings56th)

Warfield, J.N. (2006) *An Introduction to Systems.* World Scientific Publishing Co., Singapore.