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A Decision Taxonomy

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The beginning of knowledge consists of learning to call things by their names – Chinese Proverb

As Bowker and Star (Bowker and Star 1999) so eloquently explained in their book "Sorting Things Out," classification and classification systems are ubiquitous to human existence. The term "taxonomy" is unfortunately used in the literature as a synonym for "classification" when in fact it has broader implications. Taxonomy relates to a process that includes a specific type of classification as a key-defining characteristic. A taxonomic classification focuses on the general laws or principles comprising the phenomena or system of interest. The taxonomy process includes this taxonomic classification, along with methodologies for naming classes, rules for applying these names, and the procedure for identifying individual objects for inclusion in a particular class. Thus, the term "taxonomy" when used as a noun in this paper refers to the entire taxonomy process and not solely the classification or grouping of objects.

The goal of this paper is to establish taxonomy for decision problems. The procedure for identifying individual objects for inclusion in each class will be explored briefly. The taxonomic classification system and nomenclature defined, together with the identification procedures, provide the complete "taxonomy" called "decision-order theory."

THE PROBLEM DEFINED – A THEORETICAL DEFINITION

Never take the anti-intellectual side in an argument. You'll find that most of the people who applaud you will be the people you hate (Tynan 1994, p.88)

What is the best methodology for solving real-world problems and making real-world decisions? Many theoreticians promote a rational analysis approach. Described by a series of "if-then" procedures and rules, this approach can assure consistent, predictable results (Dewey 1933; Simon 1945; Bransford and Stein 1984; Russo and Schoemaker 1989; Dorner 1997). To the credit of its sponsors, rational analysis has forged the advancement of science and technology. It has allowed computer chip manufacturers to increase the processing speeds from a few mega-hertz to over 1 giga-hertz in less than fifteen years. Rational analysis has allowed immunologists to develop new vaccines that have essentially eliminated many of childhood's most devastating diseases. These advancements represent remarkable achievements, and provide strong support for utilizing a rational analysis to problem solving and decision-making. Logical atomism,[1] survival of the fittest, and analogies to Darwin's theory of evolution provide a feasible image on which to base rational arguments.

Unfortunately, rational arguments characterized by "if-then" rules and procedures fail to explain, describe, prescribe, or predict the actions of a real-world decision-maker (Lindblom 1959). Such procedures constrain thought to incrementalism and fail to promote the innovation and creativity that established the first computer chip and the first vaccine. Real-world decision-makers face situations that cannot always be subjected to decomposition into primitives, a requirement of rational techniques. Instead, decision-makers rely on experience blended with analytical tools and motivations. Although the "if-then" rules and procedures prescribed by rational analysis are important elements in the decision-making process, their application to real-world situations is limited. The difficulty is not in applying the logic that rational analysis prescribes, but instead, it lies in identifying whether or not the "if" condition has been met.

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[1] The belief that ideas and concepts can be decomposed into their natural elements is called "logical atomism." This belief was popular among philosophers during the 1920s and 1930s, and has since been abandoned. (Klein 1998, p. 262)

An enlightening book "Concepts of Science," by Achinstein (Achinstein 1968) describes the difficulty in determining whether the antecedent conditions, or "if" conditions, are satisfied. This difficulty is why many theoreticians focus on context-free laboratory situations, where the "if" conditions are unambiguous. An alternative to constraining the situational context, so that the "if" condition is clearly defined, is to identify the context of the situation and then determine whether the "if-then" rules are applicable. This latter alternative urges the development of a decision-making taxonomy to assess whether or not the "if" conditions can be identified, evaluated, and satisfied within the actual situational context. The decision-order taxonomy, described in following sections, offers a framework for placing decisions within their natural real-world context.

The decision-order taxonomy begins with a hierarchical classification of decisions into three major classes. These classes are developed from a concilience of the literature spanning the natural sciences, social sciences, applied sciences (engineering), and the arts. Each of these fields has struggled to identify real-world situations that fall within their scope of understanding and analysis. Each of these fields has developed a language and terminology that characterizes its particular situation. Each of these fields has established unique approaches to representing the real-world within the constraints of its domain. Unfortunately, these divergent approaches have made impossible an unambiguous semantic classification using the existing language. Thus, a new language, which does not possess the interpretive baggage associated with a particular discipline, is necessary.

The decision-order taxonomy is developed to provide an "Ariadne's Thread,"[2] linking the different problem-solving/decision-making theories with a common language construct. To identify the semantic descriptors that are commonly used by researchers to partition their domains, a content analysis is performed on the seminal literature in the natural sciences, social sciences, applied sciences, and the arts. This content analysis reveals a triad pattern and exposes an underlying order. The resulting triad groupings are used to construct Table 1, where the header column contains labels that indicate the discipline or scientific field from which the triads were extracted.

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[2] The phrase "Ariadne's Thread" originates in the mythological Greek story of the Cretan labyrinth and is used by Wilson (Wilson 1998) as an analogy for the common theme or connection between different academic disciplines. Wilson (Wilson 1998) recalls the Greek story as follows: "Into the heart of the Cretan labyrinth walks Theseus, Hercules-like champion of Athens. Through each corridor, past uncounted twists and turns, he unravels a ball of thread given him by Ariadne, lovestruck daughter of Crete's King Minos. Somewhere in the hidden passages he meets the Minotaur, the cannibal half man, half bull to whom seven youths and maidens are sacrificed each year as Athens's tribute to Crete. Theseus kills the Minotaur with his bare hands. Then, following Ariadne's thread, he retraces his steps through and out of the labyrinth" (Wilson 1998, p. 66).

	Decision Order		
Field of Inquiry	**1st**	**2nd**	**3rd**
Decision Making	Certainty	Risk	Uncertainty
Classical Solution Methodology	Deterministic	Probabilistic	Heuristic
Logic Methodology	Deduction	Induction	Abduction (retroduction)
Planning	Operational	Tactical	Strategic
Modeling	Mechanistic	Biological	Sociological
Process	Rules	Procedures	Politics
Economics	Equilibrium	Linearity	Non-linearity
Gambling	Odds	Bet Hedging	Betting
Investment	Money	Securities	Projects
Quandary	Puzzles	Games	Life
Supervision	Administrative	Managerial	Entrepreneurial
Valuation	Price	Expected Value	Utility
Guidance	Blueprint	Map	Compass
Response	Static	Stochastic	Dynamic
Processing	Calculation	Simulation	Experimentation
Scholarship	Facts	Information	Knowledge
Vocation	Production	Development	Research
Insurance	Underwriting	Selling	Buying
Solution Approach	Imitation	Precedence	Innovation
Business Function	Bookkeeping	Accounting	Finance
Discernment	Selection	Choice	Preference
Solution Technique	Calculating	Optimizing	Satisficing
Functional Concern	Validity	Reliability	Practicality
Measurement Scale	Ratio	Interval	Nominal and/or Ordinal
Change Mechanism	Stagnation	Evolution	Mutation
Problem Structure	Simple	Complicated	Complex
Time Focus	Current	History	Future
Process	Sequential	Feed-forward	Feed-back
Evidence	Direct	Circumstantial	Opinion
Connections	Contracts	Contacts	Relationships
Knowledge	Direct	Indirect	Tacit
Agent Characteristic	Doers	Solvers	Formulators
Problem Formulation	Independence	Actuarial	Synthesis
Thinking	Analytical	Closed Systems	Open Systems
Response Characteristic	Passive	Reactive	Active
Organizational Characteristic	Hierarchical Organization	Matrix Organization	Informal Organization
Solution Acceptance	Exactness	Consistency	Emergence
Authority	Control	Influence	Appreciative
Execution	Procedure	Course	Process
Pay	Low	Medium	High
Education	Primary / Secondary	College / University	Experiential
Skills	Focused	Narrow	Broad
Economic Structure	Communism	Socialism	Capitalism
Authoritative Control	Boss	Manager	Leader
Problem Framework	Fictional World	Academic World	Real World
Solution Focus	Exactness	Efficiency	Effectiveness
Control	Laws	Axioms	Rules of Thumb
Presentation	Drawings	Photographs	Holographs
Key Economic Variables	Cost	Price	Value
Educational Tools	Mathematics	Statistics	Experience
Design	Drafting	Specifying	Designing
Perspective	Objective Independent	Objective Dependent	Subjective
Acceptance Criteria	Provability	Observability	Usability
Decision Strategies	Rational	Reliable	Reasonable
Vision	Pin point	Focal	Peripheral
Navigation	Daytime	Fog	Night
Physics	Certainty	Chaos Indeterminism	Quantum Indeterminism
Nicholas Georgescu-Roegen	Reversible	Irreversible	Irrevocable
Negative Conclusions	Theoretical Impossibility	Statistical Improbability	Observational Impracticality
Life Cycle	Status Quo	Learning Curves	Experience Curves
Innovation	Single Path	Multiple Path	Flow
Employee Development	Training	Experience	Expertise
Options	Theoretical Financial	Real Financial	Real Non-financial
Constraints	Tight - Rigid	Tight	Loose
Human Influence	Low	Medium	High
Solution (Search)	Filtered	Selective	Adaptive
Attribute Focus	Accuracy - exactness	Accuracy - closeness	Speed
Frequency	Repetitive	Frequent	Unique

Table 1: A Taxonomy of Decision-orders - Spanning the Fields of Inquiry

The terminology contained in Table 1 provides an extensive compilation of the descriptive language that will help define the decision-orders. Using the table of triad groupings, the definitions below can be used as a basis for a first, second, and third-order taxonomy construct.[3]

- First-order

First-order problems/decisions typically have static properties and are associated with high levels of certainty and simplicity. These problems/decisions are often described by the literature using words like: simple, reversible, certain, low risk, static, small, short term, understood, common etc. Problems and decisions that are classified as first-order typically have well established solution methodologies, characterized by rational deterministic "if-then" rules and deductive procedures.

- Second-order

Second-order problems/decisions are those that have probabilistic uncertainty, are often complicated, and follow definable dynamic processes. These would be characterized with words like: complicated, stochastic, probabilistic, optimizing, efficient, frequent, irreversible, medium risk, medium term, etc. Problems and decisions that are classified as second-order rely on probability theory and inductive logic for solutions. They are typically approached using axioms, computer simulations, and a constrained model of the actual phenomena of interest.

- Third-order

Third-order problems/decisions are those that have genuine uncertainty, complexity, and dynamics. These are characterized with words like: complex, irrevocable, ambiguous, high-risk, important, big, long term, subjective, tacit etc. Third-order problems/decisions rely on abductive logic and heuristic solutions. The objective is to find an acceptability and effectiveness in the results.

These three decision-order definitions map remarkably well to the classification groupings alluded to by the different scientific disciplines and exposed in the content analysis.[4] Thus, these definitions are used as a basis for developing the three basic classes in the taxonomy, which are similarly labeled, first, second, and third-order.

By establishing an overarching terminology, it is possible to efficiently identify and effectively communicate the appropriate multidisciplinary approaches to decision-making and problem solving. The common language presented in this taxonomy has not been established by prior art. Therefore, the presentation will rely on these basic definitions supplemented with extensive references to discipline-specific examples.

DECISION-ORDERS ACROSS DISCIPLINES

Being able to uniquely classify decisions or problems as first, second, or third-order based exclusively on the semantic definitions provided is not practical. The essence of a decision-order is more than the semantic terminology, which provides its descriptive characterization. The classification of problems/decisions requires a contextual understanding that is gained through experience and is best communicated through examples. Scanning the literature in the natural sciences, social sciences, applied sciences, and the arts, produces a number of relevant examples that offer context to the class definitions.

A three-step heuristic process is used for classifying example problems/decisions in the decision-order taxonomy: soliciting, analyzing, and judging. Soliciting a verbal/written description of the decision (or problem) from the decision-maker (or problem-solver) can generate the semantic data necessary to identify the decision-order. Performing a content analysis on this description will identify whether the decision-maker (problem-solver) is using first, second or third-order language. Based on this analysis a judgment can be made, using some predefined dominance criterion,[5] as to which decision-order classification best fits the decision under investigation.

An excellent example of a decision problem that contains elements of all three decision-orders, but holistically is clearly a third-order problem can be found in automobile manufacturers discussions on the "three-day

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[3] C. W. N. Thompson (Thompson 1999/2000) introduced the terminology "first, second, and third-order" as a possible classification system."

[4] The orders are not simply categories, but represent regions along a hypothetical continuum.

[5] A dominance criterion might involve selecting the decision-order that has the highest raw count of descriptors used, or applying some additional weighting to those terms, like "uncertainty," that clearly indicate the decision belongs in a particular class.

car.”[6] The next section presents the three-day car using the decision-orders language. From this example it should be clear how the decision-orders table, Table 1, might be used to guide the classification of a decision. The terms used in describing the three-day car decision that match elements of Table 1 are underlined and followed by a subscript identifying the order.

The Three-day Car – a third-order decision?

Why the interest in the three day car? Will this really create a sustainable competitive advantage to the automobile company that first develops the capability? These are the real-world$_3$ questions being evaluated by auto industry executives who have to decide if exploration$_3$ of this real investment option$_3$ is strategically$_3$ warranted. To understand the industry’s motivation to research$_3$ this issue, some background is required on the two countries touting this capability as necessary for their future$_3$. Currently the Japanese automobile manufacturers operate from four bases-of-production: Japan, North America, Europe, and the Newly Industrialized Countries (NICs). Since the statistical$_2$ projections forecast a 20% decline in the Japanese base production over the next 10 years (Hall, 1993), the consensus opinion$_3$ indicates that there will be a shift in market focus toward the shorter production runs of higher priced, custom designed$_3$, models offering greater utility$_3$.

In North America vehicle demand is expected to be flat, creating an environment where competition will focus on the higher value$_3$ end of the market. This focus will drive adaptive$_3$ designs. Electric vehicles have become practical$_3$, however the risk$_2$ of significant market impact is low unless uncertainty$_3$ surrounding oil production increases significantly. Other sociological$_3$ changes will affect the US automobile marketplace by placing greater demands on the knowledge$_3$ and expertise$_3$ needed to build higher-value$_3$, lower volume, niche automobiles that only sell a few thousand unique$_3$ vehicles in a model lifetime.

Sociological$_3$ changes in the US market are expected to be mirrored in the domestic Japanese market as it fragments into niches. This fragmented market will likely be supplied by a variety of models with production levels on the order of a thousand vehicles. A smaller but significant portion of the Japanese consumer will seek an extensively customized vehicle. The Japanese identify the serving of these emerging$_3$ niche segments as their most significant challenge (Hall 1993). If successful tactics$_2$ can be identified, the Japanese domestic automobile industry will remain healthy. The same objectives of serving niche segments will challenge the future$_3$ of US manufacturers.

There are a number of challenges that people familiar with the automobile industry have identified as imperative to competing successfully in the new environment (Hall 1993). The first most obvious challenge is to break the industry’s dependence on economies of scale in production$_1$. Shorter production runs and smaller lots are the only way to meet the dynamically$_3$ changing market demands. Economies of scale must be sought in other areas of the business. The business must look to marketing economies, commonality of process$_3$ and systems, and efficient$_2$ networks of relationships$_3$. The industry must look to the product performance effectiveness$_3$ and process$_3$ efficiency$_2$ in parallel.

Having broken the dependence on economies of scale in production, the strategic$_3$ objective is to deliver a customized vehicle to a customer within three days of order placement. The manufacturers will be challenged to downsize the scale of production into small relationship$_3$ clusters with suppliers feeding mini-production facilities located near the customer base to optimize$_2$ delivery cost and transportation time, as well as increase feedback$_3$. If automobile manufacturers want to achieve the three-day objective, they are going to have to think of automobile production as an open system$_3$ designed to synthesize$_3$ a variety of modular components.

Clearly the above description describes a third-order decision environment rich in uncertainty$_3$ and complexity$_3$. Unfortunately, much of the discussion on the three-day car has been pursued by production-oriented engineering and has stopped with identification of the production-oriented objectives. Classically, production$_1$ is a discipline whose foundation is built on first and second-order thinking. To achieve the overall objective of a three-day car, from order to delivery, the thinking is going to have to be third-order. The decisions are not just production$_1$ decisions but they span the entire value$_3$ chain. The issues and decisions outside of production$_1$ may actually be the most formidable.

Hall (Hall 1993) visualizes a delivery system where the car is no longer ordered from a dealer lot. Instead the consumer is placed in a flight simulator-like environment and is allowed to interactively make adjustments to the location of interior controls and comforts to meet his/her individual tastes. The virtual test drive will allow the

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[6] The “three-day car” is a convenient metaphor for a car produced and delivered to the customer with significantly reduced lead-times. The actual time of “three-days” is representative of this reduction, however, four, five, six, seven, etc. days have also been used in the literature without significantly changing the issues.

customer to experience$_3$ different types of suspensions on different types of roads, under different driving conditions. The three-day car will be made to order with zero inventories. Although the three-day car may be significantly more expensive to produce, the reduction in inventory[7] may offset some of the increase. Additionally, the consumer may identify the benefit of future$_3$ upgradability as a longer usable$_3$ life, and thus, be willing to pay for these more expensive vehicles over much longer periods of time.

The fundamental issue to making this purchase process a reality, is how do you change the buying$_3$ habits of consumers? Rather than simply being consumers of a generic manufactured good, the new consumer is required to actively$_3$ participate in the production process; they are "prosumers." Another big challenge will be the ordering system that will convert the prosumers desires into a feasible design$_3$. The prosumers credit must be verified in real time and some type of contract$_1$ must be established to assure that the custom vehicle will in fact be purchased.

Data requirements would be immense if customization were allowed. Service stations would have to get car specific information to make needed repairs. The synchronization of the distributed open system$_3$ would be complex$_3$. There would be a severe information integrity crunch attempting to coordinate information between assembly plants, suppliers, dealers, planning centers, maintenance and service centers – CAD/CAM systems, production specifications, vehicle performance and manufacture data, customer credit, and delivery information.

Even though the focus has been on technical requirements, the major decisions are likely to emerge from the human development issues not the technical details. The need will exist for flat, efficient$_2$, and informal$_3$ organization structures, small relationship$_3$ driven operating units, and complete process$_3$ integration of people with computer information systems. Any scenario of a three-day car will change the basic nature of the auto industry.

Success in making decisions to pursue significantly reduced cycle time "x-day" automobiles will depend on the decision-maker's ability to identify correctly the problem order and choose "order" appropriate techniques in seeking resolutions. Third-order problems like the three-day car require an alignment of decisions both horizontally across the organization and vertically up and down the value chain. This alignment will not occur if decisions are made based solely on first and second-order techniques because they will fail to fully appreciate the inherent interconnectedness.

DECISION-ORDER FRAMEWORK

The taxonomy illustrated by Table 1 provides a useful intuitive guide for identifying the perceived decision-orders of a particular decision or problem. The three-day car example demonstrates the application of this definitional taxonomy to a specific third-order problem. Unfortunately, the implementation of the taxonomic classification is based on a subjective description of the decision/problem. Such a description is subject to a "framing bias." According to the Oxford English dictionary, "framing" is the "action, method, or process of constructing, making, or shaping anything whether material or immaterial." Thus, a "framing bias" is defined as the act of intentionally constraining/defining the limits of a decision/problem so that it falls within a prescribed classification.

Realizing that framing bias can significantly impact any subjective description, the argument can be made that all problems/decisions can be framed to fit the third-order classification. A taxonomy that allows all decisions/problems to be classified as a single class provides little practical use. Thus, the taxonomy must include a consistent methodology for framing the problem prior to classification.

Given the complexity and scale of the three-day car example, it is evident that re-framing and reclassification might be warranted. Although the overall decision to pursue a three-day car objective will remain third-order,[8] it may be possible to decompose many of the specific manufacturing issues into simpler first, second, and third-order problems/decisions. Similarly, many of the delivery and distribution issues suggest independent first, second, or third-order problems/decisions. The issue of decomposition presents several questions that must be answered. How can the decision problem be decomposed? When should the framing decomposition stop, and the classification and analyses begin?

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[7] The current level of inventory by US automobile manufacturers is on the order of 60 to 90 days. (Japanese cars in the US have on the order of 30 days inventory).

[8] The complexity and uncertainties associated with the three-day car example make a complete decomposition impossible. Thus, the decision by an automobile manufacturer to pursue this objective will remain third-order no matter how many of the underlying issues are resolved.

The answers are found in the decision-order methodology presented in Figure 1. A decision problem is subjected to a series of questions probing the decision-maker's knowledge. If the decision-maker is confident that no decomposition can be made, the decision/problem is classified using the taxonomy and an appropriate solution methodology is pursued. However, if the decomposition can be performed to parse the decision problem into independent problems/decisions, the identified decomposition is made, and the decision-order methodology is reapplied to each new decision problem. When the knowledge of the decision-maker is not sufficient to make a clear decomposition assessment, the decision problem is classified as perceived third-order and additional steps are taken to search for additional understanding.

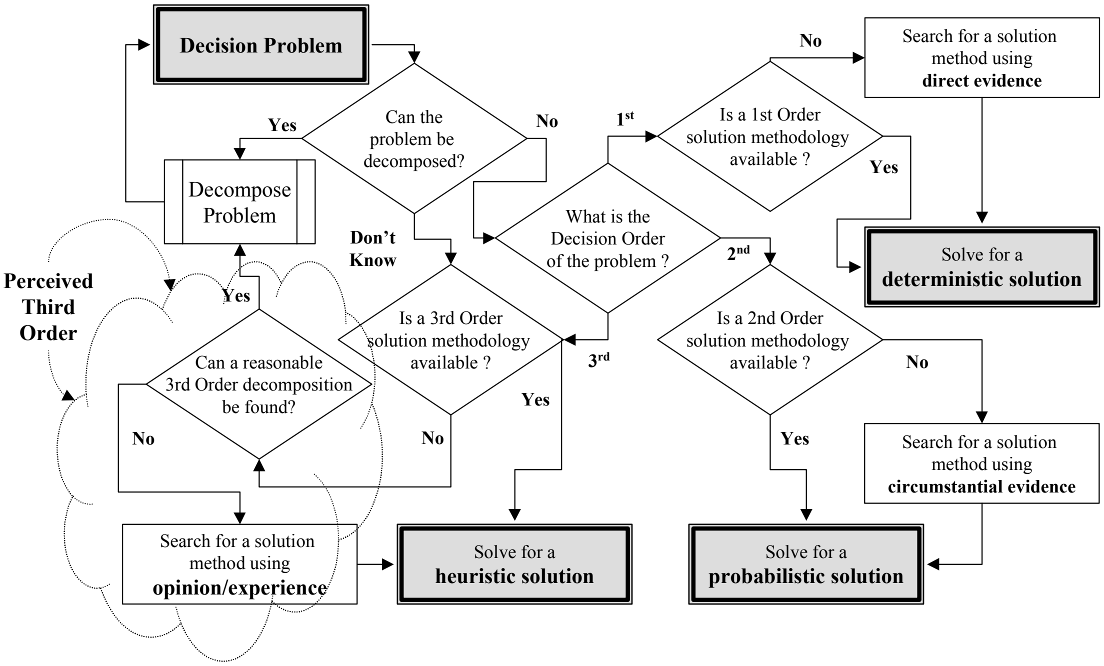

Figure 1: The Decision-order Methodology

The decision-order taxonomy can now be viewed as an inverted pyramid or funnel, representing the universe of all decision problems. Figure 2 provides this visualization. The lower portion of the funnel contains first-order decision problems, the majority of which have mathematical solutions. The middle level represents second-order decision problems. Many of these second-order decision problems have heuristic solutions and some even offer robust mathematical procedures, which typically incorporate some form of probability theory. The top-level represents all third-order decision problems. A small number of these third-order decision problems have heuristic solution methodologies that can be attempted. The area outside the regions of mathematical and heuristic solutions contains decision problems falling into the perceived third-order classification. These decision problems are potentially solvable but have solutions unknown to current science. As with other third-order problems, decision problems in this classification are communicated with metaphors and story telling.

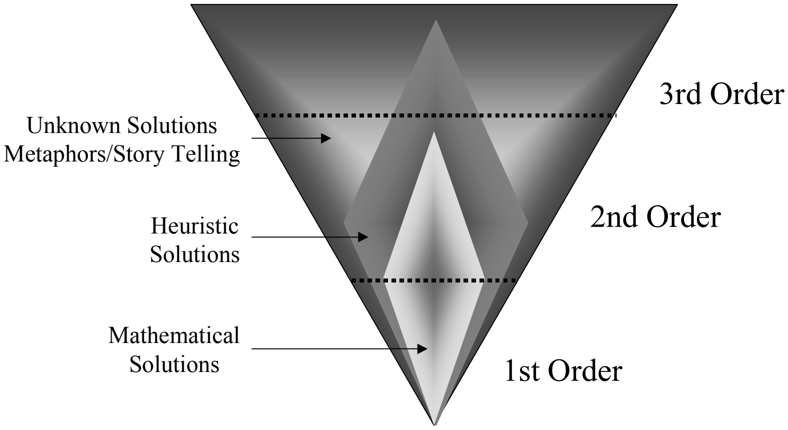

Figure 2: The Decision-order Taxonomy Funnel

ADVANCEMENT OF SCIENCE

> *No part of the aim of normal science is to call forth new sorts of phenomena; indeed those that will not fit the box are often not seen at all. Nor do scientists normally aim to invent new theories, and they are often intolerant of those invented by others. Instead, normal-scientific research is directed to the articulation of those phenomena and theories that the paradigm already supplies (Kuhn 1970, p. 24).*

The traditional incremental view of scientific advancement is challenged by Thomas Samuel Kuhn's book "The Structure of Scientific Revolutions." Kuhn (Kuhn 1970) associates "normal" scientific research with the refinement of existing theories within the constraints of the current dominant paradigms.[9] Thus, the phrase "advancement of science" is typically associated with long periods in which Kuhn's "normal" scientific research takes place. Kuhn recognizes that "normal" (incremental) science constitutes a majority of science, but emphasizes that there exist extraordinary periods of scientific revolutions where the old paradigms are replaced by new paradigms. These revolutions result in what has been popularized as a paradigm shift.

Kuhn's conceptualization of science can be described using the decision-order taxonomy funnel. In this view, science and understanding advance by opening up the funnel or by pushing more decision problems down the hierarchy. The decision-order funnel is redrawn in Figure 3 with arrows to indicate the "normal" advancement of science and with stars to represent particular decision problems. The bold black arrows indicate the process of opening up the funnel, which is equivalent to developing new methodologies. The white arrow indicates the constant force of "normal" science pushing decision problems down the funnel; a process associated with incremental changes in understanding.

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[9] Kuhn defines paradigms as "universally recognized scientific achievements that for a time provide model problems and solutions to a community of practitioners" ((Kuhn 1970, p. viii). This definition will be used in this document.

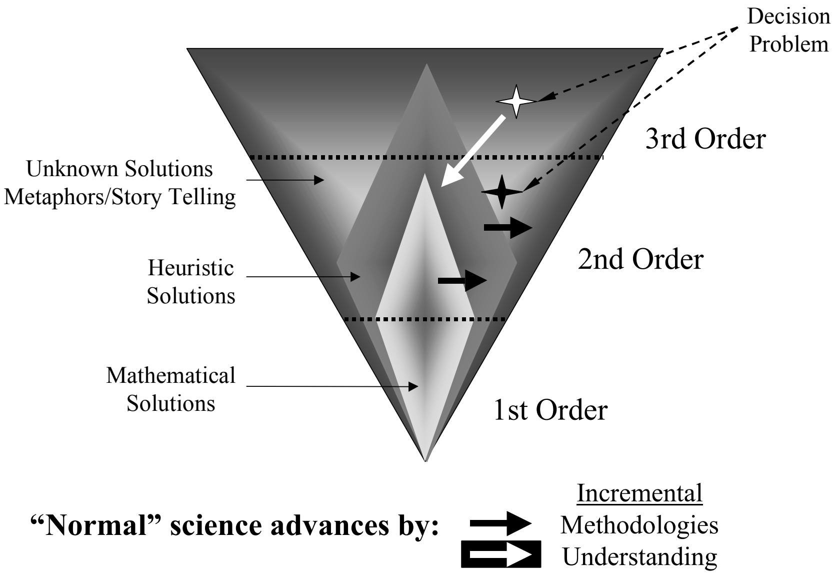

Figure 3: Advancements in Science

As science advances, the areas that have known mathematical or heuristic solutions expand slowly outward. This outward expansion over time may reach the specific decision problem, represented by the black star. When this event occurs, the decision problem is subsumed into the solution knowledge base of that particular decision-order.

There is also a constant pressure placed on the top of the funnel pushing some of the perceived second and third-order problems to a lower level in the hierarchy. The white arrow indicates this movement. As "normal" science enlightens the paradigmatic understanding of a particular decision problem (the decision problem indicated by the white star), the decision problem is pushed down and toward the center of the funnel. This progress eventually moves the decision problem into an area that allows the application of known methodologies.

Although the phrase "advancement of science" is restricted to the movements indicated by the arrows, other forces occasionally reposition decision problems within the hierarchy. These movements could be described as advancements, since they are the result of an increased understanding of the particular decision problem. This increased understanding contrasts that found in "normal" science because it embodies a fundamental redefinition of the decision problem. This shift occurs when the false paradigms protecting these decision problems are exposed. When the paradigms are broken by seminal innovations, the problem shifts to a new level of hierarchy or a different solution methodology within the same level. In the model, a shift of this type is not considered an "advancement of (normal) science," but rather, the recognition of a completely new decision problem with better-understood constraining parameters.

The movement in the decision-order funnel can be recognized in the following example of real-world problem solving. It is important to recognize that the advancement process is not a step-by-step linear progression, but involves "fits and spurts" with any number of discontinuities. Typically, the major seminal advances begin with a redefinition of the decision problem, followed by an innovative progression down the funnel. The story of Einstein's work on time and space is used to illustrate this process.

An Advancement in Science – Einstein's Theory of Relativity

In arguably the most elucidating case study conducted to study the actual thinking process, Max Wertheimer recalls in his book "Productive Thinking" a series of conversations with his friend Albert Einstein. Wertheimer (Wertheimer 1959) had the opportunity to question Einstein in depth about the thinking process that culminated in the theory of relativity. As pointed out by Wertheimer, "Einstein's original papers give his results. They do not tell the story of his thinking (Wertheimer 1959, p. 213)." The chronicle, which began in 1916, tells of a man puzzled by a world that could not be explained by the available scientific theories. Einstein had generated a fuzzy description of the problem, or initial state S_0, but at this point there was no clear solution, or end state S_x, and certainly no series of transformation rules[10] which could take one from the problem to the solution, or from state S_0 to state S_x. Einstein had identified a third-order problem that would eventually be transformed into a solvable first-order concept. The saga recanted by Wertheimer is worth paraphrasing here,[11] for it illustrates the complexity of the actual decision process and shows how some problems defined as third-order initially, can be transformed by scientific inquiry, intellectual genius, and serendipity into a first-order theory.

When Einstein was only sixteen years old his innate abilities in physics and mathematics led him to a troubling line of questioning. "What if one were to run after a ray of light? What if one were riding on the beam? If one were to run after a ray of light as it travels, would its velocity thereby be decreased? If one were to run fast enough, would it no longer move at all? …" Einstein recalled the puzzle that drove his thinking: "I know what the velocity of a light ray is in relation to a system. What the situation is if another system is taken into account seems to be clear, but the consequences are very puzzling." When Wertheimer asked Einstein, in this early period of questioning, whether he had some idea of the constancy of light velocity, which was independent of the reference system, he responded: "No, it was just a curiosity. That the velocity of light could differ depending upon the movement of the observer was somehow characterized by doubt. Later developments increased that doubt."

Einstein's training suggested that light was only a carrier of electrical phenomena. Maxwell had developed electromagnetic field equations in which a constant velocity of light was important. Einstein began to question, if the Maxwell equations are valid with regard to one system, they are not valid in another, thus, they need to be modified. For many years Einstein studied and attempted to change the Maxwell equations, only to fail in formulating a satisfactory alternative. With all his attempts, Einstein was unable to make the assumption that the velocity of light was constant and still produce a provable theory of electromagnetic phenomena. This effort illustrates Einstein's attempts to use existing theories and techniques to explain his own observations, priming him to accept the problem as subjective third-order.

Doubt was increased when the famous Michelson experiment was published. The Michelson experiment was based on the premise that "If you are running away from a body that is rushing toward you, you will expect it to hit you somewhat later than if you are standing still. If you run toward it, it will hit you earlier." Michelson took this logical truism and applied it to light. "He compared the time light takes to travel in two pipes if these pipes meet at right angles to each other, and if one lies in the direction of the movement of the earth, while the other is vertical to it. Since the first pipe, in its lengthwise direction, is moving with the movement of the earth, the light traveling in it ought to reach the receding end of this pipe later than the light in the other pipe reaches its end." To the surprise of most physicists, no difference was found. This was a significant discovery that threatened to invalidate much of the established first and second-order theory in physics.

In an attempt to save the established knowledge base and paradigms, Lorentz, a famous Dutch physicist, developed a theory that seemed to explain the Michelson result.[12] Lorentz introduced an intriguing auxiliary hypothesis: "he assumed that the entire apparatus used in the measurement underwent a contraction in the direction of the earth's motion." Making this assumption implied that the length of the pipe in the direction of the earth's movement changed in the exact proportion needed to compensate for the earth's movement. The perpendicular pipe only changed in width and not in length, resulting in pipes of different lengths. From this theory, Lorentz was able to resolve the mathematically counter intuitive results of Michelson. Thus, the traditional theories were secured in their mathematical foundations.

Einstein, however, was not satisfied. Einstein asked himself: "Except for that result, the whole situation in the Michelson experiment seems absolutely clear; all the factors involved and their interplay seem clear. But are they really clear? Do I really understand the structure of the whole situation, especially in relation to the crucial result?" In this, Einstein attempted to understand the phenomena in spite of the current paradigms.

Wertheimer described Einstein as feeling a "gap somewhere without being able to clarify it, or even formulate it." Einstein believed the problem was greater than resolving the contradiction between Michelson's

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[10] First and second-order solution methodologies are often represented by a series of transformation rules.

[11] Much of the description that follows is paraphrased from Chapter Nine of Wertheimer's 1959 edition of "Productive Thinking." It also includes a number of direct quotes from Einstein, which will be highlighted as appropriate.

[12] This provides a clear example of the scientific establishment attempting to find an explanation using existing theory, explaining away, and redefining the problem so that first and second-order techniques remain valid.

actual and the expected result. This is when Einstein asked himself again "Do I see clearly? … the relation, the inner connection between the two, between the measurement of time and that of movement? Is it clear to me how the measurement of time works in such a situation?"

The nexus of what would follow for Einstein would be a realization that time measurement involves simultaneity. "If two events occur in one place, I understand clearly what simultaneity means. For example, I see these two balls hit the identical goal at the same time. But … am I really clear about what simultaneity means when it refers to events in two different places? What does it mean to say that this even occurred in my room at the same time as another event in some distant place? Surely I can use the concept of simultaneity for different places in the same way as for one and the same place – but can I? Is it as clear to me in the former as it is in the latter case? … It is not!"

He went on to perform a mental experiment, or the third-order technique called mental simulation: "Lightning strikes in two distant places. I assert that both bolts struck simultaneously. I ask you, dear reader, whether this assertion makes sense, you will answer, 'Yes, certainly.' But if I urge you to explain to me more clearly … you will find … this question is not as simple as it at first appears. … After some deliberation you may make the following proposal to prove whether the two shafts of lightning struck simultaneously. Put a set of two mirrors, at an angle of 90 degrees to each other, at the exact halfway mark between the two light effects, station yourself in front of them, and observe whether or not the light effects strike the mirrors simultaneously.

… What happens if, in the time during which the light rays approach my mirrors, I move with them, away from one source of light and toward the other? Obviously, if the two events appeared simultaneous to a man at rest they would not then appear so to me, who am moving with my mirrors. His statement and mine must differ. We see then that our statements about simultaneity involve essentially reference to movement of the observer. … I must therefore conclude that in every such measurement reference must be made to the movement of the system. … Every system has its special time and space values. A time or space judgement has sense only if we know the system with reference to which the judgement was made."

From this insight Einstein established the theory of relativity and developed the transformational formula needed to answer the question: "… how does one find the transformation from one system to another when they move in relation to each other?" The results, which Einstein obtained when deriving the transformation formulas, were remarkably similar to the Lorentz transformations. Einstein now realized that the contraction hypothesized by Lorentz "was not an absolute event, but a result of the relativity of measurements. It was not determined by a 'movement in itself which possesses no real sense for us, but only by a movement with reference to the chosen observation system.'" After seven years of intense dynamic problem-solving, Einstein would spend only five weeks writing a paper that would change modern physics.

The Decision-order Taxonomy Revisited

The story is clear and relatively well documented by Einstein himself and others. The real insight into Einstein's decision processes can be found in a footnote in Wertheimer's book:

> *"I wish to report some characteristic remarks of Einstein himself. Before the discovery that the crucial point of the solution lay in the concept of time, more particularly in that of simultaneity, axioms played no role in the thought process – of this Einstein is sure. (The very moment he saw the gap, and realized the relevance of simultaneity, he knew this to be the crucial point for the solution.) But even afterward, in the final five weeks, it was not the axioms that came first. 'No really productive man thinks in such a paper fashion,' said Einstein. 'The way the two triple sets of axioms are contrasted in the Einstein-Infeld book is not at all the way things happened in the process of actually thinking. This was merely a later formulation of the subject matter, just a question of how the thing could afterwards best be written. The axioms express essentials in the condensed form. Once one has found such things one enjoys formulating them in that way; but in this process they did not grow out of any manipulation of the axioms.'*
>
> *He added, 'These thoughts did not come in any verbal formulation. I very rarely think in words at all. A thought comes, and I may try to express it in words afterward.' When I (Wertheimer) remarked that many report their thinking is always in words, he only laughed. I once told Einstein of my impression that 'direction' is an important factor in thought processes. To this he said, 'such things were very strongly present. During all those years there was a feeling of direction, of going straight toward something concrete. It is, of course, very hard to express that from later considerations about the rational form of the solution. Of course, behind such a direction there is*

> *always something logical; but I have it in a kind of survey, in a way visually'" (Wertheimer 1959, p. 228, FN7).*

Did Einstein arrive at his conclusions just by randomly trying different axioms until he found one that worked? Axioms allow us to derive details from a few general propositions. It is one of the most efficient techniques so far invented in logic and mathematics. It is the underlying technique used in first and second-order problem solving. With a good core set of axioms, one is able to deal with a gigantic sum of facts, with huge numbers of propositions, by substituting for them a few sentences which in a formal sense are equivalent to all that knowledge. In Einstein's case the axioms were only a matter of later formulation – after the real thing, the seminal discovery, had happened.

In this analysis, the decision-making process cannot be described ex-ante; it can only be explained ex-post. Similarly, attempting to constrain real thinking to an ex-ante or prescriptive process constrains the problem set to the relatively small universe of first and second-order possibilities. Problems and decisions that are perceived ex-ante to be third-order require third-order thinking. If however, this thinking is constrained to prescriptive first and second-order methodologies, the solutions found will be in the form of first or second-order paradigms. These derived solutions will not necessarily solve the right problem or provide direction in making the best decisions. Those who correctly identify problems as third-order and pursue third-order solutions may discover ex-post, as Einstein did, that a new first or second-order theory emerges.

Thus, proper identification of the decision or problem is critical to finding a course of action or solution. The decision-order taxonomy provides the required identification system. Identifying the problem or decision ex-ante and then searching for the solution that can be explained ex-post is the goal. If the contraire view is adopted where the solution methodology is defined ex-ante, and the effort is focused on searching for a problem or decision, real-world problems will never be solved and real-world decisions will be seriously flawed.

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