Problem-Solving in the Digital World: Synoptic Formalism, Incrementalism, and Heuristics

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Abstract

Human kinds of problem-solving involve sophisticated cognitive processes for modeling, learning, and finally solving a problem. The discourse of problem-solving has been established in strategic management, economics, computer science, artificial intelligence, mathematics, and cognitive psychology. The disciplines represent a common ground for the classification of problem-solving approaches. This entry reexamines the existing approaches, from two distinguished perspectives: 1) synoptic formalism and incrementalism and 2) (meta-)heuristics. The primary objective is to determine the characteristics of the aforementioned approaches and to discuss the possibility for combining or coexistence of problem-solving approaches. In conclusion, we provide a framework for proper selection of the approaches and assignment of activities to decision situations. Finally, we emphasize on coexistent consideration of problem-solving approaches for making human kinds of problem computable.

INTRODUCTION

As industrial Internet and cyber physical systems tend to proliferate, the demand to cognitive computing is drastically increasing. Cognitive computing aims at handling human kinds of problems and transferring human decision-making processes to artificial models and computable algorithms.[1] The human kinds of problem-solving are characterized by ambiguity, uncertainty, complexity, unpredictability, and, at the same time, adaptiveness to changes in goals, information and requirements, contextual awareness, interactivity, and continuous learning.

For many years, numerous multi- and cross-disciplinary research activities have aimed at employing sophisticated machine learning algorithms, neurocomputing applications, and knowledge-based, high-performance computing systems toward modeling human problem-solving and decision-making processes.

The digital world, distinguished by interconnection of networked systems, social networking, and web resources, fosters cognitive computing toward modeling human thought processes and developing precise (set of) rules specifying how to solve a problem. Although cognitive computing is to answer the question of "how to make human kinds of problem computable?," it is indispensable to critically reexamine the discourse of problem-solving and to determine the main characteristics of problem-solving approaches appeared in the literature. This entry, hence, lays the ground for a comparative study of existing problem-solving approaches and investigates two perspectives of problem-solving approaches: 1) synoptic and incremental and 2) heuristics and meta-heuristics. We, specifically, examine the relationships between the aforementioned approaches based on two perspectives and identify the similarities and differences with regard to their application (Fig. 1).

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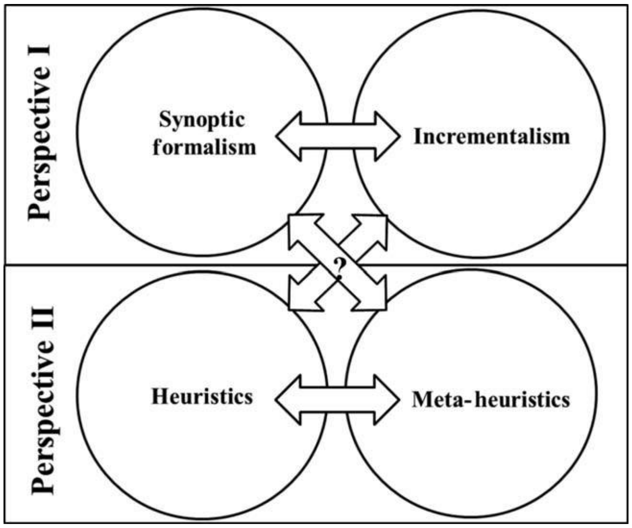

Fig. 1 Two perspectives of problem-solving approaches.

PERSPECTIVE I: SYNOPTIC AND INCREMENTAL APPROACHES

Two Schools of Thoughts: Synoptic Formalism and Incrementalism

The first perspective to human kinds of problem-solving, either as individual or collaborative decision-making, deals with two major schools of thoughts (general approaches) for strategy formulation and process modeling, i.e., synoptic and incremental. *Synoptic formalism (rationalism)* is based on the principles of rational decision-making.[2] Toft[3] defined synoptic formalism “as a wide range of problem-solving approaches that can be characterized as being ideal, rational, sequential and comprehensive.” This school of thought is originated by Andrews (1971), Ansoff (1977), Steiner (1979), and Lorange (1980) (refer Bibliography).[4]

Methe et al.[5] pointed out that an incremental approach argues that problems are too complex and ever changing. Proper and long-term decision-making, therefore, cannot be accomplished in a rational and straightforward manner, and it is coherently incremental and adaptive.[5] This school of thought is known as *incrementalism*. Furthermore, incremental approaches break through the barriers of synoptic formalism by stating that the latter (straightforwardness) is not applicable in some cases, and therefore cannot be used, and even should not be tried to be used in such cases (i.e., trying it regardless is not rational).[4]

The well-known incremental approaches are “bounded rationality,” “muddling through”/“disjointed incrementalism,” “logical incrementalism,” “piecemeal engineering,” and “Kaizen”.[4] The term “incremental approach” or “continuous improvement” is considered and examined in the management literature, especially in contributions or partial overlapping to the thematic areas such as organizational change, optimization of business process, corporate planning, account planning, product innovation (especially the discussion of radical and incremental methods to innovation management), and quality management.[6]

As a consequence, synoptic models are to maximize the individual or organizational goals that are based on a rational and comprehensive procedure.[5] Incremental models are to decentralize the selection of alternatives through adapting to environmental changes.

Synoptic vs. Incremental Problem-Solving

Synoptic and incremental approaches have been examined, criticized, and/or comparatively studied in the literature. Hard critiques and debates can be detected concerning incrementalism and/or synoptic formalism. For example, Johnson[7] argued that “consciously managed incremental change does not necessarily succeed in keeping pace with environmental changes.” This is a so-called phenomenon of *strategic drift* when the “incrementally adjusted strategic change and environmental change moved apart.”[7] This phenomenon is rooted in the characteristics of incremental approaches especially mean-end relationship (i.e., prioritization of the alternatives to goals) and concept of choice (i.e., selection of the approximate choice rather than the best choice, or the one that most closely approximates the desired end (Table 1). Seidenberg[4] reviewed and compared four incremental models, “disjointed incrementalism,” “logical incrementalism,” “piecemeal engineering,” and “Kaizen,” and concluded that these models differ in several ways; therefore, one cannot speak about one single kind of “incrementalism.”[4]

During the evolution of synoptic and incremental models over the past, they have been extensively discussed from both a practical and theoretical perspective. However, which one is “the best way of problem-solving?”

Fredrickson[2] suggested “not only organizations that employ both synoptic and incremental approaches, but the strategic process may be synoptic on some characteristics (e.g. the process is proactively initiated) and simultaneously incremental on others (e.g., strategic decision is not the result of conscious choice).” This hypothesis was reconsidered through an empirical investigation by Methe et al.,[5] They pointed out the question of selecting either incremental or synoptic is not precise, and it should be reformulated to “when and how” the two approaches could be used.[5] Hence, the question of selecting “one best way” to solve problems (either synoptic or incremental) is an imprecise one. Instead, coexistence and combination of the two basic approaches are recommended.[4]

Table 1 comparatively presents the major characteristics of synoptic and incremental approaches discussed in the literature.

Furthermore, in Table 2, we provide recommendations to decide “when and how” synoptic, incremental, or combined approaches are the better choice. With regard to the repetition of decisions in enterprises, two types can be

Table 1 Major characteristics of synoptic and incremental approaches.

Characteristics	Synoptic approach	Incremental approach
Underlying principle of cybernetics/control	Open loop	Closed loop
Initiation/trigger mechanism	Environmental observation generates opportunities/problems for strategic action	Problem/performance gaps initiate a search for solution
Relationship between means (alternatives) and ends (goals)	First, identify the ends of action and the means to achieve them (i.e., *ends–means* process)	Means and ends are not easily distinguishable. The remedial change outcome is considered at the same time that the means for achieving it is analyzed (i.e., *means–ends* process)
Concept of choice	The best choice is the one that most closely approximates the desired end	The choice of an alternative is made by combining the considered alternatives (means) and their possible consequences (ends) and simultaneously selecting the one that yields the most desired outcome (i.e., agreement achieved by choosing an alternative or the means to an end)
Involved management phases	Planning and decision-making	All, especially including monitoring
Analytic comprehensiveness	All important factors are considered	All possible factors are not considered. Analysis is based on a few alternatives only marginally different from the existing state of affairs.
Integrative comprehensiveness	Efforts are made to integrate decisions into a unified strategy.	Little attempt to integrate, consciously, the individual decisions that could possibly affect one another (i.e.. not integrated but loosely coupled)
Decision-making and planning behavior	Anticipative and goal-oriented	Reactive to urgent problems
Goal orientation	Specific	Indeterminate
Type of complexity reduction	Trivialization of source of problems by structuring	Tentativeness by the solution of the problem
Evaluation process of alternatives	Analytical and comprehensive	Piecemeal (in stages)
Type of problem shifting	Degenerative, i.e., the original problem gets transformed into more trivial solvable ones (problem structuring)	Progressive, i.e., each problem solution causes one or more new problems
Cause of the phenomenon to solve the "wrong" problem	Unsuitable modeling, especially by highly reduced complexity	Unsuitable problem selection/prioritization
Time sequence of the problem-solving process	Defined initial and defined end (project)	Without a defined end (ongoing task)
Status of problem-solving	Definitively (elimination of the problem)	Tentatively (dealing with or handling the problem)
Expected quality level of problem-solving	High	Low
Possibility of wrong decision (risk of decisions)	Not included in the basic model of decision theory	Considered in this approach
Modeling of risk	Explicit modeling or abstracted from risk (risk-free)	Probability-based analysis of alternatives, stepwise and piecemeal problem-solving
Direction of evaluation of problem-solving	Forward (based on the goal). What is left to do?	Backward (based on previous state/literal review). What has been reached?
Benchmark to assess the problem-solving	Absolute, based on optimum	Relative and comparative
Innovation-driven characteristic	Radical	Learning from experiences and evaluations of prototypes

Source: Adapted from Ansari.[6] and Seidenberg.[4]

distinguished. *Repetitive decisions* occur from time to time in the same manner or similar way, e.g., budgeting: the same procedure with different numbers. *Unique (singular) decisions* in contrast are not an element of everyday life, e.g., searching for a new location for a production plant and product innovation. With regard to their possible logical links, two types of problems can be distinguished: isolated and related/connected problems. The former ones "have nothing to do with each other," in fact, or at least are isolatable by establishing a decision model. After processing an isolated

Table 2 Decision table for assignment of problem-solving activities to decision situations.

		Scenarios for Selection							
		i	**ii**	**iii**	**iv**	**v**	**vi**	**vii**	**viii**
Decision situation	Type of problem: isolated	Y	Y	Y	Y	Y	N	N	N
	Type of problem: connected	N	N	N	N	N	Y	Y	Y
	Type of decision: repetitive	Y	N	N	N	N	Y	Y	N
	Type of decision: unique	N	Y	Y	Y	Y	N	N	Y
	Problem can be transformed in a standard problem	-	-	-	-	-	Y	N	-
	Ex ante: preparation possible (e.g., emergency plan available)	-	Y	N	-	-	-	-	-
	Ex post: further analysis reasonable for future decisions	-	-	-	Y	N	-	-	-
		↓	↓	↓	↓	↓	↓	↓	↓
Activities	Solution by standard synoptic model	✓							
	Problem structuring (transforming in a standard problem)						✓		
	Incremental approaches							✓	
	Combination of synoptic and incremental approaches								✓
	Application of a defined routine		✓						
	Intuitive decision			✓					
	Learning from past decisions				✓			✓	
	No activity required					✓			

problem, it can be considered as "resolved definitively." The problem-solving, thereby, neither results in generating consequential or new problems, nor provides knowledge for other cases. In other words, the solution neither appears a need nor holds the ability to trigger a learning process for future decision-making. Related or connected problems are, in contrast, characterized by an inseparable substantive or temporal connection, e.g., one resolved problem may cause one or more decedent problems (i.e., phenomenon of problem shift).[4]

The combination of repetitive decision and isolated problem causes a standard or routine problem situation, which is well structured and can be solved by a standard synoptic model, e.g., the Economic Order Quantity Model in logistics. The "challenge" of this particular problem situation is limited to the solution of an assignment problem, i.e., the assignment of the specific problem to a suitable synoptic model. All other steps are programmable numeric calculations. In case a repetitive decision is combined with a connected problem, the decision-maker may succeed to transform the problem into a standard one by structuring the problem, in particular decomposition of the entire problem into trivial subproblems and solving them. If problem structuring fails, then incremental approaches should be used.

The case of a singular decision by which an isolated problem to be tackled is rather atypical and should rarely occur. One might think about a corporate crisis, evacuation procedures in case of incidents, or extreme situations, in which the decision-maker has only one trial. Sometimes there are possibilities to prepare ex ante solution, based on predictions, for such a one-off situation by creating emergency plans as well as simulating corresponding scenarios, but for gradual advance steps and learning from mistakes, there is no opportunity in such a situation. Hence, in this respect, an incremental approach is futile. However, ex post conclusions might be drawn for similar future cases (i.e., learning from past decisions). It seems further analysis is not reasonable with respect to future decisions and so, no activity is required.

The possibility of failure of incremental problem solutions makes it seem quite questionable applying incremental approaches to particular cases, which are characterized by hard revisable decisions, issues with existential relevance, or a long time delay between implementation and effect of the solution. Typically, a company's strategic issues feature the aforementioned characteristics, which coherently shape an area that is not well suited for synoptic planning and is hardly satisfying requirements for the information needs as well. One way out of the outlined dilemma can be to provide concepts that combine incremental and synoptic elements.[4] In sum, Table 2 matches the selected above-discussed scenarios to decision situations and problem-solving activities. Given positive (Y), negative (N), or neutral (-) answer in response to the decision situation, an appropriate problem-solving activity is provided

(✓). For instance, "Scenario i" refers to decision situation characterized by isolated, disconnected, repetitive, and common problem that fulfills the condition to employ a standard synoptic model (Table 2).

PERSPECTIVE II: HEURISTICS AND META-HEURISTICS

Heuristics

The term "heuristic" comes from the Greek verb which can be translated as "find" or "discover."[8] Heuristic approaches are deployed in the field of economics, informatics, artificial intelligence, mathematics, and psychology. Heuristic models encompass principles of synoptic and/or incremental approaches but do not necessarily deal with mathematical formulations and in turn concentrate more on providing hypotheses and guidelines.[9] Examples of heuristic models are rules of thumb for proposing hypothetical structures for planning, monitoring, and controlling which are strengthened, not necessarily, by providing mathematical formulations. Heuristic models are usually speculative formulation serving as a guideline in problem discovery and solving and not guaranteeing the best way.[9,10]

Koen[10] listed the ideal characteristics of heuristic approaches/models and declared that: 1) Heuristics do not guarantee a solution; 2) Two heuristics may contradict or give different answers to the same question and can still be useful; 3) Heuristics permit the solving of unsolvable problems or reduce the search time to a satisfactory solution: 4) The heuristic depends on the immediate context instead of absolute truth as a standard of validity. Koen's definition of the engineering method has stressed the importance of heuristic modeling as "the engineering method is the use of heuristics to create the best change in a poorly understood situation within the available resources".[10]

Besides, Gigerenzer comprehensively reviewed heuristic approaches to problem-solving[11] and later heuristic decision-making.[8] His study was aimed at comparing statistical optimization procedures and heuristics. He pointed out that "heuristics do not try to optimize (i.e. find the best solution), but rather satisfice (i.e. find a good-enough solution)."[11] He exemplified that while "calculating the maximum of a function is a form of optimizing, choosing the first option that exceeds an aspiration level is a form of satisficing".[11] This statement, in fact, highlights the difference between synoptic approaches, including exact algorithms, and heuristics and implies that the quality of a synoptic solution (optimality) does not depend on the chosen algorithm or on the fact, who (which subject) executes it. In other words, in case of an optimal solution, it is irrelevant, how the solution has been reached, while the quality of a heuristic solution usually is path-dependent. For example, the heuristic solution may depend on the presolution one starts with or on the experience of the user. In the light of the fact that an optimal solution is only optimal in terms of the underlying mathematical model and its idealization and simplifications, there is normally a potential for improvement with regard to the real problem.[12] Here the border is, therefore, located between pure synoptic and combined approaches (i.e., the combination of synoptic and incremental approaches).

Furthermore, heuristic approaches can be divided into *constructive heuristics* and *improvement heuristics*.[9] *Constructive heuristics* generate a valid initial solution of a problem. After that, the approach terminates and the solution does not get improved. They can be classified into five subgroups as follows:[13]

- Approaches with *increasing degree of freedom*, where the decision of previous steps can be revised so that the amount of branches in the decision tree is growing. A well-known approach is the shifting bottleneck heuristic.
- Approaches with *decreasing degree of freedom*, i.e., reducing the amount of future decisions in every step. A well-known example is priority rules.
- *Greedy* or *myopic* approaches, which aim for the maximum improvement in every step like the nearest-neighbor heuristic of the Traveling Salesman Problem or the column minima method of the Transportation Problem.
- *Predictive* approaches, which determine the impact of modifications on the next steps after every step. A typical example is the Vogel's approximation method.
- *Uninformed* approaches, which do not consider the target function in the solution process, e.g., Northwest Corner Rule.

Improvement heuristics mainly try to improve an initial solution generated by a constructive heuristic. They start with a valid solution, which is applied as long as improved iteratively, until the stop criterion is fulfilled, like a certain amount of iterations or the discovery of a local minimum or maximum. At each iteration, the neighborhood NB(x) of the current solution x, which can be determined by using a specific transformation rule, needs to be examined. If there is a solution in the neighborhood, which is better than the present one, it will be replaced and a new iteration begins. Otherwise, if there is no better solution, the heuristic terminates. Nevertheless, it is possible that an improvement heuristic gets stuck in the local optimum and is not able to leave it. The value of local optimum can be worse than the value of the global optimum.

Improvement heuristics differ from each other how they examine the neighbor solutions either randomly or systematically. They can completely analyze the neighborhood and select the best solution of it (best fit) or only look for the first improving solution (first fit).[9,13] For instance, k-opt is an improvement heuristic of the Traveling Salesman Problem, which assumes, that a valid solution exists. It tries to improve that solution by swapping k edges against k other edges. Therefore, the neighborhood NB(x) of a current solution x is defined as the set of all valid solutions, which emerges by swapping k edges.

In cognitive psychology, there are two research approaches, which gained acceptance, namely *heuristic and biases* and *fast and frugal heuristics*. *Heuristic and biases* approach implies that humans use a limited amount of heuristic principles for reducing complexity. Thus, they can judge probabilities and predict values. These principles are useful but can sometimes lead to biases.[14] Biases can be caused not only for laymen, but also for experts.[14] The most common examples are "representativeness heuristic," "availability heuristic," and "adjustment and anchoring heuristic."[15]

Fast and frugal heuristics are part of the research area *cognitive heuristics*, which examines how people judge and decide in everyday life without determining probability and utility. These heuristics are fast, because they solve a problem immediately and they are frugal, because they only need little information.[8] Therefore, they can also be entitled as *simple heuristics*, which can solve problems better and faster than complex strategies in many cases.[16] By ignoring a part of information, heuristics can make decisions faster, more frugal, and more precise than complex approaches do.[8] These heuristics are part of the adaptive toolbox, which implies that the mind is a modular system, containing a collection of specialized and cognitive mechanisms.[16] They are consisting of building blocks, which give the search a direction, finish the search, and make a decision.[8]

Comparing these two approaches, both assume that heuristics can be applied for solving complex problems. They distinguish themselves, because the "*heuristic and biases*" approach assumes that heuristics are useful but lead to biases so they cause misjudgments, whereas "*fast and frugal heuristics*" are perceived positively because they are fast and frugal compared with complex approaches.

Meta-heuristics

The term "*meta-heuristics*" was used by Glover[17] for the first time, who declares his tabu search as a meta-heuristic. Meta-heuristic is a confusing term, which might be fallaciously interpreted to heuristic for/about heuristics, while it does not address a common understanding by adding the prefix "meta-" to a term for building a new term. For instance, meta-data is a kind of data that provide data about data. In contrast, meta-heuristic is an independent term referring to optimization or approximation algorithms.[9] Unlike heuristic approaches, they can be applied for every kind of problem, i.e., independent of context, because they are able to get modified and adjusted to a certain problem.[9] Hence, they are consisting of a problem-independent framework, which contains problem-specific heuristics. Meta-heuristics can be, therefore, referred to as superior strategies/algorithms, intelligent search strategies, or modern heuristics.[9]

Gass and Fu[18] studied meta-heuristic approaches and provided a pattern for the classification of the approaches into four subgroups as follows:

- *Constructive meta-heuristics*, such as Greedy algorithms, Lagrange heuristics, and Ant Colony algorithms, generate valid solutions. In every step of the solution process, an element, which leads to the largest improvement in the current step, gets added to the partial solution. Comparing to *constructive heuristics*, they deploy a memory or use random elements.
- Improving *meta-heuristics* can be divided in two different ways:
  - I. *Local search-based meta-heuristics*, which transform a known valid solution into a better valid solution, as far as a better one exists. They look iteratively for a better solution until the current solution is not improvable anymore. In contrast to improvement heuristics, local search-based meta-heuristics deploy a memory or use random elements. Simulated annealing, tabu search, variable neighborhood search, and ruin-and-recreate are typical examples of this kind of *meta-heuristics*.
  - II. *Population-based meta-heuristics*, like genetic or evolutionary algorithms, select and recombine iteratively an existing solution from a set, which is called population, to a new solution. Afterward, the new solution gets modified randomly and added to the new population.
- *Hybrid meta-heuristics* combine the above-mentioned types. For example, Greedy Randomized Adaptive Search Procedure (GRASP) is a hybrid *meta-heuristics*, which combines a greedy algorithm with the local search.
- *Matheuristics* combine *meta-heuristics* with exact (mathematical) optimization approaches.

Heuristics vs. Meta-Heuristics

Meta-heuristic approaches provide general patterns for universal problem-solving (i.e., a wide range of problem domains) instead of specific situations where heuristics are applicable.[9] They are used basically to find approximate solution(s), especially for sophisticated and complex problems.[6] In particular, such methods are used when there is neither an idea and/or information about the optimal solution (or value) nor the way to approach it, in addition to the problem domain being wide and not necessarily specific.[6] Of course, any meta-heuristic method does not necessarily equip one for solving any kinds of problem, and in each case, the most adequate meta-heuristic solution should be selected through feasibility test and usability assessment.[6] For example, using evolutionary algorithms (e.g., genetic algorithms), local search, tabu search, and the nested partitions method requires context-dependent requirement analysis.[6]

Nevertheless, the distinction between *meta-heuristics* and *heuristics* seems to be difficult. According to definition, greedy

Table 3 Decision table for the classification of problem-solving approaches.

		Rules for classification					
Characteristics of problem-solving	C1	Y	Y	Y	Y	N	N
	C2	Y	Y	N	N	-	-
	C3	N	Y	-	-	-	-
	C4	-	-	N	Y	N	Y
		↓	↓	↓	↓	↓	↓
Problem-solving Approach	Synoptic model	✓					
	Combination of synoptic model and incremental approach		✓				
	Qualitative heuristic approach for general purpose (e.g., reference model) → incremental					✓	
	Qualitative heuristic approach, which needs step-by-step improvement → incremental						✓
	Meta-heuristic model			✓			
	Heuristic model				✓		

and local search-based algorithms are *meta-heuristics*, but in literature, e.g., in Blohm et al.,[9] they are assigned to heuristics in contrast to exact algorithms. On the other side, there are several authors, who do not distinguish between *meta-heuristics* and *heuristics*, because for them, local search and evolutionary algorithms are just improvement *heuristics*. For other authors, however, they are assigned explicitly to *meta-heuristics*.[19]

DISCUSSION AND CONCLUSION

In the digital world, solving a problem may require patterns for identification and selection of a right algorithm, which resembles human kinds of problem-solving. Taking into account a holistic view of Perspective I to problem-solving, synoptic approaches consider all relevant requirements and conditions concerning the decision situation. Hence, they generate the best solution, whereas incremental approaches provide only a satisfying one. Synoptic approaches, however, have been criticized by representatives of incrementalism. Based on empirical insights, they revealed that the true encountered problem-solving and decision-making behavior is differed from the synoptic ideal. The criticism mainly refers to the existence of completed information together with the unavailability and uncertainty of information. The central characteristic of all incremental approaches is verification and provision of corrective feedback with respect to the environmental changes. It becomes apparent, though, that incremental approaches are no single alternative to synoptic approaches. Problems may not get to the bottom and only symptoms get fixed, which can lead to continuity of the problem or handling the wrong problem. In addition, there is no information about the optimum step size, i.e., the appropriate frequency of changing the status quo.[4] The reactive behavior in small steps, therefore, does not allow early identification of chances and risks,[20] but in many cases, such as innovations, a huge step is required.

Perspective II studied *heuristics* and *meta-heuristics* to problem-solving. Heuristics are problem-specific approaches, which consider only a subset of all possible solutions and give no guarantee for discovering a solution. Additionally, they should use stop rules plus controlling mechanisms for the user to obtain a valid solution. On the contrary, in the field of cognitive psychology, a heuristic is a strategy for solving complex problems. Depending on the research approach, heuristics are perceived positively (fast and frugal) or negatively (biases). Meta-heuristics are problem-unspecific approaches and get adjusted to a problem with the help of problem-specific heuristics. They have the ability to leave a local optimum.

Heuristic and meta-heuristic approaches own many similarities with incremental approaches. It is, however, too indecipherable to generally identify which heuristic or meta-heuristic method is synoptic or incremental. For example, the synoptic approach such as branch-and-bound can be interpreted in a shortened version, i.e., terminated at a certain point, as heuristic due to the fact that the generated solution cannot be claimed as optimal at that stage.[9] The genetic algorithm as a meta-heuristic approach, in contrast, behaves incremental. Therefore, one cannot classify those models in two fully separated categories. As a result, the advantages and drawbacks of synoptic and/or incremental models and their border of similarity to heuristic and meta-heuristic approaches indicate the potential for the coexistence of these approaches.

In order to classify problem-solving approaches, we have defined four major characteristics (C1–C4) of related procedures:

- C1: A formal (mathematical) model is used, consisting of decision variables, objective function, and constraints.
- C2: The model guarantees an optimal solution, i.e., minimizing or maximizing the objective function.
- C3: A procedure way is provided to refining and/or enhancing the model, e.g., using feedback loops.
- C4: The applied method or model is designed to fit exclusively the specific problem (type or domain).

Given positive (Y), negative (N), or neutral (-) answer in response to the above-mentioned characteristics as conditions, Table 3 provides the actually resulting problem-solving approach (✓). For example, when the problem-solving holds C1 and C2, while C3 is negative and C4 neutral, respectively, then an appropriate decision is to employ a synoptic model (Table 3).

In conclusion, Table 3 provides a factual framework, including set of rules, for classification of the above-discussed problem-solving approaches by defining various combinations of essential characteristics of dealing with problem-solving. Anticipating the evolution of cyber-specific solutions in the digital world and its impact on reciprocal learning and problem-solving, i.e., collaboration of human and cyber physical system in problem-solving,[21] the proposed classification framework supports proper selection of problem-solving perspectives in diverse contexts and, in particular, associated algorithms to resemble a function (set of functions) for solving a particular problem.

An important topic for further research to investigate is enhancing and refining knowledge about the collaborative use of the synoptic, incremental, and (meta-)heuristic approaches. In fact, using simulation and statistical tools may either aid the process of selecting the best fit solution or facilitate exploring new algorithms.

REFERENCES

1. Kelly, J.E.; Hamm, S. *Smart Machines: IBM's Watson and the Era of Cognitive Computing*; Columbia Business School Publishing: New York, 2013.
2. Fredrickson, J.W. Strategic process research: Questions and recommendations. Acad. Manage. Rev. **1983**, *8*, 565–575.
3. Toft, G.S. Synoptic (one best way) approaches of strategic management. In *Handbook of Strategic Management*, 2nd Ed.; Miller, J., Rabin, G.J., Hildreth, W.B., Eds.; Marcel Dekker, Inc.: New York, 2000; 1–30.
4. Seidenberg, U. *Ausprägungen und Einsatzbedingungen inkrementaler Managementansätze*; University of Siegen: Siegen, 2012.
5. Methe, D.T.; Wilson, D.; Perry, J.L. A review of research on incremental approaches to strategy. In *Handbook of Strategic Management*, 2nd Ed.; Miller, J., Rabin, G.J., Hildreth, W.B., Eds.; Marcel Dekker, Inc.: New York, 2000; 31–66.
6. Ansari, F. *Meta-Analysis of Knowledge Assets for Continuous Improvement of Maintenance Cost Controlling*; University of Siegen: Siegen, 2014.
7. Johnson, G. Rethinking incrementalism. Strateg. Manage. J. **1988**, *9*, 75–91.
8. Gigerenzer, G.; Gaissmaier, W. Heuristic decision making. Ann. Rev. Psychol. **2011**, *62*, 451–482.
9. Blohm, H.; Beer, T.; Seidenberg, U.; Silber, H. *Produktionswirtschaft*, 5th Ed.; NWB Verlag: Herne, 2016.
10. Koen, B.V. *Discussion of the Method: Conducting the Engineer's Approach to Problem Solving*; Oxford University Press: Oxford, 2002.
11. Gigerenzer, G. Why heuristics work. Perspectives on psychological science. Assoc. Psychol. Sci. **2008**, *3*, 20–29.
12. Hillier, F.S.; Lieberman, G.J. *Introduction to Operations Research*, 9th Ed.; Mc Graw Hill: New York, 2010.
13. Domschke, W.; Drexl, A. *Einführung in Operations Research*; Übungen und Fallbeispiele zum Operations Research. Springer: Berlin Heidelberg, 2011.
14. Tversky, A.; Kahneman, D. Judgement under uncertainty: Heuristics and biases. Science **1974**, *185* (4157), 1124–1131.
15. Eisenführ, F.; Weber, M.; Langer, T. *Rationales Entscheiden*, 5th Ed.; Springer: Berlin, 2010.
16. Todd, P.M.; Gigerenzer, G. Précis of simple heuristics that make us smart. Behav. Brain Sci. **2000**, *23*, 727–780.
17. Glover, F. *FuturePpaths for Integer Programming and Links to Artificial Intelligence*; Center for Applied Artificial Intelligence: Boulder, 1985.
18. Gass, S.I.; Fu, M.C., Eds. *Encyclopedia of Operations Research and Management Science*, 3rd Ed.; Springer: New York, 2013.
19. Fink, A.; Rothlauf, F. *Heuristische Optimierungsverfahren in der Wirtschaftsinformatik*; Universität Mannheim/Fakultät für Betriebswirtschaftslehre: Mannheim, 2006.
20. Picot, A.; Lange, B. Synoptische versus inkrementale Gestaltung des strategischen Planungsprozesses: Theoretische Grundlagen und Ergebnisse einer Laborstudie. Schmalenbachs Zeitschrift für betriebswirtschaftliche Forschung **1979**, *31* (8), 569–596.
21. Ansari, F.; Seidenberg, U. A Portfolio for optimal collaboration of human and cyber physical production systems in problem-solving. *Proceedings of the 13th International Conference on Cognition and Exploratory Learning in Digital Age (CELDA 2016, International Association for Development of the Information Society)*, Mannheim, Oct 28–30, 2016, 311–314.

BIBLIOGRAPHY

1. Andrews, K.R. *The Concepts of Corporate Strategy*; Dow Jones-Irwin: Homewood, 1971.
2. Ansari, F.; Fathi, M.; Seidenberg, U. Combining synoptic and incremental approaches for improving problem-solving in maintenance planning, monitoring and controlling. In *Proceedings of 9th Interdisciplinary Workshop on Intangibles, Intellectual Capital and Extra-Financial Information*, European Institute for Advanced Studies in Management (EIASM): Copenhagen, Denmark, 2013.
3. Ansari, F.; Fathi, M.; Seidenberg, U. Problem-solving approaches in maintenance cost management: A literature review. J. Qual. Maint. Eng. **2016**, *22* (4), 334–352.

4. Ansoff, H.I. Critique of Henry Mitzberg's The Design School: Reconsidering the basic premise of strategic management. Strateg. Manage. J. **1991**, *12*, 449–461.
5. Ansoff, H.I. The state of practice in planning systems. Sloan Manage. Rev. **1977**, *XVIII*, 1–24.
6. Beck, N. *Kontinuität des Wandels: Inkrementale Änderungen einer Organisation*; Westdeutscher Verlag: Wiesbaden, 2001.
7. Becker, T. *Prozesse in Produktion und Supply Chain Optimieren*, 2nd Ed.; Springer: Berlin/Heidelberg, 2008.
8. Berens, W.; Delfmann, W.; Schmitting, W. *Quantitative Planung*, 4th Ed.; Schäffer-Poeschel Verlag: Stuttgart, 2004.
9. Braybrooke, D.; Lindblom, C.E. *A Strategy of Decision: Policy Evaluation as a Social Process*; Free Press: New York, 1963.
10. Bresser, R.K.F. *Strategische Managementtheorie*; Kohlhammer: Stuttgart, 2010.
11. Dror, Y. Muddling through—"Science" or Inertia? Public Admin. Rev. **1964**, *24*, 153–157.
12. Etzioni, A. *The Active Society—A Theory of Societal and Political Processes*; Collier-Macmillan: London, 1968.
13. Evans, J.R.; Lindsay, W.M. *The Management and Control of Quality*, 8th Ed.; Cengage Learning: South-Western: Boston, MA, 2011.
14. Gigerenzer, G. Einfache Heuristiken für komplexe Entscheidungen. In *Mathematisierung der Natur: Streitgespräche in den Wissenschaftlichen Sitzungen der Versammlung der Berlin-Brandenburgischen Akademie der Wissenschaften am 10.* Dezember 2004 und am 27. Mai 2005, Berlin: Berlin-Brandenburgische Akademie der Wissenschaften, 2006; 37–44.
15. Gigerenzer, G.; Gaissmaier, W. Denken und Urteilen unter Unsicherheit: Kognitive Heuristiken. Enzyklopädie der Psychologie. Denken und Problemlösen **2006**, C (II), 8.
16. Gigerenzer, G.; Selten, R., Eds. *Bounded Rationality: The Adaptive Toolbox*; MIT Press: Cambridge, 2002.
17. Goffin, K.; Mitchell, R. *Innovation Management*, 2nd Ed.; Palgrave Macmillan: New York, 2010.
18. Grünert, T.; Irnich, S. *Optimierung im Transport, Band 1: Grundlagen*; Shaker-Verl: Aachen, 2005.
19. Homberger, J. *Verteilt-parallele Metaheuristiken zur Tourenplanung*; University Pess: Wiesbaden, 2000.
20. Imai, M. *Kaizen: Der Schlüssel zum Erfolg im Wettbewerb.*, 2nd Ed.; Econ Ullstein List Verlag: Munich, 2002.
21. Käschel, J.; Teich, T. Reihenfolgeplanung in Produktionsnetzwerken. In *IT-gestützte betriebswirtschaftliche Entscheidungsprozesse*; Jahnke, B., Wall, F., Eds.; Gabler Verlag: Wiesbaden, 2001; 239–259.
22. Leavitt, P., Ed. *Using Knowledge Management to Drive Innovation*; American Productivity & Quality Center (APQC): Houston, TX, 2003.
23. Lindblom, C.E. The science of "muddling through". Public Admin. Rev. **1959**, *XIX*, 79–88.
24. Lorange, P. *Corporate Planning: An Executive Viewpoint*; Prentice Hall: New Jersey, 1980.
25. Luke, S. *Essentials of Metaheuristics*, 1st Ed. (Online Version 1.3, 2012); Department of Computer Science, George Mason University: Fairfax, VA, 2009–2012.
26. Miller, D. *Some Hard Questions for Critical Rationalism*; University of Warwick: Coventry, 2011.
27. Mintzberg, H. The design school: Reconsidering the basic premises of strategic management. Strateg. Manage. J. **1990**, *11*, 171–195.
28. Nicholas, J. *Lean Production for Competitive Advantage: A Comprehensive Guide to Lean Methodologies and Management Practices*; CRC Press: New York, 2011.
29. Nicolai, C. *Konzepte für den organisatorischen Wandel. WISU—Das Wirtschaftsstudium*; Lange Verlag GmbH & Co. KG: Dusseldorf, 2010; Vol. 39.
30. Ólafsson, S. Metaheuristics, handbook on simulation. In *Handbooks in Operations Research and Management Science VII*; Henderson, S.G., Nelson, B.L., Eds.; Elsevier, **2006**, *23*, 633–654.
31. Pfeifer, T. *Quality Management: Strategies, Methods and Techniques*; Carl Hanser Verlag: Munich, 2002.
32. Picot, A.; Lange, B. *Strategische Planung: Synoptisch oder Inkremental?* Leibniz Universität Hannover: Hannover, 1978.
33. Popper, K.R. *Das Elend des Historizismus (The Poverty of Historicism)*, 7th Ed.; Mohr: Tübingen, 2003.
34. Quinn, J.B. *Strategies for Change: Logical Incrementalism*; Richard D. Irwin: New York, 1980.
35. Rabl, K. *Strukturierung strategischer Planungsprozesse*; Gabler: Wiesbaden, 1990.
36. Schmelzer, H.J.; Sesselmann, W. *Geschäftsprozessmanagement in der Praxis*, 7th Ed.; Hanser Verlag: Munich, 2010.
37. Schreyögg, G. *Unternehmensstrategie: Grundfragen einer Theorie strategischer Unternehmens-führung*; de Gruyter: Berlin, 1984.
38. Schütz, G. *Verteilt-parallele Ansätze zur Distributionsplanung*, Deutscher Universitäts-verlag: Wiesbaden, 1997.
39. Simon, H.A. *Administrative Behavior*, 4th Ed.; Free Press: New York, 1997.
40. Smith, K.A. *Teamwork and Project Management*; McGraw-Hill: New York, 2002.
41. Starfield, A.M.; Smith, K.A.; Bleloch, A.L. *How to Model It: Problem Solving for the Computer Age*; Burgess International Group: Edina, 1994.
42. Steiner, G.A. *Strategic Planning*; Free Press: New York, 1979.
43. Streim, H. Heuristische Lösungsverfahren: Versuch einer Begriffsklärung. ZOR. **1975**, *19* (5), 143–162.