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A First Inventory of Investigational Concerns for Prognostic Systems Thinking based on an Extended Conceptual Framework

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Abstract

As the nature of systems changes, systems thinking must also change. A currently happening strong change is proliferation of highly intellectualized and socially deeply embedded engineered systems, which raise many novel and crucial technological, managerial, social, organizational, business, environmental, human, and so forth, issues. Considering the influences of this change, it is argued that there is a need for prognostic systems thinking (PST) that considers not only the observable manifestation of systems, but also the trends of their overall development. The reported research is based on a comprehensive literature study and concept relationship analysis. Its goal was deriving a comprehensive set of investigational concerns based on an extended conceptual framework. Rendered as a semantic network, this conceptual framework rests on a set of foundational concepts (semantically interconnected pillars). The paper (i) explains the reasons of the abovementioned need, (ii) identifies the pillars of contemporary analytic systems thinking as well as a set of up-and-coming new pillars, (iii) presents a first iteration of the novel conceptual framework, (iv) discusses the proposed investigation concerns for prognostic systemic analysis, and (v) casts light on their implications with regard to PST. Furthermore, some currently open issues (such as determination of the boundaries of systems, completeness/sufficiency of a given set of concerns, and ranking/preference of concerns) and research opportunities (such as methodological support of deriving concerns, objective concerns assessment in various application contexts, and computer support of PST) are suggested.

Keywords

Trend of intellectualization, systems thinking, traditional pillars, emergent pillars, conceptual frame, investigation concerns, prognostic systems thinking

1. Introduction

1.1. A concise introduction into systems thinking

The convoluted whole of the partly naturally existing and partly human created world can be looked at from many dimensions. Analytic systems thinking (ST) is one of the systemic views on the whole and the parts of the world around us (Espejo, 1994). In simple words, systems thinking (ST) allows seeing the forest as good as the trees. It is the system for thinking about systems (Whitehead et al., 2014). Some researchers found that the foundations of systems thinking can actually be traced back as far as prior to 400 B.C. when the ancient Chinese work, in translation titled as ‘Book of Change’ was compiled (Keating, 2022). Historically, the roots of modern ST can be traced back to the 1950s. Modern ST was originated in 1956, when Forrester founded the Systems Dynamic Group at the Sloan School of Management of the MIT (Forrester, 1990). It was introduced as a new paradigm of thinking about complexities and heterogeneities, opposing the reductionist thinking that is typically pursued in mono-disciplinary science. Scientific

thinking is typically deemed to be in juxtaposition with systems thinking, since the former imposes reductionism rather than holism in its view (Albright & Runehov, 2013). Therefore, ST complements scientific thinking (Kuhn, 2010) and lends itself to other thinking frameworks. Besides the abovementioned two, other intellectual approaches, such as design thinking (Owen, 2006), computational thinking (Denning & Tedre, 2019), societal thinking (Waddock, 2016), pragmatic thinking (Weigert, 2008), and mystical thinking (Bradley, 2002) have also emerged. They reflect different human worldviews and mental models. Nevertheless,

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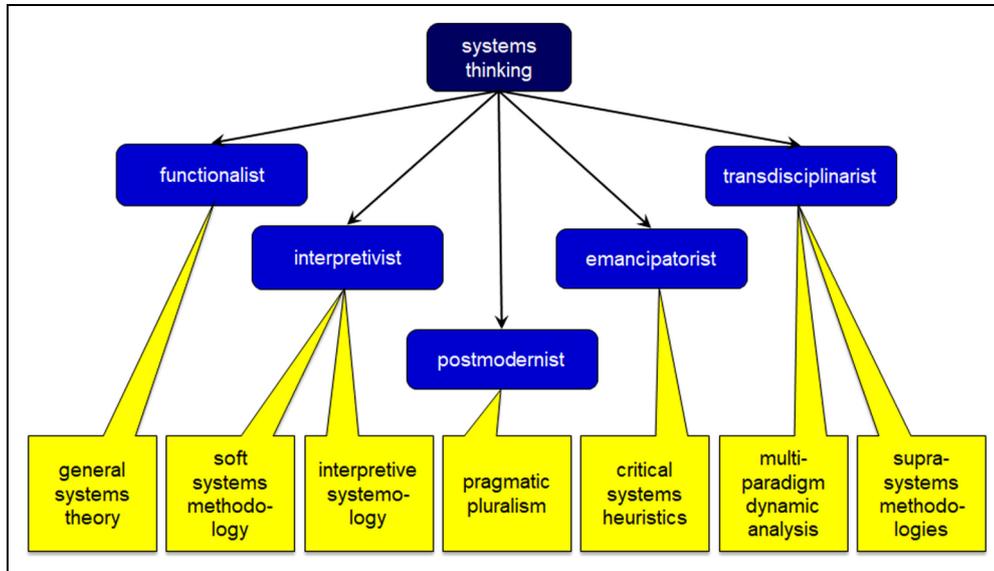


Figure 1. Philosophical platforms of systems thinking.

similarities and overlaps of the various thinking paradigms can also be observed.

There are not only many originators (offering new insights), but also many refiners (improving existing insights) of ST definitions and models (Monat & Gannon, 2015). These systems researchers placed the theory and methodology of ST onto different philosophical platforms and have made diverse and divergent attempts to provide a universal description for its goals and principles (Buckle Henning & Chen, 2012). Five major philosophical platforms of systems thinking have been identified in the related literature recently, namely (i) functionalist, (ii) interpretivist, (iii) postmodernist, (iv) emancipatorist, and (v) transdisciplinaryist, as shown and exemplified in Fig. 1. From the perspective of the theory and practice of operational research, a comprehensive historical overview of the functionalist, structuralist, and interpretivist applied systems thinking was published in (Jackson, 2009). Various conceptual frameworks have been suggested in such knowledge fields as organization, management, economy, and sociology (Barile & Saviano, 2011). Nevertheless, in the end, the meaning of ST as model of human thinking has remained ambiguous (Harel, 2019). In agreement with many researchers, Cabrera et al. (2015) posited that “systems thinking is a field characterized by a baffling array of methods and approaches”. Therefore, it is not trivial to answer the question ‘What does exist in the form and the core of ST (Mella, 2012)? Figure 2 shows an image of the recent ontological articulation (the main interpretations of the role) of ST.

1.2. The research problem, objectives, and approach

We live in the age of rapid and escalating changes. As a direct consequence, even near-future systems will be different essentially from those that were regarded as references at the time when the first efforts to develop all-embracing

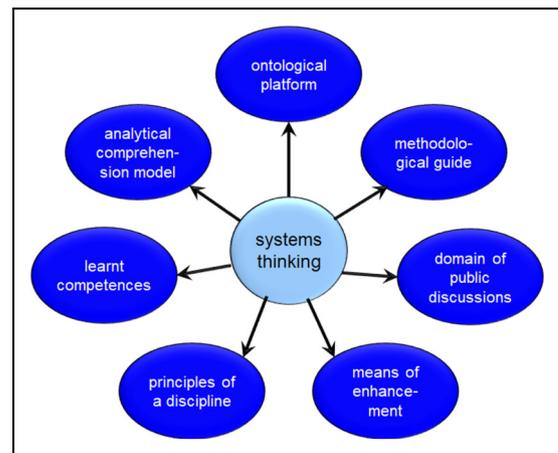


Figure 2. Ontological articulation of systems thinking.

system theories, frameworks, and methodologies were made (Tolk et al., 2011; Fazey et al., 2020). Currently happening, a strong change is proliferation of highly intellectualized and socially deeply embedded engineered systems that raise many novel and crucial technological, managerial, social, organizational, business, environmental, human, and so forth, issues (Steels & López de Mantaras, 2018). As the nature of systems changes, the views on systems, scientific theories, intellectual paradigms, reasoning models, mental reflections, etc. must also change. Systems thinking cannot be an exception.

The inspiration for this work came from the recognition that it had always been the best practice in natural sciences, especially in physics, to reconsider the existing theories in the light of the progression, and to take into account the emerging paradigms that generated new insights. Considering the aggregating changes, it is argued here

that there is a need for prognostic systems thinking (PST) that considers not only the observable manifestation of systems, but also the trends of their overall development. There is also a growing need for a prognostic normative reasoning (Oh et al., 2013). The concrete goal of this work was stated as to make a first step towards the indispensable enablers (principles, frameworks, and guides) of PST by identifying and interrelating the essential characteristics of next-generation intellectualized systems and the related societal issues. Some of these, are addressed - among others - in (Straus, 2021) and (Waddock, 2016). As a starting point, it was assumed that PST should be based on an adapted conceptual framework that considers (i) the shifting system paradigms, (ii) the outcomes, interplays, and implications of the trends of system realization, and (iii) the different humans-systems and systems-systems relationships (Hammond, 2005). The reported research is based on a comprehensive literature study, concept relationship analysis and mind mapping. Its concrete goal was deriving a comprehensive and semantically structured set of investigational concerns based on an extended conceptual framework. Rendered as a semantic network, this conceptual framework rests on a set of foundational concepts (semantically interconnected pillars).

1.3. Structure and contents of the paper

The paper (i) explains the reasons of the abovementioned need, (ii) identifies the pillars of contemporary analytic systems thinking as well as a set of up-and-coming new pillars, (iii) presents a first iteration of a novel conceptual framework, (iv) discusses the proposed investigation concerns for prognostic systemic analysis, and (v) casts light on their implications with regard to PST. Section 2 provides a concise overview of the fundamentals and approaches of traditional systems thinking, as the basis of systematic (managerial) analysis. Section 3 discusses the necessity and possibility of PST. Section 4 overviews the traditional and additional (emergent) pillars of the underpinning conceptual framework. Section 5 presents the conceptual framework as a network of semantic relationships and introduces the notion of concerns. Sections 6, 7 and 8 discuss the concerns associated with traditional and emergent conceptual pillars, and their relations. Section 9 reflects on the work, formulates a number of propositions, and further research opportunities.

2. A concise overview of the fundamentals of traditional systems thinking

2.1. Setting the stage for further discussion

System thinking has become the major enabler of complex (transdisciplinary) system analysis and assessment

(Richmond, 1993). Nevertheless, Churchman (1979) posited that the nature and rationality of systems thinking are influenced by politics, traditions, morality, religion, culture, aesthetics, and other not systemic factors. It was and is still strongly believed that the power of the systems paradigm can improve the way people exist and operate in the existing world (Ulrich, 1988). The introduction of the term 'system of systems thinking' in the professional literature is attributed to (Ackoff, 1971). It was found that ST helps identify the so-called 'leverage points' in a concrete complex system (Meadows, 1999). The notion of leverage point has been widely accepted in system dynamics research. These are places where applying a minimal change in a complex system will result in a long-lasting positive change, (Meadows, 2008).

In overall, the ontology and epistemology of contemporary systems thinking is a loose, broad, and eclectic collection of theories and methodologies, mirroring the divergence of systems engineering practice (Wan, 2011). ST has been regarded as a management discipline that concerns an understanding of a system by examining the linkages and interactions between the components that comprise the entirety of defined systems (Hürlimann, 2009). In the field of management science and practice, the view of holistic system thinkers is sharply contrasted with the view of event oriented thinkers. Event oriented thinkers assumes that each event has a specific cause and handling an event (or in other words, solve a related problem) means finding the cause and fixing the problem according to that. These systems thinkers see a problem (the structure and internal/external interactions of the system) entirely differently, namely as the cause of any regular and misbehaviour, and use potential feedback loops to achieve the goal (Keating & Gheorghie, 2016). The main assumptions of traditional systems engineering are: (i) absoluteness, (ii) unambiguity, (iii) sequentiality, (iv) rational actors, (v) reductionist, (vi) central controlling, (vii) static solution, (viii) mechanistic factors, (ix) deterministic behaviour, (x) context independence (Pennock & Wade, 2015).

As mentioned above, in our post-modern time, a determining trend is that the number and kinds of engineered systems are rapidly growing, in particular, in the realm of intellectualized systems (Wendt et al., 2009; Horváth, 2022). In this realm, the efforts for 'knowing more', 'doing more', and 'making more' in combination with the digital/cognitive transformation have resulted not only in intensification of the creative productivity, but also in acceleration of the realization processes (Dahiya et al., 2007). These are offering new opportunities, but also posing new challenges (uncertainties and incompleteness) for system science and engineering (Drack & Apfalter, 2007). Many of these challenges have been recognized and various efforts have been made to adapt the theory and practice of systems thinking (Pickel, 2007; Mahmoudi et al., 2019).

2.2. Systems thinking as the basis of systematic analysis

As hinted at above, traditional system thinking has appeared in multiple forms from the Orient to the Occident (Pan et al., 2013). Despite anything to the contrary, ST has no clear definition or usage. Senge (2006) defined ST as a specific discipline that offers a way of thinking about and understanding the effects and interrelationships that shape the systems, and a language for describing their behaviour. The explored disciplinary principles help decide on how to change systems purposefully and effectively, and how to act in line with the regular processes of the natural and economic world (Merali & Allen, 2011). With the intention of refining the interpretation of the term ‘systems thinking’, Richmond (1991) defined it as the art and science of making reliable inferences about behaviour by developing an increasingly deep understanding of the underlying structure. For other communities, ST is a holistic approach to analysis that focuses on how the constituent parts of a system interrelate and how systems work over time and within the context of larger systems (Checkland, 2000). The ST-based investigation approach is in contrast with traditional system analysis, which studies systems by breaking them down into their separate elements (Zexian & Xuhui, 2010). The human attitude and competence of ST has been characterized by maturity levels: (i) level 0 - unawareness, (ii) level 1 - shallow awareness, (iii) level 2 - deep awareness, (iv) level 3 - novice awareness, (v) level 4 - expert awareness, and (vi) level 5 - guru awareness (Buckle Henning, 2018).

To understand the behavioural patterns that arise in systems of different systemic structures, the concept and models of system archetypes were introduced (Kim & Anderson, 1998). The importance of system archetypes is in that they can be used both diagnostically (to gain insights into the behavioural structure of a system) and prospectively (to help foresee intended or unintended behavioural consequences) (Braun, 2002). The system archetypes are typically modelled by causal loop diagrams that depict non-linear cause-and-effect relationships in a simplified manner, including reinforcing loops (amplifying some changes) and balancing loops (stabilizing some changes) and harmonized or opposing change polarities in between. A reinforcing process leads to the increase of some system component. If reinforcement is unchecked by a balancing process, it eventually leads to collapse. A balancing process is one that tends to maintain equilibrium in a particular system. Attention to feedback is an essential component of system thinking. Branz et al. (2021) introduced five (stereotyped) archetypes that they called ‘fixes that fail’, ‘success to the successful’, ‘shifting the burden’, ‘drifting goals’, and ‘limits to growth’. Ammara et al (2020) showed an example for integration of the ‘fixes that fail’, ‘shifting the burden’, and ‘success to the successful’ archetypes in the

context of handling misinformation. Urze and Abreu (2014) discussed ten basic and essential system archetypes: (i) limits to growth, (ii) shifting the burden, (iii) eroding goals, (iv) escalation, (v) success to the successful, (vi) tragedy of the commons, (vii) fixes that fail, (viii) growth and underinvestment, (ix) accidental enemies, and (x) the attractiveness principle.

2.3. Alternative approaches to systems thinking

In investigative systems thinking, a phenomenon to be explained is viewed as part of a larger whole, a ‘system’, and is explained in terms of its role in that ‘system’ (Daellenbach et al., 2012). The ‘system’ is the kernel of the process of understanding the real world (Jaradat & Keating, 2016) and has been applied, among many others, to the study of medical, environmental, political, economic, human resources, and educational systems. Atave and Hopper (2007) proposed a taxonomy of what constitutes systems thinking. They argued that seven systems thinking characteristics are required and are sufficient to describe a systems thinker, which include (i) recognizing interconnections, (ii) understanding dynamic behaviour, (iii) identifying feedback, (iv) differentiating types of variables and flows, (v) using conceptual models, (vi) creating simulation models, and (vii) devising testing policies. Behl and Ferreira (2014) clarified the difference between ‘individual systems thinking’ (that is based on the ability of an individual engineer to demonstrate systems thinking) and ‘collaborative (team) systems thinking’ (that is based on an emergent behaviour resulting from the interactions of team members and utilizing a variety of thinking styles, design processes, tools and communication media to consider the system, its components and dynamics towards executing systems design).

However, the initially stated principles, the elaborated conceptual framework, and the aspects of investigations have been considered as biblical admonitions for a long time – they have been not criticized basically and, in particular, not adapted to the changing reality (Hammond, 2002). This claim is true even though Checkland has developed the notion and methodology of soft systems thinking (SST) to deal with problems that (i) are not quantified in complex problem situations, (ii) are messy, ill-defined, and/or ill structured, (iii) are not independent of people, and (iv) may miss agreement about appropriate objectives (Holwell, 2000). SST assumes the world is complex and the way to tackle the complexity of the real world is by using a learning system.

In the field of engineering education, systems thinking has been interpreted as an assessable and highly useful set of competences that can be used to achieve improvements in various knowledge fields and solve challenging or even wicked problems. Arnold and Wade (2015) synthesized a single generalized definition that posits that “systems

thinking is a set of synergistic analytic skills used to improve the capability of identifying and understanding systems, predicting their behaviours, and devising modifications to them in order to produce desired effects". These skills work together as a notional system. Later, Arnold and Wade (2017) proposed to see ST as an assessable skill set that contains 16 systems thinking competencies organized into four domains (i) mind-set, (ii) content, (iii) structure, and (iv) behaviour and can be assessed for maturity. Systems thinking professionals use a variety of visualization (diagrams and graphs) to model and illustrate, and computer simulation to predict system behaviour (Kim, 1990).

3. Necessity and possibility of prognostic systems thinking

3.1. Why is prognostic systems thinking needed?

The above overview casts light on four important issues (namely, objectives, characteristics, mechanisms, and competences) that need to be operationalized at investigating systems from a managerial, organizational, social, developmental, or other points of view. Notwithstanding the importance of these, we must not ignore those issues implied by the dramatic changes that have been taking place (both in the realm of systems and in our daily life) due to human-created intellectualized systems (often called artificial intelligence-based or simply as intelligent systems). They possess systelligence (system-level problem solving intelligence) that rests on processing application-specific synthetic system knowledge by ampliative reasoning mechanisms). One of the fastest advancements can be observed in this domain of interest, culminating in knowledge and resource exchange among cooperating systems. It can be foreseen that the next-generation intellectualized systems will largely differ from the current socio-technical systems and socialized smart cyber-physical systems. The difference will be not only in their functional complexity, architectural heterogeneity, level of intellectualization, operational smartness/intelligence, natural/social/societal embedment, personal interrelationships, but also in their value offerings, propositions, and experiences.

Dealing with systems equipped with system-level problem solving intelligence raises the need for different reasoning models and aspects of investigation. This kind of systems are deemed to (i) operate collaboratively in an environment with other systems, (ii) possess cognitive abilities such as perception, action control, deliberative reasoning, or language use, (iii) follow behavioural principles based on rationality and social norms, and (iv) have the capacity to adapt through learning. These are why it is necessary to lay down the foundation of a novel system thinking that will support not only reflective, but also prognostic problem solving. Future systems thinking is supposed to be proactive and to provide new strategies and blueprints of moving to an intelligent systems future. Prognostication is expected as a new

affordance of future systems thinking due to the inability of the conventional approaches to address forthcoming challenges. That is, future ST models, frameworks, narratives, renderings, etc. are supposed to capture not only the (operational and managerial) complexity and problems associated with next-generation systems, but also the shifts of paradigms, the observed trends of changes, the varied manifestations, realizations, and interactions of systems.

3.2. The conceptual elements of prognostic systems thinking

As introduced above, PST differs from both predictive systems thinking and critical systems thinking. The former one focuses on the phenomena expectable in a particular states of systems. A detailed discussion and application cases can be found, among others, in the works of Mesjasz (2000), Whitehead et al. (2017), and Yu (2021). The latter one is regarded as a multi-methodology that combines methods and practices from various systems thinking domains, such as system dynamics, soft systems methodology, sociotechnical system, and others, in order to better understand and address a recognized problem. Further information on the various approaches can be found, among others, in the following publications: Flood and Jackson, 1991), Jackson (2001), and Gao et al. (2003). It also differs from soft systems thinking which pursue tackling unstructured problems (soft problems) to achieve improvement to the system through a multistage process of information gathering, description, analysis and debate, for instance, in the field of human activity systems. Seminal works in this domain of interest are from: Checkland (1981), Jackson (1982), Petkov et al. (2007), and Burge (2015).

The implications of the scientific, technological, and societal progression and the transformation of systems due to the evolution of their cognitive features have not been addressed extensively yet. One reason may be that system scientists do not like to discuss questions for which they have no good answers yet or at all. It is understandable since, as Nietzsche explained, "if you gaze too long into an abyss, the abyss will gaze back into you". This is our typical relationship with traditional systems thinking. Nevertheless, as Cabrera et al. (2008) elaborated on it, changing the way how we think does not automatically solve the various problems, issues, or disputes faced. PST has the potential to reframe how we think about what we view as a problem in the first place, and what solutions might look like. Notwithstanding this, PST alone will not solve the 'big' problems of near-future systems. Informed by the novel systems thinking perspective, the vigorous problem-solving efforts in each of these areas are that will uncover a viable solution to the problems, issues, or disputes at hand.

Thus, the goal of our work was to devise prognostic analytic enablers and skills considering the paradigms and trends of the perpetual and accelerated changes. Our intension

was to move towards a system thinking that takes into account all rapid changes that influence how we see, treat, and benefit from complex systems, no matter if they are natural, fully or partially engineered, or hybrid systems. We also intended to generate new insights for systems thinking - closer to the state and the truth of today - by means of the new interpretation and the elaboration of the novel conceptual framework. These are the main ingredients of the novelty of our approach. Be that as it may, it is fair to remark that, in spite its novelty, our work is not unique in terms of rethinking systems thinking. Other authors have made similar efforts, in particular in the field of social science (Gradinarov, 2015). They typically started out from different assumptions (Wan, 2011; Mingers, 2014), or had different purposes (Lewis, 2005; Ulrich, 2013).

4. Pillars of the underpinning conceptual framework

4.1. Expectations for prognostic systems thinking

In our interpretation, first of all, an evidence-based conceptual framework (CFW) is needed that can serve as a guide to (holistic) systems thinking scenarios and models, and that can facilitate prognostic analyses (without pretending being a technological roadmap to the intelligent systems world). One of the requirements is that the conceptual framework should include ontological and methodological concepts that synergistically complement those discussed by Pickel (2007). In addition, the CFW should provide adequate view and knowledge on next-generation systems independent of their genre, and should make it possible to formulate relevant and accurate predictions about their manifestations, realizations, behaviours, and changes. Furthermore, the CFW should provide a high-level reasoning mechanism for prognostic systems thinking. Obviously, the framework cannot be restricted to the paradigmatic features of one particular system. Instead, it may cover all systems that do not contradict the conceptual pillars that the CFW is based on. However, the intension resonates with that presented in Sun et al. (2014).

A task for PST is to help identify emergent patterns conducive to explanation and prediction of future systems, and not only to their systems theoretical/engineering description and identification. PST enables, even forces, the different observers to look beyond what is in front of them and to see what is probable and what is possible. PST complement the currently identified three levels of descriptive systems thinking, that is: (i) the basic level (involving the recognition of interconnections, identifying feedback, and understanding dynamic behaviour), (ii) the intermediate level (adding the differentiation of flows and variables, and using conceptual models to the basic level), and (iii) the advanced level (including the creation of simulation models, and testing policies). It introduces three additional levels associated with fundamental

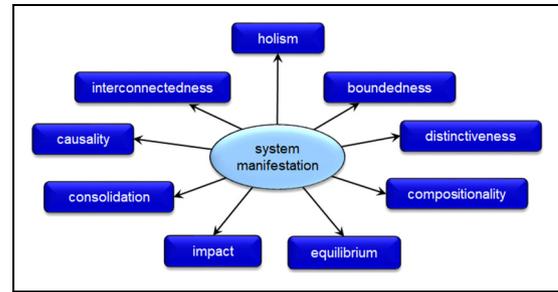


Figure 3. Conceptual pillars of traditional systems thinking.

understanding of the patterns that characterize next-generation systems and with the explanation and prediction of their behaviour under various circumstances. Furthermore, it also introduces novel system archetypes which help model the essence, operations, and implications of intellectualization of engineered systems. Actually, these archetypes are already captured implicitly in the conceptual framework that describes the paradigmatic characteristics as well as activities/behaviours.

However, the key elements of prognostic reasoning are not causal relations, but the semantic relations of the conceptual pillars. The fact of the matter is that we specified the CFW as a combination of the widely accepted conceptual pillars of traditional systems thinking and the up-and-coming (emergent) conceptual pillars of PST. The pillars have been formulated in an abstract and general manner in order to keep them applicable to different types of systems and to others.

4.2. Traditional pillars underpinning the conceptual framework

It is well-known from the literature that systems thinking revolves around a handful of concepts that anyone who is determined to learn can master, with study and practice. The key concepts of analytic systems thinking have been reused as the traditional conceptual pillars. They are shown in Fig. 3 and used in our research according to the following interpretations:

The above specifications reconfirm the fact that the traditional conceptual pillars of system thinking are about how systems manifest, rather than about how they evolve or are (self-)transformed over subsequent generations. They also disclose that traditional systems thinking (i) does not focus on evidential reasoning about possible and probable long-term developments, and (ii) does not serve as an adaptive basis for reasoning about changing humans-systems relationships.

4.3. Additional pillars underpinning the conceptual framework

Because of the abovementioned reasons, additional evolving concepts have been considered to capture the specific

boundedness	system has a domain of realization and operation defined by its individual boundaries	annihilation	systems reflect the disappearance of thingness in terms of physicality of their constitutional entities
causality	system behaviour is due to the transitive relationships of the parts as influenced by the environment	complementariness	systems complement delimited humans and humans complement delimited systems
compositionality	system as an entirety is more than the sum of its parts	exploitation	reasoning mechanisms and synthetic knowledge of systems aggregate into a shared industrial asset
consolidation	system changes towards a sustainable existence over time	ineptitude	systems are constrained in terms of replication of genuine human capabilities such as cognition, abstraction, feeling, and affection
distinctiveness	system has a purpose that defines its distinct functionality, manifestation, and/or realization	inseparableness	systems may not entangle their purpose of existence, behaviour, and performance from human will and meaning
equilibrium	system's overall behaviour is the result of triggering and balancing processes that may lead to stable or emergent phenomena	intelligence	intellectualization of systems extends the cognitive capabilities concurrently in the perceptive, reasoning, and communicative domains
holism	systems should be thought about seeing the big picture rather than the parts of it	naturalization	intellectualization, organization, socialization, and personalization of systems are coexisting dimensions of progression
impact	systems with multiple output exert cumulative patterned effects on their embedding environment and stakeholders	organization	systems are interconnected with each other in arrangements like systems, swarms, and/or societies of systems
interconnectedness	system is an arrangement of finite number of purposefully interrelated parts	personalization	functional capabilities of systems are extended with human behavioural traits and para-functional abilities
		self-management	systems are capable of purposefully changing themselves towards improved overall performance based on reflective learning
		socialization	social embedment of systems may range from socially interacting to socially behaving systems

aspects implied by the trends such as growing intellectualization, self-management of resources, increased automation, deeper social embedding, and so forth. These concepts are referred to as (the set of) emergent conceptual pillars. The sources of these conceptual pillars are varied, as well as those of the implied concerns discussed in the next sections. They can be, e.g., (i) theories produced by empirical research, (ii) trends and implications of observed technological developments and societal demands, (iii) principles derived by philosophical speculations, (iv) postulates, conjectures, and assumptions concerning future situations, (v) economic conditions and projections, (vi) political initiatives and policies and (vii) subjective personal beliefs, inceptions, and opinions. In our work, at formulating the set of emergent conceptual pillars, they have been considered with different preferences and emphasis in the order of listing above.

The set of emergent conceptual pillars of system thinking includes the following basic concepts:

These emergent conceptual pillars are exposed in Fig. 4 in combination with the traditional pillars shown in Fig. 3. They together identify the primary attention points for prognostic investigations. In addition, they help study the changes in terms of manifestations and impacts of the systems either over their subsequent generations (that is, beyond the life cycle of particular systems). A pertinent question is how the compiled set of conceptual pillars can be transferred into concrete interrogative statements for systematized investigations? In our case, the content

information for these statements, called concerns above, have been obtained by constructing the conceptual framework based on the semantic relationships of the pillars and interpreting the implications of their interplays. It needed additional knowledge exploration, chunking, and association, and eventually it has led to a semantic network.

5. Conceptual framework as a network of semantic relationships

5.1. Specification of the conceptual framework

Framing the knowledge associated with systems thinking and development of logical frameworks are widely addressed issues in the literature. By definition, a framework is a construct of assumptions, concepts, values, and/or practices that represents a part of the existing or imaginary reality and constitutes

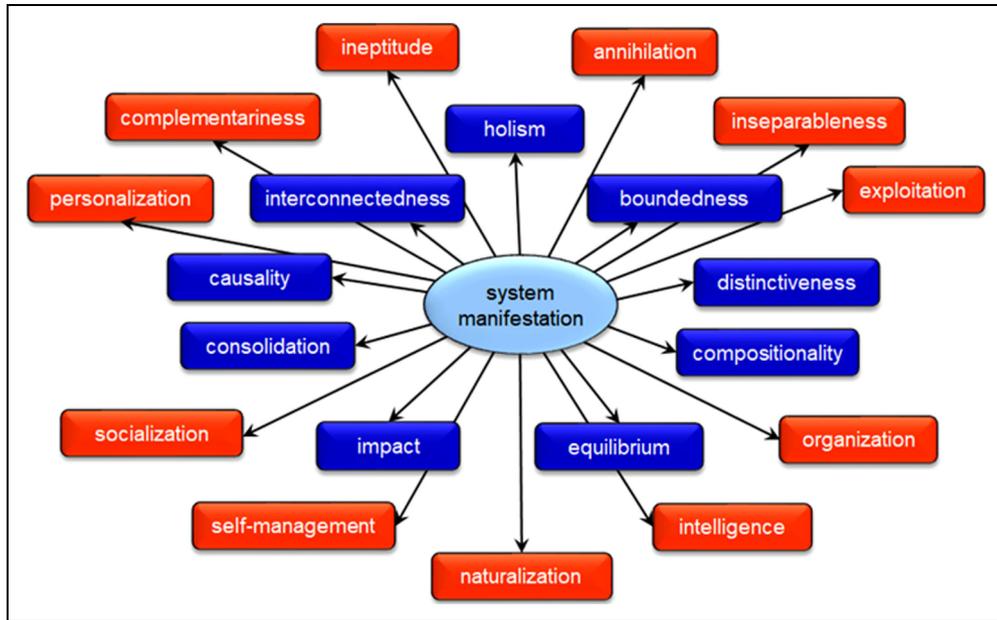


Figure 4. The emergent conceptual pillars combined with the traditional pillars of systems thinking.

a specific way of dealing with. A framework holds chunks of knowledge logically and semantically together for a particular purpose. The most frequently occurring types of frameworks are (i) conceptual (logical), (ii) taxonomic (architectural), (iii) methodological (procedural), and (iv) practice oriented (model-based) frameworks (Tepjit et al., 2019). An agreement seems to exist that a CFW is a logical arrangement of a set of physically or theoretically supported concepts and values that constitutes a way of viewing reality and serves as a frame of reference. It lends itself to making conceptual distinctions and to organizing a set of the concepts according to their semantic relationships.

In our case, the CFW is a logical construct defined by the semantic relationships of the pairs of pillars. A visual rendering of the semantic network of the proposed CFW is shown in Fig. 5. The whole of the CFW reflects a contemporary abstract view on the factors that are to be considered in current and near-future systems thinking. The pillars can be sorted into three sub-groups, which carry information about three influential factors: (i) recent trends of progression, (ii) paradigmatic features of (intellectualized) systems, and (iii) relationships with humans. This creates possibility for forward-looking projections and prognostic reasoning in various phases of system analysis. The trustworthiness of the prognostication is linearly proportional with the amount of the used data, information, rules, and experiences. In Fig. 5, the nature of the traditional and the emergent pillars are differentiated only with a view to their identified relationships. Relations may exist between two traditional pillars, between a traditional pillar and an emergent pillar, and between two emergent pillars. They are indicated by the coloured double-arrow lines. The blue ones indicate the semantic relation among traditional pillars, (ii)

the red ones the emergent pillars, and (iii) the green ones among traditional and emergent pillars. Each identified relation lends itself to a number of concerns, which are actually the means of operationalization of the CFW in systems thinking.

5.2. Introducing the notion of concerns

The term ‘concern’ is used here to refer to various essential thoughts, matters of interest, and important issues related to the conceptual pillars collectively as well as to their interplays. Concerns have been explored and formulated based on an extensive literature study and semantic concept analysis. There have been different number of concerns identified for the various pillars. A challenge was to define the concerns on the same abstraction and comprehensiveness level. In the lack of objective measures or comparison methods, this was based on subjective judgment. The identifiers of the concerns are shown in Fig. 6. The concerns can be used to develop sets of questions to collect and analyse information for PST and deriving up-to-date mental and action models. A similar work in a somewhat different context was presented by Dorani et al. (2015). Depending on the system to be dealt with, consideration of a subset of the concerns may be sufficient, but in case of a low-level comprehensive analysis there might be a need for the consideration of more or more articulated concerns. Obviously, prognostication becomes more factual when a large set or all relevant concerns are taken into account. For each edge of the semantic network, one or more concrete questions can be stated, based on which a concrete systems thinking model can be developed. On the other hand, system assessment and decision making eventually remain dependent on human views and interpretations.

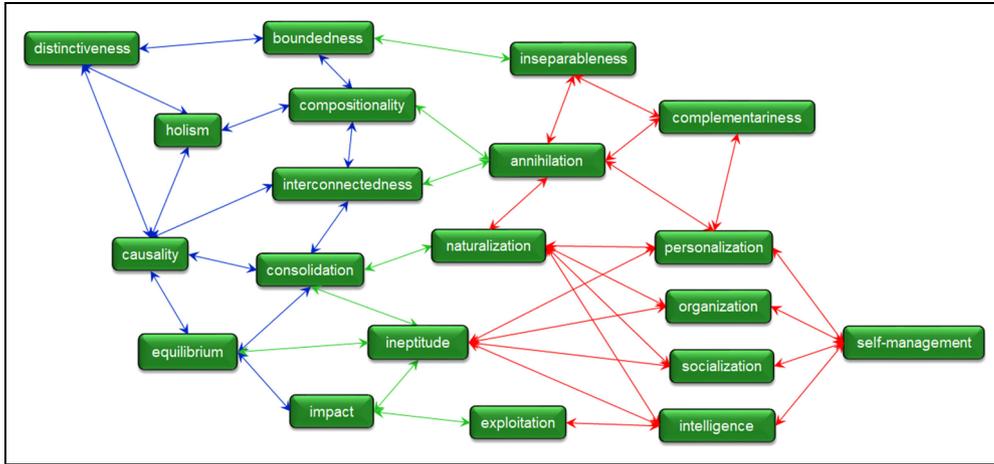


Figure 5. The proposed conceptual framework as a semantic network.

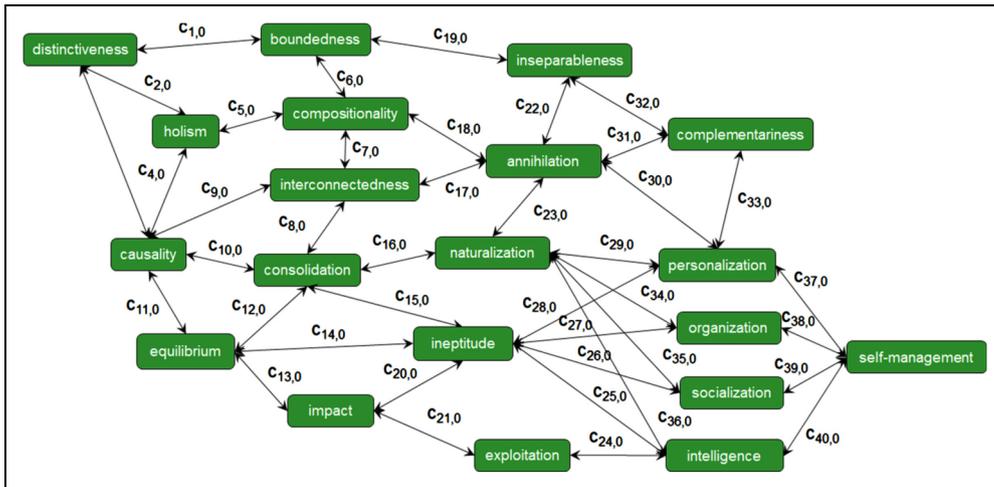


Figure 6. Concerns identified in association with the conceptual pillars and their relationships.

To impose a simple structuring on the pile of the identified concerns, we sorted them into three categories according to the classification of the pillars explained above. The exploration of all important concerns came along as an unexpectedly tough nut to crack due to the wide range of engineered systems and possible interests of human stakeholders. It is clear for the author that explaining the concerns with one or more concrete practical examples would be helpful for the readers. Notwithstanding, this could not be achieved in this paper due to the page limit and it has been left for a follow up publication. Nevertheless, it is believed that connecting the presented textual formulation of the concerns to real life examples will not be challenging for systems researchers. The next three sections provide an overview of the elaborated first library of concerns that are proposed to be taken into account not only in descriptive or

explanatory analyses, but also in prognostic analyses related to next-generation systems.

6. Concerns associated with traditional conceptual pillars and their interactions

C_{01,0}: distinctiveness \Leftrightarrow boundedness:

C_{01,1}: increase of distinctiveness of a system through the growing number of paradigmatic features and implementation characteristics

C_{01,2}: dependence and correlation of the physical, virtual, and logical system boundaries and the unique purpose, manifestation, and/or realization of a system

C_{01,3}: oneness or multiplicity of the physical, virtual, and logical system boundaries implied by the unique purpose and realization of the system

C_{01,4}: extent of detachment of a system from its embedding environments as implied by the vagueness and sharpness of its boundaries

C_{02,0}: distinctiveness <==> holism:

C_{02,1}: influence of the unique purpose, functional and structural manifestations on the wholeness of the system

C_{02,2}: impacts of local and global changes on the purpose, functionality, architecture, and behaviour on the wholeness of the system

C_{03,0}: distinctiveness <==> causality:

C_{03,1}: local and remote interconnections and interplays of the constituents and parts as a reason of the operation and manifestation of the behaviour of a system

C_{03,2}: direct and indirect influence of the environment as a reason of the operation and manifestation of the behaviour of a system

C_{04,0}: holism <==> causality:

C_{04,1}: resilience of the system as a whole against irregular operational, interactional, security, and privacy influences

C_{04,2}: measure of resilience and/or sustenance of a system as a whole as a function of cohesion and suppleness among its parts

C_{05,0}: holism <==> compositionality:

C_{05,1}: alignment of the underlying assumptions, conceptualizations, constraints, and implementation details of the constituents and the systems participating in a higher-level arrangement

C_{05,2}: operational compatibility and systemic interoperability of a higher-level arrangement of systems from conceptual, computational, contextual, and cultural viewpoints

C_{05,3}: opportunities and restrictions of a planned or unplanned, run-time, functional and architectural augmentation of a system

C_{06,0}: boundedness <==> compositionality:

C_{06,1}: influence of the purpose and working principles on the minimal number and interrelationship of the constituents of the system

C_{07,0}: compositionality <==> interconnectedness:

C_{07,1}: methods and overheads of how new constituents can connect to and connected constituents can leave a system of higher-level arrangement

C_{07,2}: methods and overheads of how an open boundary system of higher-level arrangement can handle operational and structural dynamics

C_{08,0}: consolidation <==> interconnectedness:

C_{08,1}: consistency of actions, conclusions, and interpretations with regard to the purpose, logic, functions, structure, and behaviour of the constituents (systems) participating in a higher-level arrangement

C_{08,2}: corrective actions of a system of higher-level arrangement to improve or maintain the consistency of actions, conclusions, and interpretations

C_{09,0}: causality <==> interconnectedness:

C_{09,1}: influence of defective and imperfect interrelated constituents on the overall operation and behaviour of a system of higher-level arrangement

C_{10,0}: causality <==> consolidation:

C_{10,1}: long term effects and behavioural changes on the consolidation of the system towards a sustainable existence

C_{11,0}: causality <==> equilibrium:

C_{11,2}: lasting deterministic behaviour (so as the next state of the system and the environment is or not completely determined by their current states and the completed actions)

C_{11,2}: lasting stochastic behaviour (so as the next state of the system and the environment is or not completely determined by their current states and the completed actions)

C_{12,0}: equilibrium <==> consolidation:

C_{12,1}: influence of triggering and balancing processes on the changes towards a sustainable existence

C_{13,0}: equilibrium <==> impact:

C_{13,1}: influence of triggering and balancing processes on the overall impact of the system with regards to reducing and increasing societal entropy and enthalpy

7. Concerns associated with interrelated traditional and emergent conceptual pillars and their interactions

C_{14,0}: equilibrium \iff ineptitude:

- C_{14,1}: incapability for adaptation due to the quasi-equal effects of reinforcing and balancing factors and processes
- C_{14,2}: pre-emptive reaction to state changes before they occur based on forecasting their changes on system level

C_{15,0}: consolidation \iff ineptitude:

- C_{15,1}: accountability for adaptation within a certain prescribed range of behaviours or exhibiting free adaptation
- C_{15,2}: avoiding re-occurrence of counter intuitive behaviour in order to maintain a long-term sustainable existence
- C_{15,3}: appropriateness and sufficiency of the constituents of a system to inhabit purposeful activities in order to solve some parts, or eventually the whole, of the target application problems they are designed for and/or adapted to
- C_{15,4}: abilities of the system to get to know the objective and competence limitations with regard to solving changed or new application problems

C_{16,0}: consolidation \iff naturalization:

- C_{16,1}: compliance with the AI control problem (i.e. acknowledgment of the problematic of building AI-enabled systems that aid rather than harm their creators)
- C_{16,2}: corrective self-reflection based on information about the effectiveness of the used computational approaches, the own overall behaviour, and the historical successes and failures in solving application problems

C_{17,0}: interconnectedness \iff annihilation:

- C_{17,1}: proportion of cyber, virtual, and simulated constituents of a system, and their functional, architectural, and behavioural relationships
- C_{17,2}: power of cybernation, virtualization, and simulation as means of dematerialization of engineered systems

C_{18,0}: compositionality \iff annihilation:

- C_{18,1}: effects of disappearance of thingness of the physical constituents of a system on the induced operations and emergent affordances

- C_{18,2}: proper ways and rules of managing compositionality in the case of cybernation, virtualization, and simulation of physical constituents

C_{19,0}: boundedness \iff inseparableness:

- C_{19,1}: determining the functional operation and effect boundaries of a system independently of human will and purpose
- C_{19,2}: extents and boundaries of existence, operations, interoperation, behaviour, and performance of a system entangled from human will and purpose

C_{20,0}: ineptitude \iff impact:

- C_{20,1}: exerting cumulative, patterned effects by a system with multiple outputs on its embedding environment and stakeholders
- C_{20,2}: indicators of the limitations and constrains of a system with regard to replication/reproduction of genuine human cognitive capabilities such as thoughts, abstraction, feeling, and affection
- C_{20,3}: capacity of an intellectualized system and its constituents to have computational (artificial) sentience for positive and negative experiences

C_{21,0}: impact \iff exploitation:

- C_{21,1}: possibility of defining or circumscribing success criteria and measures for an intellectualized system in individual application problem cases
- C_{21,2}: influence of technological affordances, societal demands, and acquirable resources on long term adaptation of systems in an intelligent systems world
- C_{21,3}: individual and social adaptation of a system through learning from own experiences and learning from other systems

8. Concerns associated with emergent conceptual pillars and their interactions

C_{22,0}: annihilation \iff inseparableness:

- C_{22,1}: enforced effect of the probable disappearance of thingness of human stakeholders in systems and the possible entanglement of systems from human purpose

C_{23,0}: annihilation \iff naturalization:

- C_{23,1}: interplay of possible entanglement of systems from human purpose and stakeholders and naturalization of the behaviour of systems

C_{24,0}: exploitation <==> intelligence:

- C_{24,1}: accelerating and decelerating factors (barriers and drivers) of adoption of a type of intellectualized system in various sectors
- C_{24,2}: importance and convincingness of intelligent system characteristics from an investment point of view
- C_{24,3}: relationship between the achieved level of intellectualization and the socially demanded level of intellectualization
- C_{24,4}: balance of the provided level of systelligence and the requested (dedicated) problem solving competence in application problems
- C_{24,5}: level of operational rationality of a system in terms of the decisions it makes about its actions seeking a maximum measure of performance
- C_{24,6}: transformation and utilization of the synthetic knowledge and reasoning mechanism constituents of systelligence as a shared industrial asset and capital
- C_{24,7}: capability and indicators of providing transparent results for the application problem that can be replicated and compared with respect to results achieved by using other approach and/or resources

C_{25,0}: ineptitude <==> intelligence:

- C_{25,1}: limits or deficiencies of implementation and aggregation of overall intelligence in an engineered system and synthesizing systelligence on higher-level system arrangements
- C_{25,2}: limits or deficiencies of replication of cognitive abilities such as cognition, abstraction, feeling, and affection
- C_{25,3}: potentials and impacts of a system that is capable or has no capability of supervised, semi-supervised, and/or unsupervised learning
- C_{25,4}: inward and outward self-explanation capabilities and approaches of the systems concerning the operationalization of systelligence and the reasons of self-managed initiation of changes
- C_{25,5}: sufficiency of the explanation provided by an autonomous system to its human stakeholders concerning the reasons that justify why a requested task is rejected by the system
- C_{25,6}: possibility of rejecting a human requested tasks by an autonomous system according to certain reasons (e.g., safety consideration), based on the current situation of the environment (e.g., unpredictable outcome), or the own goals of the system (e.g., social norms)
- C_{25,7}: appreciation of the criticality of the tasks to be performed autonomously and the correctness of the system own decisions on if and how to act in the environment to perform that task

C_{25,8}: combination of deliberative reasoning and immediate reactive behaviour by a system, or giving preference (favouring) deliberation over reaction

C_{26,0}: ineptitude <==> socialization:

- C_{26,1}: capability of a system to exhibit replication of social character and intuitive social behaviour in the lack of genuine feelings and affection
- C_{26,2}: constrains and hindrances of a system concerning the extents of socialization over a range of applications and environmental contexts
- C_{26,3}: managerial independence and operational usefulness of the cooperative constituents included in a higher-level arrangement of systems to expose social capabilities on their own right

C_{27,0}: ineptitude <==> organization

- C_{27,1}: scrutiny with respect to complying the input and output requirements that identify what functional and architectural (self-)organization a system needs to present
- C_{27,2}: level of dynamics achievable by a system in its self-organization and in managing its functional/structural relations with a view to higher-level organizations of systems
- C_{27,3}: limits or deficiencies of (self-)organization of the constituting systems into a higher-level organization according to changing goals or circumstances

C_{28,0}: ineptitude <==> personalization:

- C_{28,1}: limits or deficiencies of replication of individual and collective human behaviour, mental models, and social abilities according to societal contexts and behavioural norms
- C_{28,2}: tendency of a highly socialized system to exhibit counter intuitive behaviour in a society of intellectualized systems
- C_{28,3}: verification of the solvability and correctness of a human requested task by an autonomous system before it gets performed

C_{29,0}: naturalization <==> personalization:

- C_{29,1}: potentials and aspects of personalization of systems with regard to the coexisting dimensions of naturalization
- C_{29,2}: limitation of self-enhancement of naturalness of a system by learning and replicating human behavioural abilities and operation of the system according to human personal and social norms

C_{30,0}: annihilation <==> personalization:

C_{30,1}: dealing with the paradox of disappearance of thingness of the human stakeholders and being extended with human behavioural abilities by a system

C_{31,0}: annihilation <==> complementariness:

C_{31,1}: influence of delegation of responsibilities to an intellectualized and autonomous system on complementariness

C_{32,0}: inseparableness <==> complementariness:

C_{32,1}: measure of supporting or deviating from human stated overall purpose by a system in case of or towards (more favouring) opportunities and affordances

C_{32,2}: cooperation of systems that are not organized for success in the same way or are (or not) equally committed to successful goal achievement

C_{32,3}: guaranties that the system behaves as a robust (stable) transition system even under heavily dynamic operational and environmental circumstances

C_{33,0}: complementariness <==> personalization:

C_{33,1}: facilitating coadunation by compensating human limitations with systems operations and overcoming system restrictions by human operations

C_{33,2}: necessary and sufficient level of personalization of a system with a view to its social embedment, interaction with human stakeholder, and credibility and trustworthiness

C_{33,3}: indicators provided by a system concerning its deterministic or nondeterministic nature with regard to its overall purpose, capabilities, state, and performance (due to failures and degradations over time)

C_{34,0}: naturalization <==> organization:

C_{34,1}: role and contribution of organization of systems into higher-level arrangements to a high-fidelity implementation of naturalization

C_{34,2}: potentials and strength/weakness of organization of systems into higher-level arrangements with regard to the other coexisting dimension of advancement

C_{34,3}: overall reliability, manageability, and sustenance of higher-level arrangements of systems

C_{35,0}: naturalization <==> socialization:

C_{35,1}: role and contribution of socialization of a system to a high-fidelity implementation of its naturalization

C_{35,2}: potentials and strength/weakness of socialization of a system with regard to the other coexisting dimension of advancement

C_{35,3}: exhibition of counter intuitive behaviour by a system with a strong complex social character

C_{36,0}: naturalization <==> intelligence:

C_{36,1}: role and contribution of intellectualization of a system to a high-fidelity implementation of its naturalization

C_{36,2}: progression of intellectualized engineered systems towards the manifestation of naturally created (eco)systems

C_{36,3}: potentials and strengths/weaknesses of intellectualization of a system with regard to collaboration or coadunation with human society, communities, groups, and individuals

C_{36,4}: sufficiency and affordances of intellectualization of a system with regard to solving application problems efficiently

C_{37,0}: self-management <==> personalization:

C_{37,1}: self-determination of the needs and goals of personalization of a system according to real-life behavioural contexts and assumptions

C_{37,2}: self-implementation of proper forms of personalization of a system in a given environment considering real-life behavioural contexts and assumptions

C_{37,3}: capabilities and directions of a system to self-manage short-time (action) and long-time (behaviour) personalization

C_{37,4}: standardization and imposing thresholds on behavioural traits and behaviours of self adaptive, self-evolving, and self-replicating systems equipped with abilities and personal styles of human

C_{37,5}: indicators of the efforts of an intellectualized system to operate as a beneficial machine that maximize the realization of human preferences in order to cope with the AI control problem

C_{38,0}: self-management <==> organization:

C_{38,1}: integration of infrastructure, hardware, software, cyberware, human, and business processes into systems of systems, swarms of systems, and societies of systems

C_{38,2}: effects of self-adaptation, self-evolution, and self-replication on forming systems of systems, swarms of systems, and societies of systems

C_{38,3}: usefulness of the information provided to facilitate planning, scheduling or resource assignment

decisions and supporting analytic human tasks (problem diagnosis and supervision)

- C_{38,4}: applied or best practice of establishing synchronous composition (for simultaneous operation) and asynchronous composition (for interleaving operation) of related systems
- C_{38,5}: optimal composition rules and actual ampliative composition of interacting constituents of an arrangement or society of systems towards dependable operation

C_{39,0}: self-management <==> socialization:

- C_{39,1}: bridging the a cognitive-social-technical gap between what and how self-managing intellectualized systems do and what the society wants
- C_{39,2}: involvement of social components such as human, culture, organization, context of use, usefulness, policies, and regulations by a self-managing intellectualized system
- C_{39,3}: principles, norms, rules, laws, and ethics of socialization of self-adaptive, self-evolving, and self-replicative intellectualized systems
- C_{39,4}: purposes, levels, scopes, forms, and conditions of socialization of self-adaptive, self-evolving, and self-replicative intellectualized systems
- C_{39,5}: influence of intense socialization on forecasting, design, running, and management of intellectualized systems
- C_{39,6}: possibility and behavioural principles of simultaneously acting rationally and according to social norms by a self-managing intellectualized system
- C_{39,7}: ability of a system to relate to other systems without or with adaptation and to compare its performance to that of other systems
- C_{39,8}: benevolence of a system in a social organization with respect to its willingness to adopt the goals of other system even if the adoption of such goals does not help achieve its own goals

C_{40,0}: self-management <==> intelligence:

- C_{40,1}: level of providing the four primary human cognitive abilities (namely, (i) perception, (ii) deliberative reasoning, (iii) action control, and (iv) language-based communication) as they are needed for an intellectualized operation (to interact with other constituents)
- C_{40,2}: influence of technological affordances, societal demands, and acquirable resources on long term adaptation of a system in an intelligent systems world
- C_{40,3}: problem solving abilities and skills (such as perception, awareness, reasoning, decision making, learning, forecasting, etc.) of a system to address varying tasks in a dynamic environment

C_{40,4}: planning, control, and testing of self-adaptation, self-evolution, and self-replication of a system in the case of growing systelligence

C_{40,5}: run-time verification and validation of the properness, suitability, and dependability of synthetic knowledge and reasoning mechanisms of a system as interplaying components of systelligence

C_{40,6}: potential of system-level learning considering the extension of the possessed resources by the system, the human stakeholders, or the environment

C_{40,7}: collective and federated learning by an arrangement or a society of similar and dissimilar systems over a lasting operational period (e.g. to ensure fairness, avoid group biases, or limit harmful actions)

C_{40,8}: ability of learning, planning, and predicting the consequences of actions and procedures and acquiring, generalizing, and (pseudo)understanding new knowledge

C_{40,9}: comprehensiveness and timeliness of practicing advisory system functions (helping humans to decide on what actions to do in the environment)

C_{40,10}: variety of ways a system is able to change itself to complete a certain task more efficiently in response to changes in the environment

C_{40,11}: application-specific performance measures (e.g., accuracy, speed, and repeatability of unsupervised problem solving) and metrics for intellectualized operations of a system

C_{40,12}: value judgement by a system to assess its own actions and judge/moderate its behaviour based on self-observation or other more complex critiquing mechanisms

C_{40,13}: generation of positive or negative rewards by a system using simulated feelings (e.g. like pain or pleasure)

9. Reflections, propositions, and future research topics

9.1. Some reflections

Thinking about systems is like viewing a (double-sided) coin. On the obverse side of the coin is the question about what constitutes systems thinking, whereas on the reverse side is the question about what enablers, knowledge, and capabilities a systems thinker should have in order to be efficient. The contribution of this paper can be placed on the edge of the coin for it connects the principles of next-generation systems to the knowledge that system analysts should be aware of. The pillars and concerns have been interpreted from a pragmatist standpoint. This has its legitimacy because, as Gradinarov (2015) argued: “To a great

extent, systematic thinking is constructivist in nature, as is modelled not by specific preliminarily set and axiomatically adopted basic principles but is dependent on the subject and must include a preliminary analytical stage". This degree of freedom plays an important role at converting the reasoning model into PST models serving different applications and contexts.

Pragmatism is also reflected by choosing the goal and scope of the research. It was restricted to constructing a framework and exploring topics (issues) for a prognostic investigation of next-generation systems, in particular the broad spectrum of intellectualized systems, considering the trends and characteristics of their developments. The prognostic investigation includes (i) deriving arguable goals and assumptions, (ii) specification of the set of pertinent concerns, (iii) compiling expressive sets of indicators and measures, (iv) determining the extent of the investigated system, (v) comprehensive examination of the concerns, (vi) discerning influencing factors and their effects/implications, (vii) linking and evaluation of the findings, and (viii) reflections and projecting out propositions. PST requires systematic examination and validation throughout all stages of activities from the formulation of problems, through the implementation of solutions, to the evaluation of outcomes. It should be an evidence-centred comprehensive approach of addressing real life issues related to complex systems. It is of importance to objectively appreciate the systemic factors and to understand the relationships that influence decision making at conceptualization, implementation, and embedding next-generation intellectualized systems in complex dynamic environments. The proposed approach facilitates transparent and reproducible decision making, whilst supports evidence-based systematic reasoning and reliable forecasting.

9.2. Propositions

In the complexities-loaded current world, thinking about complicated problems and their intuitive solutions necessitates a whole system perspective. Systems thinking has been proposed to extend our mental models to render comprehensive perspectives. Whitehead et al. (2014) regarded systems thinking as a thought process through which assumptions about a set of interconnected system elements are made with the objective of discerning hidden values. Likewise, PST was seen in this work as an investigative thought process that is framed according to the particular subject matter, purpose, and context. The major propositions are as follow:

- Only a first inventory could be presented in this paper and obviously further studies are needed towards its completion, consolidation, and validation. Though PST supports seeing intellectualized systems and their evolution processes as a whole, it does not offer support to handling complexities. The more

pillars, concerns, and questions are considered, the larger the intellectual challenge. Further studies are needed to figure out how to reduce the innate complexities. The author also suggests to develop tools to support the management of concerns as well as to computationally assist the whole process of PST.

- In the related literature, being (i) static, (ii) descriptive, (iii) non ampliative, and (iv) non-resilient are discussed as four critical limitations of the conceptual frameworks and analysis models of traditional systems thinking. The conceptual framework as well as the set of concerns can be extended as needed according to the current and near-future state of system intelligence, autonomy, technology, and socialization. Based on this, the proposed approach itself can be seen as an adaptive system.
- Based on the overviews of the literature and the engineering practice, with regards to holistic investigations of intellectualized systems, the hottest issues of PST are related to (i) the growing functional automation and naturalization of systems in terms of organization, behavior, and socialization, (ii) self-management of personalization, organization, socialization, and cognition, and (iii) exploration of their effects on humans, organizations, and the society as a whole.
- The composition of traditional and emergent pillars in the proposed reasoning model stretches the dimensions of PST, and the library of concerns conveys information about the possible interests. Inventorying the concerns plays an important role since traditional systems thinking, as discussed by many in the literature, does not have a structured 'semantic language' that could harmonize thinking and facilitate communications across the various domains of natural, social, and (intellectualized) technical systems. This can also strengthen the transdisciplinary character of PST by integrating elements of physics, biology, phycology (Hernández-Orallo et al., 2014), informatics, and, in particular, mathematics (Ziesche & Yampolskiy, 2020; Depuydt, 2021). Elaboration on these was the most ambitious goal of our research and could be a unique selling point for our results.
- In some text books on mathematics, application of the subject matter to practical cases or proving simple theories is left to the reader as a deepening exercise. This applies to the proposed set of investigational concerns too. There are two simple reasons for this proposal: (i) there are too many application cases and aspects in which PST may be needed, and (ii) there is a space limitation on research papers that prevents the presentation and investigation of applications cases and cross-application conclusions.

Beyond these propositions, there is one thing that can be claimed with a high certainty: Guys, be cautious with

systems thinking - a new reality opens your door without even knocking on it. . . .

9.3. Open issues and future research topics

The compiled set of the pillars and the derived concerns together create a useful, practical, and adaptive platform for prediction and prognostication in the context of next-generation systems. Nevertheless, there is a likely need for extension and further refinement since there have been several open theoretical issues recognized, but not addressed, in the work reported above. For instance, (i) managing the always-changing aspects of assessing systems, (ii) consideration of the system boundary to encounter for all significant (direct or indirect) trends and influences, (iii) the amount of interrelated conceptual pillars necessary and sufficient for a fully-fledged assessment, (iv) the thematic coverage of conceptual pillars to form a sufficiently robust framework, and (v) the general principles of mapping diversification, intellectualization, socialization, personalization, automation, etc. related concerns of future systems. Additional open practical issues are such as: (i) robustness of the applied semantic categorization of concerns, (ii) completeness of a set of concerns for an assessment, (iii) influences of the lack of explicit (critical) ranking of concerns, (iv) descriptive and predictive power of concerns for PST, and (v) semantic interplay of the investigative concerns.

A short-term supplementary research may address topics such as (i) dexterous handling of innate complexities, (ii) methodological support of deriving concerns, (iii) elimination of the limitations of the conceptual framework, (iv) rendering the semantic relationships/dependences of concerns, (v) enhancing the transdisciplinary character of PST, (vi) objective evaluation of the concerns in various application contexts, (vii) computer support of deriving and selecting concerns in line with the assessment objectives, (viii) computer support of the conducts of PST, and (ix) finding the best and unique selling points for concerns-based PST.

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Dr. Imre Horváth is an emeritus professor of the Faculty of Industrial Design Engineering, Delft University of Technology, the Netherlands. In the last years, his research group focused on research, development, and education of smart cyber-physical system design, with special attention to cognitive engineering. Prof. Horváth is also interested in systematic design research methodologies. He was the promotor of more than 25 Ph.D. students. He was first author or co-author of more than 460 publications. His scientific work was recognized by five best paper awards. He has a wide range of society memberships and contribution. He is past chair of the Executive Committee of the CIE Division of ASME. Since 2011, he is a fellow of ASME.

He is member of the Royal Dutch Institute of Engineers. He received honorary doctor titles from two universities, and the Pahl-Beitz ICONNN award for internationally outstanding contribution to design science and education. He was distinguished with the Lifetime Achievement Award by the ASME's CIE Division in 2019. He has served several international journals as editor. He was the initiator of the series of International Tools and Methods of Competitive Engineering (TMCE) Symposia. His current research interests are in various philosophical, methodological, and computational aspects of smart product, system, and service design, as well as in synthetic knowledge science and development of self-adaptive systems.

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