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Theoretical Contribution

Inviting systemic self-organization: Competencies for complexity regulation from a post-cognitivist perspective

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This contribution discusses competencies needed for regulating systems with properties of multi-causality and non-linear dynamics (therapeutic, economical, organizational, socio-political, technical, ecological, etc.). Various research communities have contributed insights, but none has come forward with an inclusive framework. To advance the debate, I propose to draw from dynamic systems theory (DST) and "4E" (embodied, embedded, enactive, and extended), cognition approaches, which offer a set of perspectives to understand what expert regulators in real-life settings do. They define the regulator's agency as skillfully imposing constraints on a target system and hereby creating context-sensitive openings for self-organizing dynamics, rather than "controlling" the system. Adept regulators apply multi-pronged and multi-timescale constraints to achieve nuanced effects. Among other things, their skill set includes scarcely noted enactive processual competencies for "emergence management", which the intellectualistic and insufficiently ecologically situated accounts of the complex problem solving literature omit. To capture the nature of system regulation I advocate treating regulation dynamics and target system dynamics "symmetrically" by grounding regulator competencies in concepts from complexity theory.

Keywords: system regulation, complexity theory, agency, "4E" cognition, embodied interactivity

1 Introduction

Despite studies dating as far back as the 1970s, complexity regulation "in the wild", i.e., in naturalistic contexts, remains a frontier with many unknowns. This contribution draws attention to regulation resources that are oft-neglected, yet crucial for an integrated theory of this kind of special expertise. Many facets of regulation – especially embodied, multi-pronged or "distributed" strategies – may not strictly fit into the category of problem solving, and their recognition ultimately ushers in a wider understanding of regulation than is common among most psychologists. I will introduce a set of regulation means grounded in complexity theory itself, which suggests a more inclusive framing as competencies for *dynamic-enactive process management*. Specifically, by striking up a dialogue with post-cognitivist cognition science I hope to advertise new conceptual resources and supply prolegomena for a broadened empirical research agenda. Methods to evaluate skills remain out of scope in this theory paper, however.

To contextualize my aims, Section 1 introduces complex processes together with some central notions of complexity research. It is argued that a peculiar set of regulating challenges and difficulties emerges from the typical dynamic properties associated with the notion of complexity. Section 2 reviews the literature and identifies gaps in research, notably taking issue with the prevailing reduction to "reasoning about systems" as sole modus operandi of system regulation. Section 3 lays the meta-theoretical groundwork for a complexity-informed definition of regulative agency, centering on the ideas of constraining, enabling and exploiting system dynamics rather than controlling them. Furthermore, key topics from posit-cognitivist theory are presented, which research on system regulation would do well to heed, such as the importance of action for thought, the role of intentions that are dynamically fleshed out, or socio-material workspaces of professionals. Section 4 then presents a set of specific competencies for regulating a target system, which operate through direct coupling with the latter (i.e., without explanatory recourse to reasoning). Finally, Section 5 presents an outlook on aspects of regulation that are likely to require reasoning, notably context-specific strategy development, and on how post-cognitivist and classical approaches can become partners.

What complexity means

Modern life faces humans with many varieties of complex, non-linear and multi-causal phenomena, across economic systems, politics, business, organizations, technical, and ecological systems. Our livelihoods and even our future as a species, in many ways, hinge on the ability not only to understand, but also to be able to judiciously interact with such systems.

Complex dynamic systems, also known as complex adaptive systems (Gell-Mann, 1994; Guastello et al., 2009), include the dynamics of flocking birds, avalanches, the thermodynamics of liquids, the dynamics of people fleeing a building, pedestrian behavior and traffic jams, metabolism and the immune system, but also the dynamics of organizational or family

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dynamics, of political conflict escalation, of pandemics, and many other examples. A first step towards understanding challenges that regulators of complex dynamic systems face is to acknowledge structural and dynamic properties of the latter. My argument will be that regulating complex systems involves skillfully exploiting or "riding on" such properties, rather than working against them in an effort to "control". Analyzing this type of competency, however, presupposes a certain familiarity with technical concepts that characterize complex dynamic systems.

Complexity theory, a meta-theory of the dynamics of biological, social, ecological and physical systems, defines complexity as "the behavioral marker of systemic connectivity" (Pincus & Metten, 2010, p. 359) that arises "when a sufficient number of systemic elements form a sufficient number of information exchange relationships" whose connections "lead to complex feedback dynamics including positive (change expanding) feedback, negative feedback (change dampening), threshold effects, coupling dynamics (e.g., synchronization), and hierarchical dynamics" (Pincus & Metten, 2010, p. 354). This notably contrasts with systems in which components follow centralized control, but scarcely couple horizontally.

Especially exchanges that mix inhibitory and excitatory feedback can give rise to global self-organizing dynamics not reducible to the sum of their parts. Such systems are said to display *emergence*. Emergence means that a macro-scopic effect arises from criss-crossing networks of interconnected local activations. In some cases, this can enable a system to display globally coherent stability without any centralized control. In other cases, emergent system properties may include exponential dynamics, chaotic or paradoxical seeming effects, and counterintuitive system responses to intervention. Emergence relationships are complemented by so-called downward causation from the global dynamics to system components (e.g., by aligning outlier components with an ongoing dynamic). This double relationship has been termed *circular causality* between micro- and macroscopic system levels. A social psychology example is how totalitarian dictators create lies they end up believing themselves, because the manipulated populace repeats them over time (Ciompi & Endert, 2011). Furthermore, complex systems are known to be sensitive to context (including systemic *boundary conditions)*, interaction history (a kind of "system memory") and initial conditions (*hysteresis, path dependency*). This means that to interpret how a system behaves, its previous states need to be known.

In complex dynamic systems there can be no simple attribution of causes to effects. Such systems frequently display non-linear behavior, i.e., patterns that are neither stable nor cyclic, but buffered, delayed, amplified, "out of place", or that display leaps and fluctuations. Non-linearity variously manifests in runaway processes, conflicts that become intractable, and medical, social or ecological dynamics that are increasingly difficult to influence at all. Non-linearity can also be reflected in a puzzling non-reactance to intervention attempts. In other words, a system can have staying power despite attempts to manipulate or change its dynamic, such as when chronic ailments can become self-stabilizing and resist therapeutic intervention. These signatures of complexity stand in striking contrast to the relative predictability of most everyday contexts and its more linear phenomena.

Note, however, that certain complex systems will display some of these complexity signatures, but not others. There are, for instance, cases of low combinatorial complexity under high dynamic complexity (Sterman, 2000, p. 21) or delayed yet proportional effects of action. Note also that complexity is a technical notion and targets a specific class of tasks or systems from a formal and mathematical angle. As such it mismatches our colloquial term "complex", which often simply refers to cognitive or task difficulty or to ill-defined problem contexts, a category which includes phenomena that are not complex in the technical sense.

The human challenge

This paper is not concerned with complex systems as such, but with agents who interact with these systems *in complex dynamic regulation tasks*. However, the mentioned complexity signatures provide good indications of challenges that such tasks entail. Such tasks typically face a person with ambiguities, uncertainty, limited information, risks, and utmost context-dependency. Dietrich Dörner, among the first to study complexity regulation empirically, defines a complex problem as involving systems with (a) multiple elements, (b) interconnectedness, (c) opaqueness, (d) dynamics, and (e) multiple, possibly competing goals (Dörner, 1997). Joachim Funke adds to this list rapid, non-linear dynamics and delays (Funke, 1991), i.e., characteristics that also matter to the complexity literature.

In complex dynamic regulation tasks agents interact with a system structure whose variables change continuously, both as a result of their actions and the system's autonomous dynamic. They are faced with "a combination of nonlinear, linear, and noisy relations between inputs and outputs" (Osman, 2010a, p. 66). To name one widespread difficulty that results, when one intervenes in a complex system, effects may often be "delayed, diluted, or defeated" (Meadows, 1982). Effects never arise *only* as a consequence of the undertaken interventions; systems possess endogenous processes of self-organization. Consequently, many an intervention can be disproportionally amplified and reverberate throughout the system in unexpected places (multiple side-effects), while other interventions just "dissipate". In addition, nonlinear feedback makes it difficult to interpret the dynamics and learn about the system. Deciding whether effects result from something one did or from internal system dynamics is tricky.

To stand a chance of success with a complex dynamic regulation task, a multi-causal mindset is imperative, which recognizes mutual cross-influences, autocatalysis, and non-linear rather than simple or mechanistic causalities. These are facts that clash with deep-seated everyday convictions (Jacobson, 2000) and "reductive biases" that result from intuitively held beliefs (Feltovich et al., 1997).[1]

Economics theorist Sterman (2000, p. 21) notes that dynamic complexity, i.e., "the multi-loop, multi-state, nonlinear character of the feedback system" can result in four types of cognitive challenge. First, there are imperfect information, long-time effect delays, and confounding or ambiguous variables. Often intervention effects cannot be separated from endogenous changes. Learning is slow when many actions cannot be repeated or have irreversible effects or when multiple variables change simultaneously. A second challenge is the insufficiency of cognitive maps, notably system models that represent too few parameters, omit feedback loops or disregard boundary conditions.[2] A third challenge is the insufficient capacity to mentally simulate multi-loop systems due to attention, memory, and processing limits. Lastly, general biases can exacerbate these problems – notably the misperception of feedback (e.g., seeing what you expect to see) and poor reasoning (e.g., failure to actively check one's hypotheses, groupthink, wishful thinking, overconfidence, illusion of control, defensive routines, etc.).

Complexity regulation competencies

In view of these challenges and pitfalls it is not surprising that successful regulation of a complex system requires a highly specialized type of competency. A paper by Funke et al. (2018) introduces the notion of *systems competency* and sum this up as "skills, knowledge and abilities that are required to deal effectively with complex non-routine situations in different domains". System competency is held include "cognitive aspects of problem solving, such as causal reasoning, model building, rule induction, and information integration" (Funke et al., 2010, p. 41). With similar aims, Kimmel (2022) speaks of *complexity regulation competencies* and posits that these include not only cognitive skills, but also a set of process competencies and embodied interaction skills.[3]

What can we expect about the general characteristics of complexity regulation competencies? Firstly, they will involve an integrated suite of abilities that require a great amount of training, spanning a general mindset that sensitizes to challenges and pitfalls (see above), particular thinking abilities, as well as a number of practical handling skills. Secondly, such competencies will include, both, domain-general abilities that can be transferred to new contexts, as well as domain-specific expertise. Therefore, knowing the domain-typical forms of problem contexts, problem appearance, as well as having practiced typical forms of action makes a difference. Complexity regulation can be also facilitated by general domain knowledge and experience, e.g., the anatomy knowledge a medical practitioner has or the military experience of a strategist.

Competencies will also reflect the fact that complexity regulation is both an ongoing and an integral effort over time. This is known as *dynamic decision making* (Brehmer, 1992; Gonzalez et al., 2005, 2017; Hotaling et al., 2015). In dynamic decision making the system continuously responds to interventions and each decision changes the circumstances for the next. This requires a dynamic response in which "a series of actions must be taken over time to achieve some overall goal, the actions are interdependent so that later decisions depend on earlier actions, and the environment changes both spontaneously and as a consequence of earlier actions" (Hotaling et al., 2015, p. 709).

Thus, responses are continuously required as a problem state evolves. Regulators must decide on right interventions as they go along and must simultaneously remain sensitive to current system changes, their history, and possible future contingencies. Although decisions are made in real-time the various interventions therefore need to make sense as a whole in many complexity contexts. That is, any momentary decision needs to be seen in relation to the overall aim.

Regulators must see a system in its whole evolution and contextual boundary conditions. They must also be highly responsive and flexible. Rather than embracing a modularized, local, or mono-causal approach, they are challenged to keep many variables in view, and "stay in touch" with the evolving system while keeping on the radar parallel tasks, side-effects, delayed or noisy feedback, unpredictable exogenous changes, and autocatalytic dynamics, e.g., when tiny details create *ripple effects*. Figuring out what interventions a system best responds to is messy. We can expect this to require a well-balanced mix of practices that hold the target system in a region of "workability" as well as customized smaller scale responses.

2 Research on complexity regulation

How people regulate complex systems has been addressed by different research traditions, which this section reviews. The aim is determine where research cur-

[1] The following assumptions frequently stand in the way: (1) systems are centrally controlled; (2) feedback is immediate; (3) processes are linear; (4) effects are proportional to the size of an action and arise where one intervenes; (5) actions have one effect (i.e., no major side-effects); (6) changes result from actions on the system, not from within the system; (7) there is a clear distinction between causes and effects.

[2] A good illustration is that policy makers largely use models that do not represent feedback loops at all, treating systems as linear (Axelrod, 1976).

[3] This integrated suite of competencies includes embodied interfacing skills and perceptual skills for system probing/monitoring; pattern detection for the essence of problem constellations; knowledge of system structures or functions; technical knowledge (e.g., anatomy for a doctor or aeronautics for a pilot) supporting reasoning and cue identification; case experience, typicality or cause for alarm; strategy knowledge; as well as meta-cognitive skills.

rently stands, and to what extent complexity concerns have been recognized.

Psychological studies

Since the late 1970s regulation capacities have been comprehensively explored by psychologists under the heading of "complex problem solving" (for overviews see Funke, 1991; A. Fischer et al., 2012; H. Fischer & Gonzalez, 2016; Hotaling et al., 2015; Osman, 2010b). Experiments have been conducted with naive subjects, using interactive simulations in so-called "microworlds" (for example, Brehmer, 1992, 2005; Dörner, 2003; Dörner & Funke, 2017; Fischer & Gonzalez, 2016; Funke, 2001; Gonzalez et al., 2005). These gaming experiments provide simulations of complexity coping (Frensch & Funke, 2014; Brehmer & Dörner, 1993; Dörner, 1997) ranging from micro-worlds with 20 variables to large ones with 2000 variables, in the case of acting as the mayor of a small town. Other micro-worlds simulate contexts of developmental aid, medical treatment, controlling a company (beer distribution, tailor shop), capital investments and asset markets, and firefighting.

As Dörner and Funke (2017) state in a review, psychological research has identified inter-individual differences affecting the ability to solve complex problems, looked at cognitive processes, and sought to identify systems factors that heighten task difficulty (such as multiple goals, lacking information and hidden variables, high dynamics, high feedback delay, weak feedback, and a system that partly changes by itself). The psychological literature also describes typical dilemmas, e.g., how much information to collect before acting, and typical errors.

The sobering upshot is that our general cognitive apparatus is rather ill-adapted to complexity coping (cf. Diehl & Sterman, 1995; Dörner & Funke, 2017; Jacobson & Wilensky, 2006; Lesh, 2006). As far as laypeople are concerned complex problems bear evidence of *bounded rationality* (Feltovich et al., 1997). Thinking errors are pervasive. Even well-educated people experience problems, down to failures of grasping the system ontology as such (Diehl & Sterman, 1995; Dörner, 2003; Jansson, 1994). Why non-experts find complex tasks challenging relates to a set of "system pathologies" of poorly performing subjects: reductionistic problem diagnosis (cf. Seligman, 2005), reacting only to superficial problems, resource misallocation, oversteering, over-confidence or, frustration if the system reacts unpredictably or not at all (Dörner, 1997).

Inversely, the question of basic rules for effective system regulation has been raised. Dörner (1997) speaks of principles for system regulation ("grandmother rules"), but also notes that expertise lies in knowing which one applies when, and when not to apply some rule such as "gather information before making a decision" (a strategy that can backfire at times). The situated applicability of regulation rules is not well researched. More easily stated are abstract cognitive skill inventories. The same author, Dörner (1986; see Funke, 2001), mentions the following key skills for system regulation: (1) gathering and integrating system information, (2) goal elaboration and goal balancing; (3) planning and implementing measures of action, and (4) self-management in response to frustrations, time pressure, or stress. Other publications have suggested various cognitive resources, such as gaining input-output knowledge (Schoppek, 2002), and such as using cognitive heuristics (Brehmer & Elg, 2005; Funke, 2014), information reduction mechanisms, prior domain knowledge (A. Fischer et al., 2012), inferences from analogies or general knowledge (Dörner, 1997).

As Holt and Osman's review (2017) emphasizes, different types of tasks may require different types of strategy. This ranges from knowledge-lean stored associations between situations and strategies (which do not require "understanding" system structure) and heuristic rules-of-thumb to rich mental models that operate by transforming "abstract knowledge structures combined with complex cognitive strategies" (Holt & Osman, 2017, p. 4). For determining what strategy is needed the type of target system matters, notably the degree of lower and higher systemic complexity (Funke, 1991, 2014; Jansson, 1994). While minimal complex systems may be causally explored by varying one variable at a time, more complex systems remain opaque, nor is time sufficient for complete experimentation (Schmid et al., 2011). Since variables are prone to interact non-linearly they cannot just be varied in isolation without changing the system. The search for "input-output knowledge" (Schoppek, 2002), i.e., constructing causal input-output maps by systematic variation of parameter settings, is scarcely realistic. Any multivariate systems with movable component connections would undercut this (Funke, 2014). Accordingly, experiments have ushered in pessimism about the possibility of learning about systems (Brehmer, 1980)

From the opposite viewpoint, cognitive resources used to offset these difficulties have been proposed. They include better structural system models, decision rules/heuristics, better outcome information, more analytic reasoning, or holistic goals (Rouwette et al., 2004) as well as more opportunity to explore (Funke & Müller, 1988). Researchers have studied how mental maps shape strategies and heuristics (Gary & Wood, 2016), as well as inventorying strategies (Gary et al., 2008), elements of a complexity-aware mindset (Kriz, 2000; Manteufel & Schiepek, 1994; Sterman, 2000), and hierarchies of system thinking skills (Maani & Maharaj, 2004).

This research notwithstanding, comparatively little effort has gone into investigating whether domain experts fare any better than naive subjects, and if so, due to which specific mechanisms. Reither (1981) suggests that experts reason more via causal networks, decide more continuously and systematically check their progress without thematic vacillation, while keeping more goals in view, but struggle with exponential growth problems just as much as non-experts and may be unwilling to monitor an adapt overall strategies. Another study by Putz-Osterloh (1987) showed that economics experts had a crucial advantage in a business simulation in choosing interventions compared to similarly complex tasks in an ecological simulation, where their performance was more like that of novices. However, there was also some evidence that the economists' expertise gave them a better understanding of complex systems in general, as implied by the use of some general heuristics and the ability to generate system representations.[4]

Naturalistic macro-cognition studies

It needs to be critically observed that the discussed study paradigm is limited through its choice of "quasi-naturalistic", but in essence artificial simulations. A simulation paradigm cannot explore the full range of possible resources and context knowledge experts have at their disposal, nor can it reproduce the interaction set-up of real-life systems (see below). Thus, simulation studies have not been able to address expertise in its natural habitat.

In contrast, applied psychologists in the field of *macro-cognition* and *naturalistic decision making*, have studied experts "on the job" in contexts such as emergency response, aviation, machine operating, teamwork, policing, or military (Crandall et al., 2006; Hoffman & McNeese, 2009; Klein, 1998; Klein & Hoffman, 2008; Lipshitz et al., 2001; Schraagen, 2008). Macro-cognition approaches have concentrated on providing methods to reconstruct how experts cope with ill-defined decisions tasks and "wicked problems" when operating in time-pressured systems. Since these naturalistic settings have a higher number of variables the macro-cognition paradigm typically also stresses that model simplifications cannot be the aim and that experts may have access to a rich toolbox and considerable domain knowledge. The macro-cognition paradigm typically takes interest in "effects of high-stake consequences, shifting goal, incomplete information, time pressure, uncertainty, and other conditions that [...] add to the complexity of decision making." (Zsambok, 1993, p. 4).

The overall difference to simulations in the laboratory is that a considerably more optimistic picture emerges of highly skilled decision makers, who are capable of rapidly responding to challenges and identifying effective courses of action. Authors from macro-cognition have expressly contrasted their optimism with the emphasis on problems and biases in other research (Kahneman & Klein, 2009).

As to cognitive strategies, the focus in much of the macro-cognition literature lies on in how experts react rapidly with incomplete information and under messy circumstances rather than "understanding" the system fully. So far as *time-pressured* professions are concerned (e.g., firefighting, aviation, naval contexts, oil rigs, or intensive care units) emphasis is laid on direct pattern matching of the experienced situation with situation prototypes, which trigger associated strategies. More complex mechanisms are attributed to situations of high combinatorial complexity, justification need, and multiple stakeholders (Klein, 1998; Lipshitz et al., 2001) and include causal analysis and forward simulation of likely consequences. It has also been emphasized that complexity coping critically depends on "the ability to synthesize and interpret information in context, transforming or 'fusing' disparate items of information into coherent knowledge" (Mosier & Fischer 2011, preface p. 1). Other work emphasizes metacognitive processes of critical thinking to identify gaps in situation awareness, etc. (Cohen et al., 1996). Related research deals with uncertainty coping, ways to make systems resilient, and manage emergent phenomena (Guastello, 2002, 2016). The field of human factors literature discusses why uncertainty factors arise and become cognitively challenging (Osman, 2010a).

Much effort has gone into identifying cognitive mechanisms used in and across tasks. Research tools such as the *Critical Decision Method* have been used to annotate in detail the different kinds of cognitive foci over a task (Hoffman et al., 1998; Klein et al., 1989; Wong, 2004). On the one hand, this has produced detailed case studies discussing specific process trajectories (e.g., Plant & Stanton, 2013). On the other hand, it has been attempted to draw statistical conclusions about the frequency of various types of cognitive resources such as perceptual recognition, case analogy, and comparison of alternatives (Klein, 1998). Task analysis methods have also infused training and decision aids, the preservation of knowledge, and interface development (Hoffman et al., 1998).

Yet, abstract process generalities loom large in this publication output and the view of regulation processes seems, by and large, too idealized. To the extent that pitfalls and errors are discussed they are related to "uncertainty" or "not well-defined problems", but scarcely interpreted in the light of exponential dynamics, "delayed or diluted" effects, goal competition, or other complexity specific effects. An explicit analysis of non-linear and other multi-causal system effects is wholly absent. This arguably owes to the examples that lie in focus in macro-cognition studies, which mostly require quick decisions about one issue, but a lesser degree of integrated dynamic decision making over time.

Nor have complexity discourses themselves left any mark on macro-cognition theory in terms of how they conceptualize human psychology. To express the realities of dynamic decision making the field has worked within a traditional representational (e.g., schema-theoretic) framework. Klein's (2007), in principle powerful, *flexecution* model illustrates this limitation by conceptualizing intentionality in traditional ways (see Section 3). What is more, the field can be criticized for a naive, colloquial use of the term "complexity". Studies address *task or cognitive complexity* faced by

[4] Other studies of experts like Dew et al. (2009) and Baron (2009) say very little about specific cognitive mechanisms. Güss et al. (2017) briefly mention that experts need to explore less and that they are more flexible.

system regulators, whereas comparing different formal target system properties, viz. complex vs. non-complex ones, has not been in focus. Although some work has shown that different cognitive and practical coping strategies (Lipshitz & Strauss, 1997) tend to follow from different forms of uncertainty, there has been too little effort to apply the insight from psychological approaches that system complexity much determines the mechanisms needed (see above). For example the relatively strong reliance on rapid pattern recognition probably works well only in domains with moderate system complexity.

Complexity-informed studies and boundary cases

Recent studies in applied fields directly build on ideas derived from complexity theory. Notably psychotherapy researchers have applied a comprehensive complexity-informed framework known as *synergetics*, first developed by the physicist Hermann Haken in laser physics and subsequently extended to psychology (Haken & Schiepek, 2010), which has produced a framework that specifies a set of meta-strategies or general regulation virtues for complex contexts. Although studies of psychotherapy (Schiepek, 1986; Strunk & Schiepek, 2006; Tschacher et al., 1992) and bodywork therapy (Kimmel, 2022; Kimmel et al., 2015; Kimmel & Irran, 2021) ground this in process data, little is known about how general virtues are implemented in specific contexts (see Section 5). This notwithstanding, synergetics is a trailblazer in the endeavor of integrating complexity-oriented theories and methods into the picture. Notably time-series analysis have been pursued from both a qualitative and a quantitative angle.

Similarly, social psychology has produced a well-developed paradigm of complexity research. Although it does not study complexity regulation in the strict sense, it has described regulation dilemmas such as intractable political conflicts as well as proposing ways out (Coleman et al., 2007; Nowak, 2004; Vallacher & Nowak, 2007; Vallacher et al., 2010). Quantitative tools of time-series analysis are equally popular here, e.g., on social synchronization dynamics (Vallacher et al., 2002, 2005).

A wide category of studies has adopted complexity theory as a conceptual framework with a focus on changing the mindset of practitioners. A good example are management or governance theories emphasizing that organizations are complex systems, and argue for complexity-informed managerial tools (e.g., Van Buuren & Gerrits 2007, Gorzeń-Mitka & Okręglicka, 2015). These approaches posit regulation virtues such as "agile management", which has become a catchword of late. Similar complexity informed frameworks have emerged in healthcare management (Fairbanks et al., 2014; Gomersall, 2018; Greenhalgh & Papoutsi, 2018; Plsek & Greenhalgh, 2001), social science in general (Byrne & Callaghan, 2014), sociology (Page, 2015), political science (Axelrod, 1976; Butler & Allen, 2008; Cairney, 2012; Jervis, 1997) and historical work on why ideologies stabilize and change (Ciompi & Endert, 2011). This "armchair" approach has provided new ways of thinking for practitioners, but has not investigated regulation processes in much detail, nor does it give much thought to methods for doing so.

A similarly boundary position in our review falls to *systems thinking* and *systems pedagogy* which are complexity-aware, yet again limited to a prescriptive approach. Business and economic research has proposed tools to model strategic problems via causal loop models (Diehl & Sterman, 1995; Lane & Oliva, 1998; Strijbos, 2010) or dynamic simulations (Cavana & Maani, 2000; Sterman, 2000, cf. *system dynamics framework*) as well as taking stock of so-called system archetypes (Kim & Anderson, 2007) and error-prone types of dynamics (Kim, 1994, 2000; Kim, 2000).

Finally, in education research complex-informed systems thinking has been advocated for school curricula (Assaraf & Orion, 2005, 2010; Jacobson, 2000; Jacobson & Wilensky, 2006; Levy, 2017; Levy & Wilensky, 2008), university education (Sterman, 2000; Sweeney & Sterman, 2000), and professional training (Fraser & Greenhalgh, 2001; Greenhalgh & Papoutsi, 2018; Nguyen et al., 2012). In this literature coding schemes to diagnose competencies have been one important outcome (Jacobson, 2000; Assaraf & Orion, 2005; Schaffernicht & Groesser, 2016).

Issues and new directions

Our review reveals that no comprehensive complexity-oriented theory of system regulation has been forthcoming. Complexity theory has had, at best, a selective impact on the psychology of "complex problem solving" (mostly on system and problem definitions), and none whatsoever on macro-cognition research. Insights and methods from the synergetics framework, per se a highly promising candidate, have had only limited impact in areas other than psychotherapy research. Thus, an integrated complexity oriented approach awaits further cross-talk between scholarly communities.

In addition, there are several deeper lying theoretical roadblocks, which the remainder of this article will try to pick up on. Given its commendable theoretical explicitness and empirical achievements I will focus my assessment on "complex problem solving" research. As recognized by Brehmer, Dörner and others, we fundamentally need a theory of action that is not exhausted in a plan-goal format. Dynamic decision making accounts were proposed to overcome this problem (which Klein's "flexecution" model partly reflects). However, other problems remain to be tackled. Cognitivist concepts, notably the parlance of problem solving, are limited in scope. In psychological experimentation with micro-worlds a focus on *reasoning about* systems dominates. For example, Putz-Osterloh (1987, p. 64) states that a problem solver has the task of generating hypotheses about system variables and their interconnection in order to build up "system knowledge". Funke's (2001, p.75) view reflects a similar intellectualist angle: "The general task is (a) to find out how the exogenous and endogenous variables are related to each other, and (b) to control the variables in the system so that they reach certain goal values." And, Sterman's (2000) reported list of complexity challenges sets the emphasis on cognitive maps, mental simulation, and reasoning biases.

In thinking about the modus operandi of system regulation, the problem solving view capitalizes too much the discernment of "variables" and reasoning about the system. The most evident point is that building a detailed internal mental model of the system's behavior cannot offer the royal road to regulating multivariate systems (a measure of pessimism has emerged about this). Reducing regulation to solving a mind-puzzle is limited.

Even if I do not wish to reject the notions of reasoning or problem solving as such or deny the many achievements of the problem solving paradigm, we should approach the topic from an as broad as possible basis. We do well to be cautious concerning assumptions that are overly intellectualistic or dualistic in that they imply a disembodied remoteness of the agent from the system. Such ways of thinking neglect the importance of embodied presence, multi-scalar interaction between the regulator and the system, and of a broad set of process related skills.

3 Post-cognitivist foundations of regulatory agency

These under-explored foci begin to meet the eye once we delve deeper into post-cognitivist theories that critique the very foundations of classical cognitive psychology and cognitive science. A fresh perspective can draw from dynamic systems theory (DST) and "4E" (embodied, embedded, enactive, and extended) approaches to cognition (de Bruin et al., 2018; Robbins & Aydede, 2009), which reveals a whole range of neglected topics in complexity regulation research. These approaches variously emphasize that cognition extends beyond the brain, and even beyond the skin; they stress ongoing coupling between agent and task ecology as a larger unit of analysis; and they understand cognition in terms of continuous embodied adaptiveness and dynamic interaction patterns.

Constrained self-organization

I will begin my argument with a bid to reconceptualize the very nature of what a system regulator does. Looking asking afresh at regulative agency is crucial because psychological notions of causality have historically emerged from the study of non-complex settings. With the intention of calling into question the assumption that causality is linear Brehmer (1996) characterizes actors as "stabilizers" of systems, with a nod towards Brunswik's outlook on psychology as well as Dewey's framework. Brehmer pushes for "a cybernetic approach that relies on circular causality between the organism and its environment" (Brehmer, 1996, p. 225). Regulators and target systems are coupled as a single dynamic entity. For example regulators often need to factor in that others react to their interventions by changing their goals which impacts them in return. E.g., if you are a manager and cut prices, sales will rise, but then your competitors also cut prices, making your sales fall again. In other words, a larger process pattern establishes itself through the various feedforward and feedback linkages between the regulator and the system.

My next argument is that complexity settings preclude a strategic approach in which one controls the system as an externally conceived *puppeteer*, to use Osman's (2010b) catchy metaphor. One factor that undercuts a "remote control" view is the fact that a system's behavior only partly (or sometimes not at all) reflects the effects of your own intervention, and partly changes due to its internal workings and in ways often hard to factor apart. This makes a regulator one player among several in a network of interacting components. Consequently, regulators are perhaps not best thought of as controllers but as smoother and enablers, and sometimes even as systems participants who work with the system from the inside.

We can turn to dynamic systems theory (DST) here which describes intentionality in biological systems as self-organizing processes (Carver & Scheier, 2002; Dale et al., 2014; Juarrero, 1999; Van Orden & Holden, 2002) and adaptive coupling with ecology. DST approaches define biological systems, and agency as part of them, through the lens of self-organizing and far-from-equilibrium dynamics. Organisms are "self-creating", i.e., *autopoietic* (Varela et al., 1991), and it stands to reason that cognition inherits and complexifies such basic properties (Froese & Di Paolo, 2011). The notion of self-organization highlights that global system behavior is due to auto- and cross-catalyzing dynamics that emerge from the interplay of a collection of elements. The target system and the regulator exchange information in ways that enable certain self-organizing patterns of the former.

Therefore, regulatory agency means imposing constraints on ongoing dynamics. Well-chosen constraints can invite or enable desired forms of self-organization, but they never exert deterministic influences or eliminate surprises. According to DST theorist Juarrero (1999) intentions can be conceived as the setting of constraints, whose purpose it is to set the scope of possible future behaviors, create new probability distributions, and "stack the odds". Juarrero's view reconceptualizes the causality of action in terms of alterations in probability and frequency distributions. Under this perspective, a system regulator's task is to find a balanced level of constraint and freedom for the situation. As stated by Juarrero, constraints are *generative*; they enable behaviors or dynamics that would otherwise be impossible. (More specifically, constraints tend to be limiting at longer timescales, but generative at shorter ones.) This claim could be read to imply that constraints on a target system preorganize its dispositional possibilities.

Constraints avoid arbitrariness, but ensure flexibility by "limiting some degrees of freedom, leaving others unconstrained, thereby resulting in coordinated, yet flexible, action" (Rączaszek-Leornardi & Kelso, 2008, p. 194). Importantly, the open degrees of freedom leave room for action variability and disambiguation through the local dynamics of the situation. Even the use of concepts can be seen as "constraints on dynamics" (Rączaszek-Leonardi, 2009). This, among other things, stresses that the purpose of a regulator's reasoning is to constrain dynamics, while leaving open whether and how "understanding" is really involved.

Within this broader view, the question of regulation competency appears in a new light: It relates to setting up constraints judiciously, possessing sensitivity for ongoing feedback, and context-sensitively managing emergent effects. Interventions may be non-deterministic, but in return impact the system in multiple ways or "trickle through" the system. Regulation competency means imposing constraints in the right way for a situation, whether this may involve amplifying nascent system trends, reining in the dynamics, or creating context-sensitive openings for new kinds of self-organizing dynamics.

This perspective has profound implications for a regulator's role and self-understanding. Multi-causality and non-deterministic agency via constraints makes a person a player in a wider self-organizing system. This calls for adopting a modest view of one's own role (cf. Carver & Scheier, 2002; Juarrero, 1999, 2015; Van Orden & Holden, 2002), and knowing one's limits. On the positive side it draws attention to less obvious ways of acting, in which success often results from nudges, multiple distributed interventions, preparedness and well-timed response, as well as the availability of multiple routes of action and redundancies.

Multi-scalar intervention

Regulatory agency is not a "flat" momentary response, but involves activity at multiple timescales. This is already hinted at by the importance of prospective and retrospective awareness required for dynamic decision making, e.g., when navigating a ship one must remember previous decisions (Anzai, 1984). But there is more to it. Multi-scalar agency also implies entertaining a *simultaneous* relationship to process dynamics at various time scales and accordingly encompasses the concurrent monitoring of slow and fast dynamics. Loaiza et al. (2020, p. 3) speak of "time ranging" as a performative skill for entangling and disentangling events at different scales through an "ability to modulate temporal ranges in ways that grant a unique degree of adaptive behaviour". This chimes with Dörner (1980) who warns that one of the most fundamental complexity reasoning errors is to relate only to the present state, rather than dynamic patterns over time.

Given that regulatory activity encompasses different timescales constraints need to be imposed across slow dynamic "background" activities and "foregrounded" processes of the present moment. Agency spans the gamut of system framing and enabling down to micro-regulatory actions during a process. At the micro-scale this involves nudges and occasional disruptions of the system dynamics, inviting reaction, nudging, buffering, amplifying and exploiting. At the macro-scale this involves setting boundary conditions and general constraints, poising the whole system in certain regions of probability, large-scale system enablement, and "managing moves" to keep the system in an operable state or smoothing it for optimal running. Thus, effective action is never just deciding on a momentary response to a systemic occurrence. A regulator's intentionality must therefore keep multiple timescales in view, typically by imposing global constraints that change slowly or remain stable and leave many degrees of freedom for momentary actions to narrow down.

Enactive intentionality

Similar themes as in DST are reflected in how enactive cognitive science treats agency. This school of thought emphasizes that cognition is a form of doing and that its purpose is adaptive regulation of behavior relative to a dynamic environment. This would make the regulation of a complex system a special case of the interplay of two adaptive systems (Froese & Di Paolo, 2011). Enactivists stress that this coupling process can establish an autonomous organizational pattern, a wider system with its own dynamics, similar to the Brehmer's discussed cybernetic view.

Furthermore, the enactive perspective gives us a way to conceptualize the forms of *intentional relationship* that a regulator entertains with a target system. The regulator's agency is exercised through the recursive adjustment of the coupling relationship.[5] Agency is also not exhausted in representations (Gallagher, 2017), but rooted in the coupling processes and refined forms of embodied perception. Enactivists stress that action is driven to large extent by perceived "affordances", i.e., information-rich perceptual arrays that mediate direct responses in a continuous way as a person navigates an ecology. This perspective, in itself, shifts the emphasis from reasoning to skilled perception (where macro-cognition research points in a similar direction). It might turn out that competent regulation experts are not exceptionally gifted as abstract problem solvers, but that their main skill investment lies in how they attuned their perceptual apparatus to the context and in how well they are able to interface. Although the scope of this hypothesis needs to be tested in different contexts, many of the mechanisms to be introduced in Section 4 are amenable to this kind of explanation.

The conceptualization of intentionality is also not well served by the traditional language of goal-directed action. Those who plan and then execute discrete in-

[5] This is chimes with the emphasis on an iterative and cyclic approach as a hallmark of highly performing complexity reasoning (Maani & Maharaj, 2004) and the finding that the failure to adapt recursively, notably through strategy fixation, frequently results in errors.

terventions are rendered too inflexible in a coupled system that changes rapidly and is devoid of set decision points. Actions are typically non-discrete and dynamically fleshed out while being underway. Intentions-before-action, to the extent that they play a role, must be fleshed out by intentions-in-action. Leaving room for things to be figured out as one acts is both a necessity and an asset. We thus see a need for a notion of intentionality that stays highly responsive to emergence, yet is sufficiently constrained. To capture this middle ground, macro-cognition research speaks of "flexecution" (Klein, 2007), i.e., semi-specified intentions that are open to revision or development in the process. A more radical "4E" account underlies the notion of "directive" intentionality (Engel, 2010), whereby agents explore specific directions of action without following well-defined goals. Intentionality is described as knowing how and where to probe for further information. While directive intentionality is selective, it is also open to emergence. Directive intentionality means embracing certain degrees of freedom, while curtailing other and doing so in ways that reveal further information.

Ultimately, what is at issue is a new view of how different cognitive faculties "loop" with each other. Enactive perspectives emphasize recursively braided processes and reject stage models of cognition, which separate out goal elaboration, diagnostics/hypothesis formation, forecasting/strategy planning and implementation of strategies. The "sandwich model" of cognition, which projects a linear "perceive-think-act" logic, has come under attack (Hurley, 2001). A more realistic, non-serial view would emphasize that processes may intersect in recursive ways. Problem understanding (i.e., diagnostic information gathering) does not necessarily precede decision making and intervention; they can be parallel and interwoven (Beer, 2003; Kirsh & Maglio, 1994). This implies that perception is not just about information gathering for a central processor; nor are actions simply executing fully developed solutions. These erstwhile "peripheral" processes are now seen as integral to cognition. Unfortunately, regulation research has held on to discretizing and serializing tendencies. Dörner and Schaub (1994, p. 437) illustrate the problem when they posit a "system of six phases of action regulation, serves as an ideal norm of information processing, as a kind of stencil to be compared with real behaviour". Even if this is intended as an idealtypical posit it is fundamentally misleading for characterizing the fluidly braided way in which dynamic decision making operates.

Interactivity

A major limitation of problem solving theories of regulation is their placing cognition exclusively "in the head". Disregarding the causal effects of action in the world fundamentally distorts how dynamic decision making operates in naturalistic contexts. For example, Napoleon is reputed to have explained that, as to his military command, he first engages with the enemy and then decides about strategy ("on s'engage et puis on voit"). Such interaction-based strategies have led "4E" cognition theories to look at cognition in a new light. Cognition is held to extend into the world and is just as much a form of doing as a form of thinking. It is a well supported claim in studies of "4E" cognition that "thinking" can be partly offloaded to cascades of embodied interaction (Clark, 2008; Hutchins, 2011).

Studies of interactivity demonstrate how interacting in physical ways supports problem solving, reasoning and creativity (Kirsh, 2009, 2014; Kirsh & Maglio, 1994; Steffensen, 2013). People in offices, in clinics, in games, and many other naturalistic settings of embodied on-site presence exploit cascades of exploring and manipulating the ecology, changing perspective, or interpersonal interaction to "scaffold" cognition. For instance, *collaborative problem solving* depends crucially on mutual "scaffolding" activities with co-present others that stimulate, query, or provide input to one another (Steffensen, 2013). This provides benefits such as dynamic perceptual specification and solution probing through actions that generate further perceptual feedback (Kirsh & Maglio, 1994). Thus, tasks can be more easily handled by skillfully exploiting the ongoing embodied coupling and re-afferent stimuli from a system. An experimental regulation study by Funke and Müller (1988) supports this perspective, in which an active exploration condition of the task got better results that passive observation.

Examples of interactivity can be found in how bodywork therapists make decisions in Feldenkrais, Shiatsu, or physiotherapy (Kimmel et al., 2015; Kimmel & Irran, 2021; Normann, 2020; Øberg et al., 2015). Embodied interactivity plays a key role in diagnosis and strategy finding, without any strict delineation between perception, action, and reasoning. Diagnosis and intervention overlap to an extent, because early "broadband" interventions that "never hurt" are used to generate more feedback while the diagnosis is still sketchy. Also, diagnostic functions continue during stimulation of the client such that "epistemic" actions for information gathering can be cleverly woven in "pragmatic" actions. Subtle stimulations of the client's system also play a diagnostic role. Seeing a problematic body function "in action" may clarify the coordinative interplay with other body functions. Lastly, effects of an intervention allow deciding about next steps or treatment priorities. In these different ways, experts use exploration "queries" and self-generated feedback (i.e., stimulated re-afference) to find the path "as it is walked".

Professional experts are known to employ *reflection-in-action* (Schön, 1991) and have been shown to benefit from this to update evaluations, fine-tune their means, switch strategy, adopt new ideas or detect unexpected leverage. Rather than decide in a "one shot" manner, a strategy of dynamic task specification can increasingly narrow down the strategy as more system feedback arrives.

Distributed cognition

It is rarely taken into account that professional system regulators operate in structured cultural work environments, use tools (some of them endowed with cognitive functionalities), and operate in teams. This perspective has been developed by another important branch of "4E" cognition.

Since the 1990s, research on distributed cognition has emphasized that cognitive processes may be distributed across the members of a social group, that the may involve coordinating internal and material or environmental structures, and may be distributed through time so that products of earlier events can transform the nature of later events (Hollan et al., 2000). Clark (2001, p. 121) speaks of a "hybridization in which human brains enter into an increasingly potent cascade of genuinely symbiotic relationships with knowledge rich artifacts and technologies". Thus, many tasks rely on interactions with tools and cognitive artifacts (e.g., maps, slide rules, or sextants), with one's body or surrounding spaces (e.g., current body position can serve as memory aid) as well as with specific forms of team coordination (e.g. information protocols). This is evidenced, for example, in research on ship navigation and coordination in cockpits (Hutchins, 1995a, 1995b) which traces how coordinating the interplay between these resources gives rise to successful behavior.[6]

Cognitive performance in these demanding contexts, then, is an emergent property of internal and external resources that interact in the right ways. Among other things, this means that "social organization is itself a form of cognitive architecture" as it determines the way information flows through a group (Hollan et al., 2000, p. 177).

The pervasiveness of distributed cognition settings in professional contexts has significant implications for the study of complexity regulation. It implies that, firstly, the cognitive ability to regulate systems need not inherently be sought in properties of an individual. It can be the property of a whole socio-technical system. Secondly, it implies that cultural environments contribute to cognition, because these provide "a reservoir of resources for learning, problem solving, and reasoning" (Hollan et al. 2000, p.178) and have accumulated partial solutions to typical challenges. A great deal of task difficulty can be "offloaded" to clever ways of organizing a workspace, coordinated tool use, and the ability to harness social information flows to a problem setting. Thirdly, regulation pathologies can be themselves distributed across socio-technical systems. Dörner (1997), for instance, discusses the Chernobyl disaster, a classical "distributed failure" (albeit without calling it distributed). This means that breakdowns of complexity regulation can be integral failures of socio-technical systems, rather than the linear sum of individual reasoning failures.

A distributed perspective implies no less than a change of research strategy and to make individuals in their socio-material ecology the unit of analysis. Unfortunately, research on complexity regulation remains too individualistic and mentalistic to look beyond the system bounded by the skin.

Action skills

Another pressing task for complexity regulation research is to remedy the trivializing treatment of execution related, embodied, and technical skills. Decision making and execution are often more interdependent than we tend to think, a point already made in the critique of the "sandwich model" of cognition. It has been observed that lower-level problems are impossible to separate tidily from higher-level ones (Lindblom, 1959). Good complexity regulation depends on a rich and versatile repertoire of procedural knowledge (cf. Güss et al., 2017).

A hallmark of experts is their ability to improvise and tailor solutions in fine-grained ways. This ability is evident in crafts experts, musicians, or dancers, but extends to doctors, technical operators, school teachers, managers, and many other professions. Experienced professionals typically leave behind fixed action scripts or rule-based protocols, because they offer insufficient flexibility. With stereotypical actions one will often run into trouble when atypical situations, novel challenges or contingencies arise. The ability to go beyond "pre-formatted" scripts is vital here, as is the ability to decompose best practices and single out (and selectively use) elements.

This presupposes a differentiated and flexibly recombinable repertoire structure. How action repertoires are structured has wholly escaped attention in the complexity regulation research. It may be instructive to apply ideas from motor control theory to complexity regulation. Biological agents are known to create contextually customized *synergies* by combining action components (Latash, 2008, 2012; Turvey, 2007). They coordinate the many degrees of freedom of their action system in a context-sensitive way.[7] The effectiveness of synergies can be well explained by how an expert soccer player just uses muscles in the right synergies and with the right timing to kick much harder than a novice, rather than using more force.

Creating effective synergies presupposes being sensitive to the relationship between micro-components in a task and the macro-scopic outcome that results from their interplay. The broader applicability of this idea is that complexity regulators have to possess a good sense of how component arrays form desirable conjoint effects. To understand how regulators create context-sensitive synergies we first need to investigate which

[6] An example from Shiatsu bodywork is Kimmel and Irran's (2021) analysis of how diagrammatic reasoning tools from Traditional Chinese Medicine are deployed in a tight interplay with and embodied interaction between a therapist and a client.

[7] Synergies are defined as a temporary (and mathematically low-dimensional) organization of, or synchronization of, components, hereby creating a coordinated global state that supports a particular action aim. They are said to organize a set of action components interdependently, so they display situated variability, and e.g., resist perturbation.

micro-forms of action they differentiate and are able to re-combine.

Typically multi-pronged system regulation strategies will require combining techniques in novel ways, or extending a familiar action mix with new elements. This combinatoric ability has been described as a temporary *soft assembly* of small action components (Kello & Van Orden, 2009; Kugler & Turvey, 1987) – which allows for basic action variability, but also confers creative and improvisational ability. Furthermore, the soft assembly notion highlights that synergistic element combinations can incorporate the ecology's dynamics to get effects "for free". Competency often means using minimal effort through proper timing and harnessing external factors to the task, such as when a dancer works with gravity or the elastic properties of the floor or coordinates movement impulses with others so they amplify each other (cf. Kimmel, 2021). It can be expected that regulators of complex system similarly incorporate endogenous target system dynamics for optimal synergistic effect.

4 Tools of enactive complexity management

After this introduction to the"4E" cognition paradigm I propose to take a closer look at how system regulation works beyond a problem solving perspective, as a kind of *emergence management* (Kimmel et al., 2018). This will enable us to express regulation tools in ways that start from basic properties of complex dynamic systems.

Modulating system dynamics

Across the literature a number of general virtues for regulating complex systems have been described. These include the ability to create multiple pathways and redundancies, increase buffer capacity, strengthen balancing loops, moderate self-reinforcing loops, and optimize system diversity. Ghosh (2017), for example, lists as process modulation strategies the removing of obstacles, minimizing delays and dead time, or increasing robustness through redundancy (in addition addressing constraints, and reducing unintended consequences are mentioned). Notably the field of synergetics (Schiepek et al., 2018), proposes a set of *generic principles* which has been applied in psychotherapy research: synchronizing with the system; creating stable framing conditions (so destabilization of other variables is possible without compromising system integrity); energizing and lifting inhibitors; ensuring that inputs cohere with endogenous aims; ensuring that inputs synergize; destabilizing detrimental dynamics or amplifying spontaneous deviations; presenting new input at conducive moments; tipping the system in the right direction; and assisting restabilization after changes.

Complexity-informed approaches to psychotherapy also stress that adept regulators must be able to perceive how systemic processes evolve, both with respect to faster and to slower processes. The ability to monitor dynamic patterns is deemed critical and hinges on the ability to identify *process gestalts* (Tschacher, 1997). Regulators should pay attention to these dynamic signatures, e.g., with respect to intervals, fluctuations, repetitions, or fractal similarities across timescales (Haken & Schiepek, 2010). A process-sensitive regulator can also learn to identify phase transitions in progress, the moments when a complex system transitions to a new dynamic regime.[8] Noticing such critical moments helps to accompany, support, or buffer the incipient change. For example, bodywork experts frequently report that tonic or nervous system states begin to fluctuate or tensions intermittently flare up just right before a client's system changes (Kimmel et al, 2015).

On a similar note, Haken and Schiepek (2010) emphasize how vital it is to accompany the target system through well-timed nudges at critical moments. Tweaking and nudging endogenous system processes can occur through so-called *symmetry breaking* actions when the system is currently situated right between different possible dynamic regimes, and can be economically tipped in the right direction (Haken & Schiepek, 2010). Other interventions work by dampening overshooting autocatalysis, amplifying desirable trends, or taking the lead if chaotic phases do not transit into more ordered trends. Incipient auto-catalysis can be strengthened by amplifying micro-dynamics the moment they occur. Yet, another factor is good timing: Windows of opportunity can be used to support a system's dynamics and thereby achieve great effect for little cost ("order for free").

Regulators may also engage in continuous "smoothing" operations that make a desired outcome more likely. Removing obstacles to self-organization (rather than "pushing" the system harder) is such a strategy (Ghosh, 2017). Of course, de-blocking impediments is no guarantee a desired outcome will manifest, but it increases the likelihood of small events triggering the required process.

An under-explored, but important topic concerns the ways in which system regulators choose regions of interest and temporarily direct a system towards the most productive zones of the possibility field. Regulators can move the target system into a particular range of dynamics, and narrow or expand this range on purpose. One motivation for doing so may be to avoid regions where one risks tipping into negatively escalating dynamics; and another to move into regions where desired changes are likely to happen. An example from previous research of myself and my colleagues (Kimmel et al., 2018) is how creative improvisers commonly gravitate to particular regions of the possibility

[8] Complexity models would speak of moments in which the system rests on a saddle in a state space, so that the dynamic can still continue its path to different systemic "attractors" (see Section 6). It is likely that such subjectively perceived process signatures relate to the complexity-theoretic ideas of critical instabilities and critical slowing down before a system changes to a new regime.

space considered to be particularly creative or provide springboards into new behaviors. Future studies may want to garner data on how regulators perceive regions of interest.

Enabling and constraining a system

My next topic continues the points made in from Section 3 about the multi-scalarity of system regulation. In addition to the ongoing system modulations that have just been discussed, the creation of general enabling states and situation specific constraints is vital for successful system regulation.

There are specific competencies involved in establishing a specific regulation set-up. Experienced regulators know how to shape the *boundary conditions* of their coupling with the target system, which govern all further interactions. In the external dimension, this includes how one sets up the communication channels, makes information resources and tools available, and ensures the target system's receptiveness. In the internal dimension this includes how regulators calibrate their own attentional system, how they prepare their own action tools, and how "present" they stay. States of readiness, which continuously operate in the background, either amplify the effects of foregrounded activities or constitute their very condition of possibility.

Subtly present enabling factors are crucial for self-organized effects. Many desired effects depend on the regulator's ability in keeping basic conditions in place (Haken & Schiepek, 2010). These general enablers, as we might call them, set higher-timescale parameters and constrain the target system so its elements can auto- and cross-catalyze in the right ways.

Enabling procedures may also be needed with respect to having a good information interface with the target system. For example, in economics, politics, and diplomacy one can cultivate permanent information channels that can readily kick in when needed. These steps are especially relevant with systemic dilemmas that can be best handled by forestalling them, whereas when one is forced to counteract a negative dynamic things get difficult (e.g., Meadows & Wright, 2009).

To mention another example of enablement, creativity scholars emphasize how creativity comes to the prepared (e.g., Malinin, 2016). Evidently, creativity cannot be intended or willed, nor can a new insight be known before it occurs. What can be done is to collect inspirations, set up tools, get into a productive frame of mind, and so on. In addition, it is frequently emphasized that creativity benefits from actively setting task constraints, which shape what is likely to emerge.

Complementarily to general enablement, there is a broad range of expertise for imposing a more situated set of constraints on a self-organizing dynamic. A good example is the constraints-led approach to sports coaching where learners are offered a number of specifically selected tasks and challenges that encourage exploration (Chow et al., 2011; Hristovski et al., 2011). Setting the appropriate constraints encourages learners to engage in playful variability and explore context-adaptive solutions. Rather than providing a precise "how-to", the presence of constraints allows learners to organize their activity in semi-open ways while coupling with the ecology.

The idea of constraints broadly reflects Juarrero's abovementioned views on the creation of new probability distributions to "stack the odds" in a complex system. The same idea can be expressed in other ways as well. Animals are known to sculpt their ecological action niche and alter their environments actively (Heft, 2007). This idea, for instance, applies to creative experts who set up their workspace and materials so that inspiring feedback is encouraged (Malinin, 2016). Niche shaping makes useful information and action possibilities available down the line. Evidently, shaping a niche never specifies the outcomes deterministically. It merely specifies a range of likely systems dynamics, and importantly, also the re-afferent stimulation one is likely to receive that make further action possibilities visible.

Participatory resonance

As claimed earlier, the relationship between regulator and target system is of a participatory nature. The concept of *resonance* with a system (Raja, 2018) captures this well. Take as an example the rapport skills needed in therapies. To regulate a client's system adaptively it takes an "art of encounter" (Kimmel et al., 2015). A capable psychotherapist will shape a good therapeutic alliance, provide high-quality feedback, and offer a safe environment, all of which makes "difficult topics" more acceptable to the client (Haken & Schiepek, 2010). This includes an ability to engage with a client with trust, empathy, an acceptant attitude, and by attuning to the client's dynamics, all powerful effectiveness factors. Similarly, continuity, attuned breath, or voice modulation can greatly enhance the client's active participation and receptiveness.

A highly responsive "resonance loop" allows therapists to monitor and optimize the process continuously. In addition, perceptual readiness matters. In a body-therapeutic context this includes how the hands or eyes are calibrated for mindful touch. In a psychotherapeutic context this includes a specific attention to the client's body-language or vocal patterns. One can speak of interpenetration with the nervous system of the client.

Resonance, in the case of biological systems, means attuning to an organism's rhythms, a mechanism that is known to benefit smooth embodied interaction. Human bodies are "by design" meant to resonate. Resonance has been credited with the function of a social glue of sorts, as shown by the ease by which attuned rhythms in walking or breathing kick in. Resonance, however, is much more than just exploiting the automated sync-ing of rhythms. Coupling with a system dynamics can and must be strategically selective. E.g., a therapist's interpersonal synchronization is a per se good thing, but will not necessarily move along with a client's rhythms of distress or pick up on them only briefly in order to modulate them. The underlying point is that a regulator must find a mix that respects the intrinsic dynamics of a system, while constraining and nudging these dynamics in judicious ways (see "judicious minimalism" below).

The specific forms or participatory resonance provide a fruitful topic for future research. The question is which specific modes of engagement expert regulators prefer in different contexts during a process. For example, managers may find it easiest to modulate the dynamics of an organization by starting from an attuned and interactive state, instead of a remote state that is based on abstract data points.

Adaptive equipoisedness

A central task of a regulator is to ensure that the target system acquires (or keeps) the ability to react adaptively and flexibly. Studies in embodied cognition suggest that able regulators keep the system capable of diversity, as a pre-condition for adaptive self-organization in response to external stimuli and optimal responsiveness. This idea resonates the complexity-theoretic concept of *metastability* (Kelso, 2012; Pinder et al., 2012; Rabinovich et al., 2008; Torrents et al., 2021). Bruineberg et al. (2021) argue that "that both the sensitivity to novel situations and the sensitivity to a multiplicity of action possibilities are enabled by the property of skilled agency that we will call metastable attunement". Metastability refers to a state that is equi-poised for multiple futures and that permits equal responsiveness in many directions. Metastable states poise a system between the tendency of the system to express its intrinsic dynamics and the tendency to coordinate globally to create new dynamics. Remaining around metastable dynamics poises regulators at a place where they can draw on existing or explore new "modes of engagement", as Bruineberg et al. term it.

When a system is metastable multiple system tendencies are subtly realized *in nuce*. Complexity theorists speak of *critical states* (Bak, 1996) that are poised on the "edge of chaos/instability", an idea scholars of embodied cognition have fruitfully applied in their research as well (Hristovski et al., 2011). As van Orden and colleagues (2003, p. 333) state: "Criticality allows an attractive mix of creativity and constraint. It creates new options for behavior and allows the choice of behavior to fit the circumstances of behavior". Critical states are neither over-random nor over-regular. They involve incipient states of readiness for multiple action possibilities, which can be selected through the constraints of the moments to generate a specific context-fitting action, "rather than a dormant system that is merely reactive to a stimulus" (Kloos & Van Orden, 2009).

Given that the opposite of metastability is, roughly speaking, fixation on a particular course of action or even imperviousness to changes of feedback, able regulators will strive to keep both the target system and their own action system as metastable as possible. Keeping a system flexibly poised and "on its toes" is seen as crucial to respond to novelty in a fluid and uncertain environment. Expressions of metastability are found in business and military contexts, where the notion of *agility* has been proposed (e.g., Dyer & Ericksen, 2010). While organizational structures of agile enterprises afford enough flexibility to adapt to changing business conditions and form context-adaptive forms of structuration, rigid organizational hierarchies may struggle with this. Furthermore, interaction experiments have shown that experienced subjects "stay in the zone" (Noy et al., 2015) when coupling with another person and hereby ensure a successful dynamic.

Moving with emergence

Another key ability is to move with the system in real time and keep things just open enough. In some domains it may be crucial to rapidly move with emergence and avoid action delays. This ability can be termed "dynamic immediacy" (Kimmel et al., 2015, 2018); the regulator attunes to emergent occurrences through continuous micro-decisions that never overshoot or lag behind. This permits staying in tune with transient windows of opportunity (e.g., for serendipity). It also prevents excessive repairs that become necessary after delays or the need for too massive interventions. Small dynamic repairs will often as long as the interaction dynamic "stays in the zone" (see above). This requires being sensitive to dynamics as well as skills for producing a constant flow of micro-actions that respect ongoing dynamics and intervene only at selected junctures. A strong awareness for process implies relating to multiple timescales and a "feel for" interdependencies between slow and fast dynamics as characterized in Section 3.

A topic to be explored is how, and how well, this works in systems with delayed feedback. For example, the fact that a ship reacts in delayed fashion and depending on what happened minutes earlier (Anzai 1984) implies that higher timescale sensitivities must be factored into real-time regulation attempts. Unfocused "adhoc-ism" without this longer-term sensitivity in mind is a frequent reason for regulation failure (Dörner, 1987). It would be a major misunderstanding to define dynamic immediacy as constant frenzied response. Often, it takes calm poisedness and measured interventions with just the right timing, our next topic.

Judicious minimalism

Judicious and well-timed interventions in a system refract the seeming paradox of "trying not to try" in ancient Chinese discourses. Daoist and Confucian philosophers stressed the sage's ability for giving naturally evolving processes subtle direction, but without imposing force on its internal logic. Slingerland (2014) relates this to the twin concepts of *wuwei* (effortless action) and *de* (charisma). Ancient Chinese philosophers, when they speak of wuwei, project an ideal of "non-action", describing expertise as a seamless fusing with the systems natural dynamics.

Originally, Confucius and Xunzi emphasized the idea of conscious self-cultivation and later the Daoists (i.e., the tradition of Laozi) responded with the alternative position of just leaving their natural dynamics undisturbed. The crucial connection to our present topic appears in the synthesis of these positions by Mencius, who emphasizes the importance of getting the mix right between cultivating good existing tendencies and overcoming less beneficial ones. The tradition of Mencius exemplifies wuwei in stories, for example that of a butcher artfully up carving a bull. An expert butcher does this with grace and ease by not struggling against blocked paths, but moving with the nature of the bull's flesh.

Wuwei thus refers to a kind of practical wisdom or skill of relating to natural state (and dynamics) of a system. We can translate it into respecting, and to some extent preserving ongoing features and dynamics, but also knowing how to gracefully shape them. While effortless action does not imply minimalism at all times, it highlights a need to respect and exploit a system's deeper nature, judiciously intervening at the right time, and reserving incisive actions for some key moments. A sensitive balance between leading and following the system is implied. It means getting the mix right between adding to ongoing processes in useful ways, and reining in, nudging or reorienting undesirable aspects in low-cost ways. Thus a keen sense for a system's endogenous self-organizing tendencies may be critical to work out the most efficient interventions.

Importantly, the Chinese tradition underwrites the same non-dualism/non-separation of agent and the target system that was discussed under the heading of participatory resonance. System regulators are, in this sense, not thought of as being remote from the system they regulate; they form a single continuous system – a point coupling-based approaches to cognition share in common with ancient Chinese thought.

5 Towards a partnership of perspectives

Given what was said, reasoning about complex systems is not nearly the only available regulation resource. However, reasoning will play some role or other and it can be embedded in a coupling process, i.e., there is no fundamental contradiction between the different perspectives. To come full circle, I will now try to identify where reasoning will likely play role and how to discuss this in a complexity-informed manner.

Global, multi-pronged, and mixed intervention strategies

A simple "digest" of complexity-aware principles as proposed by synergetics and others says little about how regulators make specific decisions, e.g., as to when and how much to buffer an ongoing system process, how to time decisive interventions, with which actions to enable a process, what forms of participatory resonance to choose, and what overall regulation strategy to pick, to name but a few factors.

If macro-cognition approaches are to be trusted,[9] professional experts have a keen perceptual ability to holistically discern the status of a target system (and possess a number of loosely associated strategic alternatives, which can be fleshed out or revised in the process). To understand a system's state, successful regulators continuously monitor, or intermittently check, telltale variables known to be informative about problems or known to alert to exceptional or dangerous situations. It has been proposed that regulators consult (domain- or even case-specific) status indicators which provide a quick "system report". To do so, they use so-called *indicator variables* (Dörner, 2003; Vester, 2007), i.e., variables that respond to many others in the system, without being as influential themselves. In a psychotherapy client, for example, this might be breath and voice as a sign of stress. Some such variables can support evaluating long-term success, e.g., water levels in the ecological-developmental micro-world simulation known as MORO. It requires the expert's skill to figure out what variables have the status of indicators (or prior experience).

In terms of strategies, regulators may choose between different general approaches. One approach is to tweak strong, but unspecific parameters that produce globally effective interventions: Systems are said to be sensitive to particular global *control parameters* (Haken & Schiepek, 2010; Kelso, 1995; Thelen & Smith, 2004). Control parameters are variables that influence many other variables without being themselves as heavily influenced. Thus, a major task of a regulator can be to identify variables that are causally powerful and offer leverage over the whole system. They globally govern systemic change or inertia, albeit in a non-deterministic fashion. Induced relaxation in a bodywork therapy, for instance, can lead to conducive changes across the whole body. Thus, the system can globally transform its dispositions and possibilities for self-organizing, or increase its receptiveness to further input.

Another approach to strategy is to intervene in systemically more local aspects and combine several such actions so a wider effect manifests. Regulators may identify fitting *intervention combinatorics* for the context at hand, such as sequential combinations or incremental interventions from multiple angles that gradually build up an effect. To take a therapeutic context again, bodywork experts often work with repetition of stimulus, redundancy, and effect build-up strategies, which combine local interventions such that a larger functional structure of the body is targeted from different angles (Kimmel et al., 2015; Kimmel & Irran, 2021).

[9] As discussed in Section 2, the strong empirical evidence on perceptual skills comes from domains with target systems that may not always be complex in a technical sense.

Based on the distinction between global and local leverage means, it is also useful to contrast broader *strategy combinations* over the duration of an intervention task, namely such that start bottom-up by modulating several system elements and such that start top-down from global control parameters. To illustrate this point, in bodywork contexts specific local interventions are often preceded by more unspecific and global ones. For instance, massaging different limbs can serve as an unspecific warm-up so that more specific sensorimotor issues can subsequently be addressed.

The general implication from these observations is a need for exploring how intervention tools are selected, sequentially combined, and mixed in order to understand how effect synergies emerge over time. As Kimmel et al. (2015) point out, the toolbox of regulation allows combining local with global interventions, specific with unspecific interventions, stabilization with perturbation, mono- with multi-pronged approaches, as well as using repetition, switching tack, applying "homeopathic" nudges, or just patiently waiting to let the system evolve naturally.

Reasoning from system constellations to strategies

When regulators choose intervention strategies a central question is how the recognition of system patterns triggers strategic inferences. A hypothesis in this regard is that professionals with domain knowledge can, e.g., identify self-reinforcing systemic loops causing a specific problem and decide on this basis which factors could be available to counteract this.

A reasoning-based approach, the systems thinking literature (e.g., Meadows & Wright, 2009) has identified characteristic contexts that pose complex problems in real-life domains. It is proposed that a regulator can learn to recognize clues to a systemic problem constellation via the system's dynamics or appearance. These prototypical challenges include "competing system tendencies", "unwanted side-effects", "vicious circle", "problem propagation", or "change buffering". The assumption is that a regulator can learn to associate a problem constellation with characteristic pitfalls. Examples for strategies that seem intuitive at the surface, but often backfire include "purely symptom-oriented actions", "unintended consequences of a problem fix", "short-term gain for a long term cost", or "diminishing gains through overuse" (Kim & Anderson, 2007; Kim, 2000). In contrast, a regulator capable of identifying the deeper causal essence of the problem (e.g., feedback loops that cancel out attempts to change) has a major advantage in finding an effective intervention focus and in avoiding futile strategic responses.

Empirical indications that relatively abstract causalities are reasoned about are provided by a study of bodywork therapists who, *inter alia*, learn to reason in terms of higher-level network properties of the system (Kimmel et al., 2015). They conceptualize some symptoms of a client as being due to individual system functions that compete for resources or block each other, while other problems are interpreted to result from functions that are inherently too weak to make their normal contribution, and yet others from sufficiently active functions that are, however, caught in a vicious circle in their interplay.

In asking how regulators select a strategy, another attractive avenue for the future is the notion of *attractor landscapes* (e.g., Haken & Schiepek, 2010; Vallacher et al., 2010): Complexity theorists conceptualize the behaviors that a system can display as a "phase space" in which particular regions are repeatedly visited, known as attractors. This reflects the basic observation that a complex system may abruptly revert to earlier states of shift from great stability to disorder, or vice versa. Among other things, the idea of a landscape of system attractors helps to explain why systems get stuck in non-desirable states or refuse to settle in desirable ones. This way of thinking has led to the proposition that system dysfunctionalities may be characterized by different attractor relationships and, what is more, that the distinctions regulators draw may reflect this, as Kimmel et al. (2015) explicitly argue. One frequent context occurs when a system, that is per se capable of adaptive behavior, has gotten stuck in a dysfunctional attractor and simply needs to be coaxed back through the right encouragement. To invite a system to reorganize itself more adaptively, regulators may "alert it" to its functions or jog system memory of previous states. In other constellations the system has no available state yet "in its repertoire" to cope with a challenge. The task of the regulator is to develop new forms of order, e.g., by "creating a hidden attractor" first which later gets fully activated (Vallacher et al., 2010). In systems that are too stereotypical the task may be to invite "healthy" system variability. Here, regulators may explore alternatives or diversify behavior (they "deepen alternative attractors" or make them more easily accessible). In yet other systemic contexts, the task simply is to ensure that the dynamic does not veer off into extreme attractors and stays in a circumscribed region of behavioral options. Of course, it remains to be empirically substantiated to what extent regulators in real-life settings make use of such relatively abstract systemic distinctions.

The dialectics of enactive reasoning

The wider issue to address is how mechanisms of processual coupling with a target system, as described in Section 4, can become partners to problem solving and causal reasoning about systemic constellations.

Despite the well-attested limitations of "understanding" complex systems (see Section 2), the good news is that enactive-dynamic resources may offset the relative cognitive opacity of a system's inner workings. This class of resources may allow for partial "offloading" of reasoning challenges. For example, by honing perceptual capabilities a regulator is put into a position to respond more swiftly, which in turn forestalls excessive deviations of a systemic dynamic from its "sweet spot" and thus avoids the need for troubleshooting. At the same time, reasoning competencies are unlikely to become superfluous just because of their limited scope. An important question thus arises: If regulation experts use strategies that are just as much reasoning-based as based on skilled system perception, exploration and interactivity, how does thinking *about* complex systems add to dynamically coupling *with* them?

A case in point is the question of how skillful system monitoring and expert knowledge *about* the system interconnect. Under the rubric of interactive and perceptual skills we find a set of practical strategies to explore system boundaries, players, connectivity and feedback, probe preferred dynamics, or detect scale interdependencies, i.e., to test whether combinations of small action have particular global effects.

All these skills are clearly much more effective if they can be brought to bear on what a person knows about the system's appearance forms, components and connectivity, their possible functions, and knowledge about possible interdependencies or synergies between system components. When someone possess such structural knowledge of a system (Schoppek, 2002, 2004) the person is likely to make more accurate judgments about the situated state of affairs. This also provides a template for imagining a system in its dynamics, i.e., for conceptualizing a web of elements in its current interplay. Partial evidence in that direction comes from studies of regulators who judge the direction and weights of component interplay (Gary & Wood, 2016) or create a macro-scopic condensation of how multiple variables connect (Maani & Maharaj, 2004).

However, none of this need be static or decoupled from interaction with a system. In bodywork domains subjective expert reports indicate that that specific (although rarely complete) *conceptual maps of a system* are created while enactively diagnosing (Kimmel, 2022). Such images may include facets of system structure, their connectivity and parametric values in the system's present state. The maps can contain considerable detail about a problem's appearance and context, but it may also provide a basis for making more abstract judgments at the level of systems thinking to determine the class of problem and possible responses (see above). Crucially, these images in return require embodied functions. They can only arise from, and be updated through, a set of system probing techniques, notably skills to gauge preferred and non-preferred dynamics (i.e., system habits) and test system stability (i.e., how easily the system recovers from small perturbations). Active checks of component interplay allow reasoning to causal origins of a problem (Kimmel et al., 2015).[10] This largely happens as ongoing *reflection-in-action* and such that perceptual-interactive functions and reasoning functions augment each other and give each other direction. Thus, active embodied exploration suggest specific steps for developing the causal reasoning framework which in turn suggest next perceptual checks and exploration strategies. In this light, a key desideratum for future work, in keeping with the discussed "4E" cognition approaches, is to track the intricate braiding of perception, action, and thought in a dialectic manner (Kimmel & Irran, 2021).

6 Conclusions

By drawing from post-cognitivist and complexity-theoretic ideas I have proposed, in the spirit of a constructive critique, to expand the purview of complexity regulation scholarship beyond "problem solving", "reasoning, and "control". My aim was to provide a more inclusive framework, notably for professional regulation contexts.

I have argued that classical intellectualistic notions such as problem solving pose the question in overly restrictive ways, veiling a whole range of competencies the real world expertise depends on. They need to be complemented with a notion of dynamic-enactive *emergence management* (Kimmel et al., 2018), which throws into relief the experts' ability for recursive and multi-timescale coupling activity as they relate to the self-organizing dynamics of the target system. This makes regulation an interactive – indeed sometimes participatory – form of "total" engagement and casts a critical light on the erstwhile dualism between regulator and target.

For this new perspective to get off to a good start, the ontology of complex systems and the nature of interactions with them should be revisited. Rather than using the language of problem solving, we should strive for a unified approach that conceptualizes system regulation in ways *symmetrical* to the characteristics that are attributed to complex systems, as has been suggested by Schiepek, Tschacher, Strunk, Vallacher, Nowak and others. This perspective allows cross-talk between complexity theory and psychology and strives for a common language.

By consequence, in order to understand regulative agency, we must conceive of system interventions as imposing *constraints on self-organizing processes*. This a priori makes agency non-deterministic and multi-causal, hence different from "control". The idea is present in Magda Osman's (2010b) catchy critique of the puppeteer metaphor, but needs to be taken further in its implications. An emphasis on constraints actually shifts our view of what decisions are about. It implies that interventions are mixes of effects that give a system suitably leeway in the some dimensions, keep

[10] Embodied checks can involve testing the responsiveness of components, if ensemble performance is as desired, dysfunctional, or components communicate little. E.g., to observe feedback loops "in action", they co-activate two or more anatomical structures by stimulating the client's body. How adaptively component interplay behaves in response to different challenges can be of equal interest ("healthy variability") (cf. Pincus & Metten, 2010; Vargas et al., 2015; Woods, 2006). Similarly, micro-macro co-variation can be monitored, by moving attention between parts and wholes. This is vital when a regulator needs to determine whether changes at the local system level translate into changes of emergent global patterns.

others reined in, and energize or modulate a system to enable desirable self-organizing trends.

How, then, do system regulators tweak, nudge, invite or channel ongoing system dynamics? And how can we recast their activities in terms of dynamic patterns, network interchanges, connectivity, multi-causality and emergent dynamics? What I have proposed amounts to re-describing a regulator's decision making in functional-systemic terms, i.e., by using concepts such as setting boundary conditions, metastability, smoothing a system, resonance, "niche shaping", working with global control parameters, imposing convergent low-level constraints, reading process signatures, modulating or tipping ongoing dynamics, and interventions that synergize with system dynamics for nearly "free" effects.

From this perspective it is evident why post-cognitivist approaches with their emphasis on context-embedded multi-scale coupling can effectively complement traditional accounts of complexity regulation, which stress reasoning abilities and knowledge-based inference. To bring together the best of both worlds we need to intensify our efforts to empirically investigate the role of enactive-dynamic skills and clarify their scope in different tasks and domains. Only then will we be in a position to investigate the work-sharing and mutual facilitation between coupling-based and reasoning-based regulation mechanisms. A good heuristic for thinking of this are *synergies* between skilled forms of doing, reasoning abilities proper, and a backdrop of synoptic and meta-cognitive abilities used in orchestrating these resources.

A theoretical implication is that psychological simulation studies (see Section 2) may be presenting an altogether too pessimistic picture of regulation expertise. It stands to reason that constant system "cultivation", perceptual ability, skillful interfacing, and the ability to exploit interactivity itself can do much for successful regulation. (To be fair, it needs to be explored to what extent the more "mediated" regulation set-up in domains such as politics or economics similarly exploits embodied, processual, and participatory mechanisms.) A second theoretical implication is that regulation success crucially depends on how different types of resources are co-orchestrated and how well integrated a regulator's competency system is as a whole. At the plane of methodology, this translates into a need for naturalistic designs capable of studying the processual interplay of multiple mechanisms, which track how slower and faster regulation activities work together and how parallel layers of leverage are exploited. Study designs with a sufficient ability to address this interplay are not a small thing to ask for, but will be rewarded with a more comprehensive perspective that steers clear of excessive intellectualism.

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References

Anzai, Y. (1984). Cognitive Control of Real-Time Event-Driven Systems. *Cognitive Science*, *8*(3), 221–254. https://doi.org/10.1207/s15516709cog0803_2

Assaraf, O. B.-Z., & Orion, N. (2005). Development of system thinking skills in the context of earth system education. *Journal of Research in Science Teaching*, *42*(5), 518–560. https://doi.org/10.1002/tea.20061

Assaraf, O. B.-Z., & Orion, N. (2010). System thinking skills at the elementary school level. *Journal of Research in Science Teaching*, *47*(5), 540–553. https://doi.org/10.1002/tea.20351

Axelrod, R. (1976). *Structure of decision*. Princeton University Press.

Bak, P. (1996). *How nature works: The science of self-organized criticality*. Oxford University Press.

Baron, R. A. (2009). Effectual versus predictive logics in entrepreneurial decision making: Differences between experts and novices. *Journal of Business Venturing*, *24*(4), 310–315. https://doi.org/10.1016/j.jbusvent.2008.04.001

Beer, R. D. (2003). The Dynamics of Active Categorical Perception in an Evolved Model Agent. *Adaptive Behavior*, *11*(4), 209–243. https://doi.org/10.1177/1059712303114001

Brehmer, B. (1980). In one word: Not from experience. *Acta Psychologica*, *45*(1–3), 223–241. https://doi.org/10.1016/0001-6918(80)90034-7

Brehmer, B. (1992). Dynamic decision making: Human control of complex systems. *Acta Psychologica*, *81*(3), 211–241. https://doi.org/10.1016/0001-6918(92)90019-A

Brehmer, B. (1996). Man as a Stabiliser of Systems: From Static Snapshots of Judgement Processes to Dynamic Decision Making. *Thinking & Reasoning*, 2(2–3), 225–238. https://doi.org/10.1080/135467896394528

Brehmer, B. (2005). Micro-worlds and the circular relation between people and their environment. *Theoretical Issues in Ergonomics Science*, *6*(1), 73–93. https://doi.org/10.1080/14639220512331311580

Brehmer, B., & Dörner, D. (1993). Experiments with computer-simulated microworlds: Escaping both the narrow straits of the laboratory and the deep blue sea of the field study. *Computers in Human Behavior*, *9*(2–3), 171–184. https://doi.org/10.1016/0747-5632(93)90005-D

Brehmer, B., & Elg, F. (2005). Heuristics in dynamic decision making: Coping with the time constants of a dynamic task by doing something else. In J. D. Sterman, N. P. Repenning, R. S. Langer, J. I. Rowe, & J. M. Yanni, (Eds.), *Proceedings of the 23rd International Conference of the System Dynamics Society*. The System Dynamics Society. https://proceedings.systemdynamics.org/2005/proceed/papers/BREHM340.pdf

Bruineberg, J., Seifert, L., Rietveld, E., & Kiverstein, J. (2021). Metastable attunement and real-life skilled behavior. *Synthese*, *199*(5–6), 12819–12842. https://doi.org/10.1007/s11229-021-03355-6

Butler, M. J. R., & Allen, P. M. (2008). Understanding Policy Implementation Processes as Self-Organizing Systems. *Public Management Review*, *10*(3), 421–440. https://doi.org/10.1080/14719030802002923

Byrne, D., & Callaghan, G. (2014). *Complexity theory and the social sciences*. Routledge.

Cairney, P. (2012). Complexity Theory in Political Science and Public Policy. *Political Studies Review*, *10*(3), 346–358. https://doi.org/10.1111/j.1478-9302.2012.00270

Carver, C. S., & Scheier, M. F. (2002). Control processes and self-organization as complementary principles underlying behavior. *Personality and Social Psychology Review*, *6*(4), 304–315. https://doi.org/10.1207/S15327957PSPR0604_05

Cavana, R. Y., & Maani, K. E. (2000). *A methodological framework for integrating systems thinking and system dynamics*. Paper presented at the the 18th International Conference of the System Dynamics Society: "Sustainability in the Third Millennium", 6–10 August, Bergen, Norway, 1–13.

Chow, J. Y., Davids, K., Hristovski, R., Araújo, D., & Passos, P. (2011). Nonlinear pedagogy: Learning design for self-organizing neurobiological systems. *New Ideas in Psychology*, *29*(2), 189–200. https://doi.org/10.1016/j.newideapsych.2010.10.001

Ciompi, L., & Endert, E. (2011). *Gefühle machen Geschichte* [Emotions make history]. Vandenhoek & Ruprecht.

Clark, A. (2001). Reasons, robots and the extended mind. *Mind & Language*, *16*(2), 121–145. https://doi.org/10.1111/1468-0017.00162

Clark, A. (2008). *Supersizing the mind: Embodiment, action, and cognitive extension*. Oxford University Press.

Cohen, M. S., Freeman, J. T., & Wolf, S. (1996). Metarecognition in time-stressed decision making: Recognizing, critiquing, and correcting. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *38*(2), 206–219. https://doi.org/10.1518/001872096779048020

Coleman, P. T., Vallacher, R. R., Nowak, A., & Bui-Wrzosinska, L. (2007). Intractable conflict as an attractor: A dynamical systems approach to conflict escalation and intractability. *American Behavioral Scientist*, *50*(11), 1454–1475. https://doi.org/10.1177/0002764207302463

Crandall, B., Klein, G., & Hoffman, R. (2006). *Working minds: A practitioner's guide to cognitive task analysis*. MIT Press.

Dale, R., Fusaroli, R., Duran, N. D., & Richardson, D. C. (2014). The self-organization of human interaction. In B. H. Ross (Ed.), Psychology of learning and motivation (Vol. 59, pp. 43–95). Academic Press. https://doi.org/10.1016/B978-0-12-407187-2.00002-2

de Bruin, L., Newen, A., & Gallagher, S. (Eds.). (2018). *The Oxford handbook of 4E cognition*. Oxford University Press.

Dew, N., Read, S., Sarasvathy, S. D., & Wiltbank, R. (2009). Effectual versus predictive logics in entrepreneurial decision-making: Differences between experts and novices. *Journal of Business Venturing*, *24*(4), 287–309. https://doi.org/10.1016/j.jbusvent.2008.02.002

Diehl, E., & Sterman, J. D. (1995). Effects of feedback complexity on dynamic decision making. *Organizational Behavior and Human Decision Processes*, *62*(2), 198–215. https://doi.org/10.1006/obhd.1995.1043

Dörner, D. (1986). Diagnostik der operativen Intelligenz [Assessment of operative intelligence]. *Diagnostica*, *32*, 290–308.

Dörner, D. (1997). *The logic of failure: Recognizing and avoiding error in complex situations*. Perseus Publishing.

Dörner, D. (2003). *Die Logik des Misslingens Strategisches Denken in komplexen Situationen (2. erweitere Auflage)*. Rowohlt.

Dörner, D., & Funke, J. (2017). Complex problem solving: what it is and what it is not. *Frontiers in Psychology*, *8*, Article 1153. https://doi.org/10.3389/fpsyg.2017.01153

Dörner, D., & Schaub, H. (1994). Errors in planning and decision-making and the nature of human information processing. *Applied Psychology*, *43*(4), 433–453. https://doi.org/10.1111/j.1464-0597.1994.tb00839

Dyer, L., & Ericksen, J. (2010). Complexity-based agile enterprises: putting self-organizing emergence to work. In A. Wilkinson, N. Bacon, T. Redman, & S. Snell, *The SAGE handbook of human resource management* (pp. 438–459). SAGE Publications. https://doi.org/10.4135/9780857021496.n26

Engel, A. K. (2010). Directive minds: How dynamics shapes cognition. In J. Stewart, O. Gapenne, & E. Di Paolo (Eds.), *Enaction: Towards a new paradigm for cognitive science* (pp. 219–243). MIT Press.

Fairbanks, R. J., Wears, R. L., Woods, D. D., Hollnagel, E., Plsek, P., & Cook, R. I. (2014). Resilience and resilience engineering in health care. *The Joint Commission Journal on Quality and Patient Safety*, *40*(8), 376–383. https://doi.org/10.1016/S1553-7250(14)40049-7

Feltovich, P., Spiro, R. J., & Coulson, R. L. (1997). Issues of expert flexibility in contexts characterized by complexity and change. In P. Feltovich, K. M. Ford, & R. R. Hoffman (Eds.), *Expertise in Context: Human and Machine* (pp. 125–146). AAAI, MIT Press.

Fischer, A., Greiff, S., & Funke, J. (2012). The process of solving complex problems. *The Journal of Problem Solving*, *4*(1), 19–42. https://doi.org/10.7771/1932-6246.1118

Fischer, H., & Gonzalez, C. (2016). Making sense of dynamic systems: How our understanding of stocks and flows depends on a global perspective. *Cognitive Science*, *40*(2), 496–512. https://doi.org/10.1111/cogs.12239

Fraser, S. W., & Greenhalgh, T. (2001). Coping with complexity: Educating for capability. *BMJ*, 323, 799–803. https://doi.org/10.1136/bmj.323.7316.799

Frensch, P. A., & Funke, J. (2014). *Complex problem solving: The european perspective*. Psychology Press.

Froese, T., & Di Paolo, E. A. (2011). The enactive approach: Theoretical sketches from cell to society. *Pragmatics & Cognition*, *19*(1), 1–36. https://doi.org/10.1075/pc.19.1.01fro

Funke, J. (1991). Solving complex problems: Exploration and control of complex systems. In R. J. Sternberg & P. A. Frensch, *Complex problem solving: principles and mechanisms* (pp. 185–222). Lawrence Erlbaum.

Funke, J. (2001). Dynamic systems as tools for analysing human judgement. *Thinking & Reasoning*, *7*(1), 69–89. https://doi.org/10.1080/13546780042000046

Funke, J. (2014). Analysis of minimal complex systems and complex problem solving require different forms of causal cognition. *Frontiers in Psychology*, *5*. https://doi.org/10.3389/fpsyg.2014.00739

Funke, J., Fischer, A., & Holt, D. V. (2018). Competencies for complexity: problem solving in the twenty-first century. In E. Care, P. Griffin, & M. Wilson (Eds.), *Assessment and teaching of 21st century skills* (pp. 41–53). Springer. https://doi.org/10.1007/978-3-319-65368-6_3

Funke, J., & Müller, H. (1988). Eingreifen und Prognostizieren als Determinanten von Systemidentifikation und Systemsteuerung [Intervening and anticipating as determinants of system identification and system regulation]. *Sprache & Kognition*, *7*, 176–186.

Gallagher, S. (2017). *Enactivist interventions: rethinking the mind*. Oxford University Press.

Gary, M. S., Kunc, M., Morecroft, J. D. W., & Rockart, S. F. (2008). System dynamics and strategy. *System Dynamics Review*, *24*(4), 407–429 https://doi.org/10.1002/sdr.402

Gary, M. S., & Wood, R. E. (2016). Unpacking mental models through laboratory experiments: Unpacking mental models through laboratory experiments. *System Dynamics Review*, *32*(2), 101–129. https://doi.org/10.1002/sdr.1560

Gell-Mann, M. (1994). Complex adaptive systems. In G. Cowan, D. Pines, & D. Melitzer (Eds.), *Complexity: Metaphors, models, and rseality* (pp. 17–45). Addison-Wesley.

Ghosh, A. (2017). *System dynamics for everyone: understanding how our world works*. Springer.

Gomersall, T. (2018). Complex adaptive systems: A new approach for understanding health practices. *Health Psychology Review*, *12*(4), 405–418. https://doi.org/10.1080/17437199.2018.1488603

Gonzalez, C., Fakhari, P., & Busemeyer, J. (2017). Dynamic decision making: learning processes and new research directions. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *59*(5), 713–721 https://doi.org/10.1177/0018720817710347

Gonzalez, C., Vanyukov, P., & Martin, M. K. (2005). The use of microworlds to study dynamic decision making. *Computers in Human Behavior*, *21*(2), 273–286. https://doi.org/10.1016/j.chb.2004.02.014

Gorzeń-Mitka, I., & Okręglicka, M. (2015). Managing complexity: a discussion of current strategies and approaches. *Procedia Economics and Finance*, *27*, 438–444. https://doi.org/10.1016/S2212-5671(15)01018-7

Greenhalgh, T., & Papoutsi, C. (2018). Studying complexity in health services research: Desperately seeking an overdue paradigm shift. *BMC Medicine*, *16*, Article 95. https://doi.org/10.1186/s12916-018-1089-4

Guastello, S. J. (2002). *Managing emergent phenomena: Nonlinear dynamics in work organizations*. Lawrence Erlbaum.

Guastello, S. J. (2016). A nonlinear paradigm for resilience, workload, performance, and clinical phenomena. *Industrial and Organizational Psychology*, *9*(02), 509–516. https://doi.org/10.1017/iop.2016.48

Guastello, S. J., Koopmans, M., & Pincus, D. (Eds.). (2009). *Chaos and complexity in psychology: The theory of nonlinear dynamical systems*. Cambridge University Press.

Güss, C., Devore Edelstein, H., Badibanga, A., & Bartow, S. (2017). Comparing business experts and novices in complex problem solving. *Journal of Intelligence*, *5*(2), 20. https://doi.org/10.3390/jintelligence5020020

Haken, H., & Schiepek, G. (2010). *Synergetik in der Psychologie: Selbstorganisation verstehen und gestalten* [Synergetics in psychology: Understanding and shaping self-organization]. Hogrefe.

Heft, H. (2007). The social constitution of perceiver-environment reciprocity. *Ecological Psychology*, *19*(2), 85–105

Hoffman, R. R., Crandall, B., & Shadbolt, N. (1998). Use of the critical decision method to elicit expert knowledge: A case study in the methodology of cognitive task analysis. *Human Factors*, *40*(2), 254–276

Hoffman, R. R., & McNeese, M. D. (2009). A history for macrocognition. *Journal of Cognitive Engineering and Decision Making*, *3*(2), 97–110

Holt, D. V., & Osman, M. (2017). Approaches to cognitive modeling in dynamic systems control. *Frontiers in Psychology*, *8*, Article 2032. https://doi.org/10.3389/fpsyg.2017.02032

Hotaling, J. M., Fakhari, P., & Busemeyer, J. R. (2015). Dynamic decision making. In N. Smelser & P. B. Batles (Eds.), *International encyclopedia of the social & behavioral sciences* (2nd ed., pp. 708–713). Elsevier. https://doi.org/10.1016/B978-0-08-097086-8.43040-0

Hollan, J., Hutchins, E., & Kirsh, D. (2000). Distributed cognition: Toward a new foundation for human-computer interaction research. *ACM Transactions on Computer-Human Interaction*, *7*(2), 174–196. https://doi.org/10.1145/353485.353487

Hristovski, R., Davids, K., Araujo, D., & Passos, P. (2011). Constraints-induced emergence of functional novelty in complex neurobiological systems: A basis for creativity in sport. *Nonlinear Dynamics-Psychology and Life Sciences*, *15*(2), 175–206.

Hurley, S. (2001). Perception and action: Alternative views. *Synthese*, *129*, 3–40.

Hutchins, E. (1995a). *Cognition in the wild*. MIT Press.

Hutchins, E. (1995b). How a cockpit remembers its speed. *Cognitive Science*, *19*(3), 265–288. https://doi.org/10.1207/s15516709cog1903_1

Hutchins, E. (2011). Enculturating the supersized mind. *Philosophical Studies*, *152*(3), 437–446. https://doi.org/10.1007/s11098-010-9599-8

Jacobson, M. J. (2000). Problem solving about complex systems: differences between experts and novices. In B. Fishman & S. O'Connor-Divelbiss (Eds.), *Fourth International Conference of the Learning Sciences* (pp. 14–21). Lawrence Erlbaum.

Jacobson, M. J., & Wilensky, U. (2006). Complex systems in education: scientific and educational importance and implications for the learning sciences. *Journal of the Learning Sciences*, *15*(1), 11–34. https://doi.org/10.1207/s15327809jls1501_4

Jansson, A. (1994). Pathologies in dynamic decision making: Consequences or precursors of failure? *Sprache & Kognition*, *13*(3), 160–173

Jervis, R. (1997).*System effects: Complexity in political and social life*. Princeton University Press.

Juarrero, A. (1999). Dynamics in action: Intentional behavior as a complex system. MIT Press. https://doi.org/10.1207/S15327000EM0202_03

Juarrero, A. (2015). What does the closure of context-sensitive constraints mean for determinism, autonomy, self-determination, and agency? *Progress in Biophysics and Molecular Biology*, *119*(3), 510–521. https://doi.org/10.1016/j.pbiomolbio.2015.08.007

Kahneman, D., & Klein, G. (2009). Conditions for intuitive expertise: A failure to disagree. *American Psychologist*, *64*(6), 515–526. https://doi.org/10.1037/a0016755

Kello, C. T., & Van Orden, G. C. (2009). Soft-assembly of sensorimotor function. *Nonlinear Dynamics, Psychology, and Life Sciences*, *13*(1), 57–78.

Kelso, J. A. S. (2012). Multistability and metastability: Understanding dynamic coordination in the brain. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *367*(1591), 906–918. https://doi.org/10.1098/rstb.2011.0351

Kelso, J. A. S. (1995). *Dynamic patterns: The self-organization of brain and behavior*. MIT Press.

Kim, D. H. (1994). *Systems archetypes*. Pegasus Communications.

Kim, D. H. (2000). *Systems thinking tools*. Pegasus Communications.

Kim, D. H., & Anderson, V. (2007). *Systems archetype basics: From story to structure*. Pegasus Communications.

Kim, D. H. (2000). *Systems archetypes i: Diagnosing systemic issues and designing high-leverage intervention*. Pegasus Communications.

Kimmel, M. (2017). The complexity of skillscapes: Skill sets, synergies, and meta-regulation in joint embodied improvisation. In J. Gore, J. & P. Ward (Eds.), *Naturalistic decision making and uncertainty: Proceedings of the 13th Bi-Annual Naturalistic Decision Making Conference University of Bath, UK.* (pp. 102-109). University of Bath.

Kimmel, M. (2021). The micro-genesis of interpersonal synergy. insights from improvised dance duets. *Ecological Psychology*, *33*(2), 106–145. https://doi.org/10.1080/10407413.2021.1908142

Kimmel, M. (2022). Complexity regulation competencies: a naturalistic framework. *Nonlinear Dynamics, Psychology, and Life Sciences*, *26*(1), 45–79.

Kimmel, M., Hristova, D., & Kussmaul, K. (2018). Sources of embodied creativity: Interactivity and ideation in contact improvisation dancing. *Behavioral Sciences*, *8*(6), Article 52. https://doi.org/10.3390/bs8060052

Kimmel, M., & Irran, C. (2021). Decision-making in Shiatsu bodywork: Complementariness of embodied coupling and conceptual inference. *Phenomenology and the Cognitive Sciences*, *21*, 245–275. https://doi.org/10.1007/s11097-020-09718-7

Kimmel, M., Irran, C., & Luger, M. A. (2015). Bodywork as systemic and inter-enactive competence: Participatory process management in Feldenkrais® Method and Zen Shiatsu. *Frontiers in Psychology*, *5*, Article 1424. https://doi.org/10.3389/fpsyg.2014.01424

Kirsh, D. (2009). Problem solving and situated cognition. In P. Robbins & M. Aydede (Eds.), The Cambridge Handbook of Situated Cognition (pp. 264–306). Cambridge University Press.

Kirsh, D. (2014). The importance of chance and interactivity in creativity. *Pragmatics & Cognition*, *22*(1), 5–26. https://doi.org/10.1075/pc.22.1.01kir

Kirsh, D., & Maglio, P. (1994). On distinguishing epistemic from pragmatic action. *Cognitive Science*, *18*, 513–549. https://doi.org/10.1016/0364-0213(94)90007-8

Klein, G. (1998). *Sources of power: How people make decisions*. MIT Press.

Klein, G. (2007). Flexecution as a paradigm for replanning, part 1. *IEEE Intelligent Systems*, *22*(5), 79–83. https://doi.org/10.1109/MIS.2007.4338498

Klein, G., Calderwood, D., & MacGregor. (1989). Critical decision method for eliciting knowledge. *IEEE Transactions on Systems, Man, and Cybernetics*, *19*(3), 462–472.

Klein, G., & Hoffman, R. (2008). Macrocognition, mental models, and cognitive task analysis methodology. In J. M. Schraagen, L. Militello, T. Ormerod, & R. Lipshitz (Eds.), *Naturalistic decision making and macrocognition* (pp. 57–80). Ashgate.

Kloos, H., & Van Orden, G. C. (2009). Soft-assembled mechanisms for the unified theory. In J. Spencer (Ed.), *Toward a unified theory of development connectionism and dynamic system theory re-consider* (pp. 253–267). Oxford University Press. https://doi.org/10.1093/acprof:oso/9780195300598.003.0012

Kriz, W. C. (2000). *Lernziel: Systemkompetenz. Planspiele als Trainingsmethode* [Learning objective system competency: simulation games as a training method]. Vandenhoek & Ruprecht.

Kugler, P. N., & Turvey, M. T. (1987). *Information, natural law, and the self-assembly of rhythmic movement*. Lawrence Erlbaum.

Lane, D. C., & Oliva, R. (1998). The greater whole: Towards a synthesis of system dynamics and soft systems methodology. *European Journal of Operational Research*, *107*(1), 214–235. https://doi.org/10.1016/S0377-2217(97)00205-1

Latash, M. L. (2008). *Synergy*. Oxford University Press.

Latash, M. L. (2012). Movements that are both variable and optimal. *Journal of Human Kinetics*, *34*(1), 5–13. https://doi.org/10.2478/v10078-012-0058-9

Lesh, R. (2006). Modeling students modeling abilities: The teaching and learning of complex systems in education. *Journal of the Learning Sciences*, *15*(1), 45–52. https://doi.org/10.1207/s15327809jls1501_6

Levy, S. T. (2017). Learning about complex systems from the bottom up: Role-playing together in a participatory simulation. In I. Levin & D. Tsybulsky (Eds.), *Optimizing STEM Education With Advanced ICTs and Simulations* (pp. 158–185). IGI Global. https://doi.org/10.4018/978-1-5225-2528-8

Levy, S. T., & Wilensky, U. (2008). Inventing a “mid level” to make ends meet: Reasoning between the levels of complexity. *Cognition and Instruction*, *26*(1), 1–47. https://doi.org/10.1080/07370000701798479

Lindblom, C. E. (1959). The science of “muddling through.” *Public Administration Review*, *19*(2), 79–88

Lipshitz, R., Klein, G., Orasanu, J., & Salas, E. (2001). Taking stock of naturalistic decision making. *Journal of Behavioral Decision Making*, *14*(5), 331–352. https://doi.org/10.1002/bdm.381

Lipshitz, R., & Strauss, O. (1997). Coping with uncertainty: A naturalistic decision-making analysis. *Organizational Behavior and Human Decision Processes*, *69*(2), 149–163. https://doi.org/10.1006/obhd.1997.2679

Loaiza, J. M., Trasmundi, S. B., & Steffensen, S. V. (2020). Multiscalar temporality in human behaviour: A case study of constraint interdependence in psychotherapy. *Frontiers in Psychology*, *11*, Article 1685. https://doi.org/10.3389/fpsyg.2020.01685

Maani, K. E., & Maharaj, V. (2004). Links between systems thinking and complex decision making. *System Dynamics Review*, *20*(1), 21–48. https://doi.org/10.1002/sdr.281

Malinin, L. H. (2016). Creative practices embodied, embedded, and enacted in architectural settings: Toward an ecological model of creativity. *Frontiers in Psychology*, *6*, Article 1978. https://doi.org/10.3389/fpsyg.2015.01978

Manteufel, A., & Schiepek, G. (1994). Systemkompetenz: Orientierung und Handeln in komplexen Sozialsystemen [Learning objective system competency: Siimulation games as a training method]. *Verhaltenstherapie und psychosoziale Praxis*, *26*(2), 203–216.

Meadows, D. H. (1982). *Whole earth models and systems*. *Co-Evolution Quarterly*, *34*, 98–108.

Meadows, D. H., & Wright, D. (2009). *Thinking in systems: A primer*. Earthscan.

Mittleton-Kelly, E., Geyer, R., & Cairney, P. (2015). Effective policy making: Addressing intractable problems. In R. Geyer & P. Carney (Eds.), *Handbook on Complexity in Public Policy* (pp. 111–127). Edward Elgar Publishing.

Nguyen, N. C., Graham, D., Ross, H., Maani, K., & Bosch, O. (2012). Educating systems thinking for sustainability: Experience with a developing country. *Systems Research and Behavioral Science*, *29*(1), 14–29. https://doi.org/10.1002/sres.1097

Normann, B. (2020). Facilitation of movement: New perspectives provide expanded insights to guide clinical practice. *Physiotherapy Theory and Practice*, *36*(7), 769–778. https://doi.org/10.1080/09593985.2018.1493165

Nowak, A. (2004). Dynamical minimalism: Why less is more in psychology. *Personality and Social Psychology Review*, *8*(2), 183–192. https://doi.org/10.1207/s15327957pspr0802_12

Noy, L., Levit-Binun, N., & Golland, Y. (2015). Being in the zone: Physiological markers of togetherness in joint improvisation. *Frontiers in Human Neuroscience*, *9*, Article 187. https://doi.org/10.3389/fnhum.2015.00187

Øberg, G. K., Normann, B., & Gallagher, S. (2015). Embodied-enactive clinical reasoning in physical therapy. *Physiotherapy Theory and Practice*, *31*(4), 244–252. https://doi.org/10.3109/09593985.2014.1002873

Osman, M. (2010a). Controlling uncertainty: A review of human behavior in complex dynamic environments. *Psychological Bulletin*, *136*(1), 65–86. https://doi.org/10.1037/a0017815

Osman, M. (2010b). Controlling uncertainty: decision making and learning in complex worlds. Wiley-Blackwell. https://doi.org/10.1002/9781444328226

Page, S. E. (2015). What sociologists should know about complexity. *Annual Review of Sociology*, *41*(1), 21–41. https://doi.org/10.1146/annurev-soc-073014-112230

Pincus, D., & Metten, A. (2010). Nonlinear dynamics in biopsychosocial resilience. *Nonlinear Dynamics, Psychology, and Life Sciences*, *14*(4), 353–380. https://doi.org/10.1037/e581062010-001

Pinder, R. A., Davids, K., & Renshaw, I. (2012). Metastability and emergent performance of dynamic interceptive actions. *Journal of Science and Medicine in Sport*, *15*(5), 437–443. https://doi.org/10.1016/j.jsams.2012.01.002

Plant, K. L., & Stanton, N. A. (2013). The explanatory power of Schema Theory: Theoretical foundations and future applications in Ergonomics. *Ergonomics*, *56*(1), 1–15. https://doi.org/10.1080/00140139.2012.736542

Plsek, P. E., & Greenhalgh, T. (2001). Complexity science: The challenge of complexity in health care. *BMJ*, *323*(7313), 625–628. https://doi.org/10.1136/bmj.323.7313.625

Putz-Osterloh, W. (1987). Gibt es Experten für komplexe Probleme? [Are there experts for complex problems?] *Zeitschrift Für Psychologie*, *195*, 63–85.

Rabinovich, M. I., Huerta, R., Varona, P., & Afraimovich, V. S. (2008). Transient cognitive dynamics, metastability, and decision making. *PLoS Computational Biology*, *4*(5), e1000072. https://doi.org/10.1371/journal.pcbi.1000072

Rączaszek-Leonardi, J. (2009). Symbols as constraints: The structuring role of dynamics and self-organization in natural language. *Pragmatics & Cognition*, *17*(3), 653–676. https://doi.org/10.1075/pc.17.3.09ras

Rączaszek-Leonardi, J., & Kelso, J. A. S. (2008). Reconciling symbolic and dynamic aspects of language: Toward a dynamic psycholinguistics. *New Ideas in Psychology*, *26*(2), 193–207. https://doi.org/10.1016/j.newideapsych.2007.07.003

Raja, V. (2018). A theory of resonance: Towards an ecological cognitive architecture. *Minds and Machines*, *28*(1), 29–51. https://doi.org/10.1007/s11023-017-9431-8

Reither, F. (1981). Thinking and acting in complex situations: A study of experts' behavior. *Simulation & Games*, *12*(2), 125–140. https://doi.org/10.1177/104687818101200202

Robbins, P., & Aydede, M. (2009). *The Cambridge handbook of situated cognition*. Cambridge University Press.

Rouwette, E. A. J. A., Größler, A., & Vennix, J. A. M. (2004). Exploring influencing factors on rationality: A literature review of dynamic decision-making studies in system dynamics. *Systems Research and Behavioral Science*, *21*(4), 351–370. https://doi.org/10.1002/sres.647

Schaffernicht, M. F. G., & Groesser, S. N. (2016). A competence development framework for learning and teaching system dynamics: A Competence Framework for Learning and Teaching. *System Dynamics Review*, *32*(1), 52–81. https://doi.org/10.1002/sdr.1550

Schiepek, G. (1986). *Systemische Diagnostik in der klinischen Psychologie* [Systemic diagnostics in clinical psychology]. Beltz.

Schiepek, G., Eckert, H., & Weihrauch, S. (2005). Prozessmonitoring dynamischer Systeme. [Process monitoring of dynamic systems] *Systeme*, *19*(2), 177–209.

Schiepek, G. K., Tominschek, I., & Heinzel, S. (2014). Self-organization in psychotherapy: Testing the synergetic model of change processes. *Frontiers in Psychology*, *5*, Article 1089. https://doi.org/10.3389/fpsyg.2014.01089

Schiepek, G., Schöller, H., Carl, R., Aichhorn, W., & Lichtwark-Aschoff, A. (2018). A nonlinear dynamic systems approach to psychological interventions. In Kunnen, E. S., De Ruiter, N. M., Jeronimus, B. F., & Van der Gaag, M. A. (Eds.), *Psychosocial development in adolescence: Insights from the dynamic systems approach* (pp. 51–68). Routledge.

Schmid, U., Ragni, M., Gonzalez, C., & Funke, J. (2011). The challenge of complexity for cognitive systems. *Cognitive Systems Research*, *12*(3–4), 211–218. https://doi.org/10.1016/j.cogsys.2010.12.007

Schön, D. (1991). *The reflective practitioner*. Ashgate Publishing.

Schoppek, W. (2002). Examples, rules, and strategies in the control of dynamic systems. *Cognitive Science Quarterly*, *2*(1), 63–92.

Schoppek, W. (2004). Teaching structural knowledge in the control of dynamic systems: Direction of causality makes a difference. In K. Forbus, D. Gentner, & T. Regier (Eds.), *Proceedings of the Twenty-Sixth Annual Meeting of the Cognitive Science Society* (pp. 1219–1224). Lawrence Erlbaum.

Schraagen, J. M. (Ed.). (2008). *Naturalistic decision making and macrocognition*. Ashgate.

Seligman, S. (2005). Dynamic systems theories as a metaframework for psychoanalysis. *Psychoanalytic Dialogues*, *15*(2), 285–319. https://doi.org/10.1080/10481881509348832

Slingerland, E. G. (2014). *Trying not to try*. Broadway Books.

Steffensen, S. V. (2013). Human interactivity: Problem-solving, solution-probing and verbal patterns in the wild. In S. J. Cowley & F. Vallée-Tourangeau (Eds.), *Cognition beyond the brain* (pp. 195–221). Springer. http://link.springer.com/10.1007/978-1-4471-5125-8_11

Sterman, J. D. (2000). *Systems thinking and modeling for a complex world*. McGraw-Hill.

Strijbos, S. (2010). Systems thinking. In R. Frodeman, K. J. Thompson, & C. Mitcham (Eds.), *The Oxford handbook of interdisciplinarity* (pp. 453–47). Oxford University Press.

Strunk, G., & Schiepek, G. (2006). *Systemische Psychologie. Einführung in die komplexen Grundlagen menschlichen Verhaltens.* [Systemic psychology. Introduction to the complex foundation of human behavior]. Spektrum Akademischer Verlag.

Sweeney, L. B., & Sterman, J. D. (2000). Bathtub dynamics: Initial results of a systems thinking inventory. *System Dynamics Review*, *16*(4), 249–286. https://doi.org/10.1002/sdr.198

Thelen, E., & Smith, L. (2004). *A dynamic systems approach to the development of cognition and action*. MIT Press.

Torrents, C., Balagué, N., Hristovski, R., Almarcha, M., & Kelso, J. A. S. (2021). Metastable coordination dynamics of collaborative creativity in educational settings. *Sustainability*, *13*(5), Article 2696. https://doi.org/10.3390/su13052696

Tschacher, W. (1997). *Prozessgestalten*. Hogrefe.

Tschacher, W., Schiepek, G., & Brunner, E. J. (Eds.) (1992). *Self-organization and clinical psychology*. Springer. http://link.springer.com/10.1007/978-3-642-77534-5

Turvey, M. T. (2007). Action and perception at the level of synergies. *Human Movement Science*, *26*(4), 657–697. https://doi.org/10.1016/j.humov.2007.04.002

Vallacher, R., & Nowak, A. (2007). Dynamical social psychology. Finding order in the flow of human experience. In A. Kruglanski & E. T. Higgins (Eds.), *Social Psychology: Handbook of Basic Principles* (pp. 734–758). Guilford Press.

Vallacher, R. R., Coleman, P. T., Nowak, A., & Bui-Wrzosinska, L. (2010). Rethinking intractable conflict: The perspective of dynamical systems. *American Psychologist*, *65*(4), 262–278. https://doi.org/10.1037/a0019290

Vallacher, R. R., Nowak, A., & Zochowski, M. (2005). Dynamics of social coordination: The synchronization of internal states in close relationships. *Interaction Studies*, *6*(1), 35–52. https://doi.org/10.1075/is.6.1.04val

Vallacher, R. R., Read, S. J., & Nowak, A. (2002). The dynamical perspective in personality and social psychology. *Personality and Social Psychology Review*, *6*(4), 264–273. https://doi.org/10.1207/S15327957PSPR0604_01

van Buuren, A., & Gerrits, L. (2007). Complexity. In M. Bevir (Ed.), *Encyclopedia of governance* (p. 131–135). Sage.

Van Orden, G. C., & Holden, J. G. (2002). Intentional contents and self-control. *Ecological Psychology*, *14*(1–2), 87–109.

Van Orden, G. C., Holden, J. G., & Turvey, M. T. (2003). Self-organization of cognitive performance. *Journal of Experimental Psychology: General*, *132*(3), 331–350. https://doi.org/10.1037/0096-3445.132.3.331

Varela, F. J., Thompson, E., & Rosch, E. (1991). *The embodied mind: Cognitive science and human experience*. MIT Press.

Vargas, B., Cuesta-Frau, D., Ruiz-Esteban, R., Cirugeda, E., & Varela, M. (2015). What can biosignal entropy tell us about health and disease? Applications in some clinical fields. *Nonlinear Dynamics, Psychology, and Life Sciences*, *19*(4), 419–436.

Vester, F. (2007). *Die Kunst vernetzt zu denken* [The art of network-based thinking]. dtv.

Wong, W. (2004). Critical decision method data analysis. In D. Diaper & N. Stanton (Eds.), The handbook of task analysis for human-computer interaction (pp. 327–345). Lawrence Erlbaum Associates.

Woods, D. D. (2006). Essential characteristics of resilience. In E. Hollnagel, D. D. Woods, & N. Leveson (Eds.), *Resilience rngineering: Concepts and precepts* (pp. 21–34). CRC Press. https://www.ida.liu.se/textasciitilde729A71/Literature/Resilience_T/Woods_2012.pdf

Zsambok, C. (1993). Naturalistic decision making: Where are we now? In C. Zsambok & G. Klein, *Naturalistic decision making* (pp. 4–16). Routledge.