Study of Organization without Strategy: Structural Rationality

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[E]conomists see rationality in terms of the choices that people make. Other social scientists view rationality in terms of the processes. I call the rationality of economics substantive rationality and the rationality of psychology procedural rationality.

Simon, 1986, p. 2

Abstract

Deliberate human action receives the first priority in researchers' attempts to understand social phenomena. Organization theory and strategy literature are no exceptions. Strategy as a purposive plan of action or path towards intended ends has been studied in the context of agents' cognition and rationality, subject to conditions in the implementation environment and interactions with its structures. Turning the focus from construction of strategy towards organization structures allows for the possibility that (1) aggregate-level outcomes with specific properties may emerge from structures through complex micro-level interactions among even non-strategic agents, and (2) these properties may exhibit some robustness to variations in individual behaviour. Extending on the counterintuitively efficient performance of 'zero intelligence' agents in certain markets, we explore the implications of supplementing the well-established framework of substantive and procedural rationality with *structural* rationality. In its minimalist spirit, structural rationality uses neither intent nor deliberate formation of strategy to arrive at the outcomes, and thus allows for differentiation among organizational outcomes arising from strategies and from structures.

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1 Modeling Elements: Agents, Paths, and Outcomes

Most extant models of human action have three main components: agents, paths and outcomes. Modelers characterize the properties of agents based on some notion of rationality and then construct a path which leads the agent from an initial condition to a desired outcome. In Herbert Simon's terminology, optimizing agents are characterized by *substantive rationality* and they arrive at the optimum outcome logically constructed from initial assumptions. Characterized by *procedural rationality*, boundedly rational agents attain near-optimum outcomes[2] through adaptive strategies, which lead them to (slightly) different outcomes along different paths. Substantively rational agents and their modelers use the same methods to construct the path to the optimum outcome. Modelers of boundedly rational agents do not themselves act as boundedly rational; they use instrumental logic to construct paths to be taken by adaptive agents themselves. Although both kinds of modelers use partially overlapping 'tool-sets', the procedural rationality approach takes empirical observations of paths taken by agents seriously, and tries to adjust the model of adaptive agents so their behaviour corresponds to what is observed. In Simon's words:

> [In treating rationality,] other social sciences [outside of economics] are more concerned about studying the individual and social processes in which individuals decide and act on their decisions. They study empirically the origins of values and how and why values change as individuals move through time and gain new experience. Economic theorists assume givens, as if they were facts, whereas in other social sciences, the investigator tries to determine empirically the substance of those givens. *Other social sciences also try to determine the calculating strategies that individuals use in the reasoning process that leads to decisions and actions*: people have limited information and limited computational abilities with which to function in a complex real world. In psychology, at least, researchers also have to describe and explain how nonrational processes [such as] human emotions and sensory stimuli shape the individual's focus of attention, which in turn fixes those aspects of the decision-making process that economists typically assume as givens. In short, economists see rationality in terms of the choices that people make. Other social scientists view rationality in terms of the processes. I call the rationality of economics *substantive rationality* and the rationality of psychology *procedural rationality*. (Simon, 1986, p. 2; emphasis added)

Simon describes economists as not concerned with establishing the empirical basis for the substance of their assumed givens. A common practice in economics is to choose a set of

[2] This raises the important question of which environments allow us to know the optimum, addressed in the final section.

givens from which it is mathematically tractable to derive an optimizing path that yields an optimum outcome – substantive rationality – for agents to follow (Simon, 1978; Mousavi & Tideman, 2019). Simon's work (1957, 1972) bridged the gap between human cognition and the assumptions required for achieving substantively rational outcomes by introducing the concept of bounded rationality. It considerably relaxed the demands that substantive rationality places on agent cognition and showed that near-optimum outcomes can be achieved with less-than-perfect cognition[3]. Simon's boundedly rational agent has since been developed in many forms, such as satisficer, heurist, maximiner, imitator, reciprocator (e.g., tit-for-tat), and in all cases the agent's path to the outcome is reconstructed logically from the respective specification of such an agent. That is, substantive and procedural rationality offer different approaches to micro-level modeling of agents and outcomes, but they share the same logical approach to and an overlapping tool set for (re)constructing the path to outcomes from their respective assumptions (Mousavi & Garrison 2003). They also share their constructivist approach to rationality (Smith, 2008) by deriving the final outcomes' properties from individuals' behaviour. It is central to our argument in this chapter that this methodology has given rise to a paradigm in which goals and even intent are attributed to inanimate organizations but attainment of these goals is assumed to require deliberately devised paths constructed by agents following logical strategies. Aggregation of micro-level models has shaped a sizable portion of literature on macro-level formalizations.

As an alternative approach to the goal-seeking paradigms mentioned above for the study of macro-level phenomena, we propose the concept of *structural rationality.* Under structural rationality, macro-level outcomes are seen as emergent properties of a complex system instead of being mere aggregates of actions of individual agents. In this approach, the details of how elemental interactions shape and emerge are not the modelers' target; in most cases, such derivations are not possible either. Complexity theory and the emergence literature leapfrog the exercise of reconstructing the path from micro-level behaviour to macro-level outcomes, thereby limiting agents' incentives and cognition to a minimal level in their models.

The concept of emergence in economics is traceable to Scottish Enlightenment thinkers such as Adam Ferguson (1767, p. 187), for whom spontaneous orders are "of human action, but not of human design", and to Hayek's analysis of sensory order with reference to the biology work of Bertalanfy (1933) and Woodger (1929):

[3] In the absence of optimum, real people, as opposed to the substantively rational agent, are not paralyzed with indecision but instead attain good-enough outcomes and move on. This is an empirical fact that,when taken into account, can also reduce demands on formalization.

> The peculiar properties of the elementary neural events which are the terms of the mental order have nothing to do with that order itself. What we have called physical properties of those events are those properties which will appear if they are placed in a variety of experimental relations to different other kinds of events. The mental properties are those which they possess only as a part of the particular structure, and which may be largely independent of the former. (Hayek, 1952, p. 47)

Beyond analyzing the human mind, Hayek placed emergent information aggregation and social coordination properties of markets at the centre of his understanding of prices arising in spontaneous social and economic orders (Lewis, 2016; Hayek, 1945; for a contemporary account with a similar thrust, see also Smith, 2008).

When Gode and Sunder (1993) discovered the allocative efficiency as a structural property of the outcomes in their market simulations, they labeled their minimalist agents *zero intelligence* (ZI). ZI studies use minimalist models of agent behaviour so as to identify properties of outcomes of social systems that might be relatively robust to a broad range of variations in how agents act. When a property of a social system (e.g., a market, an electorate, or an organization) is identified to be robust under alternative patterns of agent actions, it can be said to emerge from micro-level interactions among the behaviours of many agents who act within the environment and constraints defined by the social system. It can therefore be associated with the structure of the system instead of being attributed to agent behaviour. For example, Gode and Sunder (1993) found that in double auction markets, extraction of maximum possible surplus is relatively robust to variations in agent behaviour. Farmer, Patelli and Zovko (2005) report that the ZI model explained 96% of the variance in bid-ask spreads and 76% of the variance of price diffusion rates across 11 stocks traded in the London Stock Exchange. Their data "suggest that institutions strongly shape our behavior, so that some of the properties of markets may depend more on the structure of institutions than on the rationality of individuals" (p. 2259). For a broader survey of some of the related literature, see Ladley, 2012).

This very emergence of system-level properties from statistical mechanics of micro-interactions is the phenomenon of structural rationality that we emphasize. We use the insights from this literature to offer a new building block for the study of organizational strategy and to add a new element to the typology of rationality put forward by Simon in the epigraph above.

Our investigation here concerns the methods of modeling used for the formalization of these concepts, not the actual processes involved. As mentioned above, the paths of substantive and procedural rationality models assume different paths made by agents but use similar tools and in general the same method of logical reconstruction to formally capture those paths. Note that these well-established and familiar approaches of substantive and procedural rationality posit strategy-based analysis of organizations. Alternatively, in our attempt to understand organizations, we let the emergent outcomes from actions of minimally intelligent agents – who function within the structural constraints of complex systems – have the first shot at explaining macro-level outcomes. By decomposing modeling of action into three elements and elaborating on the features of modeling methods, we effectively propose a new building block for the science of strategy. Using this third approach allows for an understanding of aspects of organizational outcomes through the structures in which agents interact without intelligence, intention or purpose, and thus do not strategize. As such, this approach can enrich theorizing about strategy by including attention to cases where organizational outcomes emerge from complex interactions but are not derivable or derived from individual actions. For example, a boundedly rational entrepreneur has been conceptualized as an effectuating agent. In effectuation theory of entrepreneurship (Sarasvathy 2001, 2008), organizational outcomes are not derivable from principles such as *bird-in-hand*, *affordable loss*, *patchwork quilt* and *pilot-in-the-plane*. Instead, these characteristics of entrepreneurs are generalized from careful direct observation of their behaviour. Our proposed approach differs from effectuation in that it is not confined within the bounded rationality paradigm. Moreover, it is orthogonal to the existing work in strategy science that builds on characterization of organizations choosing their strategy as a deliberate attempt to compete in market settings (see, e.g., Porter, 1979).

<Table 1 –About here>

Table 1 juxtaposes our approach to substantial and procedural approaches in terms of the three elements of modeling. Row 1 in Table 1 shows that substantive rationality modeling begins with the specification of optimizing agents with personal goals, no cognitive limitations and logically chosen acts that lead them towards their optimal ends. Row 2 shows that procedural rationality modeling begins with the specification of a boundedly rational agent with specified cognitive limitations and aspiration to attain a satisfactory approximation of its goals, along with specification of the environment in which this agent acts. Under substantive rationality, the path to the goal is uniquely given. In contrast, approaching satisfactorily close to that goal may involve multiple iterations. Note that while substantive rationality implies both normative and descriptive accounts, procedural rationality may improve through iterations that can be envisioned as 'inner' loops of corrective feedback.

While gradual improvement through iterations in (procedural) rationality reflects the reality of limited cognition, as well as of an unforeseeable future, it also calls for repeated construction of the path to a goal in an adaptive manner, allowing for and generating multiple models of the same phenomenon for agents whose rationality is bounded in different ways, thus leading them on different adaptive paths. Table 2 summarizes this point.

<Table 2 – About here>

Modeling according to the structural rationality approach involves cognitively and economically minimalist agents along with environmental constraints within which the agents can act without any strategy, even randomly. There is no derivation of actions, strategies or paths, given that the aggregate-level outcomes emerge from interactions among numerous individuals' actions and environmental constraints.[4] What we propose is to complement the well-established and familiar substantive and procedural approaches to strategy science with structural rationality – a mapping from a combination of minimal non-strategic agents operating inside a set of institutional rules or environmental constraints that define the structure of a system onto characteristics of aggregate-level outcomes. This approach allows us to identify and isolate structural features of organizational (aggregate) outcomes from those arising from aspects of individual behaviour. The purpose here is emphatically not to claim that all or even most organizational outcomes are consequences of their structure and that individual human behaviour and characteristics are irrelevant at an aggregate level. Instead, structural rationality refers to the emergence of aggregate outcomes with distinct properties arising from interactions among micro-level actions of a large number of individuals. Both organizations and individuals may evolve over time, depending on their respective environments. (For a discussion of inner versus outer environment, see Sunder, 2004). Structural rationality applies to the emergence of a link between micro- and macro-levels at all points of time, and to the stages of evolutionary adjustments (Mousavi & Sunder, 2022).

Definitions, derivations, or descriptions of paths that logically or adaptively link agents to outcomes are not the focus of the emergence-based structural rationality approach. Parenthetically, we are aware of the existing use of the term *structural rationality* in philosophy. In particular, Nida-Rümelin (Gutwald & Zuber 2018) has reconciled instrumental

[4] The reader familiar with the metaphor of Simon's scissors (see Chapters. 7–9) might wonder whether structural rationality focuses on only one of the two blades, the task environment. However, the scissors metaphor is not applicable to structural rationality. The two blades of the scissors concern modeling of individual behavior as a result of interactions between agent cognition and the environment in which the agent acts. In contrast, structural rationality models aggregate outcomes which are linked to micro-level interactions only through complexity and emergence.

rationality with rational choice theory, whereby the philosophy of action challenges instrumental rationality on normative grounds by questioning the very premise of the latter: Must an action be rational? This question is especially pertinent to modeling practice in economics. Economists have used the logic of instrumental rationality as the basis for axiomatizing rational choice theory, where the criterion of consistency mandates a unique reasoned path towards achieving a given goal. Nida-Rümelin draws attention to the plurality of reasoning evident in patterns of interaction and meaning. His concept of structural rationality bypasses the problem of accounting for sources of these patterns. In this sense, his view corresponds to the emergence-based formulation we present here, which also bypasses the reconstruction of path(s) from the agent to aggregate outcomes altogether. In recognizing a certain commonality with Nida-Rümelin, we maintain the instrumental functionality of rationality without attempting to specify its process in a coherent, logical format. The latter, however, is the primary thrust of modeling in both substantive and most procedural rationality models. One exception is the tradition of ecological rationality, with correspondence and adaptive fit between heuristic strategies and environmental structures at its heart (Gigerenzer, Reb, & Luan, 2022; Remic & Dekker, 2017; Mousavi & Kheirandish, 2014; Mousavi, Neth, Meder, & Kheirandish, 2017; Smith, 2008, Gigerenzer, Todd, & the ABC Research Group, 1999; see also Chap. 8 in this volume.)

Finally, de-emphasizing the specific characterization of individual choice (of which the ZI approach is an example) contrasts with a game theoretic approach to organizational strategy and is therefore a substantial departure from methodological individualism as a 'touchstone' of mainstream economics (Arrow, 1994; on the centrality of methodological individualism across social sciences, see also Longino, 2019). We invite the reader to experiment with our non-strategic stance and get a taste of structural rationality to explore complexity and the emergence of outcomes in organizations. The rest of this chapter is a companion for such exploration: Section 2 clarifies our intended meaning of complexity and casts it as a system-level property; Section 3 brings home our main points on institutions and rationality.

2 Complexity

Complexity arises in models in several ways. *Constructive complexity* involves the familiar dictionary meaning of a complicated or intricate nature of an object, phenomenon or process. *Representational/computational complexity* refers to the difficulty of solving a problem, or the time it takes for a given algorithm to find the solution. These constructive and representational/computational aspects are not the forms of complexity we explore here. We reserve the term *complexity* for a third meaning familiar from complexity theory, commonly labeled as *structural complexity*. It refers to the emergent properties of outcomes observed at a more aggregate level that arise from difficult-to-analyze local interactions among elements of the system *at a level next beneath*.

In their focus on different aspects of complexity, each approach to rationality devises a different modeling method. Substantive rationality modelers rely on abstraction and axiomatization to retain optimizability throughout the construction of the path. Procedural (bounded rationality) modelers, in the main, study the adaptive use of heuristics and their ecological rationality in situations of uncertainty and intractability, that is, where optimization is not an option (see the comparison of the axiomatic-based approach to ecological rationality in Gigerenzer, 2019). These methods have been extensively applied to organizational strategy. Our proposed structural rationality approach is fundamentally different from these methods in that it bypasses the path-building stage of modeling altogether; it offers a framework for exploring emergent outcomes that arise from complex interactions. Our approach also differs from the line of work using complex adaptive systems to study organizational structures and outcomes (for an extensive review of management strategy in relation to complex adaptive systems, see Anderson, 1999, and for internal vs. external complexity, see Jost, 2004).

2.1 Organization as a complex physical phenomenon

In the conventional approach to organizational behaviour, both the structure and the properties of organizations are thought to be derived from the nature, preferences, abilities, circumstances and motivations of their constituent parts – their individual members. In our proposed approach, the complexity of a system arises from the presence of non-linear feedback loops that may generate, from even small differences in initial conditions, large and unpredictable consequences for the system outcomes. Such properties, well documented in physical systems and increasingly in social ones, make it impossible to have any simple mappings (e.g., regression and analysis of variance models, often used in many social sciences) between the properties and behaviour of individual components of a system and the system-level outcomes.

Non-linear feedback loops are generically present in organizations just as they are in physical systems. Given that exploration of complexity is already advanced in physics, using that scaffolding is prudent for our study of the consequences of complexity for organizational strategy. Turner and Killian’s (1987) emergent social norms theory and other theories of crowd behaviour (see Reicher, 2000) and theories of fashions and fads (Bikhchandani, Hirschleifer, & Welch, 1992) are examples of social science's attempts to capture non-linear feedback in complex systems and its consequences.

Drawing on physical laws to frame the structure for modeling human behaviour has solid precedents. For instance, movement of large crowds has been modeled as the flow of fluids (see Helbing, 1992, 2001; Moussaid & Nelson, 2012). However, that does not mean that individuals in a crowd lose their identity or agency; all it means is that when analyzing the behaviour of a large crowd of human beings as a whole, analysis of an individual's conscious thoughts, efforts, actions and strategies – the higher faculties with which we humans so proudly believe ourselves to be uniquely endowed – may be of only limited value.

The approach we discuss in the current chapter is an application and extension of a broader programme outlined in Mousavi and Sunder (2019). They presented a three-tier framework for the study of action and propose modeling in this order: physics, biology and socio-psychology. Following this order, a modeler starts by choosing a universal law of physics such as the principle of least action (PLA) to organize the observed phenomenon. Choosing PLA amounts to specifying the method of decomposing an observed phenomenon of interest in terms of three components: optimization or action elements, external or fixed elements and configuration of the resulting path between the start and the end points. Applying this method to model a player catching a fly ball consists of an optimum path between the start and end points, and identical travel time of the ball and the player (the external elements); and the (parabolic in vacuum) path of the ball. Notice that both the external elements and the path are merely physical entities. Before discussing and configuring the physical form of the action element, we digress to address a commonly asked question in this context: *How* does the runner catch the ball? Richard Dawkins famously answered the question from an evolutionary biology stance:

> When a man throws a ball high in the air and catches it again, he behaves as if he had solved a set of differential equations in predicting the trajectory of the ball. He may neither know or care what a differential equation is, but it does not affect his skill with the ball. (1976, p. 96)

Cognitive scientists have formulated an explicit answer based on the evolutionary capacity of humans and animals to hold their gaze on moving objects. The process has been dubbed the *gaze heuristic* (Hamlin, 2017). In the case of a baseball game, it refers to a player keeping the angle of gaze on the ball constant with respect to the horizon while moving towards the ball until the player and the ball meet, just before the latter falls to the ground. It is in addressing the practice of modeling the *how* of action that Mousavi and Sunder (2019) chose to start with physics instead of the higher faculties such as cognitive and evolutionary endowments. By reversing the traditional order of modeling and starting with physics, they formalized the observed phenomenon. In their three-tier framework, an action is viewed simply as a movement between two specified points. The thrust of the exercise is to remain within the boundaries of physics until its explanatory power is fully exploited. In modeling the catching of a fly ball, the action element that fits the physics law of PLA is the *change* in the gaze angle, which has to remain near zero; no biological or higher-order endowments are called upon. Table 3 compares the elements of modeling in the three-tier framework: the extant exercise versus the proposed reversed order. Following the latter method, the modeler looks to biology (second tier) and uniquely human endowments of social psychology (third tier) to assess residual observational variation only after the explanatory power of physics has been fully exhausted.

<Table 3 –About here>

Extending this approach, we propose viewing an organization, at a first tier of inquiry, as consisting of interacting individuals treated as if they are particles with given properties. An organization is thus defined by the rules of interaction among these individuals who, stripped of motivation, do not devise strategies. Because it bypasses strategy, our approach may be seen as an alternative to game theory that explores systems populated with strategizing agents. Although strategies and organizations may evolve over time, we focus on the link between micro-behaviour and macro-outcomes at *any* given point in time. One may ask if the ever-changing landscapes call for the organizations to anticipate the future and strategize more, not less. We favour exploring the limits of using simple and robust structural features before resorting to more complex and anticipatory strategy construction. Corroborating this approach in practice are the simple rules for dealing with a complex world of entrepreneurship studied by Eisenhardt and colleagues (see, e.g., Sull & Eisenhardt, 2016). We intend to focus on organizational outcomes, the ‘givens’ in Simon’s terminology, which can be configured without reference to strategies – an extension of allocatively efficient outcomes arising from complex interactions among zero intelligence agents in markets. All arguments we put forward on organizational structure are susceptible to being amended by dynamic approaches to organizational processes for dealing with external changes of variant nature and frequency.

The first tier of our approach is purely physical. It abstracts from the ‘human’ elements, treating organizations as a collection of interacting particles subject to a set of rules defined by their structure. Because the properties of the whole may emerge from micro-level interactions among components, decomposing the collective to its elements is neither feasible nor attempted. To put this view in perspective, consider the fact that known matter in the physical universe has cohered into discrete, mutually interacting aggregates at various levels – asteroids, satellites, planets, stars, galaxies and clusters of galaxies. At the first level of approximation, astrophysicists examine the properties of these heavenly bodies without paying much attention to the detailed properties of the particles that cohered to form them. The laws of physics brought these particles to cohere in discrete bodies without collapsing the universe into a single mass (indeed, there is evidence that the universe is expanding and bodies in it are flying apart from one another). To explain this agglomeration into larger clusters of varied shapes and sizes, the law of gravity applied to particles in a gravitational field seems to suffice.

Aside from in astronomy, a well-defined organization of smaller elements into collectives with predictable attributes occurs at innumerable other levels in physical (inanimate) nature: rivers, tornadoes, hurricanes, clouds, rocks and crystals, mineral deposits, volcanoes, fires and waves. As with human organizations, it is difficult to predict the existence of such 'organizations' in nature at any particular time or place, yet information about some of their aspects can teach us about other unobserved aspects of phenomena. The predictability of these attributes implies that even if outcomes might have arisen through random processes governed by laws of physical nature, they can be well organized and have emergent properties often absent, or undetectable, in their constituent elements.

By analogy, we can think of human organizations as agglomerations of people brought together by the 'gravitational' forces of human sociality, economies of scale and network effects. The same argument would apply to observed collectives or organizations of many biological organisms: a pride of lions, a gaggle of geese, a cloud of starlings, a beehive or a termite hill. Even the ganglia in a nematode worm provide a simple version of a biological organization (Cherniak, 1994).

The three parts presented in Table 1 (Section 1) – agents, paths and outcomes – appear in many models of different forms of organizations. For example, Boyd & Richerson (2005) compiled and shared their decades of research on how genes and cultures co-evolve to shape the sociality of our species, and Jackson (2008) used network analysis to portray human behaviour (including strategizing) arising in a host of individual and social contexts by drawing on psychology, economics, sociology, computer science and physics. Our proposal adds to this research and offers an alternative approach to studying outcomes, while bypassing the construction of paths and limiting each agent to minimal levels of rationality. In what follows, we explain how agents with minimal or no strategy and intelligence can generate efficient aggregate outcomes, depending on the structure of their environment – hence, the name *structural rationality*.

2.2 Near-decomposability versus structural continuity

Each organization has its structure that defines the environments in which various tasks are pursued. We ask whether the complexity of tasks must be reflected in the complexity of strategies to achieve them[5] (this use of *complexity*, referring solely to complicated formats of tasks, differs from what our specified meaning of the term earlier). We note that when phenomena of interest occur at a higher level of aggregation, it is not necessarily useful to dig deep into the behaviour of micro-level components of the system, akin to the way in which Simon pictured the scientific endeavour:

> This skyhook-skyscraper *construction of science* from the roof down to the yet unconstructed foundations was possible because *the behavior of the system at each level depended on only a very approximate, simplified, abstracted characterization of the system at the level next beneath.* This is lucky, else the safety of bridges and airplanes might depend on the correctness of the 'Eightfold Way' of looking at elementary particles. (1996, p. 16; emphasis added)

Practical examples of this wisdom regarding the decomposability of systems at various hierarchical levels are present in all fields of human endeavour. According to Simon in his last public lecture (2000, p. 8): "[Such systems] are arranged in levels, the elements at each lower level being subdivisions of the elements at the level above. Molecules are composed of atoms, atoms of electrons and nuclei, electrons and nuclei of elementary particles. Multi-celled organisms are composed of organs, organs of tissues, tissues of cells". Simon argued that near-decomposability is an efficiency-enhancing feature in evolution because it enables evolution of one layer through natural selection without too much drag from interaction with other layers. Although Simon also mentioned the evolutionary advantage of near-decomposability across layers (see his example of specialization of labor across sub-units), there are arguments in biology to the contrary, such as Darwin's (1858) and Gould's (1985) argument about functional change and structural continuity in the evolution of various organs that makes evolution possible.

[5] This question has been famously addressed with a resounding 'no' in Simon's (1956) example of an ant moving along a sandy beach in complicated paths following a simple rule: change direction when hitting an obstacle. Here, we consider this problem from a different angle of aggregate-level emergence.

Visual images can be broken down into their elements, all the way to the smallest pixels discernible to the human eye. Yet landscape painters do not paint each leaf of a tree nor each tree in a forest, just as portrait painters do not paint each hair on a head or crease in the skin. Instead, painters skillfully apply paint with practiced strokes of a brush or knife – which may appear to be chaotic on closer scrutiny –to appear as an artistic composition when seen from a distance (see Monet's "The Turkeys" from 1877 in Figure 1). In another case of visual aggregation, the 1968 Apollo space mission photograph of earth as a blue marble suspended in black space above the lunar surface exhibits hardly any similarity to a close-up photograph of grass in a lawn on the same surface (Figure 2). At the aggregate level, in the view from deep space, the details of each blade of grass one sees sitting in a lawn are discarded and a totally different, previously unseen big picture of our place in the larger universe – all eight billion of us clinging to a ball floating in empty darkness – emerges before our eyes. Neither of the two views of the earth is better or worse, nor is either derivable from the other. Buddhist Madhyamika philosophy offers a parallel concept to this, *dependent co-arising* (*pratityasamutpada* in Sanskrit; see Macy, 1979).

<Figure 1 –About here>
<Figure 2A and 2B –About here>

These examples illustrate that the distance from the object matters not only in terms of how much is seen but also in terms of what is seen by the observer. Distance being a physical magnitude, its effect on transmission of information is subject to laws of physics. But the difference it makes to perception is a matter of cognition and neuroscience. Studies of optical illusions focus on the gaps between these two perspectives.

Decomposability of systems into their components does not mean that the properties of systems are necessarily derivable from the properties of their components. The time-keeping property of a watch cannot be derived from identifiable properties of its components any more than the life of an organism can be attributed to the properties of its organs, or the frenzy of a mob traced back to the personalities, motivations and circumstances of individuals in the group.

The new insight we attempt to provide here comes from examining the properties of various organizational structures when they are assumed to be populated by ZI or minimal-intelligence agents. In economics, Gode and Sunder (1993) showed that the aggregate-level allocative efficiency of simple double auctions[6] is robust to variations in agent behaviour.

[6] In a double auction, both buyers and sellers, endowed with their respective private values of costs, are free to announce bids (prices at which they are willing to buy) and asks (prices at which they are willing to sell).

> Some features of market outcomes are largely robust to variations in the decision-making behavior of agents who participate in them. Allocative efficiency, a key measure of market outcomes, is one such feature. *Adam Smith's conclusion that the allocative efficiency arises from individual pursuit of self-interest may be more general than it appears.* Efficiency is achievable in double auction markets even if agents act randomly within their budget constraints. Random choice within one's opportunity set is, at best, only a weak form of "pursuit of self-interest." The use of the maximization assumption to derive market equilibria in economics and the findings from cognitive psychology that individuals cannot and often do not know how to maximize need not be seen to be mutually inconsistent. Market institutions may be the society's way of dealing with the human cognitive limitations. In classical environments, markets can approach the aggregate maximum even if the individuals do not know how to. (Sunder, 2004, pp. 518–519)

Specifically, markets populated with simple ZI agents can have the same allocative efficiency as similar markets populated by profit-motivated human agents. In other words, the surplus extraction property of these markets is relatively robust to variations in agent behaviour. This approach has been applied to study a variety of systems, of which a few examples are given below.

Much research has followed the initial report on findings on ZI agents, including attempts to bridge the gap between ZI and fully rational agents. Adding elements of rationality to agents does, as one would expect, tend to bring more aspects of aggregate-level outcomes – especially transaction prices – closer to observations from institutions populated with motivated human agents. Readers interested in the literature on incrementing the intelligence of agents by equipping them with more sophisticated strategies, such as ZI-Plus (ZIP) can find a rich sample of published work, including Chan, LeBaron, Lo, and Poggio (1998), Gjerstad and Dickhaut (1998), Yeh (2007, 2008), Cliff (2009), Chen, Zeng, and Yu (2009), Huber, Shubik, and Sunder (2010), De Luca and Cliff (2011), and Palit, Phelps, and Ng (2012). This literature on the outcomes of markets populated with agents of varying levels of intelligence and trading strategies, and on comparisons with human-agent markets, is of substantial interest, especially in theories of learning, computational economics and psychology. The question addressed in this literature is: What features of artificial agents are sufficient to achieve market-level outcomes close to markets populated by human subjects in the laboratory or field?

However, the direction of this pursuit to create artificial intelligence is diametrically opposed to the focus of our present inquiry, which is aimed at exploring emergence and

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Whenever the bid price equals or exceeds the ask price, a transaction is executed between the buyer and the seller.

structural rationality as an alternative to the conventional modeling practice of constructing and deriving strategies, paths and outcomes from the behaviour of goal-oriented rational agents. The key feature of the present inquiry is not the characteristics, in particular the intelligence, of agents, but the structural properties of social institutions that are relatively robust to agent behaviour. This inquiry is an alternative to game theoretic strategy refinement and to reinforcement and other schemata based on learning. For example, markets with minimally intelligent agents can generate outcomes that closely approximate the equilibrium results from Walrasian *tâtonnement* (Crockett, Spear, & Sunder, 2008) even under a variety of market protocols (e.g., sealed-bid and double auctions). Critical assessments and explorations of the limitations of the initial and subsequent findings of ZI agents are available in a body of literature, including but not limited to the following: Cliff and Bruten (1997), Chen and Tai (2003), Posada, Hernández, and López-Paredes (2006), Miller (2008), Schwartzman and Wellman (2009) and Othman and Sandholm (2010).

2.3 From markets to organizations

Economic studies of markets have revealed institutional properties to be governed by structural rationality. This phenomenon is summarized in Sunder (2004):

> As social artifacts, markets are the arena for the interplay of demand and supply. Functionality of markets can be assessed by their robustness to certain environmental variations and responsiveness to others. We prefer markets to be robust to variations in individual cognitive capabilities and responsive to their wants and resources. If creation without a creator and designs without a designer are possible, we need not be surprised that markets can exhibit elements of rationality absent in economic agents. (p. 517)

Applying the structural rationality of complexity in the economics of markets to organizational science calls for specifying answers to at least three important questions.

- What are the defining features/characteristics of organizations and institutions?
- What are the important aspects of the environment in which the organization operates?
- What are the important characteristics of outcomes of organizations?

Organizations are viewed as networks of economic agents, each endowed with knowledge, opportunity sets and preferences, related to one another by links of communication, expectations and opportunities for voluntary exchange. In this sense, each family, neighborhood, school, hospital, town, professional association and country is an organization. A society has many organizations with overlapping participation, seeing as any single individual typically participates in numerous organizations in a variety of roles. As Barnard (1938, p. 73) eloquently put it:

> I select at random a man who is chiefly identified by his connection with the organization with which I am also ordinarily identified. He is an engineer whose career and living for many years have depended upon that organization. Without enquiry, I know he has the following organization connections also: He is (1) a citizen of the United States, the State of New Jersey, the County of Essex, and the City of Newark—four organizations to which he has many inescapable obligations; he is a member of (2) the Catholic Church; (3) the Knights of Columbus; (4) the American Legion; (5) the Outanaway Golf Club; (6) the Democratic Party; (7) the Princeton Club of Newark; (8) he is a stockholder in three corporations; (9) he is head of his own family (wife and three children); (10) he is a member of his father's family; (1l) he is a member of his wife's family; (12) to judge from his behavior he belongs to other less formal organizations (but often seems not be aware of it) which affect what he wears, how he talks, what he eats, what he likes to do, how he thinks about many things; and (13) finally he gives evidence of "belonging" also to himself alone occasionally. Lest it be thought that his "major" connection is predominant, and the others trivial, it may be stated that he devotes to it nominally less than 25 percent of his approximately 8760 hours per annum; and that actually while he thinks he is working, and despite his intentions, he dreams of fishing, reflects on family matters, and replays a part of the previous evening's bridge, etc.

An institution is a social framework of norms, expectations, laws, rules, customs and contracts that defines the context or environment in which organizations are created, run and liquidated (For an extensive discussion of institutions in relation to economics, see North, 1990). For example, marriage and family are two institutions within which millions of specific couples and kinship groups live. Nation state is an institution that defines the context of much larger groups of individuals, often but not always with shared culture, language, laws, customs and governance, who live in a shared territory within which they are free to move. A democracy can also be seen as an institution, which many nation states and other forms of organizations may choose as their framework. In common usage, the term *institution* is sometimes used to denote a specific organization to emphasize its importance, longevity, name recognition and good reputation. Yet, as a technical term, it seems better to reserve it for a more abstract concept of some shared characteristics of a given *class* of organizations. In this sense, marriage and family are two institutions, whereas a married couple exists in the institution of marriage and, together with their children and some others, may exist in the institution of family, clan or tribe.

The meaning of *goals of an organization* remains ambiguous. When an organization is seen as a set of mutual expectations and contracts among various agents, the union of goals of all participating individuals can also be attributed to the organization. However, this set is almost always quite diverse, and not a good instrument for attributing agency to the organization itself. Often, the goals of some subset of organization's participants, such as owners of capital or top managers, are also attributed to the organization itself. This practice has little theoretical basis and is not useful for analysis. The concept of organizational strategy likely arises from this perspective on organizational goals, and we shall not defend it. Instead, we choose to take a ZI approach to agent behaviour and focus on assessing how organizational outcomes emerge from complex interactions among the actions of their participating agents within the constraints of its structure. The existing findings that agents in certain markets do not have to devise intelligent strategies to produce efficient outcomes (ZI results) justifies this approach in the study of strategy in organizations. Stripping agents of strategy relieves modelers from the challenges of capturing and representing complicated individual objectives and capabilities. What remains can be viewed as the environment, consisting of laws, social norms and expectations, in which the agent is constrained to operate (See Gode & Sunder, 2004, and Sunder, 2006 on economic interactions within constraints).

The performance of organizations is measured by properties of their outcomes, including efficiency, effectiveness and longevity. Identifying important outcomes can be a first step towards sorting out what features of an organization are relevant to them. Using simulations, we are currently examining the distinction between hierarchy and centralization in organizations and its relevance for their efficiency. We have not yet found solid evidence of this effect but are devising different schemes to probe the idea by defining measurable proxies, as explained below.

The effectiveness of an organization is assessed according to its ability to reach its purported objectives or goals, without regard to the necessary resource sacrifices. If a business sets a goal of reaching a sales revenue of $1 million and its revenue is $900,000, it is 90% effective.

Efficiency, by contrast, modifies effectiveness by assessing the achievement of goals under consideration of the resources sacrificed in the process. When goals can be quantified in commensurate units in denominator, and sacrifices can be quantified in commensurate units in numerator, the input/output ratio is called efficiency. Engineers may assess the fuel efficiency of a car as a ratio of miles/gallon, and economists may assess the efficiency of a factory as the ratio of the sum of values of all its products and the sum of costs of various inputs such a labor, material and machinery. Under the network of (or set of contracts among) agents, the representation of organizations alluded to earlier in this section, we can employ the following simple definition of efficiency: Calculate the sum of resources all agents receive from the organization and the sum of resources sacrificed by all agents in their relationship with the organization after reducing these two quantities, if possible, to a common unit of measurement. Then, in resource units, organizational efficiency can be defined as the difference between these two sums because that is the total surplus generated by the organization. Alternatively, in percentage terms, used more often in engineering, efficiency can be defined as the ratio of these two sums. We assume that the challenging problem of commensurability – reducing all resource flows to a single unit – has somehow been addressed because all resource flows are rarely in the same units and may not always be quantifiable.

3 Structural Complexity of Organizations

To address the structural complexity of organizations, we focus on organizational outcomes, or 'givens', to use Simon's terminology. Simon named two primary forms of rationality used in the social sciences for modeling human behaviour: (i) substantive rationality (used mainly in economics) to optimally characterize agent behaviour and outcomes and (ii) procedural rationality (used across the social sciences) to explore the processes that generate individual behaviour. We argued that modelers in both approaches share a common ground in the construction of best possible paths based on individual choice derivable from specifications of the agent's rationality. Bringing the third notion of structural rationality into the mix, we set out on a new exploration of 'organizational behaviour' that leapfrogs (re)construction of paths and strategizing altogether. Viewing outcomes as (given) emergent phenomena, the task of the modeler becomes specifying the structure of environments, which generate outcomes through complex interactions among agent actions. This third approach to rationality focuses on identifying those characteristics of aggregate-level outcomes which are relatively robust to variations in agent behaviours and strategies. To elaborate, we recounted the three decades of work on randomly acting agents in double auction and other markets, namely, the ZI agent.[7]

We argued that development of a strategy science would benefit from incorporating the cases of organizational outcomes that are not derived from agents' deliberate strategy

[7] While the statistical characterization of ZI agents acting randomly according to a uniform distribution in the context of computational experiments is relatively recent, the general idea has earlier roots. According to Jaffe (1976, p. 521), Carl Menger, a pillar of Austrian economics, thought: "Man … far from being a 'lightening calculator,' is a bumbling, erring, ill-informed creature, plagued with uncertainty, forever hovering between alluring hopes and haunting fears, and congenitally incapable of making finely calibrated decision in pursuit of satisfactions". This description contrasts sharply with Veblen's (1919, p. 73) widely known criticism of 'man' in Austrian economics as a "lightning calculator of pleasures and pains, who oscillates like a homogeneous globule of desire of happiness under the impulse of stimuli that shift about the area but leave him intact."

choice but instead simply emerge from the structure of the organization as defined by its operating rules. Examining the efficiency of outcomes of organizational structures under a variety of agent behaviours, especially the extreme of random behaviour, is a useful approach to identifying organizational performance characteristics that arise from their structure rather than from the specifics of their members' behaviour. This approach therefore dispenses with the methodological individualism that governs both substantive and procedural rationality modeling.

The central thesis of the current chapter is twofold. First, the study of strategy as a science can begin by clarifying the issue of organizational outcomes in absence of deliberate strategies. Second, the ZI agents can serve as a starting point in investigating structural properties of organizations. With these two premises, we proposed exploration of the complexity in organizations through the lens of structural rationality. Procedural rationality and (structural) emergence approaches share two important features. First, the two admit a multiplicity of paths to a given outcome. The relationship between structural rationality of emergence and ecological rationality is described by Sunder (2009, p. 107) as follows.

> Deliberate as well as intuitive actions that arise beyond the reach of conscious reason are taken within the social environment defined by the rules and institutions and interact in complex ways. These interactions define institutions and give rise to the aggregate level outcomes and institutions. The resulting tacit knowledge and tendencies constitute the ecological order of rationality beyond our self-awareness.

Second and perhaps more important, the applicability (and likely the effectiveness) of both approaches to rationality has a broader scope as compared with that of substantive rationality.[8] Substantive rationality is concerned with optimum solutions which are definable only when the decision problem is fully specified, that is, when all possible options and states of the world (and their probabilities, when appropriate) are known. This is hardly ever true outside of completely structured environments such as a game of roulette in a casino. Savage (1954/1972) labelled such situations as 'small-world' scenarios, where knowledge of states and their probabilities renders it possible to conduct 'risk' analysis. In small worlds optimum is well defined, and it possible to deploy the concept of substantive rationality. But in Savage's 'large worlds' in which we actually live and work nearly all the time, either the states of the world, or their probabilities or both are unknown. Knight (1921) clearly distinguished this environment of 'uncertainty' from the above-mentioned 'risk'. Substantive

[8] We are grateful to Gerd Gigerenzer for raising this important issue.

rationality, with its total dependence on knowledge of optimum solutions, cannot be deployed under uncertainty. In contrast, structural rationality and procedural rationality, with its emphasis on bounded cognition, rules of thumb and heuristics, face no such limitations and perform robustly in worlds both small and large, under risk as well as uncertainty.

Aggregate outcomes can be descriptively relevant without individual optimization. This issue has been a challenge in economics (Simon, 1978, 1996), and has been addressed from many perspectives.

> "Why is it that human subjects in the laboratory frequently violate the canons of rational choice when tested as isolated individuals, but in the social context of exchange institutions serve up decisions that are consistent (as though by magic) with predictive models based on individual rationality?" (Smith, 1991, p. 894).

> "In spite of its mathematical complexity, the competitive model is very crude when placed in the context of these interactive markets and behaviors. Nevertheless, if the assumptions of the model are applied with an „as if" interpretation, the resulting model is very powerful. ... The markets appear to be capable of solving not only the problem as posed by the competitive theory but also even harder problems. ... In essence, the mathematical problem was solved quickly and without all the relevant information existing in a single place. The participants knew only their own parameters and none of the theory. Some sort of processing appears to be taking place but its form remains a mystery." (Goodfellow & Plott, 1990, p. 983)

This magic embedded in the processes governing complex interactions has been extensively studied as strategy choice attributed to the operators inside an organization. In our proposed approach, however, it is left a mystery and thus allows for the success of unsupervised processes in organizations.

Here we looked at three approaches to rationality for modeling human behaviour and organizations. Conventionally, both the structure and the properties of organizations are thought to be derived from the nature, preferences, abilities, circumstances and motivations of substantive or procedurally rational agents. We introduced a third approach, that of structural rationality, which bypasses the reconstruction of paths. Whereas an optimizing agent follows a logical path to arrive at the optimum outcome, a boundedly rational agent can arrive at a satisficing outcome by choosing from a variety of ecologically rational paths. A ZI agent, on the other hand, devises no strategies. Our paper initiates an effort to develop a configuration of organizations with ZI agents as a new building block for the science of strategy. Here, specification of the path or strategy is not of primary concern. Instead, we extend on a three-tier framework in which human action is explained, at its first approximation, by physical principles. We propose to transition from individual to collective outcomes through a similar physical-based configuration of the emerging properties of organizations. This idea can be viewed as a contribution to the literature on the structural aspect of complexity, wherein properties of a collective need not be derived from properties of its elements.

Our position on theoretical concepts of complexity is twofold. First, we distinguish between its common-sense meanings and formal mathematical definitions. Constructivist efforts, including those of strategy science, are primarily concerned with the common-sense meaning of complexity (i.e., complicatedness) and simplification of it by making explicit representations of the processes that lead to outcomes. This practice can be precise, as in substantive rationality, or made operationally tractable by allowing for sub-optimality, as in procedural/bounded rationality. Second, we use the mathematical definition of complexity (as conceived in complexity theory) and place it at the centre of our inquiry. The focus is on the structural or aggregate phenomena whose properties are not to be sought directly and exclusively in the properties of its elements. We start with observed outcomes as givens, thus minimizing the need to specify goals and strategies.

If a strategy is viewed as consciously building a path towards an intended end, we propose studying organizations without considering strategies. For this reason, ours may appear to be an unusual contribution to strategy science (and more like anti-game theory). But developing the science of strategy also calls for exploring the properties of organizations that are achievable without a strategy. Putting aside all outcomes that emerge from minimal-intelligence or non-strategizing agents within the structure of an organization leaves us with the outcomes associated with deliberate and possibly complex strategic behaviour. This subset of outcomes observed or desired (that do not simply result from organizational structure) can be thus understood by reconstructing the strategies that would generate them. We hope that such a radically different perspective will stimulate heterodox scholarly thinking and prompt further debate, adding to the original frames of organizational behaviour put forward by Herbert Simon.

References

Anderson, P. (1999). Complexity theory and organization science [Special issue]. *Organization Science*, *10*(3), 216–232.

Arrow, K. J. (1994). Methodological individualism and social knowledge. *American Economic Review*, *84*(2), 1–9.

Barnard, C. I. (1938). *The functions of the executive*. Harvard University Press.

Bertalanffy, L. V.(1933). *Modern theories of development: An introduction to theoretical biology* (J. H. Woodger, Trans.). Oxford University Press.

Bikhchandani, S., Hirschleifer, D., & Welch, I. (1992). A theory of fads, fashion, custom, and cultural change in informational cascades. *Journal of Political Economy, 100*(5), 992–1026.
Boyd, R., & Richerson, P. J. (2005). *Not by genes alone: How culture transformed human evolution*. University of Chicago Press.
Chan, N., LeBaron, B., Lo, A., & Poggio, T. (1998). Information dissemination and aggregation in asset markets with simple intelligent traders (C. B. C. L. Paper No. 164; A.I. Memo No. 1646), MIT. https://dspace.mit.edu/handle/1721.1/7174; and https://www.researchgate.net/publication/2825017.
Chen, S. H., & Tai, C. C. (2003). Trading restrictions, price dynamics and allocative efficiency in double auction markets: Analysis based on agent-based modeling and simulations. *Advances in Complex Systems*, *6*(3), 283–302.
Chen, S. H., Zeng, R. J., & Yu, T. (2009). Co-evolving trading strategies to analyze bounded rationality in double auction markets. In B. Worzel, T. Soule, & R. Riolo (Eds.), *Genetic programming theory and practice VI. Genetic and evolutionary computation* (pp. 1–19). Springer.
Cherniak, C. (1994). Component placement optimization in the brain. *Journal of Neuroscience 14*(4), 2418–2427.
Cliff, D., & Bruten, J. (1997). *More than zero intelligence needed for continuous double-auction trading*. Hewlett Packard Laboratories HPL-97-157, December, 1997. https://www.hpl.hp.com/techreports/97/HPL-97-157.pdf
Cliff, D. (2009). ZIP60: Further explorations in the evolutionary design of trader agents and online auction-market mechanisms. *IEEE Transactions on Evolutionary Computation 13*(1), 3–18.
Crockett, S., Spear, S., & Sunder, S. (2008.) Learning competitive equilibrium. *Journal of Mathematical Economics 44*(7–8), 651–671.
Darwin, C. (1859). *On the origin of species by means of natural selection, Or, the preservation of favoured races in the struggle for life*. John Murray Publisher.
Dawkins, R. (1990). *The selfish gene*. Oxford University Press.
De Luca, M., & Cliff, D. (2011). Human-agent auction interactions: Adaptive-aggressive agents dominate. *Proceedings of the 22nd International Joint Conference on Artificial Intelligence*, 178–185. https://www.ijcai.org/Proceedings/11/Papers/041.pdf
Farmer, J.D., Patelli, P., & Zovko, I. (2005). The predictive power of zero intelligence in financial markets. *Proceedings of the National Academy of Sciences USA, 102*(6), 2254–2259.
Ferguson, A. (1767). *An essay on the history of civil society.* https://oll.libertyfund.org/title/ferguson-an-essay-on-the-history-of-civil-society
Gigerenzer, G, Todd, P. M., & the ABC Research Group. (1999). *Simple heuristics that make us smart*. Oxford University Press.
Gigerenzer, G. (2021). Axiomatic rationality and ecological rationality. *Synthese*, *198*, 3547–3564.
Gigerenzer, G., Reb, J. , & Luan, S. (2022). Smart heuristics for individuals, teams, and organizations. *Annual Review of Organizational Psychology and Organizational Behavior*, *9*(1), 171–198.
Gjerstad, S., & Dickhaut, J. (1998) Price formation in double auction markets. *Games and Economic Behavior 22*, 1–29.
Gode, D. K., & Sunder, S. (1993). Allocative efficiency of markets with zero intelligence traders: Market as a partial substitute for individual rationality. *The Journal of Political Economy 101*(1), 119–137.
Gode, D. K., & Sunder, S. (2004). Double auction dynamics: Structural effects of non-binding price controls. *Journal of Economic Dynamics and Control 28*(9), 1707–1731.

Goodfellow, J., & Plott, C. R. (1990). An experimental examination of the simultaneous determination of the input prices and output prices. *Southern Journal of Economics*, *56*(4), 969–983.
Gould, S. J. (1985, October). Not necessarily a wing. *Natural History*, *94*, 12–25. (Reprinted in *Bully for Brontosaurus,* W.W. Norton & Co. 1991, pp. 139–151).
Gutwald, R., & Zuber, N. (2018). The meaning(s) of structural rationality. *ProtoSociology*, *35*, 314–321.
Hamlin, R. P. (2017). The gaze heuristic: Biography of an adaptively rational decision process. *Topics in Cognitive Science*, *9*, 264–288.
Hayek, F. A. (1945). The uses of knowledge in society. *American Economic Review*, *35*, 519–530.
Hayek, F. A. (1952). *The sensory order: An inquiry into the foundations of theoretical psychology*. University of Chicago Press.
Helbing, D. (1992). A fluid-dynamic model for the movement of pedestrians. *Complex Systems*, 6, 391–415.
Helbing, D. (2001). Traffic and related self-driven many-particle systems. *Review of Modern Physics*, 73, 1067–1141.
Huber, J., Shubik, M., & Sunder, S. (2010). Three minimal market institutions with human and algorithmic agents: Theory and experimental evidence. *Games and Economic Behavior*, *70*(2), 403–424.
Knight, F. H. (1921). *Risk, uncertainty and profit.* Houghton Mifflin Co.
Jackson, M. O. (2008) *Social and economic networks*. Princeton University Press.
Jaffe, W. (1976). Menger, Jevons and Walras de-homogenized. *Economic Inquiry*, *14*(4), 511–524. DOI: 10.1111/j.1465-7295.1976.tb00439.x.
Jost, J. (2004). External and internal complexity of complex adaptive systems. *Theory in Biosciences*, *123*, 60–88.
Ladley, D. (2012). Zero intelligence in economics and finance [Special issue]. *The Knowledge Engineering Review*, *27*(2). 273–286.
Lewis, P. (2016). The emergence of "emergence" in the work of F. A. Hayek: A historical analysis. *History of Political Economy*, *48*(1), 111–150.
Longino, H. (2021) Scaling up; scaling down: What's missing. *Synthese*, *198*, 2849–2863.
Macy, J. R. (1979). Dependent co-arising: The distinctiveness of Buddhist ethics. *The Journal fo Religious Ethics*, *7*(1), 38–52.
Miller, R. M. (2008) Don't let your robots grow up to be traders: Artificial intelligence, human intelligence, and asset-market bubbles. *Journal of Economic Behavior and Organization*, *68*(1), 153–166.
Mousavi, S., & Garrison, J. (2003). Toward a transactional theory of decision making: Creative rationality as functional coordination in context. *Journal of Economic Methodology*, *10*(2), 131–156.
Mousavi, S., & Kheirandish, R. (2014). Behind and beyond a shared definition of ecological rationality: A functional view of heuristics. *Journal of Business Research* *67*(8), 1780–1785.
Mousavi, S., Neth, H., Meder, B., & Kheirandish, R. (2017). Heuristics: Fast, frugal, and smart. In M. Altman (Ed.), *Handbook of behavioral economics and smart decision-making: Rational decision-making within the bounds of reason* (pp. 101–118). Edward Elgar.
Mousavi, S., & Sunder, S. (2019). Physical laws and human behavior: A three-tier framework. (Cowles Foundation discussion paper No. 2173). Yale University. https://ssrn.com/abstract=3374715" \t. doi:10.31219/osf.io/nmpc8
Mousavi, S., & Sunder, S. (2022). Emergence and embodiment in economic modeling. *Frontiers in Psychology, 13*: 814844.

Mousavi, S., & Tideman, T. N. (in press). Beyond economists' armchairs: The rise of procedural economics. In R. Viale (Ed.), *Handbook of bounded rationality*. Routledge.
Moussaid, M., & Nelson, J. D. (2012). Simple heuristics and the modeling of crowd behaviors. In U. Weidmann, U., Kirsch, U., & Schreckenberg, M. (Eds.), *Pedestrian and evacuation dynamics* (pp. 75–90). Springer..
North, D. C. (1990). *Institutions, institutional change, and economic performance*. Cambridge University Press.
Othman, A., & Sandholm, T. (2010). When do markets with simple agents fail? In *Proceedings of the 9th International Conference on Autonomous Agents and Multiagent Systems* (Vol. 1, pp. 865–872). International Foundation for Autonomous Agents and Multiagent Systems. https://dl.acm.org/doi/10.5555/1838206.1838322
Palit, I., Phelps, S., & Ng, W. L. (2012). Can a zero-intelligence plus model explain the stylized facts of financial time series data? In *Proceedings of the 11th International Conference on Autonomous Agents and Multiagent Systems* (Vol. 2, pp. 653–660). International Foundation for Autonomous Agents and Multiagent Systems. https://dl.acm.org/doi/10.5555/2343776.2343790
Porter, M. E. (1979). How competitive forces shape strategy. *Harvard Business Review* 57(2), 137–145.
Posada, M., Hernández, C., & López-Paredes, A. (2006). Strategic behaviour in continuous double auction. In C. Bruun (Ed.), *Advances in artificial economics: Lecture notes in economics and mathematical systems* (Vol. 584, pp. 31–43). Springer. https://doi.org/10.1007/3-540-37249-0_3
Reicher, S. D. (2000) Crowd behavior. *Encyclopedia of psychology* (Vol. 2, pp. 374–377). Oxford University Press.
Remic, B., & Dekker, E. (2017). *Ecological rationality: A conceptual history*. Erasmus University Working Paper. https://medialibrary.uantwerpen.be/oldcontent/container42730/files/Dekker%20and%20Remic-367765.pdf
Sarasvathy, S. D. (2001). Toward causation and effectuation: A theoretical shift from inevitability to economic entrepreneurial contingency. *The Academy of Management Review* 26, 243–263.
Sarasvathy, S. D. (2008) *Effectuation: Elements of entrepreneurial expertise. New horizons in entrepreneurship*. Edward Elgar Publishing.
Savage, L. J. (1972). *The foundations of statistics*. Dover. (Original work published 1954)
Schwartzman, L. J., Wellman, & M. P. (2009). Stronger CDA strategies through empirical game-theoretic analysis and reinforcement learning. *Proceedings of the 8th International Conference on Autonomous Agents and Multiagent Systems* (Vol. 1, pp. 249–256). International Foundation for Autonomous Agents and Multiagent Systems.
Simon, H. A. (1956). Rational choice and the structure of the environment. *Psychological Review*, *63*(2), 129–138.
Simon, H. A. (1957). *Models of man: Social and rational. Mathematical essays on rational human behavior in a social setting*. John Wiley.
Simon, H. A. (1972). Theories of bounded rationality. In C. B. McGuire & R. Radner (Eds.), *Decision and organization* (pp. 161–176). North-Holland.
Simon, H. A. (1978). Rationality as process and as product of thought. *American Economics Review*, 68(2), 1–16.
Simon, H. A. (1986). Interview with Herbert A. Simon: The failure of armchair economics. *Challenge*, *29*(5), 18–25. https://www.jstor.org/stable/40721040
http://digitalcollections.library.cmu.edu/awweb/awarchive?type=file&item=34037.
Simon, H. A. (1996). *The sciences of the artificial* (3rd ed). MIT Press.
Simon, H. A. (2000). *Public administration in today's world of organizations and markets*

(Public lecture). https://inst.eecs.berkeley.edu/~cs195/fa14/assets/pdfs/simon_last_lecture.pdf

Smith, V. L. (1991). Rational choice: the contrast between economics and psychology. *Journal of Political Economy*, 99(4), 877-897.

Smith, V. L. (2008). *Rationality in economics: Constructivist and ecological forms*. Cambridge University Press.

Sull, D., & Eisenhardt, K. M. (2016). *Simple rules: How to thrive in a complex world*. Mariner Books.

Sunder, S. (2004). Markets as artifacts: Aggregate efficiency from zero intelligence traders. In Augier, M. E., & March, J. G. (Eds). *Models of a man: Essays in memory of Herbert Simon* (pp. 501–519). MIT Press.

Sunder, S. (2006). Determinants of economic interaction: Behavior or structure. *Journal of Economic Interaction and Coordination*, *1*(1), 21–32.

Sunder, S. (2009). Book review of *Rationality in economics: Constructivist and ecological forms* by Vernon L. Smith. *Journal of Economic Psychology*, 30, 107–110.

Turner, R. H., & Killian, L. M. (1987). *Collective behavior* (3rd ed.). Prentice-Hall.

Veblen, T. (1919). *The place of science in modern civilization and other essays*. Huebsch.

Woodger, J. H. (1929). *Biological principles: A critical study*. Kegan Paul, Trench, Trubner & Co.

Yeh, C. H. (2007). The role of intelligence in time series properties. *Computational Economics*, *30*(2), 95–123.

Yeh, C. H. (2008). The effects of intelligence on price discovery and market efficiency. *Journal of Economic Behavior and Organization*, 68, 613–625.

Tables and Figures

Table 1: Agent, path and outcome in three approaches to rationality

Three Parts of Model / *Approaches to Rationality*	**Agent**	**Path**	**Outcome**
1. Substantive	Goal optimizer	Optimized: logically constructed	Optimum
2. Procedural	Goal satisficer, adaptive, heurist, imitator, maximiner	Optimized: logically constructed	Near-optimum, boundedly rational
3. Structural	Minimally-intelligent	Complex interaction defined by structure and its constraints	Emergent and possibly efficient

Table 2: Ecological rationality as refinement of modeling in three approaches to rationality

Ecological Rationality: Correcting for difference between empirical observation and model outcomes.		
Feedback loop	**Outer loop**	**Inner loop**
Substantive rationality	Present	Absent
Procedural rationality	Present	Present
Structural rationality	Present	Absent

Table 3: To catch a ball can be modeled in physical terms, with and without drawing on higher faculties.

The Methods of Modeling	***WHAT:*** **Fixed/ exogenous element**	***HOW:*** **Action element**	**Observed Path**
Conventional approach, using animate faculties	Time a fly ball takes to reach ~1.5 m above ground	Use the evolutionary capacity of holding gaze on a moving object	A curved path, depending on when the angle of gaze is first fixed
Bounded to the first physical tier of the three-tier framework	Same as above	Keep a *fixed angle* of gaze (change=0)	Same as above

Figure 1: Claude Monet (1877): The Turkeys (from Artstor.org) with Area of Detail

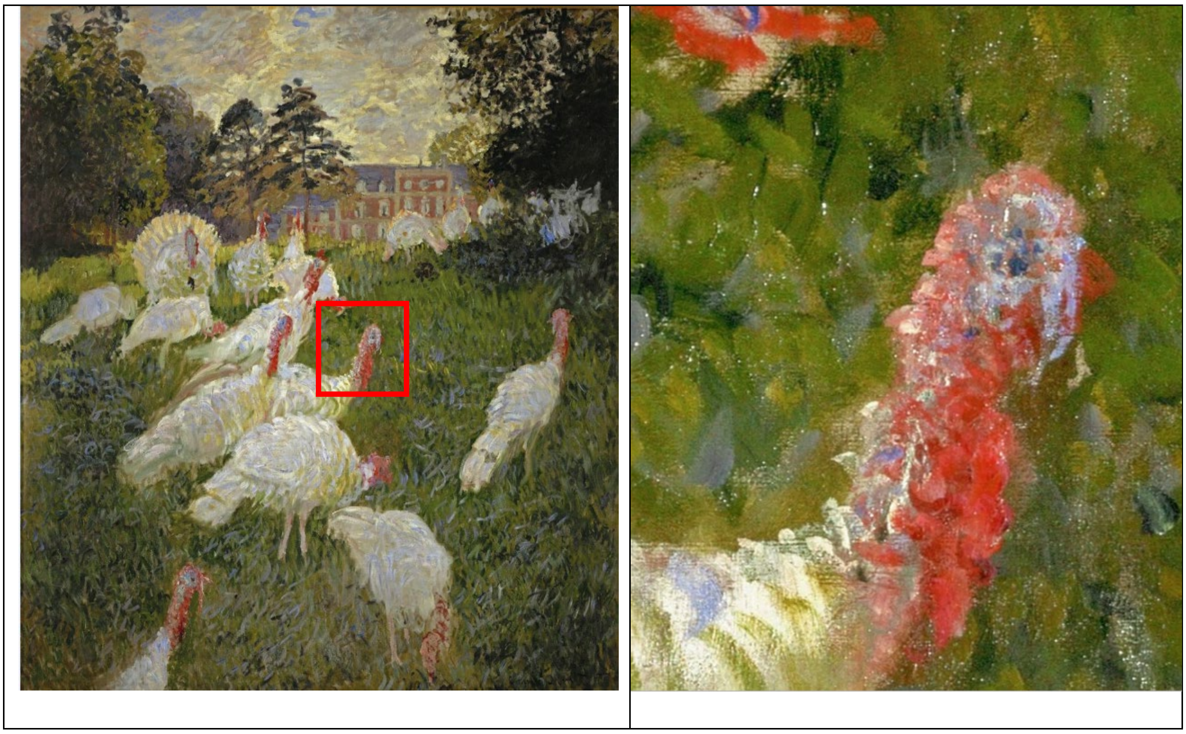

Figure 2A: Earthrise above Moon
(https://eoimages.gsfc.nasa.gov/images/imagerecords/82000/82693/earthrise_vis_1092.jpg)

Figure 2B: Lawn Grass (Photograph by the Author)