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Organizations and Constraint-Based Adaptation

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Organizations can and do adapt to their environment; however, this adaptation is subject to various institutional constraints. Laws, institutional norms, and so forth set the parameters in which the organization can adapt. A question that arises in this context is whether organizations can locate optimal forms if they are subject to such constraints. That is, does constrained but strategic adaptation admit optimization? Further complications arise for organizations because they are composed of intelligent agents who themselves are learning as they pass through a multitude of experiences. Organizations alter their forms and adapt to their environments (Stinchcombe 1965a; DiMaggio and Powell 1983; Romanelli 1991) both through strategic reorganization (Kilmann and Covin 1988; Butler 1993) and through accumulative experience on the part of the organizational members (March 1981). Thus, a second question is

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whether the institutional constraints on strategic adaptation interact with the ability of the organization to take advantage of the experience gained by the individual members of the organization, who themselves are continuously adapting.

Organizational change dynamics result from simple, but nonlinear, processes. An example of such a nonlinearity is the decreasing ability of a new piece of information to alter an agent's opinion as the agent gains experience. Such nonlinearities make it nontrivial to think through the implications of the combined experiential and strategic adaptation processes. Computational analysis enables the theorist to think through the possible ramifications of such nonlinear processes and to develop a series of consistent predictions. Consequently, computational models can be, and have been, used in a normative fashion to generate a series of hypotheses by running virtual experiments. The resultant hypotheses can then be tested in other empirical settings.

This is the approach taken herein. Specifically, the potential impact of constrained adaptation will be examined from a computational theoretic perspective. Organizations are modeled as complex adaptive agents composed of complex adaptive agents. As in any complexity model, stable structures and patterns of behavior emerge from the application of simple rules on the part of the agents and agents coevolve. Rate of learning influences what patterns emerge. The process of strategic organizational adaptation is modeled as a simulated annealing process in which the organization seeks to locate its optimal form but is subject to constraints on its ability to change. The process of experiential learning is modeled using a stochastic learning model with limits on attention, memory, and information processing that effectively bound the agent's rationality. Both of these models are combined into a single computational framework called ORGAHEAD. To use ORGAHEAD, a virtual experiment is run in which the types of constraint on adaptive mechanisms are altered. At the strategic level, the adaptive mechanisms examined include adding personnel, dropping (or firing) personnel, altering the reporting structure (who reports to whom), or altering the task structure (who is doing what).

ORGAHEAD

ORGAHEAD is a dual-level information processing model of organizational adaptation. The two levels are the strategic and the operational. At the strategic level, organizational performance is affected by the CEO's ability to take the appropriate strategic actions, to alter the organization in response to environmental cues, and to anticipate the future. Institutional constraints affect this process by limiting or defining the set of options for change that the CEO can choose among. A computational analog of this process is simulated annealing (Carley and Svoboda 1996). At the operational level, organizational performance is affected by the actions of the organizational members (or agents) as they work on specific tasks, communicate to others, and learn. At this level, constraints take the form of bounding rationality both by socially limiting who has access to what information and by cognitively limiting the individual's ability to process acquired information (Simon 1955, 1956; March and Simon 1958). A computational analog of this process is the CORP model (Carley 1992; Carley and Lin forthcoming).

ORGAHEAD is used to estimate the performance of an organization as it adapts in response to cues from its environment. The cues take the form of the question, is performance higher or lower than it was previously? Performance is measured as accuracy in classifying objects. In other words, the organization is facing a sequence of classification choice tasks and must determine for each time (or equivalently, task) whether the object it is seeing is of type A or type B. The specific task used is a binary choice task, also referred to as a pattern matching and classification task. Classification tasks such as this have been widely studied in the organizational literature, both in a binary version (Carley 1992; Ouksel and Mihavics 1995) and in a trinary version often described as a stylized radar task (Ilgen and Hollenbeck 1993; Carley and Lin 1994, 1995; Tang, Pattipati, and Kleinman 1992), and in a dynamic version (Lin and Carley forthcoming; Carley and Lin forthcoming).

Each time period, the organization receives a new choice task and makes a decision as to how to classify that task. The specific task used is a binary choice in which the organization sees a binary string of length 9 and must determine on the basis of the pattern whether that overall pattern indicates an A (1) or a B (0) choice. There is, unbeknownst to the organization, a correct classification. The correct value is defined to be A (1) if the majority of bits in the string are 1, else B (0). Again, performance within a given period is measured as the fraction of the tasks seen during that period that were correctly classified.

Strategic Adaptation and Simulated Annealing

Strategic adaptation refers to the changes the organization (due to its CEO or executive committee) makes to its structure. Strategic adaptation is modeled as a simulated annealing process (Kirkpatrick, Gelatt, and Vecchi 1983; Rutenbar 1989), such that the organization's strategies are the move set. Simulated annealing is a reasonable computational analog of the way in which organizations, over extended periods of time, alter their structures (Eccles and Crane

1988). The set of potential moves includes augmentÑadd n personnel, downsizeÑdrop n personnel, retaskÑmove agent i from task s to task j, reassignÑhave agent i stop reporting to j and start reporting to agent k.

At any one time, all personnel changes made are of the same type; however, the number of personnel changes made that time is given by a Poisson distribution. Each type of allowable move is initially equally likely. However, over time, the CEO will learn which moves are more likely to improve performance and so will change which adaptive strategies are employed. Institutional constraints can be modeled in this framework by fixing the probability of a particular move at a particular level and not allowing it to change. For example, tenure could be modeled by setting the probability of downsizing to 0 for all time.

The organization continuously cycles through a series of stages: general operation, evaluate performance, suggest form, evaluate form, select form, and alter form. Each time period, the organization observes the environment (sees a new task). After a sequence of 500 tasks (general operation) performance is calculated (evaluate performance), then the CEO proposes a strategy from the move set for altering the organization's structure (suggest form), then the CEO "looks ahead" and tries to imagine how the proposed new organizational structure will affect performance (evaluate form), then the CEO determines whether or not to implement the new structure (select form), and then the organization's structure may be changed (alter form). The limited lookahead is simulated by creating a hypothetical organization with the proposed new structure and simulating its performance on a sequence of 100 tasks. After the lookahead, the CEO decides whether or not to accept the new design. The probability of accepting the new form is based on the Boltzman probability criteria.

According to this criteria the CEO always accepts the change if the resulting hypothetical organization exhibits better performance during the 100-task lookahead than the current organization has recently (past 500 trials). Otherwise, the risky change is accepted with a probability given by $e^{-\delta \,\mathrm{cost}(t)/T}$ such that $\mathrm{cost}(t) = 1/\mathrm{performance}(t)$. If the structural change is accepted the CEO puts the change in place and then proceeds to process another sequence of tasks, at which point another alteration to the organizational form is considered. If a proposed change is not accepted the organization continues with its current structure for another sequence of 100 tasks. The rate of organizational change is set by the temperature cooling schedule.

Temperature (T) will drop each time period (such that one time period equals 100 tasks) as $T(t + 1) = a * T(t)$, where a is the rate at which the organization becomes risk averse and t is time. In other words, over time the CEO and the organization become increasingly risk averse, increasingly conservative. The initial high-risk-taking behavior can be thought of in terms of the liability of newness (Stinchcombe 1965b; Bruderl and Schussler 1990).

Experiential Learning and Bounded Rationality

Experiential learning refers to the ability of the agents within the organization to garner experience and improve their ability to perform the task. At this operational level the CORP model of organizational performance is used. Within CORP an organization is composed of a set of complex adaptive agents who are responsible for doing the task and who are situated within an organization with a particular structure. Each time period each agents sees a set of information (a certain number of bits). These bits may be information from the task or they may be the "recommendations" of other agents as to the classification of the string. Each agent is limited to being able to handle a maximum of seven bits of information at a time (thus a maximum of $2^7 = 128$ patterns). Which agent sees which bits of information, and which agent reports what to whom, depends on the organizational structure.

Agents are thus boundedly rational both from a cognitive or information processing standpoint (can only handle seven bits) and from a social standpoint (what information they have access to is determined by their position in the organizational structure) (March and Simon 1958). Given these bounds on rationality, no agent in the organization has the capability or sufficient information to make the decision completely unassisted.

Training

If the agents follow standard operating procedures (SOPs) then they always act as majority classifiers and return a 1 if they see more 1s than 0s and a 0 otherwise. If there is no majority they guess (basically, flip a fair coin). If the agents followed their experience then they keep track of the frequency with which each pattern they see is associated with a correct answer of either a 1 or 0. For each task, the agents return a 1 if the correct answer most frequently observed for this pattern was a 1, and a 0 if that was historically the most frequently observed answer. If neither answer historically dominates then the experiential agents simply guess (flip a coin). This experiential procedure is similar to a stochastic learning model (Busch and Mosteller 1955). With sufficient experience for binary tasks, experiential agents come to resemble those following a SOP of majority classification. Specifically, they can only remember the first 100 and most recent 250 tasks that they have done. This gives a forgetting, a recency, and a primacy effect. Experiential agents, however, have an additional cognitive constraint. CORP, specific elements of CORP, and predictions from the CORP model have been extensively described in previous studies (e.g., Carley 1992; Carley and Lin 1995, forthcoming). CORP has been shown to be a reasonable model of organizational performance both against experimental lab studies (Carley 1996, forthcoming) and archival data on actual organizations (Lin 1994; Carley and Lin 1995), particularly for more complex organizational structures. Models like CORP, or extensions of CORP, have received extensive attention (Ouksel and Mihavics 1995; Mihavics 1996; Mihavics and Ouksel 1996) as has the binary and trinary choice tasks underlying CORP (see, e.g., Tang et al. 1992; Pete, Pattipati, and Kleinman 1993, 1994; Pete 1994; Carley 1992; Lin and Carley forthcoming; Hollenbeck, Ilgen, Sego, Hedlund, Major, and Phillips 1995; Hollenbeck, Ilgen, Tuttle, and Sego 1995).

Initial Conditions

The organization begins with a particular organizational structure chosen at random from the possible set. These organizations have from one to three levels below the CEO, with a maximum of fifteen personnel per level, from one to forty-five personnel (not counting the CEO), and nine distinct subtasks. The initial determination of size, the organizational structure (who reports to whom), the resource access structure (who has access to information on what subtasks), and how many individuals occupy each organizational level is determined randomly from the set of possibilities.

The CEO always acts as a majority classifier and is not cognitively limited. All other agents are either trained as experiential learners or follow SOPs. If they are experiential learners then they begin by knowing nothing and build up their patterns over time. Agents, when they have no information to go on, make their decisions by guessing. Individual learning occurs using a stochastic experiential learning process (Carley 1992). Over time, agents build up their experience and begin to act as majority classifiers if they experience a random sample of tasks with an equal expectancy for the true answer to be an A (1) or a B (0). If the agents follow SOPs then they always act as majority classifiers.

Performance Criteria

Performance is calculated over a sequence of 500 tasks (evaluate performance) as the percentage of tasks that were correctly classified. The level of performance expected by chance is 50.00%. Performance is also looked at categorically, by dividing up the organizations into the following categories based on their final performance: $x \leq 70$ (0), $70 < x \leq 75$ (1), $75 < x \leq 80$ (2), $80 < x \leq 85$ (3), $85 < x \leq 90$ (4), $90 < x$ (5). In addition to performance the level of redundancy in access to resources (average number of personnel accessing the same bit of information on the task), average span of control (measured as the average number of subordinates per manager below the CEO), average density (ties between personnel), isolation (measured as the number of agents who neither report to others nor have others report to them), and overlooks (measured as the number of decision-making factors that are not attended to by any agent) are considered. These measures are calculated both at the beginning of the simulation for each organization and after it reaches quiescence.

Virtual Experiment

Using ORGAHEAD, the computational model just described, a virtual experiment was run. In this virtual experiment the following factors were systematically varied: training, a tenure-based dismissal constraint, and a redesign-based constraint. Agents could be trained either to follow SOPs (Carley and Lin forthcoming) or to follow their experience (Carley 1992). Organizations either had a tenure system (in which cases agents could not be dismissed or fired from the organization), or did not. Organizations either used a redesign strategy, simply altering the connections between existing agents (or agents and tasks), or used a flexible strategy, in which they either could redesign or could alter their personnel base by hiring (or firing if they were not in a tenure situation). This is a $2 \times 2 \times 2$ design. For each cell in this design, a total of 1,000 different organizations were simulated, for each condition, such that the organization's initial design was randomly generated from the set of all possible organizational designs.

The specific task used was a nine-bit binary string resulting in a population of 512 distinct tasks. The correct answer is defined to be a 1 if there are more 1s than 0s in the string and a 0 otherwise. Each organization was simulated for 20,000 tasks (time periods) or until it reached quiescence, whichever came first. Organizations were defined as reaching quiescence when the approximate probability of accepting a new design dropped to 55% (which corresponded to a "freezing" temperature of 0.0345). The initial temperature was 0.433; consequently, approximately 90% of the proposed changes were initially accepted. The organization became increasingly risk averse at a rate of $\alpha = .975$. The timing of the organization's life cycle is controlled by multiple windows defined in terms of the number of tasks. The 20,000 tasks are divided into a sequence of 200 cooling windows each of length 100. Temperature is dropped after each cooling window. The proposed hypothetical design is simulated for 100 tasks (the length of the lookahead window). The expected performance of the proposed design is calculated in just this lookahead window and contrasted against actual performance of the organization during the previous 500 tasks. Initial analyses indicated that there were no significant differences in the long-term behaviors due to the training condition. Essentially, even though the organization's structure can be changed every 100 time periods, the structures that emerged were such that very few bits of information were assigned to any one agent. Thus, experiential learners developed their repertoire of rules sufficiently quickly that most of the agents were acting as majority classifiers regardless of whether they were trained to act on experience or SOPs. Consequently, in the ensuing analysis these cases will be combined, and the analyses will be run using a basis of 2,000 organizations. The reduced 2 × 2 design then simply looks at the type of constraints—tenure or strategic. This final design is displayed in Table 17.1. As can be seen, the two types of constraints combine to create relatively severely and unconstrained institutional contexts.

Results

Institutional constraints are expected to have important effects on organizational behavior. For example, we might expect that severe constraints on the organization's ability to restructure itself might limit its performance and might decrease the variance in the types of forms observed. In the first case, the idea is that organizations are trying to optimize their form for a specific task environment; however, the optimal form might require the organization to take a nonallowable action. For example, if the organization cannot fire personnel, then getting rid of personnel who have learned the wrong behavior and simply are making wrong decisions—thereby lowering overall performance—would not be an option. As to the second point, constraints are expected to lower variance because there will be fewer organizational forms to choose among, and so organizations that are trying to locate the best form are more likely to end up in the same place and so are more likely to have the same performance.

In Table 17.2, the results from the virtual experiment that speak to this issue are displayed. As can be seen, the prediction with respect to performance did not hold out. That is, while severely constrained organizations are more similar in their performance, their performance is higher (and significantly so) than the relative unconstrained organizations. Why are we seeing higher performance in the severely constrained case? The answer has to do with averaging. Severe constraints by restricting the number of forms are restricting not only what good forms are possible but what bad ones are possible as well. In this particular case, the specific set of constraints, tenure and only redesign, serves to eliminate those organizational forms where performance is very bad, thus, on average, resulting in better performance. If, rather than looking at average performance, we look at the number of organizations that make more than 90% of their decisions correctly, we see that there are fewer (in fact no) top performers in the case of severe constraint (see Table 17.3). However, being unconstrained does not

Table 17.1 Design of Virtual Experiment

Constraint	*Tenure*	*No Tenure*
Redesign strategy	Severe	Moderate
Flexible strategy	Moderate	Unconstrained

Table 17.2 Mean Effect of Constraint on Performance

Constraint	*Tenure*	*No Tenure*
Redesign strategy	82.30	79.00
	(2.83)	(5.18)
Flexible strategy	75.51	76.03
	(5.84)	(5.53)

Note. N = 2,000 per cell. Standard deviations are in parentheses.

Table 17.3 Mean Number of Top Performers by Type of Constraint

Constraint	*Tenure*	*No Tenure*
Redesign strategy	0	3
Flexible strategy	27	13

Note. N = 2,000 per cell.

maximize the number of top performers (note there are only 13 organizations in this case). No constraints on organizational adaptation may actually overly facilitate experimentation and decrease the likelihood of finding the optimal form.

Another assumption that we might make about institutional constraints is that severe constraints will decrease organizational efficiency and decrease the variance in efficiency across organizations. That is, severe constraints may cause the organization to retain certain pockets of inefficiency. We can measure inefficiency as the number of agents that are isolated or the number of decision factors that are overlooked.

The results of testing these assumptions are shown in Table 17.4 for isolates and Table 17.5 for factors overlooked. For both isolates and factors overlooked, we see that there is greater efficiency (significantly lower values) and lower variance in the severely constrained than the unconstrained situation. In this case, the default assumption is seen to hold.

We might expect that high-performance organizations are high performance because they start out as highly efficient and remain so. This question is addressed in Table 17.6 where the percentage change over time in various factors

Table 17.4 Mean Effect of Constraint on Number of Isolates

Constraint	*Tenure*	*No Tenure*
Redesign strategy	2.06	1.90
	(0.85)	(1.10)
Flexible strategy	2.74	2.75
	(1.22)	(1.24)

Note. N = 2,000 per cell. Standard deviations are in parentheses.

Table 17.5 Mean Effect of Constraint on Number of Factors Overlooked

Constraint	*Tenure*	*No Tenure*
Redesign strategy	0.05	0.29
	(0.21)	(0.52)
Flexible strategy	0.39	0.39
	(0.66)	(0.65)

Note. N = 2,000 per cell. Standard deviations are in parentheses.

Table 17.6 Percentage Change by Level of Final Performance

	Final Performance Level					
Variable	*0*	*1*	*2*	*3*	*4*	*5*
No tenure						
Redundancy						
Redesign strategy	−0.13	−0.59	0.00	−0.45	−0.22	0.00
Flexible strategy	−25.64	−12.92	−2.73	14.24	19.36	20.21
Isolates						
Redesign strategy	0.79	−1.35	0.77	1.73	1.56	0.00
Flexible strategy	−4.87	−19.08	−29.54	−36.19	−47.84	−37.40
Factors overlooked						
Redesign strategy	−0.86	−7.94	0.00	−36.36	−66.67	0.00
Flexible strategy	147.92	0.00	−52.54	−85.37	−84.21	−100.00
Tenure						
Redundancy						
Redesign strategy	−1.01	0.47	−0.34	−0.22	−0.11	N/A
Flexible strategy	65.15	47.38	44.45	36.25	30.59	23.19
Isolates						
Redesign strategy	−0.26	1.40	1.19	−0.46	0.00	N/A
Flexible strategy	−14.03	−26.43	−33.03	−24.81	−21.93	−15.14
Factors overlooked						
Redesign strategy	−6.78	8.33	−12.50	−25.00	−100.00	N/A
Flexible strategy	−43.82	−88.46	−85.97	−92.11	−100.00	−100.00

indicating inefficiency is shown. This percentage change is measured as 100 times the average value for all organizations at that level of performance at the end of the simulation minus the average value that those same organizations had at the beginning of the simulation divided by their value at the beginning. Since for each of these measures a higher value indicates lower efficiency, and since the contrast is new minus old, a negative value indicates an increase in efficiency.

In general, regardless of their final performance level, all organizations tend to overlook fewer factors in making their decisions. However, organizations that do not have flexible strategies often end up with more isolates, and those that do have flexible strategies often end up with a more redundant workforce. Second, the organizations that manage to locate the high-performing, more optimized forms are not those that started out more efficiently.

Within organizational theory it is generally recognized that there is no one right form. Indeed, the dominant claim is that the optimal form depends on, or is contingent on, the task environment that the organization is facing and the specific task being pursued (Lawrence and Lorsch 1967). For a particular task environment, however, there should generally be a simple pattern relating the various aspects of form, such as size and span of control, to performance. Institutional constraints, in other words, should not matter.

However, the results from the virtual experiment suggest that institutional constraints can alter the perception of the relation between organizational form and performance even when holding constant the task environment. For example, in Figure 17.1 we see the relationship between performance and size and span of control for the organizations where there was little institutional constraint (flexible strategy and no tenure). In Figure 17.2, the same relationship is shown for severely constrained organizations (redesign strategy and tenure). There is quite a contrast between the two figures. Under these different types of institutional constraints, the relationship between organizational form and performance appears to vary.

It is important to stress that this is a perceptual and not a real difference. That is, if two organizations had exactly the same form, but one was in a severely constrained environment and one was in an unconstrained environment, they would exhibit the same performance if given the same set of tasks. Different institutional constraints lead to different organizational forms emerging over time. Thus, in the long run, the field of organizations that emerges under one set of constraints may tend to exhibit a different relationship between form and performance than will a set of organizations that emerges under a different set of constraints. Thus, one would expect that individuals working under different sets of institutional constraints will perceive, and so learn, different lessons about the relationships between form and performance.

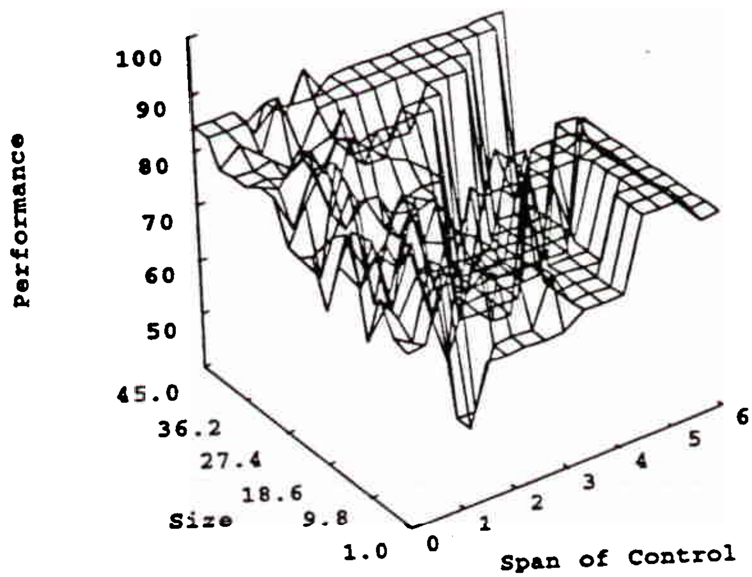

Figure 17.1. Effect of size and span of control on performance for unconstrained organizations.

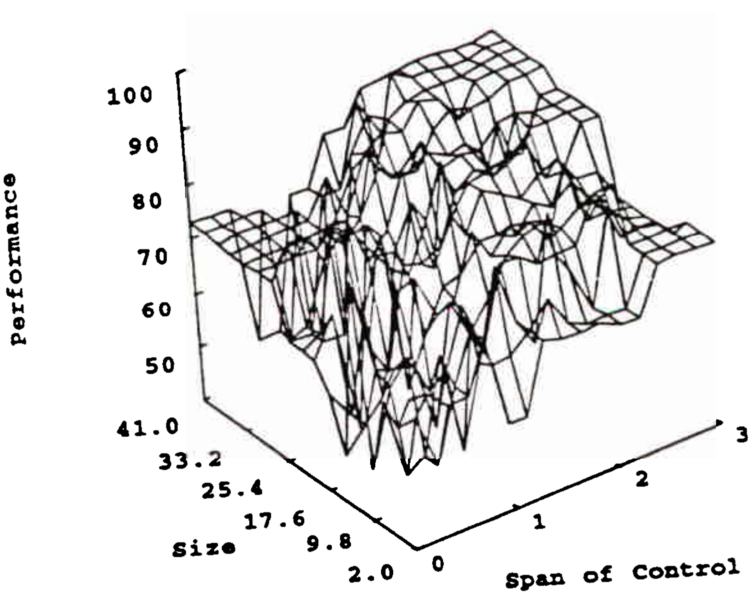

Figure 17.2. Effect of size and span of control on performance for severely constrained organizations.

Discussion

In the foregoing analysis the organizations were attempting to optimize their performance defined simply as accuracy. As such, no cost was attached to size or connections among individuals. A consequence was that since additional personnel added resolution on problem solution, the organizations grew arbitrarily large. Alternative cost functions, such as simultaneously optimizing performance and minimizing personnel, could be considered. Work on computational models suggests that changing the cost function can affect the particularities of the results. In this case, it would affect the number of decision factors overlooked, the level of redundancy, and the tradeoff between accuracy and organizational form.

Future studies should investigate alternate cost functions to locate the relation between form and performance. However, changing the cost function is unlikely to change the following results: there are few high performers, there are equi-performance plateaus, small changes in the organization's architecture can result in dramatic changes in performance, the way in which the organization alters its structure and its initial form combine to affect ultimate performance, institutional constraints affect what forms emerge and the apparent relation between form and performance.

Despite altering their structure, organizations are typically trapped in equi-performance plateaus. This equi-performance result suggests that CEOs can, within reason, reorganize their organization with relative impunity. Moreover, the mere act of reorganization, while it may not generate improvements in performance, is likely to be advantageous to the organization from an efficiency standpoint (that is, such reorganization may minimize isolates or the number of decision factors that are overlooked).

The model examined in this chapter is not a classic chaos model; that is, it is not a set of difference or differential equations, but rather has a few stochastic elements. Behavior, even that which is process driven such as in this simulation, often appears chaotic without a simple relation between input/independent and output/dependent variables. Indeed, the results reported here, and others from this same model (Carley and Svoboda 1996), are consistent with the behavior one would expect from a chaotic system. For example, small changes in organizational form can result in dramatically different performance level. Organizations with almost equivalent organizational forms can exhibit very different performance profiles. Organizations, as complex systems, have the characteristic that the organizational design features are not systematically related to performance; rather, small differences in the initial design for a set of organizations, particularly when coupled with their response to the environment can result in dramatically different emergent structures and final performance.

Furthermore, although organizations can locate good designs regardless of the intelligence of the agents with them, they may not locate the optimal design, and what designs emerge depends on the specific institutional, cognitive, and social constraints that influence individual and organizational behavior. In a constrained environment, organizations can rarely locate the optimum form simply through heuristic-based search procedures like that embodied in a simulated annealing process. Indeed, in such an environment, standard procedures for optimizing performance may not be sufficient. Alternative mechanisms for optimizing performance, such as mimicry, should be examined.

The model used herein is highly nonlinear. The resultant performance surfaces, such as those relating performance to size and span of control, can be seen as highly nonlinear. What are the implications of this for organizational theory? In most organizational studies, the R^2 for models exploring performance tends to be quite small. Such low R^2s are often attributed to measurement error or missing variables. An alternate explanation suggested by the foregoing results is that organizations and their performance are essentially chaotic. Organizations as complex systems composed of adaptive agents may engage in relatively simple rules of operation; however, the coadaptation of the agents and the organization may result in complex patterns of behavior. In such systems, linear models cannot capture the complexities, and the use of such models enables only low levels of prediction.

In this essay, these results have specific implications for institutional constraints. The results from the virtual experiment demonstrate that naive intuition about organizations and the impact of constraints can be wrong, particularly when there are complex interactions. For example, it was demonstrated that while the naive expectation might be that severe institutional constraints will lower performance, in actuality, severe constraints may result in performance improvements by keeping organizations from going down erroneous paths. Institutional constraints may improve performance if they happen to take advantage of individuals' cognitive capabilities. Institutional constraints can actually create a supportive environment. Finally, fields of organizations faced with different sets of institutional constraints may "learn" or perceive different relationships among organizational form and performance even when faced with the same task.

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