Exploring a Model of Organizational Adaptability

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ABSTRACT

We report findings from an investigation of organizational adaptability and robustness in dynamic environments. This research centered on a known agent-based model of adaptive organizations. We extended the model with an accounting system and watched it respond to changing business environments. We executed simulations using multiple organizational characteristics and examined robustness as demonstrated by financial measures.

Our conclusions were as follows:

- Of the settings we explored, the most sensitivity was found when we varied the size of the workforce, the tolerance to missed opportunities in the first management level and the ease of dissolving the hierarchy. The genomes we selected to study due to their adaptability were highly robust based on financials and their ability to survive over time.
- Creating the agent-based model involved a large number of parameters and understanding its behavior; making changes quickly increased the complexity.
- Searching through the results to discover essential organizational and environmental characteristics involved an enormous volume of data. A more intelligent search strategy was needed.

Keywords

Adaptability, Agent-based Modeling, Agility, Collapse, Robustness, Resilience

INTRODUCTION

The purpose of an organizational structure is to provide a framework to allocate and manage workload within a social system. Key concepts include roles and responsibilities, tasks and division of labor, communications channels and decision making. Traditionally, the *hierarchy* is the primary form of organizational structure. In the idealized hierarchy, people are organized in ranked tiers where subordinates report to superiors, who maintain a span of control. Work is carried out by subordinates under direction of the superiors, who make staffing decisions to allocate workers. Supervisors also provide the conduit for communication between tiers.

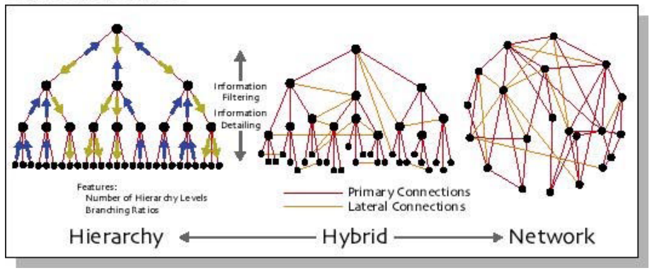

Figure 1: Control Structures [2]

In addition to hierarchy there are other types of control structures including hybrid and network [2]. The hybrid model maintains some amount of hierarchy and adds an overlay network where people make lateral connections. In the network model, there is no hierarchy. Instead, there are many lateral connections between people, who make decisions by talking to one another. Information flows across the across the organization as opposed to up and down hierarchical tiers.

As firms compete with one another in dynamic environments, they seek the optimal organizational structure to meet their business objectives.

LITERATURE REVIEW

Organizational adaptability is the capacity of a system to change its organizational structure to fit itself to survive in the business environment. Organizational adaptability encompasses robustness, resilience and agility.

Robustness refers to the ability of a system to return to an equilibrium state after a perturbation. This definition assumes that a system has a state of equilibrium (an attractor) to which it will automatically return. In the organizational model this could be tested by keeping the environment static, disrupting the organization and then measuring t, the time it takes for the organization to return to a steady state. The disruption could be an internal event such as organizational attrition. External events such as changing business conditions could also cause perturbation.

Agility describes how fast an organization reacts to environmental changes. More specifically, it measures the average velocity with which the organization responds to threats and opportunities. When an organization is the most agile it can be, it has the smallest possible t when reacting to a deviation from equilibrium.

Multiple equilibriums can exist for many social-natural systems [2]. This means that robustness is an incomplete measure of stability over a long period of time. In ecological systems [3] utilized the term resilience as it more accurately reflected the experience of natural ecosystems. This term has subsequently been applied to a wide range of social and natural systems [4]. Resilience can be defined as the magnitude of disruption required to transform a system to an alternative set of mutually reinforcing processes i.e., a different system. A system with high resilience can adapt to a wide range of conditions and still function successfully.

METHOD

Our multi-disciplinary team at the Santa Fe Institute convened to examine and broaden the agent-based model developed by Joshua M. Epstein and his associates [3].

The original model showed that the optimal organizational structure oscillated between a flat, free trade structure and a hierarchy for organizations with a "genome" which balanced profit maximization and market share, under changing business conditions. See Figure 2. Using costs to determine robustness, the team built upon the defined adaptive organizational model [7] to explore additional questions:

- What is the effect of start up capital and size of workforce in relation to average daily bank balance?
- Is there a zone of survivability that defines how the firm can maintain positive cash flow while responding to changing business dynamics?

We instantiated the model and extended it to consider robustness. The model was run in multiple business scenarios. We collected and analyzed the results to form the observations and insights described in this paper.

Adaptive Organization Model

The original agent-based model by Joshua Epstein's team was constructed in the Ascape modeling environment [1]. We developed a similar model using the defined detailed description using NetLogo modeling environment [9].

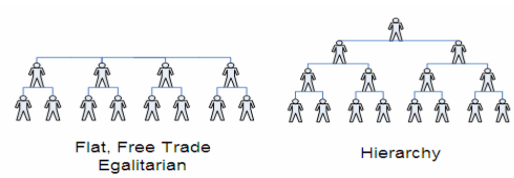

Figure 2: Control structures modeled

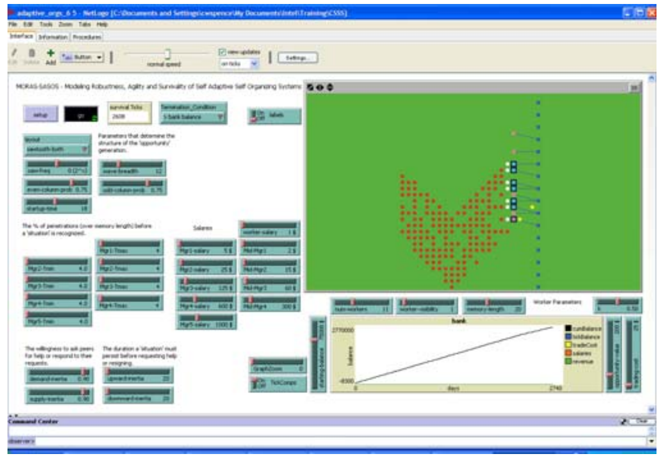

Figure 3: Organizational Adaptability Model in NetLogo

Figure 3 illustrates the graphic display was a grid of 32 by 56 cells. Business opportunities were represented by a flux of red dots approaching an agent-based market enterprise from left to right. This flux of approaching opportunities was variable in density, width, vertical location and time variant pattern. The market enterprise consisted of an initial vertical row of the labor force, which occupied at most 32 of the 32 possible vertical positions of the incoming points. Number and position of the labor force agents were part of the initial conditions for the model.

The enterprise goal was to intercept as many opportunities as possible while minimizing missed opportunities, or *penetrations*. Each member of the labor force intercepted the incoming opportunities that hit its occupied cell directly. Workers could not move themselves in order to intercept opportunities; they could only be moved by managers. Each agent in the model was bound by a set of simple defined rules, with operator determined parameters. Labor force workers were represented as blue squares, interceptions were white dots, and penetrations were yellow dots.

A subsequent row of 16 stationary managers moved idle workers to intercept incoming opportunities when necessary. The managers had a variable depth of vision of the incoming flux to allow them to move workers appropriately. Span of control of these managers was between zero and two workers. Managers with workers in their span of control were represented by solid blue dots. Managers controlling no workers were represented by hollow blue dots. Solid managers became hollow dots when superiors were activated, as control passed to the superior manager. Additional levels of management, with similar spans of control over immediate lower level managers, were generated as needed to facilitate greater response to intercept opportunities. Up to a fourth level manager, the CEO, was created with the ability to shift workers across the entire enterprise in a one-day time step or *tick*. The agents endogenously generated and dissolved these hierarchies locally, again based on simple rules. All managers functioned identically, but higher level managers had increasing span of control over workers, as follows:

1. The level N manager executed an internal trade with adjacent level N manager in order to transfer them to area of greater need. Resistance to trade was a controllable parameter. A manager with penetrations greater than Tmin could post a demand D=P-Tmin. Other managers transfered excess supply of labor minus interceptions, S=L-I. Trade rules:
   a. Demand: if P> T_{max}, post excess D to layer.
   b. Supply: Transfer to posting agent if S>D.
2. A higher level manager (N+1) was created to allow the shift of a free resource to a more efficient location if inter-manager trade met a penetration threshold.
   a. Each manager had two penetration thresholds (T_{min} and T_{max}) with a finite memory (m) of penetration count (P) over the last 10 time periods.
   b. If P was greater than or equal to T_{max}, a level N + 1, manager was created, subject to upward inertia parameter.
   c. If P was less than T_{min}, the manager was terminated and control reverted to the subordinates, subject to downward inertia parameter.

A system of financial accounting was created for the enterprise in order to obtain a quantitative measurement of performance. A bank account was established with startup capital and the account balance was updated at each tick. Revenue was added to the account for each intercepted opportunity. Costs were assessed for each penetration. Wages were determined for labor and management, calculated daily and deducted from the bank balance. Active, solid dot managers received full pay; inactive hollow dot managers were paid less.

Some of the differences between the Ascape model and the Netlogo model were as follows:

- T_{min} and T_{max} were specified in mean penetrations over memory in the Ascape model. The Netlogo model used percent of penetrations over memory. This was not a significant difference, impacting results.
- In the Ascape model, when an agent successfully found a trading partner that partner provided as much resource as it could. In the Netlogo model any one trading partner transferred only one worker per tick. That had a number of subtle impacts. The Netlogo model was more likely to have acquired workers from different parts of the organization and somewhat less likely to find needed workers at all, especially as the management chain was traversed and there were fewer trading partners.
- The Ascape model allowed up and down inertia to be specified independently for each management level. We applied the same inertias for all management levels.

Assessment of robustness of the organization was based on financial viability as measured by the bank balance over a time period of ticks. If the bank balance fell at or below zero then the organization did not survive, as it was out of business. If the organization maintained a positive bank balance throughout the timeframe then it was designated robust for this study.

Scenarios

We ran two sets of experiments at different levels. There was a broad evaluation with very large set of organizational genomes. Second, there was an in-depth evaluation of a three targeted genomes.

In all cases, the structure of opportunity generation was a saw tooth wave with a formation from both the north and south directions and a frequency set at 0. The Even-Column-Probability, set at .75, was the probability of an opportunity generated within each defined location of the opportunity stream for even numbered stream columns. Similarly, Odd-Column-Probability, also set at .75, was the probability that an opportunity was generated within each defined location within the specified opportunity stream for odd numbered stream columns. Startup-time was set to 18 ticks. The startup time determined how far the opportunities were generated in front of the organization at model start time, influencing the required 'startup costs' of the organization.

Environmental settings were fixed for all model runs as follows:

- Worker-visibility=1
- Memory-length = 20
- Trading-cost =25
- Graph zoom = 0
- Survival mode = off
- Termination condition = > bank balance

Broad Evaluation Experiments

The broad evaluation consisted of a number of different permutations of genome values as specified in Figure 4.

Genome:	Starting Value	Increment Amount	Ending Value
Mgr1 Tmax	0.0	3.0	9.0
Mgr2 Tmax	0.0	3.0	9.0
Mgr3 Tmax	0.0	3.0	9.0
Mgr4 Tmax	0.0	3.0	9.0
Demand- inertia	0.0	0.5	15.0
Supply-inertia	0.0	0.5	15.0
Upward-inertia	0.0	3.0	9.0
Downward-inertia	0.0	3.0	9.0
K	0.5 for all runs		

Figure 4: Tested Genomes

Figure 5 shows the worker and manager salaries that were used.

Org Level	Worker	Active Manager	Inactive Manager
1	$1.00	$5.00	$2.00
2		$25.00	$10.00
3		$125.00	$50.00
4		$600.00	$300.00
5		$3,000.00	N/A

Figure 5: Daily Salary Structure

We evaluated the robustness of the genomes at a starting bank balance of $30,000 and three worker levels (8, 10 and 12). The starting locations of the workers were set at random. The average cumulative bank balance and average number of ticks were calculated for each test scenario over 10 iterations. Each individual run was stopped if the bank balance dropped to less than $0 or a total of 500 ticks were reached.

Detailed Investigation Experiments

We ran the model again for three specific organizational genomes (G1, G2, and G3) as defined in Figure 5. All three genomes selected demonstrated adaptability by oscillating between a hierarchical and a flat organizational structure. These characteristics prevented the organizations from staying in a long-term state of expensive hierarchy.

Genome:	G1	G2	G3
Mgr1 Tmax	4	4	4
Mgr2 Tmax	4	4	4
Mgr3 Tmax	4	4	4
Mgr4 Tmax	4	4	4
Demand- inertia	0.5	0.3	0.9
Supply-inertia	0.5	0.3	0.9
Upward-inertia	10	5	20
Downward-inertia	15	5	20
K	0.5	0.5	0.5

Figure 6: Tested Genomes

Worker and manager salaries were the same as shown in Figure 5 with the exception that we reduced the level 5 CEO salaries to $1,000. We also added one additional opportunity wave-breadth, testing 10 and 12.

We evaluated the robustness of the genomes at two starting bank balances and three worker levels. The starting bank balances were $30,000 and $75,000. The worker levels were 7, 9, and 11 workers, with the starting location of the workers set at random at startup. The average cumulative bank balance and average number of ticks were calculated for each test scenario over 20 iterations. Each individual run was stopped if the bank balance dropped to less than $0 or a total of 1500 ticks were reached.

FINDINGS

In this section we report out findings in two parts. In the first part, we summarize the results of the experiments. In the second part, we describe interpretations and observations based on the overall project.

Experimental Results

This section contains the description of what happened when we ran our experiments and the data we collected.

Results: Broad Evaluation Experiments

Of the 196,608 permutations of genomes and environmental settings 20,230 survived the 500 ticks and were profitable. Statistical analysis is provided in Figure 7.

Run_#	Mgr1-Tmax	Mgr2-Tmax	Mgr3-Tmax	Mgr4-Tmax	up-iner	down-iner	supply-iner	demand-iner	num-worker	profit
mean	4.10	5.91	4.92	4.58	12.91	7.50	0.76	0.86	11.54	
std dev	3.80	3.10	3.31	3.34	2.83	5.58	0.18	0.10	0.84	
correlate	0.12	-0.08	-0.13	-0.03	0.08	-0.01	0.15	0.23	0.16	1.00

Figure 7: Broad Evaluation Results

A closer examination of the top performers is contained in Figure 8. All of the top performers had 12 workers, the maximum number that was tested. The most highly correlated setting is the T_{max} value for the level 1 manager. This is negatively correlated which means that there is an inverse relationship between this value and whether the genome is successful. As smaller T_{max} value is better, this translates to a lower tolerance to penetrations. Downward inertia is the next highly correlated value, but positively. This means that the ease of dissolving the hierarchy contributes to the organization's success.

	Mgr1-Tmax	Mgr2-Tmax	Mgr3-Tmax	Mgr4-Tmax	upward-iner	down-iner	supply-iner	demand-iner
mean	6.85	4.96	5.15	4.52	12.89	7.47	0.89	0.90
std dev	2.30	3.27	3.46	3.44	2.59	5.55	0.06	0.00
correlate	-0.58	-0.13	0.03	0.16	0.10	0.23	0.08	0.00

Figure 8: Top 96 Performers

Results: Detailed Investigation Experiments

Results for the three studied genomes are shown in the tables below.

Run	Starting Balance	Num Workers	Wave Breadth	Ave Cum Balance	Ave Ticks	Survived?
R1	$30K	7	10	-$455.15	541.15	No, never
R2	$30K	9	10	$95,843.15	1456.5	Yes, sometimes
R3	$30K	11	10	$193,833.50	1500	Yes, always
R4	$75K	7	10	-$353.35	597.7	No, never
R5	$75K	9	10	$144,416.25	1500	Yes, always
R6	$75K	11	10	$283,297.50	1500	Yes, always
R7	$30K	7	12	-$416.10	361.3	No, never
R8	$30K	9	12	$30,376.65	1051.5	Yes, sometimes
R9	$30K	11	12	$225,679.60	1500	Yes, always
R10	$75K	7	12	-$436.50	421.55	No, never
R11	$75K	9	12	$40,153.35	1133.3	Yes, sometimes
R12	$75K	11	12	$329,595.60	1500	Yes, always

Figure 9: Genome G1 Results

Run	Starting Balance	Num Workers	Wave Breadth	Ave Cum Balance	Ave Ticks	Survived?
R13	$30K	7	10	$51,861.40	1462.55	Yes, sometimes
R14	$30K	9	10	$191,917.05	1500	Yes, always
R15	$30K	11	10	$281,292.70	1500	Yes, always
R16	$75K	7	10	$96,889.85	1500	Yes, always
R17	$75K	9	10	$227,411.00	1500	Yes, always
R18	$75K	11	10	$329,584.60	1500	Yes, always
R19	$30K	7	12	$112,924.35	1500	Yes, always
R20	$30K	9	12	$290,651.90	1500	Yes, always
R21	$30K	11	12	$412,919.20	1500	Yes, always
R22	$75K	7	12	$173,530.90	1500	Yes, always
R23	$75K	9	12	$329,134.65	1500	Yes, always
R24	$75K	11	12	$457,945.40	1500	Yes, always

Figure 10: Genome G2 Results

Run	Starting Balance	Num Workers	Wave Breadth	Ave Cum Balance	Ave Ticks	Survived?
R25	$30K	7	10	$515,453.75	1500	Yes, always
R26	$30K	9	10	$1,079,462.25	1500	Yes, always
R27	$30K	11	10	$1,180,626.70	1500	Yes, always
R28	$75K	7	10	$628,739.10	1500	Yes, always
R29	$75K	9	10	$1,101,724.25	1500	Yes, always
R30	$75K	11	10	$1,281,594.70	1500	Yes, always
R31	$30K	7	12	$322,931.75	1409.4	Yes, sometimes
R32	$30K	9	12	$738,367.65	1500	Yes, always
R33	$30K	11	12	$1,340,306.05	1500	Yes, always
R34	$75K	7	12	$316,080.35	1425.65	Yes, sometimes
R35	$75K	9	12	$758,429.75	1500	Yes, always
R36	$75K	11	12	$1,428,553.90	1500	Yes, always

Figure 11: Genome G3 Results

These scenarios demonstrate that robustness increases with startup capital and the number of workers. This makes sense logically as you can produce more revenue with more workers and you can afford more workers if you have the cash. Further, more revenue can be generated by intercepting more opportunities. Therefore, in these particular organizations, the most revenue was generated when the wave breadth was larger. Overall, the most interesting finding was that the biggest impact in our experiments was the number of workers.

Genome G1 was particularly sensitive to the number of workers. If the organization started out with fewer workers, it was less likely to survive. The threshold was lowered slightly as additional startup capital was added. More workers also translated into larger ending bank balances.

Genome G2 was very robust. All of the combinations of business dynamic, starting bank balance and number of workers had a good chance of surviving. This genome was less likely to trade resources but more quickly able to form a hierarchy.

The most profitable genome was G3. It was also very robust, although not as robust as G2. G3 had a higher probability of trading resources and was more resistant to creating hierarchy. The flatter organizational structure improved profitability.

In summary, the genomes that we selected to study for their adaptability showed a high degree of robustness using financial viability as a measure.

Model Insights

Model Construction

Exploration of the problem space from the Complex Systems perspective revealed that much is learned during the construction of a model while framing the problem. In our project, we had the benefit of working from a well thought-out design. The team gained an appreciation for the dynamics of how organizations operate and the effort it takes to produce a model. Josh stressed that his model was not close to representing a real organization; by comparison it was fairly simplistic. The complexity increased as we extended the model with our relatively minor enhancements. It's clear that it would be a significant effort to make the model more realistic where it could represent an actual organization. CEOs and the management team must have a good heuristics and intuition to articulate the appropriate connections to be modeled.

The model was constrained by the size of the grid, which could be saturated by opportunities and workers. For example, if the grid was filled with workers in every available space, it would guarantee that all opportunities could be captured. Common sense tells us that it would be too expensive to hire that many workers and that additional management would be required as the numbers scale. It would be interesting to explore the boundaries for the optimal number of workers.

Other explorations could involve cost of labor. Salaries in organizations are not static. In many companies there is a relationship between profitability and salaries. As the company makes more money, it can afford to reward its employees. The model could be extended to provide "bonus" money to workers and managers as the bank balance increases. Also, the cost structure could be extended to provide yearly salary increases.

The model did not factor in that other organizational changes impact operating costs. One example is employee attrition. Another example is the costs associated with collapsing the hierarchy as the organization adapts.

Agent-Based Modeling using Netlogo

A significant portion of this project was the development of the organizational adaptability model in Netlogo. Overall, the team had a positive experience with Netlogo. Using the pre-existing organizational design, the substantial model was built in approximately two months with a small team of developers. Netlogo proved to be a handy, easy-to-use, low/no cost modeling environment, appropriate for use in learning situations and for rapid prototyping.

Data Evaluation

We started with a huge data set in a broad evaluation and then focused in on three genomes with two starting bank balances, three worker levels and two different business dynamics. This focus was selected after the research team started down the path of a systematic search of all possible combinations. The "brute force" method quickly turned out to be problematic. We encountered issues with compute power including processing speed, space and memory. By focusing our search space and developing more experiments with a smaller number of varying settings, we were able to create a more manageable data set.

With additional time, a more intelligent search of genomes and environmental settings could be made. Clearly there are some hot zones in the landscape where robustness is affected by changing one setting. It would be desirable to be able to detect emergent behavior as the space is explored at a higher level and then drill down into the hot zones for more fine grained analysis. Hill climbing techniques would be a good method to explore.

CONCLUSION

Much was learned by the team during this investigation of organizational adaptability and robustness. Our examination demonstrated sensitivity to initial conditions and small perturbations. Robustness was conferred by a net positive bank balance over a period of time. The characteristics that had the biggest impact were the workforce size, the tolerance to missed opportunities in the first management level and the ease of dissolving the hierarchy. The specific organizational genomes that we down into were found to be highly robust.

Creating the model involved understanding organizational control structure behavior and dealing with many parameters. The addition of the accounting system and varied business dynamics greatly increased the complexity of our system. However, a substantial model was created in a relatively short timeframe using Netlogo.

Volumes of data were generated by a traditional search of the permutations of all the available model parameters. In order to be able to consume the results we fixed most of the variables and focused on a limited set. We also divided our experiments into smaller portions to make more efficient use of computing resources.

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