Writing Sample 1: Data Driven Dynamics

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ABSTRACT

In a study of business organizations in different countries and industries, it was found that the use of whole-system orchestrated changes by the organization was positively and significantly correlated with measures of effective organizational performance. Given that whole-system transformation is relevant to organizational level systems, there is a need to identify models that aid in understanding how such transformations take place. The dissipative structure paradigm describes a type of system transformation that takes place under turbulent conditions and is facilitated by the breakdown and rebuilding of of a structure arrangement. These type of problems are often encountered in the world of intelligent operations and international affairs. Having models that allow us to better analyze complex situations in a predictable way is imperative to the national security.

A DYNAMIC MODEL FOR LARGE-SCALE ORGANIZATIONAL CHANGE

Introduction

What does it mean for a system to be well-adapted to its environment? In the context of Darwinian evolution, an organism living in a particular environment is well-adapted if its qualities, behaviors, and capacities allow it to survive and reproduce. For example, the single-cell eukaryote Euglena uses a red eyespot as a filter allowing only certain wavelengths of light to reach the flagellum and stimulate movement towards the light in a process called phototaxis. This mechanism allows the Euglena to actively adapt to changes in environmental stimuli while simultaneously maintaining an internal objective, the search for food. The present day market is a complex system of interacting organizations constantly impacted by environmental fluctuations. In the same way the Euglena is endowed with an internal structure that allows it to actively respond to changes in its environment, a business too must maintain an internal structure that allows it to actively respond to the ever changing market. A successful business must be able to navigate itself through the domain of consumer demands without compromising it's structural integrity.

During an organizational transformation, the state of the system undergoes massive internal restructuralization. Typically, the process is delegated by a small management team, or a single person, however this introduces bias and human error into the decision making process and often leads to less than optimal performance, or worse, dissolution of the business. A potential solution to this problem is the use of data analytics and machine learning to hand-craft the optimal business strategy under the desired constraints. This approach requires objective measures of performance to guide the internal change during the transformation. In this way, one can obtain a more complete picture of system performance that includes hidden contributions from correlations accessible only at the statistical scale.

The central focus of this work discusses a novel framework for describing large scale-organizational change. The approach is rooted in the notion that the "living business" describes the state of an organization in " dynamic equilibrium" with the needs of the consumer and demands of the market. The framework allows a description purely in terms of physical properties and provides a quantitative measure of stability, efficiency, and growth of an organization. Our model is based on the assumption that a system responding to a stochastic driving signal, by means of its dynamics, can be interpreted as computing an implicit model of the environmental variables. In this sense, the physical principles used to describe biomolecular machines and other small thermodynamic systems can be applied to describe the order, evolution, and efficiency of business transformations.

Organizational change as a computational model

All systems perform computations by means of responding to their environment. When a business undergoes a transformation to meet the needs of an expanding market it must balance the rate at which it acquires information with the rate it makes decisions. The dynamics of the system perform a computation by changing the state of the system as a response to the external driving signal. As a result, the new state of the system implicitly contains some memory about the driving signal, i.e., the market dynamics. Only a fraction of the information contained in the memory of the past economic is predictive of future ones. The remaining non-predictive information reflects model complexity that does not improve predictive power, and thus represents the ineffectiveness of the business model. There exists a fundamental equivalence between this model inefficiency and thermodynamic inefficiency, measured by dissipation. The result is a profound connection between the effective use of information and efficient thermodynamic operation: any system constructed to keep memory about its environment and to operate with maximal energetic efficiency has to be predictive [1].

Learning and adaptation within business dynamics can be understood from two mathematically equivalent perspectives; (i) optimizing computational efficiency and (ii) maximizing its energy efficiency. In order to demonstrate the relationship between information, energy, and system dynamics we construct an explicit model for the system dynamics. Let s_t define the state of the system at time t and x_t the state of the market at time t. Note, we will often refer to the state of the market x_t as the "driving signal" because it serves to guide the transformations taken by the system. The behavior of the system is completely described by the preceding state of the system. These types of dynamics are called Markovian and introduce conditional state-to-state transition probabilities $p(s_t|s_{t-1}, x_t)$. Because the state of the market is typically unpredictable, changes in the driving signal are governed by a probability density $P(X) = p(x_0, ..., x_\tau)$.

Let us consider a step-by-step process of the model dynamics. At time $t = 0$, the system is in contact with some idealized heat bath with inverse temperature $\beta = 1/kT$.

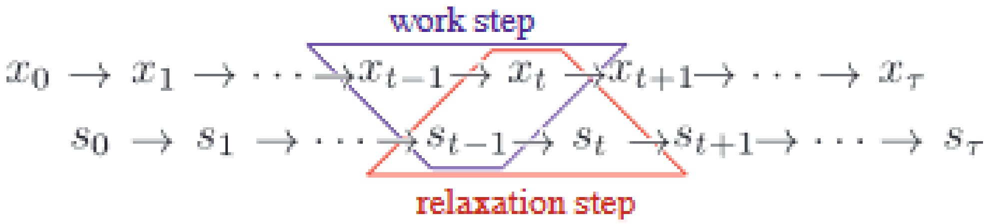
1. The market changes from $x_0 \longrightarrow x_1$ pushing the system out of equilibrium and initiating the dynamic transformation.

2. The system responds by changing its state $s_0 \longrightarrow s_1$ according to the probability $p(s_1|s_0, x_1)$

3. The market changes again $x_1 \longrightarrow x_2$ and the cycle is repeated until some later time τ.

This cycle is summarized by the following schematic taken from [1].
Given the current state of the system s_{t-1} and the probabilistic map $p(x_{t+1}|s_t)$, the system dynamics map a signal x_t onto a state s_t. The implicit model computed by the dynamics represents the prediction of x_{t+1} given the value of s_t.

Figure 1.



Information, dissipation and organizational efficiency

The system state and the external signals can be treated as random variables that share information. A measure of the information shared between two random variables is given by the mutual information

$$I[s_t, x_t] = H[s_t] - H[s_t|x_t] = H[x_t] - H[x_t|s_t]$$

When two random variables share information, a measurement of one variable reduces the uncertainty of the other variable, and vice versa. This implies that if the business and the market share information, a measurement of the market value can reduce the uncertainty in the values of the business variables. The uncertainty is typically quantified by the entropy

$$H[s_t] = -\langle lnp(s_t)\rangle_{p(s_t)}$$

and the conditional entropy,

$$H[s_t|x_t] = -\langle lnp(s_t|x_t)\rangle_{p(s_t,x_t)}$$

respectively [1]. The system's transition probability $p(s_t|s_{t-1}, x_t)$ is assumed to depend on the current value of the signal x_t and the state of the system s_{t-1}. These two dependencies are enough to induce correlations between the system's current state and the system's previous state. The memory the system keeps about the external signal is measured by the information the system state s_t keeps about a trajectory $\{x_{t-\tau_m,\ldots,x_t}\}$.

The memory of the model allows us to introduce a measure of model ineffectiveness as the difference between the *instantaneous memory* $I_{mem}(t) \equiv I[s_t, x_t]$ and the *instantaneous predictive power* $I_{pred}(t) \equiv I[s_t, x_{t+1}]$. The so called *instantaneous nonpredictive information* is proportional to the average work dissipated while the signal changes from x_t to x_{t+1}

$$\beta \langle W_{diss}[x_t \longrightarrow x_{t+1}]\rangle = I_{mem}(t) - I_{pred}(t)$$

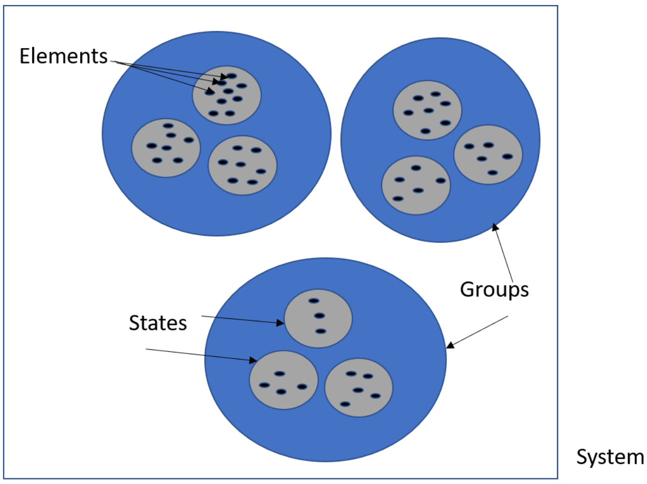
This expression says that any uncalled for retention of past information is equivalent to energetic inefficiency. This result allows us to define the most efficient state of the business as the state that retains only the necessary information and dissipates the rest. Efficiency in this context means that the operation of the business requires very little work to gain a large amount of information. The information-work trade-off is measured by the dissipation of the system.

Organization of a two-level system business model

The central focus is that dissipation can be used to measure the inefficiency of the current state of the business. This is important for the following reason; we can think of a business undergoing a transformation as a change in the balance between work-required and information-gained. In a steady-state the exchange between these two are maximally balanced, a transformation represents some external perturbation to the system. The system must respond in a way that it regains its balance by either maintaining its internal structure and integrity or by breaking and rebuilding a new structure arrangement; it must do this in a way that is maximally efficient. The question then becomes, how do you effectively manage the relationship between the internal structure of the business, which is responsible for the current operational state of the business, and changes in the external environment which influences the operational state of systems? Can the relationship between internal business structure and external influence be controlled in a systematic way that allows for the business to always maintain a "steady-state", i.e., maximally efficient, balance between work-required and information-gained?

We can construct a simple business model as a hierarchically organized two-level system. The system is composed of three components; elements, states, and groups, as shown in Figure 2.

Figure 2. Hierarchically organized two-level system



The internal structure of the system allows for two types of communication flows; flows inside a group *intra-group flows* and flows between two groups *inter-group flows*. These flows mitigate transitions between members of the same hierarchy class (horizontal exchange) and between members of a different hierarchy class (vertical exchange). We can assign *flow rates* a_{ij}^{n} and $A_{m,n}$ to the transitions between states and groups, respectfully. The total state of the system is described by the distribution of values for the flows comprising the internal structure of the system. Thus, for a system not interacting with the environment, the set of business operations depends on the orientation and value of the flows within the system. In this way the "internal structure" of the organization defines the "function" of the operation.

However, real world organizational change is far more complicated and the notion of an "isolated state" is a mere idealization. A business must be able to actively respond to the changing needs of the consumer. This requires a channel of communi-

Figure 3. Hierarchially organized transition graph

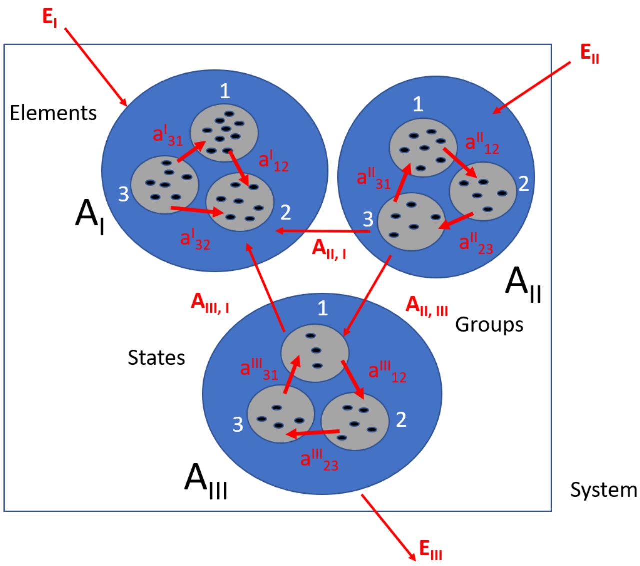
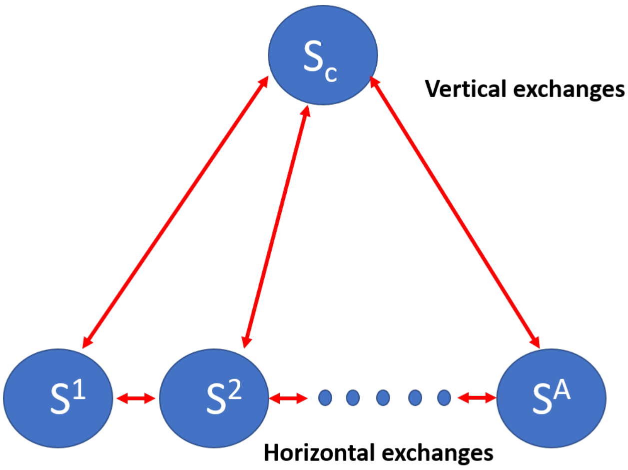


Figure 4. Horizontal and vertical exchanges of information



cation between the organized structure and any external factors that may influence a change. This flow of information and energy between the entire system and the environment is represented as E_n. This flow represents the influence of the unpredictable market on the function of the organization. The interaction with the environment causes a flux of new information to enter the system. This causes a change in the value and direction of the system's internal flows, and as a consequence, a change in the function of operation.

The dissipative structure transformation can be viewed as a type of system evolution in which a whole system change increases resilience and system functioning capabilities within an environment. The dissipative change, as a type of evolution, differs from evolution through adaptation and selection; it takes place quickly, not on slow biological time-scales.

[1] Still, S., Sivak, D. A., Bell, A. J., and Crooks, G. E., Physical Review Letters **109** (2012), 10.1103/PhysRevLett.109.120604.