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Dynamic capabilities and business processes: a trajectory view

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ABSTRACT

In this paper, we use a computer simulation to explore the effects of dynamic capabilities on the evolution of business processes. Dynamic capability is conceptualized as variation and selective retention (Campbell, 1965; Bickhard and Campbell, 2003) which governs the development and adaptation of business process. The model demonstrates that variation and selective retention of business processes explain the evolution of business process. The effect between variation and selective retention is offsetting. When variation dominates the evolution, business process will become increasingly more complex, however when selective retention dominates, business process will become less complex. The interaction between variation and selective retention also determines the evolutionary trajectory of business process.

Keywords

Capabilities, processes, trajectory, evolution, variation, selection and retention.

INTRODUCTION

Competitive advantage arises from the ability to better reconfigure existing resources and business process to match changes in environment. This ability has been broadly described as dynamic capabilities. Dynamic capability is IT enabled, as business units need to leverage IT to better reconfigure and execute business processes (Sambamurthy, et al, 2003; Pavlou and El Sawy, 2006 and 2010). Many different kinds of IT investments can serve as a platform for the creation of dynamic capabilities (Sambamurthy et al, 2003). Advances in IT such as service oriented architecture, (Papazoglou and Georgakopoulos, 2003) and software as a service have made it possible to create much more focused, efficient, and flexible organizational structures (Merrifield, et al, 2008). As a result, IT is becoming an inseparable part of organizational processes and capabilities.

In this paper, we put forward a trajectory view that explains how variation and selective retention affects the evolution of business processes over time. This view is consistent with the notion of path dependence, but it allows for the offsetting effects of variation and retention to determine the trajectory of the process. Rather than having a life-cycle that consists of a one-way transition from disorder to "lock-in", the trajectory view suggests that processes may increase or decrease in complexity over time, as shown on the right side of Figure 1. We begin by defining the key theoretical concepts and their relationship to the dynamics of business processes. We then introduce a model that allows us to simulate the performance and dynamics of business processes. The model suggests that the process complexity, variation and retention shape the trajectory of a business process to increasing or decreasing levels of complexity.

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THEORY

A business process is a set of logically related tasks performed to achieve a defined business outcome (Hammer, 1990). In our study, we model a business process as an action network (Pentland, 1999; Pentland and Feldman, 2007). In an action network, the nodes are actions (*action* refers to a step in a process to accomplish an organizational task). The ties in a network of action represent sequential relationships between actions. Unlike a social network, nodes in a network of actions can be self-connected. Actions and the sequence of actions constitute the action network that represents a process (Pentland et al, 2010). When a network of action is summarized as a matrix, the elements in the matrix, $a_{ij,}$ express conditional probabilities that one action will occur, given that another action has occurred. Therefore, business processes can be conceptualized as generative structures that can produce a wide variety of different patterns or sequences of actions (Fararo and Skvoretz 1984, Pentland 2003). While this model is simpler and less accurate than other kinds of models (e.g., petri nets), it provides a useful basis for an evolutionary analysis.

Different business processes, or more specifically, different action networks have different structure. By structure, we mean the number of branches and loops in the network of action that describes the process. Branches mean there is more than one choice action to go or they mean two or more actions could happen at the same time before and/or after another action. Loops mean the process can go back to a previously occurring action, namely redoing previous actions. Together, branches and loops provide an index of the complexity of a process. The action network can be thought of as a flexible repertoire of action patterns. This action network of process represents Cohen's "Pattern-in-variety" (2007). Even with the same structure, an action network could have many different performances depending on specific branches or loops through which a performance goes. In this way, it represents both the actual and potential patterns of action that could occur within a business process.

Action networks express the steady state structure of a process, but they can also be used to model the dynamics of a process by adding a mechanism of variation and selective retention (Pentland et al, 2010). This approach has been widely used in social and biological science (Bickhard and Campbell, 2003). Zollo and Winter (2002) used VSR as a theoretical model to explain changes in organizational capabilities and routines. Their model relied on the variation, selection and retention of knowledge. Here, we offer a more precise model of variation and retention of action patterns within processes, as hypothesized by Feldman and Pentland (2003). Variation and selective retention (VSR) provides the mechanisms by which the past informs the present and the present gets incorporated into the past (Weick, 1979). The past informs the present by exhibiting the range of variation that has occurred, and performance associated with the different alternatives that were chosen. The present gets incorporated in the past through selective retention. The realized action sequences that meet a certain performance threshold are retained.

The development and adaptation of business processes are directed by higher level processes (processes for changing processes) usually referred to as dynamic capabilities (Zollo and Winter, 2002). Zollo and Winter (2002) define dynamic capabilities as "a learned and stable pattern of collective activity through which the organization systematically generates and modifies its operating routines in pursuit of improved effectiveness." Dynamic capabilities, which are associated with change (Winter, 2003), can adapt, integrate, and reconfigure clusters of resources and processes to match requirements of a changing environment (Teece, 1997). Processes are referred to as "organizational routines" in the organization literature and "services" in technological literature, but the ideas are very similar.

TRAJECTORY OF PROCESS EVOLUTION

Van de Ven and Poole (1995) classify different kinds of change processes, such as the life cycle mode of change. A life-cycle view sees the process of change as progressing through a sequence of stages: start-up, grow, harvest and terminate (Van de Ven and Poole, 1995). The developing entity has an underlying form, logic, program, or code that controls the process of change and moves the entity from one stage to another (Van de Ven and Poole, 1995).

Because the evolution of organizational process is often regarded as path dependent phenomenon (Sydow et al, 2009), it has been hypothesized that the evolution goes through a simple life cycle that consists of three stages, such as preformation, formation and "lock-in" where dominant pattern of actions become fixed into one path, as shown on the left side of Figure 1. Constitutive elements of path dependence include initial condition, "lock-in" and underlying mechanism. (e.g. Vergne and Durand, 2010; Driel and Dolfsma, 2009; Sterman and Wittenberg, 1999).

In contrast, a trajectory view doesn't necessarily require "lock-in": the offsetting effects of variation and retention determine the process trajectory and these effects can change over time. Metaphorically, variation is like the accelerator, retention is like the brakes. Also, the trajectory view suggests that business processes may increase or decrease in complexity over time, as shown on the right side of figure 1. And any process can evolve into any other process (given a set of actions, and appropriate levels of variation and Retention). Consistent with current theories, which describe business process as generative systems (Becker, 2004), our model lead us to conceptualize business processes as having on-going dynamics. The tendency for processes to increase in complexity can be seen whenever a new procedure or control is added to account for a new perceived risk (e.g., credit card payment systems or airport security procedures).

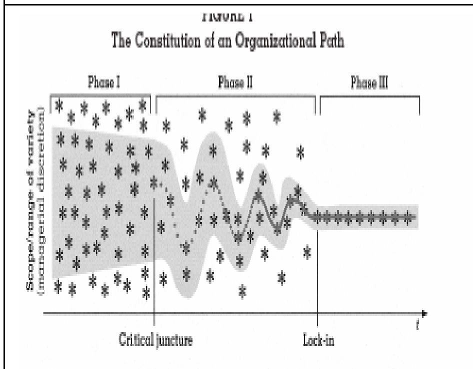
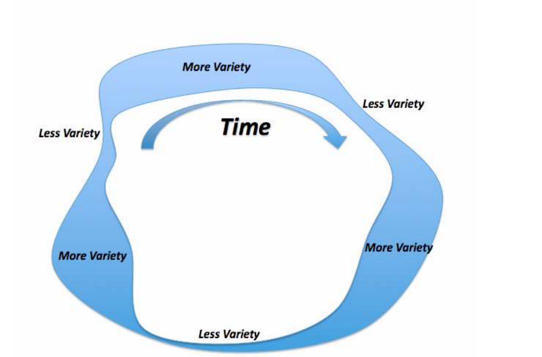
<table>
<tr><td>A life cycle view: retention leads to lock-in (Sydow et al, 2009)</td><td>A trajectory view: on-going process evolution</td></tr>
<tr><td>
</td><td>
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Figure 1: Life cycle view vs. trajectory view

Magnitude and direction of change.

To assess the trajectory of a process, we need to measure the magnitude and direction of change. The network of action provides a convenient way to represent the magnitude and direction of change.

- The magnitude of change can be computed by comparing the network of action at two points in time. There are several metrics available for this comparison, including Hamming distance, Euclidean distance and matrix correlation using Quadratic Assignment Procedure (Hubert and Schultz, 1976).
- The direction of change indicates whether the process is moving towards "lock-in" (complexity is decreasing) or away from "lock-in" (complexity is increasing).

Table 1 identifies four idealized cases that can occur within the trajectory model. Each of these idealized trajectories can be characterized in terms of the magnitude of change and direction of change (increasing or decreasing complexity). On one diagonal of table 1, we find the extreme cases where the trajectory is either "fully locked-in" or "non-routine." When a process is fully locked in, the trajectory is characterized by a lack of change. This is most likely when the current structure is relatively simple and retention is dominant. There might be variations, but they do not influence future actions. At the other extreme, the current structure of the process is complex and variation is dominant. Patterns of action might not be recognizable as instances of the same process. Here, the magnitude of change is small and direction of change is neutral.

On the other diagonal of table 1, we have trajectories where complexity is either increasing or decreasing. The complexity of a process will tend to increase when the current structure of the process is simple, and variation is dominant. The complexity of a process will tend to decrease when the current structure of the process is complex, and retention is dominant.

Table 1: Four kinds of trajectories

<table>
<tr><td colspan="2"></td><td>Simple Process Structure</td><td>Complex Process Structure</td></tr>
<tr><td rowspan="2">Main Driver of Evolution</td><td>Variation</td><td>Complexity-increasing
Magnitude = large
Direction = increasing</td><td>Non-routine
Magnitude = small
Direction = neutral</td></tr>
<tr><td>Selective Retention</td><td>Fully Locked-in
Magnitude = none
Direction = neutral</td><td>Complexity-decreasing
Magnitude = small
Direction = decreasing</td></tr>
</table>

Propositions

The model developed by Pentland et al (2010) shows that "lock-in" and endogenous change can be caused by the same underlying process of variation and selective retention. "Lock-in" does not always happen, because variation within a process can lead to new paths if that variation is retained (Garud et al, 2010; Rerup and Feldman, 2010). In this study we go a step further to explore conditions under which each trajectory is likely to happen. If there is certain level of retention, "lock-in" will occur. The greater the retention, the more time will be needed to reach "lock-in" (Pentland et al, 2010). If we turn to structure of action network, it is more complex before "lock-in" than after "lock-in." The change leading to "lock-in" can be described as the action network changing from more loops and/or more branches to fewer loops and/or fewer branches, from complex to simple. We refer to this process as complexity-decreasing drift, and it is the common cited path dependent process leading to "lock-in". When variation dominates the evolution, however, there is complexity-increasing drift where process moves away from "lock-in" and goes to endogenous change. The change leading to endogenous change can be described as the action network changing from simple to complex. So the process trajectory is determined by the offsetting effects of selective retention and random variation. This leads to a more interesting proposition:

P_1: Balance of variation and retention can lead to no change in direction (neutral).

In the real world, all the factors interact with each other in process evolution. The interaction between variation (accelerator) and retention (brake) can influence the magnitude and direction of change. When we only consider variation, magnitude of change is large and direction of change is complexity increasing when variation is large. When we introduce retention, the smaller retention, the stronger the "braking effect", the smaller the magnitude of change and the less likely the complexity increasing happens.

P_2: The effect of variation is moderated by the level of retention.

Variation can lead to complexity increase that has a big magnitude of change, but when a process is getting increasingly more complex, the effect of variation gradually disappears and the magnitude of change is getting smaller and direction is becoming less complexity increasing. So variation has stronger effects on a simple process than a complex process.

P_3: The effect of variation is moderated by the degree of process complexity.

This proposition goes beyond the idea that processes can undergo endogenous change, as proposed by Feldman and Pentland (2003). It suggests the possibility of a self-reinforcing feedback loop where complex process becomes more complex over time. Rather than gravitating inexorably towards "lock-in" around a fixed pattern of action, a process on this evolutionary trajectory could generate continuously changing, ever more varied patterns of action.

Formal Model

In this section, we describe the formal model, which is implemented in Matlab 7.2. [2] The core of the model is a first order Markov transition matrix that is continuously updated through a process of variation and selective retention. The model is summarized in Figure 2.

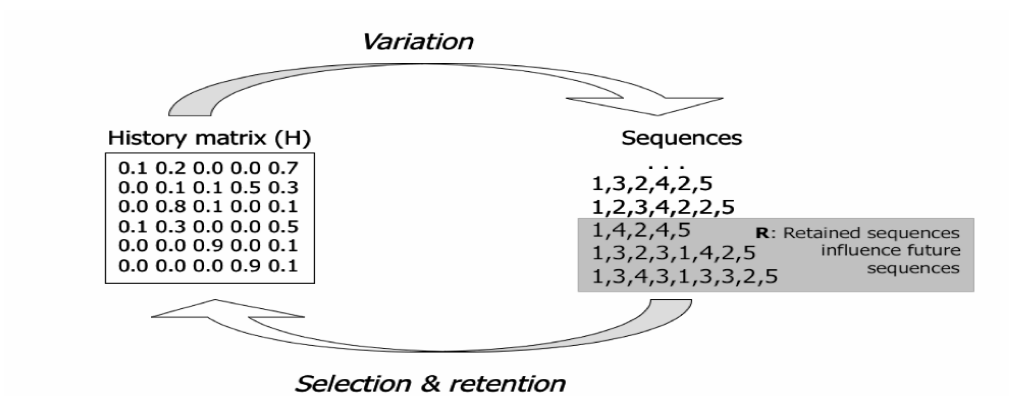

Figure 2. Overview of simulation model

[2] Because we use the same basic model, this section of the paper follows the model description in Pentland et al (2010) very closely.

Choice set: A

Actions are chosen from a set of possible actions, the choice set, A. We represent the choice set as a set of integers, (1, 2, 3, … , A). An important assumption of this model is that the choice set is relatively stable. In our model, the choice set is fixed. We consider the choice set given by the context. We thus assume that the time scale of repetition for a process is shorter than the time scale of exogenous change pertaining to possible actions. For instance, artifacts such as keyboards provide a choice set (the keys on the keyboard) and limit the degree to which that choice set can change. While the stability of the choice set in organizational processes is a matter of empirical investigation, our model makes the conservative assumption that the choice set is stable. In our model, we use A=10. We have tested other values of this parameter and results are qualitatively similar.

History: H

Actions and the sequence of actions in an action network can be summarized into a matrix in Figure 2 which represents an action network (Pentland et al, 2010). The accumulated history of past sequences is modeled as an AxA transition matrix (Pentland, 1999; Pentland, Haerem and Hillison, 2009a,b). The history matrix implements the concept of interdependence within the performance of a process (i.e., in the patterns of action), where one action predicts the likelihood of the next. Analysis of data on real organizational process indicates that the first order Markov model is justified (Pentland, Haerem and Hillison, 2009a,b).

This history matrix, H, can be translated as a network graph, where the transition probabilities represent tie strength (Pentland, 1999). Each cell (i,j) in the matrix represents the probability pij that action ai will be followed by action ai. This matrix can be interpreted as a first order Markov transition matrix (Anderson and Goodman, 1957). The history matrix describes the potential action sequences that are likely to emerge.

The transition matrix has a simple practical interpretation. Entries in the upper right triangle (above the diagonal) represent branches if they are non-zero numbers. Branches mean there is more than one choice action to go or they mean two or more actions could happen at the same time before and/or after another action. Likewise, non-zero entries in the lower left half (including the diagonal) represent loops. Loops mean the process can go back to a previously occurring action, namely redoing previous actions.

Variation, Retention and Selection: V, R & S

When a sequence is generated, it may be subject to random variations. For example, the sequence (1,2,3,4…) might become (1,7,3,4…). The frequency of these variations is governed by the parameter V, which is the probability, $0 <= v <= 1$, that any action in a sequence may be replaced with another action drawn randomly from the choice set. The variation is applied at the level of the individual actions, so a given sequence can have more than one variation. This random variation is applied when sequences are generated, before they are selected or retained. In this way, the variations may be selectively retained in the history matrix, H.

The parameter R refers to how many past action sequences are incorporated into the history matrix, H. It defines the depth of the record of the past that is retained, and thus, the effect of history. R is defined as a "moving window" of previous sequences – when the most recent action sequence is added to the history matrix, H, the oldest action sequence in the 'window' is dropped. In figure 5, it is represented as the shaded area. In our simulations, R varies from 1 to 100. When R=0, there is no effect of history and the process is stationary.

The history matrix is computed as a simple average. Thus, in the history matrix, the probability that action j will follow action i is given by h_{ij}, which is simply the number of times that pair of actions occurred in the set of retained sequences divided by the total number of retained sequences. We considered a log-weighted average based on time, so that the most recent sequences would have the greatest influence (Abbott, 1992), but this refinement does not change the substantive results of the model.

In this model, all the performances are selected (S) and retained in transition matrix. We do not apply any additional selection criterion.

Branches and Loops: B & L

Branches occur whenever there is more than one non-zero probability in the upper-right half of the history matrix. Loops occur whenever there is any non-zero probability in the lower-left half of the history matrix, including the diagonal. Non-zero probability on the diagonal indicates that a process step can repeat.

METHOD

Simulation is an increasingly significant method to theory building and theory testing in strategy and organization studies (Davis et al., 2007). Many organizational concepts and constructs imply complex and dynamic process, such as path dependence, dynamic capability, and endogenous change and so on. Computational simulation is an ideal way to study and build theory for these organizational phenomena (Davis et al. 2007; Carley, 2001). Simulations enable researchers to define starting conditions, take a complex set of assumptions, and observe and record detailed characteristics of organizational processes (Lant and Mezias, 1995). These processes are difficult to observe and collect empirical data using traditional methodology, (Davis et al., 2007), so simulations are well suited to build theory in a longitudinal process such as path dependence.

MEASUREMENT

For each simulation, we generate 1000 networks of action. In effect, we are sampling 1000 networks from the space of all possible networks of action - every combination of branches and loops - for the given choice set. The 1000 randomly drawn networks are independent from each other. We examine short term effects after 50 iterations.

Complexity, variation and retention

Given the matrix, complexity is measured by the total number of non-zero entries in the matrix, which equals the total number of branches and loops. We vary retention between 1 and 50, and variation is any value between 0 and 0.05.

Magnitude of change

We use Hamming distance to measure the magnitude of change (Hamming, 1950 and 1986). This variable always has positive value. If a matrix entry change from non-zero at early evolution trajectory to zero at later evolution trajectory (or change from zero to non-zero), the hamming distance of this entry is 1. If there is no change, namely from non-zero to non-zero or zero to zero, the hamming distance is 0. Then the sum of hamming distance for all matrix entries is the measure for magnitude of change. OLS regression is used for the magnitude of change.

Direction of change

We can measure the direction of change by whether complexity increases or decreases. Dependent variable is treated as 1 if complexity increases from early evolution trajectory to later evolution trajectory (complexity change is greater than zero). Otherwise dependent variable is 0 (complexity change is smaller than zero). Logistic regression is used to measure direction of change.

RESULTS

Table 2 shows the descriptive statistics for each variable. The independent variables we tested include the complexity (C), variation (V), and retention (R); interaction terms (CxV, VxR). To facilitate the analysis of interaction effects, the variables were centered (Cohen, Cohen, West, & Aiken, 2003).

Based on model 2 in table 3, we were able to draw the balanced line between variation and retention for short run and long run. The interaction effect is significant, so the balanced line is a curve (see figure 3). Proposition 1 is supported. For simple and median complex process, variation needs to increase to maintain balanced if retention increases, while for complex process, variation needs to decrease a little. So for simple process, high variation needs to work with high retention to maintain balanced. For complex process, high variation need to work with low retention to maintain balanced.

The interaction effect between variation and retention is significant for both magnitude and direction of change. So the effect of variation is offset by the stronger effect (low retention level). Interaction effect is significant in the direction of change. The interaction effect between variation and process complexity is significant for both magnitude and direction of change. So proposition 3 is supported.

Table 2 Descriptive Statistics

	Mean	S.D.	Min.	Max.	C	V	R
Complexity (C)	0	10.460	-42.923	20.077			
Variation (V)	0	0.014	-0.024	0.025	-0.01		
Retention (R)	0	14.216	-25.006	23.994	-0.04	-0.12***	
Hamming distance	49.564	7.650	22	86	-0.01	-0.03	0.05

Note: sample size =1000

Table 3 Regression and logistic regression results

	Magnitude of change		Direction of change	
	Model 1	Model 2	Model 3	Model 4
Complexity (C)	-0.680***	-0.689***	-4.801***	-4.801***
Variation (V)	0.123***	0.121***	0.664***	0.377
Retention (R)	-0.309***	-0.299***	-0.429**	-0.388
Interaction (VxC)		-0.187***		-0.917*
Interaction (VxR)		0.140***		0.626***
Sample size (N)	1000	1000	1000	1000
R^2 (%)	56.75%	62.74%	60.41%	63.46%

Notes: standardized coefficients; p<0.05 *, p<0.01 **, p<0.001 ***.

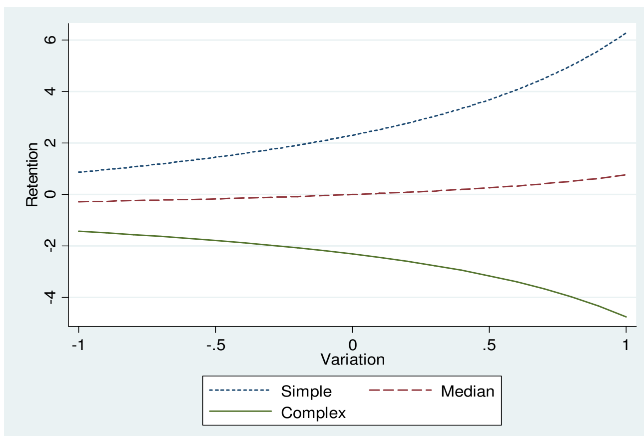

Figure 3. Offsetting effects of variation and retention

DISCUSSION

Normally, the IT literature treats processes as static object that are the result of deliberate design. In contrast, the analysis here assumes that processes can evolve towards increasing or decreasing complexity. Designers may strive for a particular process configuration, but over time, that configuration is not necessarily achieved or maintained consistently. Processes and systems can drift (Ciborra, 2002). Variation and selective retention provide theoretically meaningful and practical ways to influence these dynamics. Variation means new ways of doing an organizational task. In real organizations, variation can be good and bad, as it comes from different resources. It could from innovation or merely error; managers can deliberately encourage or suppress variation. Information technology is often used to suppress variations – to increase the uniformity and control of a business process (McAfee and Brynjolfsson, 2008). Likewise, information systems are used to retain process information and organizational memory. Retention may also come from other resources, such as individual and organizational memory (Schulz, 2008).

Variations and selective retention can be thought of in terms of March's (1991) concepts of exploration and exploitation respectively. It is not easy to pursue exploration and exploitation simultaneously, but our simulation suggests that such balance may be essential to maintain the complexity of business processes that are subject to evolutionary change. Increasing V will increase the tendency for exploration (change). Increasing R will in increase the tendency towards exploitation (stability). The results presented here provide another way of thinking about balancing exploration and exploitation in the evolution of organizational processes. Stability and change are evolving on the trajectory of a process. Dynamic capabilities can be thought of as evolutionary mechanisms that operate through variation and selective retention. As such, they govern the direction (drift towards increasing or decreasing complexity) and the evolution of business processes.

CONCLUSION

We use simulation to explore business process evolution over time. In contrast to the life-cycle view which is often applied to this area, we propose a trajectory view, where processes can evolve continuously. We observe two kinds of drift in the process evolution, one where the process becomes increasingly varied; the other where it becomes less varied and moves towards "lock-in." When retention dominates the evolution, there is complexity-decreasing drift, where process moves toward "lock-in" or inertia. When variation dominates the evolution, there is complexity-increasing drift, where process moves away from "lock-in."

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