Reactive or Stable: A Plant-inspired Approach for Organisation Morphogenesis

Payam Zahadat[1,3], Ada Diaconescu[2]

[1] IT University of Copenhagen, paza@itu.dk
[2] Telecom Paris, LTCI, Institute Polytechnique de Paris, ada.diaconescu@telecom-paris.fr
[3] Artificial Life Lab, University of Graz

Abstract

Communication networks are prevalent in both natural and artificial systems, enabling information and resource exchanges amongst system parts. In most systems, the network topology influences system performance, which, in turn, reshapes the network topology; hence creating one or several feedback cycles. Understanding how such system growth and restructuring processes function becomes critical in today's increasingly connected world. This paper describes a generic model of feedback-based growth and adaptation for systems with tree-like control topologies. Inspired by plant vascular morphogensis, the model is transferred here for studying the development and adaptation behaviour of business organisations, operating in fluctuating economic environments. Experimental results show the impact that various degrees of internal competition have on overall business growth, productivity and reactivity to changing business landscapes. The preliminary findings presented seem to fit existing economic studies on related topics. The proposed model offers a solid basis for studying morphogenetic processes and associated performance indicators, applied to tree-shaped business organisations, and transferable to further domains.

Keywords: vascular morphogenesis controller, organisation growth, self-adaptation, competition, tree topology

1 Introduction

Communication networks are prevalent in both natural and artificial systems (Barabasi, 2016). They are indispensable for system integration, i.e. for exchanging information and resources (Bejan and Zane, 2012; Zahadat, 2019). In general, system viability imposes high-level constraints on network topology (Ravasz and Barabási, 2003; Bejan and Zane, 2012; Bettencourt et al., 2007)). Within these constraints, the concrete topology of each system may adapt to changes in internal resources, objectives and the external environment; so as to optimise its efficacy, efficiency and/or resilience. Notably, in a self-organising system, information and resource flows continually influence network structure, adapting it to internal and environmental dynamics.

In an increasingly-connected, ever faster-changing socio-cyber-physical world (e.g. social change (Archer, 2013), innovation and city scaling (Bettencourt et al., 2007), accelerating digital economy (Kim et al., 2014)), understanding how performance feedbacks continually shape self-organising and self-adapting systems becomes vital.

The presented research is part of a longer-term project that aims to help address this vast challenge (Zahadat, 2019). Drawing inspiration from plant growth processes, previous work has distilled a generic model of feedback-based growth and adaptation for systems with tree-like control topologies (also extendable to non-tree-like topologies of directed acyclic graphs). This paper's contribution is threefold: i) illustrate the model's cross-domain applicability by transferring it to business organisations; ii) offer a domain-specific simulation model for experimenting with organisation growth and adaptability strategies under varying economic conditions; and, iii) report preliminary findings on the impact of internal competition on business profits and restructuring needs; pointing to economic studies that support the observed behaviours.

Our experiments show how various competition rates among internal branches, offering different services, impact immediate system performance and stability, as well as reactivity to future changes in service demand. Namely, equal resource sharing amongst branches (i.e. low competition) provides more stability (systemic and individual), while entailing slower system growth and lower overall profits. Conversely, higher competition capitalises on new demand opportunities and hence ensures faster growth and higher system gains; at the cost of more topological and individual changes. Interestingly, further increasing competition actually hinders system adaptability, as previously well-established branches prevent new branches from growing into new profitable sectors. These preliminary findings seem to fit economic studies on related topics (Cf. sec. 3).

As the best solution is ultimately business-specific, the proposed model helps to simulate and analyse a wide variety of scenarios and outcomes, getting a better intuition of determining factors, benefits and risks. The current implementation and results offer a stepping stone in this direction; and will be extended for considering further factors (e.g. individual objectives, employment costs and delays), and a wider variety of changing economic landscapes.

2 Plant-inspired Morphogenesis For Organisation Growth and Restructuring

2.1 Plant and Organisation Branching Analogies

Plants typically have a repeated pattern of branching, where each branch may be divided into several subbranches, each of which may be further divided into smaller ones (Fig. 1a). Such structure may be represented by a tree graph, where the graph's root represents the plant's root system, providing the plant with common resources (e.g., water and minerals); and the graph's leaves represent the plant tips. A plant grows within its environment, tending to optimise its shape so as to benefit from local resources (e.g., light). Apart from the plant's genetics encoding several growth parameters in the genome, the mechanisms that guide the plant's shape are based on two flow types: a *forward flow* of a common resource from the root towards the tips, and a *backward flow* of a guiding signal from the tips towards the root. The guiding signals are produced at the tips proportionally to the local resource available there (e.g., local light intensities). If a branch is located in a relatively more favorable region, the guiding signals produced at its tips result in a higher share of the common resource being sent to that branch. With a sufficient amount of the common resource, a branch can grow into several subbranches, hence further expanding the plant into that region of the environment. Plant branching (rather than e.g., linear) structures result from evolutionary processes that tend to facilitate chemical flows throughout a system, i.e. two-way transfers between roots and leaves (Bejan and Zane, 2012).

Similarly to plants, tree graphs may also represent the structure of business organisations that provide different services within an economic environment. A business organisation is branched into sub-units, where each sub-unit might be further branched into smaller ones (see Fig. 1b). The various nodes of a graph can be grouped into three types, representing various functionalities in a business structure: *service units*, *intermediate units*, and the *root*. The root provides the common budget for maintaining the organisation, including worker salaries. One can imagine an organisation growth mechanism based on the two opposite flows, similar to plant growth. The leaf nodes here represent the organisation's service units, where workers produce profits via service provisioning to the outside world. Profits act as the guiding signal flowing root-wards via the intermediate units. The organisation's common budget acts as the forward flow from the root, divided amongst the branches, until reaching the leaf nodes. A service unit that produces relatively higher amounts of profits for the organisation may receive higher shares of the common budget. With a sufficiently large budget, a service unit may hire more workers and expand into further sub-units (i.e. branching). Unlike the plants, where the common resource provided at the root has external origins (e.g., water and minerals from the soil), in the case of organisations the common resource is the budget resulted from the profits produced by the service units. Initially, external investment may also be injected as a common resource to ensure minimal growth, and hence economic viability. Similarly to plant branching structures, organisations also tend to develop into tree-like shapes that facilitate the flows of information and control between productive force and management (L. Gulick, 1937; Bejan and Zane, 2012; Diaconescu et al., 2019).

2.2 VMC: Plant-based Branching Model

The VMC (Vascular Morphogenesis Controller) model (Zahadat, 2019; Zahadat et al., 2017) abstracts the mechanisms of dynamic plant branching for directing the adaptive growth of acyclic directed graphs (see Fig. 1). As in plants, the growth of a VMC graph is directed by two flows: a *forward flow*, R, representing a shared resource, and a *backward flow*, S, that is produced at the graph's leaves according to their local success (e.g., local access to light as perceived by local sensors, or local production of profit by a service unit).

The success S_j produced at a leaf node j according to the local environmental conditions and constant parameters is:

$$S_j = f(\omega_{\rm c} + \sum_{s \in \text{sensors}} \omega_s I_s) \tag{1}$$

where $f(x) = \max(0, x)$, ω_c is the constant term for the success production, and ω_s is the environment-dependent production term determining the dependency of success production on a local environmental quantity I_s.

Success signals flow towards the root via intermediate nodes. At an intermediate node i, the flow can be altered by a transfer rate $\rho_c \in [0, 1]$:

$$S_{\rm i} := \rho_{\rm c} \sum_{b \in \text{children}} S_b \tag{2}$$

where *children* is the set of all children of node i.

The success signal S_j flowing from a node j to its parent node i adjusts the connection weight $V_{i,j}$ according to a parameter β_i, which determines the *competition* intensity between the sibling nodes, and a parameter α determining the connection's *adaptation speed*:

$$V_{i,j} := V_{i,j} + \alpha(S_j^{\beta_i} - V_{i,j}) \tag{3}$$

The common resource R_{root} starts at the root and is distributed through available connections. At every node, a part of the resource is consumed and the remaining resource is divided between the node's children, proportionally to their connection weights. A node j receives the resource R_j from

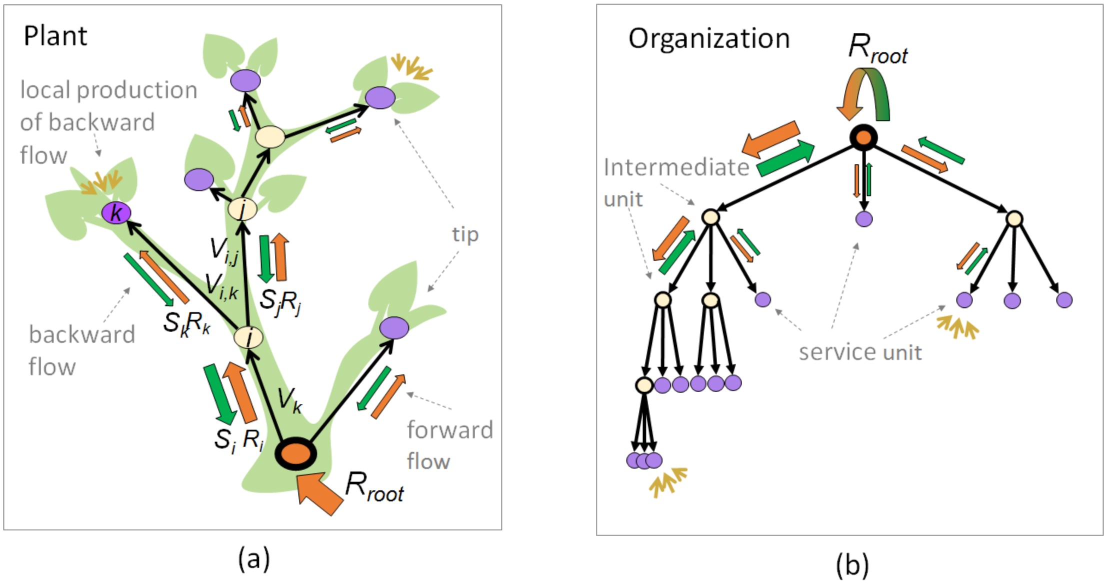


Figure 1: Schematic comparison between the branching structures of plants and business organisations

its parent i via a connection of weight $V_{i,j}$ as:

$$R_j := (R_i - c)\frac{V_{i,j}}{\sum_{b \in \text{children}} V_{i,b}}, \tag{4}$$

where c is a constant parameter representing the resource consumed at the parent node. The amount of resource at a leaf R_i determines whether or not it can branch-out (e.g., if $R_i > th_{add}$). Similarly, an intermediate node's resources determine whether it may lose its leaves (e.g. $R_i < th_{del}$). The exact implementation of these operations is application-dependent (subsec. 4.3 for the current implementation).

2.3 Applying VMC to Organisation Branching

Here we define an organisation's hierarchical structure, as well as its dynamic development and restructuring as a VMC tree. The leaves represent the service units that produce profit for the organisation via service provisioning to the environment (e.g., their customers). The structure develops in time according to the available budget (common resource), service demand, and the profits produced by different units. Produced profits flow from the tree's leaves towards its root and contribute to the organisation's common budget. In addition to profits accumulated at the root, an organisation may benefit from external resources. E.g., a start-up company may benefit from an initial investment for a limited time.

The common budget at the root is distributed over the entire organisation for needed expenses. The weights of links between a unit and its sub-units are used to distribute the budget from that unit to its sub-units (Eq. 4). Profits produced by the service units flow toward the root and regulate the link weights over time (Eq. 3). To reflect administrative overheads at every tree level, each unit reduces its budget by a consumption-rate $c > 0$ before distributing it. If the share of the common budget reaching a service unit is larger than a threshold (th_{add}), the unit is divided (i.e. the service unit becomes an intermediate unit with several sub-units). If all of the sub-units of an intermediate unit are service units and its budget is lower than a threshold (th_{del}), the intermediate unit shrinks into a service unit (i.e. its sub-units are dissolved and it takes over their services). Hysteresis effects can be implemented to prevent the system from fast structure changes. E.g., before an intermediate unit shrinks back into a service unit, it waits for a given period; the shrinkage is enforced only if the conditions are met for this entire period. In the implementations here, the transfer rate of the profit flow is set to $\rho = 1$, allowing all profits made in the service units to flow to the root.

3 Related Work

The original VMC model was detailed in previous work (Zahadat, 2019), and adapted here for business organisations. In brief, VMC fits the general idea of *morphogenetic engineering* (Doursat et al., 2012), which focuses on multi-agent programming that can produce self-assembling, self-architecting systems. The generic VMC approach aims to grow directed acyclic graphs including tree-like systems with various shapes (e.g. more-or-less symmetric) determined by growth configuration parameters (e.g. competitiveness β) and by the environmental context (e.g. available resource distribution, or service demand).

Lindenmayer systems (L-systems) (Prusinkiewicz and Lindenmayer, 1990), also produce varying tree shapes, by relying on a predefined formal grammar (i.e. symbols and production rules). L-system rules are executed recursively, without considering the performance of intermediate shapes. VMC adapts the growth process depending on its success within its current (business) environment. This was also attempted in e.g. Risi et al. (2016), via evolutionary approaches, which would not react immediately to changing resource landscapes (e.g. moving light sources). Such reactivity is essential in our proposal, which aims to apply dynamic tree shaping to organisational growth in rapidly-fluctuating economic contexts. Importantly, the proposed growth model corresponds to a top-down approach (from roots to leaves), typical for business organisations; rather than a bottom-up self-organisation, as in grass-roots collective-action organisations (Perret et al., 2017).

We focus the remaining related work around our current contribution – studying organisational adaptability via different growth and restructuring strategies. Our experimental findings seem compatible with the results of empirical economic studies, e.g. Topel (1982), Abraham and Houseman (1995), which support the idea that companies use temporary layoffs and reemployment to deal with short-run demand fluctuations. This approach provides a viable alternative to keeping inventories or excess capacity of idle workers (Stigler, 1939); especially when layoffs and employment are relatively cheap and inventory management expensive. As reported in Feldstein (1975), more than two-thirds of layoffs in American manufacturing were temporary (at the time), followed by rehire by the same employers. This strategy is confirmed in Abraham and Houseman (1995), where the difficulty of layoffs in European countries (e.g., Germany) was compensated by more flexibility in working hours. This resulted in the same overall workforce flexibility as in less worker-protective countries, where layoffs were privileged (e.g. USA). More recent studies confirm the effectiveness of both flexibility-enabling methods – hours reallocation and short-term employment – e.g. coping with the 2008 economic crisis in Germany via short-time employment (Kruppe and Scholz, 2014), or via working hours adjustments (Burda and Hunt, 2011). Both methods can be mapped to our simulation model, corresponding to worker replacement or re/allocation from an idle pool, respectively.

Surely, the cited studies and our simulation model only consider the impact on productivity at the organisation level, and on the short-term, of these adaptation mechanisms. They ignore negative impacts on long-term productivity (Sheaffer et al., 2009), as well as on employee well-being (Meier, 1972; Tubaro and Casilli, 2019). Future work will include additional factors into the simulation and evaluation criteria (e.g. employment costs and delays); impacts on in-house expertise; contact networks; and productivity.

Further studies compatible with our findings focus on explaining an organisation's drive for various adaptations. E.g., Desai (2008) indicates the organisational factors (e.g. age, experience and legitimacy) that may impact risk-taking (e.g. for restructuring and re-specialisation, in our case), as an important means to adapt and surpass under-performance in new economic contexts. March (1991) suggests that organisational adaptation tends to refine exploitation processes more rapidly than exploration ones, leading to short-term efficiency but long-term degradation (consistent with our simulation results for high-competition, $\beta = 1.2$ in sec. 5).

Further research studies correlate organisation structure and performance from different perspectives. E.g., Parkhe (1993) adopts a game-theoretic approach to study how the structure of inter-company alliances impacts on their long-term performance. Gaba and Joseph (2012) analyse multi-goal multi-divisional firms, showing how different reactions to performance feedback, at different levels (i.e. corporate and business units), impact adaptability (via new product launching). Csaszar (2013) explores the impact of organisation design on exploration and exploitation capabilities. None of these studies analyse the correlation between an organisation's performance and its adaptive growth strategy.

4 Simulation Model of Organisation Growth

4.1 Competition-oriented Resource Sharing

The VMC simulation model defines the development and adaptation of an organisation's structure in a dynamic environment, where the demands for services change over time. We demonstrate an organisation's restructuring behaviour for various competition-rates, β, in two environments – with slow and fast dynamics, respectively. The parameter β determines the intensity of competition among sub-units, within each unit. Namely, if sub-units produce unequal profits then the difference in their received budgets is larger for higher values of β than for lower values. This leads to more symmetric organisation shapes growing for lower competition rates, and more asymmetric ones for higher rates (Fig. 2).

4.2 Defining the Environment as a Service Space

We define a tree-shaped organisation as a set of units $U = \{u_n | n = 0..N\text{-}1\}$, with N the total number of units. The number of direct sub-units of a unit u_n is denoted via $subunits(u_n)$. There are three unit types: one root unit ($RT = u_0$); several intermediate units ($I = \{i_k \in U | subunits(i_k) \neq \emptyset \wedge i_k \neq RT\}$); and service units ($SU = \{su_j \in U | subunits(su_j) = \emptyset\}$). Note that the root can also be a service unit, if it is the only tree node.

We define the environment as a 1-dimensional service space that is divided into M segments, each representing a particular service type (c_m, $m = 0..M\text{-}1$). Each segment has a maximum demand, $max\text{-}demand_m$, for its service type c_m. The set of service units provisioning a particular service c_m at time t is designated by $su\text{-}prov(c_m, t)$; and the set of services provisioned by a service unit su_j at time t is returned by $serv\text{-}prov(su_j, t)$. Provisioning a service returns an associated profit, up to $max\text{-}profit_m$, to the providing service unit(s). The exact profit $P_{su_j,t}$ that a service unit su_j receives at each time step t, depends on the services it provides, C, and the number of other service units covering the same service(s) – Equation 5.

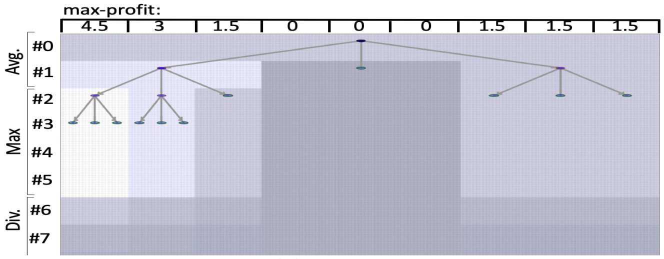
More precisely, a service unit that serves several segments at the same time equally divides its working capacity among those services. Hence, the profit it can produce is the average of the profits of all those services. If a service unit serves a single segment, it can produce the maximum profit associated with that segment. If the number of units providing the same service is beyond its maximum demand, there will be insufficient work for all the units and thus the max-profit is divided amongst them.

$$
\begin{aligned}
&C = serv\text{-}prov(su_j, t) \\
&P_{su_j,t} = \begin{cases} \dfrac{1}{|C|} \displaystyle\sum_{c_m \in C} max\text{-}profit_m, & \text{if } |C| > 1 \\ max\text{-}profit_m, & \text{if } C = \{c_m\} \wedge \\ \qquad\qquad |su\text{-}prov(c_m, t)| \leq max\text{-}demand_m & \\ max\text{-}profit_m / K, & \text{if } C = \{c_m\} \wedge \\ \qquad |su\text{-}prov(c_m, t)| = K > max\text{-}demand_m & \end{cases}
\end{aligned} \tag{5}
$$

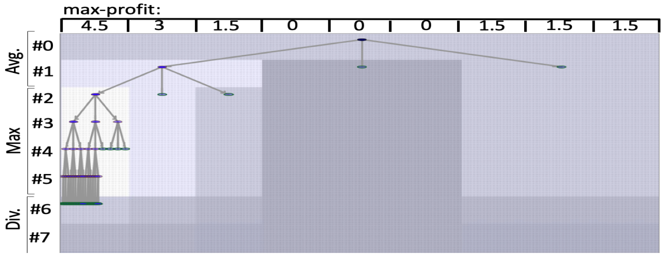
Fig. 2 depicts an example environment, with two organisations developed within that. Here an organization has a fixed branching degree of 3, i.e., each unit is either a service unit (leaf) or it has exactly 3 sub-units. The environment has M=9 service segments with equal *max-demand*$_m$=27; and with different *max-profit*$_m$ indicated on top of each segment (Fig. 2). The index of each organisation level is indicated on the left side of the figure. The background gray-scale colors indicate the profit that a service unit in that level can produce—brighter colors indicate higher profits. Since the branching degree is 3, the number of units cannot exceed 27 (max-demand) before level #6.

Below level #2, each unit serves several segments, hence producing the averaged profit of those segments (depicted by *Avg.*). The units in the levels #2 to #5 can produce the max-profit (depicted by *Max*). For deeper levels (depicted by *Div.*), the number of units serving a segment exceeds 27 and hence the max-profits are divided among them. At level #1, a service unit covers 3 segments and the profit it produces is the average of those 3 max-profits. A service unit at level #0 covers all the 9 segments, hence producing a profit that is the average of their max-profits. Note that only service units (leaves) produce profits and hence the discussion above, and the gray-scales, only apply to the intermediate steps of the organisation's growth. E.g, if the organisation starts from a single unit (the root), this unit is initially a service unit that produces the average of the 9 max-profits.

With this environment definition, a small organisation (e.g, a root unit and 3 sub-units) does not differentiate between various service types and may only make average profits leading to small growth opportunities. Once the organisation grows sufficiently to dedicate individual units to different services, it can benefit better from high-profit services by adding increasingly more units for those services, until max-demand is reached. Afterwards, the organisation no longer profits from further expansion in those segments.



(a) Low competition



(b) high competition

Figure 2: Two sample organisations with different competition rates β, in an environment with 9 hypothetical services. The 9 services are represented on the horizontal axes, with the max-profit of each service indicated on top. The environment's gray-scale colors indicate a service unit's profit in that segment area, computed according to the max-profit and the number of units that potentially fit in that area. Avg., Max, and Div. indicate how the produced profit of a service unit is computed in each level (details in sec. 4.2 and equation 5).

4.3 Implementation Details

The simulation model of the organisation and its environment is implemented in Java, within the Processing platform[1]. The implemented organisations' structure starts from a root with its three sub-units, and grows over time. As shown in Fig. 2, the segments' initial max-profit sequence is $(4.5, 3, 1.5, 0, 0, 0, 1.5, 1.5, 1.5)$. The environment is dynamic, in that the segments' max-profit sequence switches between the initial one and its reverse $(1.5, 1.5, 1.5, 0, 0, 0, 1.5, 3, 4.5)$. The switching frequency varies with the experiment (Cf. below).

The organisation's common budget is the total amount of profits reaching the root from the leaves, plus an *external-budget* = 10 provided for the first 10 time steps. These values are set based on preliminary experiments in the above

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[1] Processing 3.5.3, https://processing.org

environment, where zero external-budget leads to no growth from the initial state. A service unit grows into an intermediate unit if it receives a budget higher than $th_{add} = 4$. An intermediate unit shrinks into a service unit if its budget is below $th_{del} = 4$. Hysteresis is implemented for the shrinkage with a wait period of 3 steps. Administration overheads are represented by a consumption-rate of c= 1 at intermediate units. The transfer rate is set to $\rho = 1$ to allow all profits produced to reach the root. The adaptation rate is set to $\alpha = 0.9$ to allow a fast adaptation of the weights. The production-rate of the profits at the leaves depends solely on the provided services (environmental factor) and thus $\omega_s = 1, \omega_c = 0$. (For a discussion on the parameter effects and directives on how to set them see Zahadat (2019)).

Experiments are executed in discrete time steps, with all values updated synchronously. All operations, except growth, are implemented deterministically. At each step, the shrinking operation is applied to all susceptible units. The growth operation is executed on a single service unit, which is selected randomly among those with *budget* $> th_{add}$.

5 Experimental Results

Two sets of experiments were conducted, with different switching frequencies between the two opposite max-profit sequences. The sequence is switched in every 200 time steps for the first set of experiments and in every 50 time steps for the second one. Every set of experiments consists of 10 independent runs, each running for 800 time steps. The following presented results are the medians of the 10 runs. The system behaviour is shown for each frequency and for different β values that determine the competition intensity between sub-units (Fig. 3 and Table 1).

Fig. 3 shows the organisation's structural dynamics in this changing environment, for five different competition-rates β. Three structural quantities are presented: R_{root}, $asymmetry$ and the number of units, or $Nodes$, for two of the main organisation branches (the third main branch is omitted due to having no dynamics). R_{root} is the current budget (resource) at the root. The initial value of R_{root} is 10, corresponding to the root's initial external-budget=10. $Asymmetry$ is a simple indication of the structure's asymmetry, defined as the number of service units working in the environment's most-crowded service segment, divided by the total number of service units.

As shown in Fig. 3-Top, a small competition value $\beta = 0.5$ leads to a relatively low common budget (R_{root}) and number of $Nodes$ for the entire experiment. The low asymmetry over the entire experiment indicates a small difference between the number of nodes in different segments. The initial asymmetry is slightly higher initially, due to the initial effect of the extra-budget.

With $\beta = 0.8$, there is an increase in the number of nodes, asymmetry, and common budget. The higher competition-rate attracts relatively higher budget shares to service units in more profitable segments. Where the budget is high enough at a service unit, it leads to more growth in the corresponding segments, and thus to a higher asymmetry. At time step 200, the environment switches to the reverse sequence where more favorable segments lay at the right side. After time step 400, i.e. first switch back to the initial sequence with more favorable segments at the left side, a significant raise occurs in the R_{root}. This is due to the fact that the organisation has kept some of its units at the left side even during the time when the right side was more favorable (Cf. blue line in Nodes between time steps 200 and 400).

A similar but stronger effect is visible for $\beta = 0.9$. Note the structure's higher asymmetry, as β induces a higher emphasis on the more favorable segments. Nonetheless, this moderate β value still keeps a reasonable number of units in the less favorable segments after each switching.

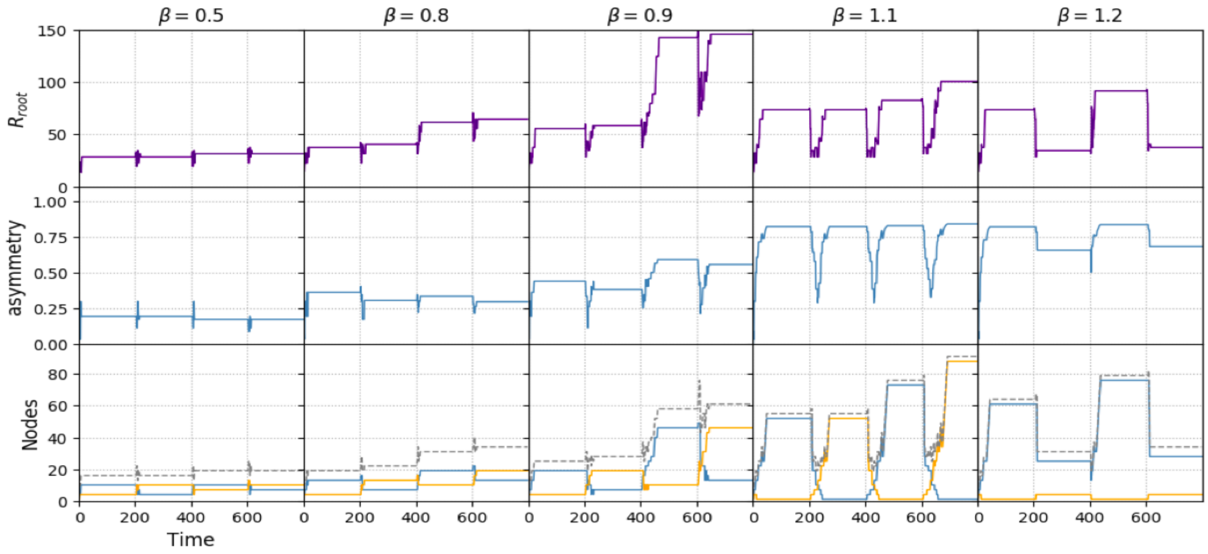
For $\beta = 1.1$, all units in the less favorable segments are removed and the structure grows intensively in the more favorable side, with each switching. This leads to a high decline in the common budget at every change, i.e., lower adaptivity, compared to $\beta = 0.9$. The shape in this case is too asymmetric, with an excessive number of units being built in the most favorable segments. Recall that the segments have a max-demand representing the maximum number of units that can benefit from a segment's max-profit. For more than that number, the benefit is divided between the units working in the segment because there is not enough service demands to keep all the units fully occupied. This explains the lower common budget when $\beta = 1.1$ compared to $\beta = 0.9$, although the asymmetry is higher.

For $\beta = 1.2$, the competition-rate is so high that it prevents the structure from adapting to new conditions. Initially, the structure grows significantly in the favorable segments. After the first switch, the budget drops while many units in the currently less favorable segments produce a total benefit that is still higher than the few units in the other region (now more favourable). The excessively high competition-rate keeps the resources focused on the more developed side, preventing the structure from loosing more units in that side, and hence not providing sufficient resource for building new units in the more profitable side.

In the second experiment, the environment switches between the two max-profit sequences at every 50 time steps. Fig. 3-Bottom shows the common budget dynamics for the five β values. The budget increases faster compared to slow switching (above). It is relatively stable for lower values $\beta = 0.5$ and 0.8, while highly fluctuating for medium to high values $\beta = 0.9$ and 1.1. Similar trends can be observed for the structure *asymmetry* and *Nodes* (not shown).

For both experiments and for every value of the parameter β, Table 1 shows an overview of the restructuring effort and profit. The table depicts the number of added and deleted units after each switching event, averaged over all the switches during the experiment. The values are com-

Slow switching:



Fast switching:

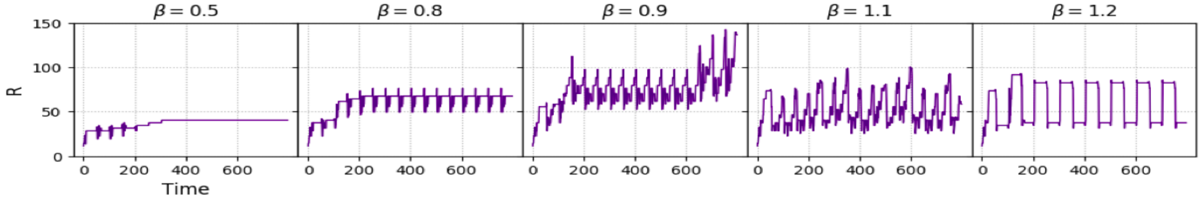


Figure 3: different competition rates (β) with slow environment switching (every 200 time steps) between the two opposite sequences of max-profit. The upper diagram shows the root's common budget, R_{root}. The mid-diagram shows the organisations' structural $asymmetry$. The lower diagram shows the number of service units ($Nodes$) in the organisation's left and right branches (blue and yellow lines); as well as the total number of service units (gray dashed line).
the root's budget, R_{root}, for different competition rates (β), in a faster-switching environment (every 50 time steps).
All diagrams depict the median value of 10 independent runs.

Table 1: Profits and Restructuring Efforts

Slow switching					
competition rate β	0.5	0.8	0.9	1.1	1.2
avg. unit-addition ($\bar{A}$)	13	15	44	83	24
avg. unit-deletion ($\bar{D}$)	12	10	32	71	34
avg. R_{root} budget	29.7	49.8	91.5	72.8	57.7
efficiency	2.3	3.9	2.4	0.9	1.9
Fast switching					
competition rate β	0.5	0.8	0.9	1.1	1.2
avg. unit-addition ($\bar{A}$)	3.2	12.8	34.6	46	24
avg. unit-deletion ($\bar{D}$)	2.4	11.6	32.2	47.4	26
avg. R_{root} budget	36.9	59.8	73.8	51.5	58.5
efficiency	13.2	4.9	2.2	1.1	2.3

puted as $\bar{A} = \frac{1}{|S|}\sum_{s \in S} add_s$ and $\bar{D} = \frac{1}{|S|}\sum_{s \in S} del_s$, where S is the set of all switching events, add_s and del_s represent the number of added units and deleted units related to a switch event s. These represent the extent of restructuring effort incurred during each adaptation. Table 1 also shows the overall budget (R_{root}), averaged over the entire experiment. Various metrics can be defined to indicate *efficiency*. The table here demonstrates an efficiency indicator, which divides the average budget by the restructuring effort: *efficiency*= $\bar{R}_{root}/(\bar{A}+\bar{D})$. The relative importance of the two efficiency factors (budget and restructuring) can be factored in via weight coefficients. Importantly, the table shows that efficiency trends for different competition rates change with the demand dynamism (switching frequency).

6 Discussion

Obtained results support several intuitions concerning an organisation's growing processes. Initially, investment resources are critical for exploring the service demand landscape and extending sufficiently to become self-sustainable. Further growth strategies depend on objective priorities (Cf. Table 1 and Fig. 3). Namely, moderate competition (β=0.9) enables fast reactions to demand fluctuations, taking advantage of new opportunities to grow in new sectors; and hence accumulate more profit overall. In turn, this requires a certain amount of restructuring that impacts service units (e.g. short-term employment, schedule changes, respecialisation); and causes corresponding revenue fluctuations. The topology is asymmetrical towards services with most demand, and flips rapidly when demand fluctuates. For highly-volatile environments (Fig. 3-Bottom) such rapid reactions may incur too high restructuring costs and actually hinder overall revenues.

Low competition (β=0.5) provides more stable revenues and individual employment during fluctuating demand periods; at the cost of lesser overall profits and slower business growth. The organisation topology is more symmetrical, covering all sectors more equally, regardless of immediate demand. Finally, too much competition (β=1.2) hinders adaptability, as large service branches established for exploiting initial opportunities continue to attract most revenue even when demand changes, thus preventing new branches from developing to address new demands. This behaviour resembles low competition cases, except that the stable state is asymmetrical towards branches with most initial success.

7 Conclusions

This paper proposed a plant-inspired model for analysing an organisation's growth and adaptation to changing service demands. Simulation results showed the impact that various competition rates among internal service branches have on an organisation's revenues, adaptability and stability. The main findings indicated that more internal competition ensures faster adaptations to changing demands (than lower competition); hence accumulating more profits overall. This comes at the cost of higher restructuring requirements and profit fluctuations. Still, too much competition may have the opposite effect and stiffen the organisation, locking it in asymmetric states. These behaviours match existing trends in related economic studies, in terms of short-term employment and hours rescheduling as means of adaptations to shifting economic demands. Future work will extend the model to also consider employment costs and delays, and to explore further varying economic landscapes. The provided modelling tool allows exploring various strategic scenarios and analysing their potential consequences. Finally, we believe that the provided growth model is sufficiently generic to be transferred to other application domains involving context-sensitive tree-like (or DAG) structures.

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