Complexity Study of Flow-Driven and Ecosystem-Oriented Distributed Computing (PhD project)

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Abstract

Digital transformation in organizations consists of weaving new Information and Communication Technologies (ICT) into complex business/industrial operations. However, in a dynamic world like ours, many disruptions could arise at the strategy and operation levels impacting the already-established plans. Since each level influences each other, additional flows can be established on top of those issued from digitized entities that become proactive and socialized. Moreover, emergent interactions in next-gen distributed computing ecosystems make the flow complexity analysis more problematic. This PhD project aims at modelling and estimating the complexity and capacity of this kind of ecosystems, from the communication perspective so, that, organizations improve their effectiveness despite disruptions. Flow complexity will be approached from the perspective of chaotic dynamical systems.

1 Introduction and Background

Known as a disruptive development, globalization is "forcing" organizations, among many other things, to adjust their business processes, to question their best practices, and to tap into the latest Information and Communication Technologies (ICT), so they could respond to all forms of competition like Internet of Things and Cloud Computing.

In 1999, M. Weiser's vision for ubiquitous computing described a future world where "*the most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it*" [13]. Weiser's future world is omnipresent in our world today.

During digital transformation, decision makers quickly recognized the benefits of weaving the latest ICT into their complex operations that usually cross

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many boundaries, run for long periods of time, and are costly to fix (e.g., [11]). This weaving allowing better data availability and traceability for decision makers [6]. However, in a dynamic world like ours, many disruptions could arise impacting the already-established plans. This impact means suspending ongoing operations, initiating new operations to look after the disruptions, and, finally, resuming the suspended operations with the "hope" of minimizing delays and avoiding penalties. Examples of disruptions could be urgent fixes to deal with breakdowns and crucial upgrades to comply with government regulations.

To track disruptions from detection till handling and then, mining, and to assess their impacts on organizations, we differentiate disruptions arising at the strategy level from those arising at the operation level. The objective is to ensure that appropriate measures are taken in response to the complexity of each disruption that could be due to their types, triggers, scopes, and duration. Disrupting an organization's strategies has a wider effect to the extent that its growth and even future could be at risk. Contrarily, disrupting an organization's operations has a "limited" effect to the extent that other ongoing operations could continue running. First, disruptions would influence the decisions to make at either the strategy level or the operation level, and, second, decisions at the strategy level would influence the operation level (top-down) and *vice versa* (bottom-up). This reflects interaction flows between the both levels. These flows capture to what extent side-effects of any disruption are extended and therefore convey relevant details to take/make appropriate actions/decisions.

In this project, we aim at modelling and estimating the complexity and capacity of next gen-distributed computing ecosystems, from the communication perspective so, that, organizations improve their effectiveness despite disruptions.

2 State of the Art and Problem Statement

First, we shed light on the way flows can be designed in smart factories. Wang et al. identify 3 perspectives for flow establishment: horizontal integration, vertical integration, and end-to-end engineering of the overall value chain [12]. The first refers to entire value creation between organizations for enriching product life cycle using information systems, efficient financial management and material flow. The second requires the intelligent cross-linking and digitization of business units in different hierarchical levels within the organization. As investigated in [9], we propose a vertical integration of new latest ICTs with business processes from storytelling perspective. Last but not least, the third assists product development processes by digital integration of supportive technologies taking into account customer requirements, product design, maintenance, and recycling.

Existing studies discuss how and to what extent digital transformation capitalize on latest ICTs from either horizontal or vertical integration perspective. Some assess information flow (structural or behavioral) complexity using indicators like entropy measurements and heuristics (e.g., [14], [1]) while others investigate the effort to new ICT adoption (i.e., before and after shifting) in term of information flow readiness through modelling and quantifying the complexity of new-gen distributed computing ecosystems (e.g., [5], [10]).

However, all these approaches overlook the 3^{rd} perspective where processes and executors are utmost of importance for successful ubiquitous computing adaptation. Coupled with disruption handling, massive information management at operation level significantly increases the new-gen ecosystem's complexity that turns out to be a real challenge. Indeed, different flow patterns would co-exist and should be evolved in a synchronized way. For instance, intelligent cross-linkage among entities, whatever organizational or cyber-physical, is required. Moreover, emergent interactions make the flow complexity analysis more problematic (e.g., (e.g., [3]), [2]. To our best of knowledge, flow complexity was never approached from the perspective of chaotic dynamical systems. Indeed, many research initiatives, including ours, put emphasis on how to make digitized entities socialized or proactive (e.g., [4] and [7]). This would render ubiquitous systems more complex as reported in [8].

3 Methodology

We start with the strategy level that is about making decisions, identifying targets, and defining performance indicators. These decisions, targets, and indicators are conveyed to the operation level as a set of directives that are actionned according to the organization's ecosystem. This actioning is about implementing decisions, pursuing targets, and assessing indicators while keeping the strategy level informed about the outcomes of what is happening at the operation level. We anchor goals (G) & beliefs (B) and tasks (T) & resources (R) to the strategy and operation levels, respectively, in preparation of deploying digital transformation-related initiatives. Although existing works suggest other levels like data and control, we all remain committed to the importance of defining who directs what and who feeds what in these initiatives so, that, communication flows for conveying decisions and details between levels are established. On top of a deeper literature review, we will conduct this research as follows:

1. **Formalize flows**. During this phase, we will formally define the GBTR framework in the context of ubiquitous computing. For instance, goals would enact and drive the growth of organizations so, that, decisions are made and plans are developed. Challenging, yet, achievable goals would acknowledge the advances in latest technologies like wireless sensor networks and smart sensors. We will, also, examine the types of information exchanged between the GBTR framework's elements (G, B, T, R).

2. **Analyze disruptions related to next-gen distributed computing ecosystems**. During this phase, we will identify disruption types and scrutinize their impact on organizations' assets (intangible with goals and beliefs and tangible with tasks and resources). This would require to

formally represent the life-cycle of each element with stochastic models like Markov chains.

3. **Model and assess the complexity of the new-gen distributed computing ecosystem**. During this phase, we will shed light on the structural and functional complexity of flows developed in the previous phases. We will survey findings from neighboring disciplines on how complexity can be measured. In particular, we will gather insight from cognitive science, complex systems, and graph theory, and adopt or adapt analogous metrics for flows.

4. **Check flow soundness and completeness**. During this phase, we will investigate how well flows with partially unknown dynamics are sound and complete so, that, the GBTR framework could properly assist organizations complete their scenarios despite of disruptions. To this end, we will rely on verification techniques like stochastic hybrid models.

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