Robustness of Coordination Mechanisms in Distributed Problem Solving against Erroneous Communication

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Abstract. This paper investigates how robust coordination mechanisms employed by distributed problem solving systems are against communication errors. For this, an agent-based simulation based on the framework of NK fitness landscapes is applied. The study controls for different levels of erroneous communication and of interdependencies among the distributed problems to be solved. The results provide broad, though not universal support for detrimental effects of erroneous communication. Moreover, the results indicate that the complexity of the overall problem to be solved considerably shapes the sensitivity of coordination mechanisms to erroneous communication.

Keywords: agent-based simulation, communication errors, complexity, coordination, NK fitness landscapes

1 Introduction

The coordination of autonomous agents’ actions with respect to the overall systems’ objective in Distributed Problem Solving (DPS) is an interdisciplinary field of research employing ideas from various disciplines, like computer science, organization theory or economics to name but a few [7]. Coordination is of particular relevance when interrelations among the agents’ tasks occur (e.g., [2], [8], [14], [15]). Whether a system of distributed problem solvers works as a unit, i.e. in a coordinated manner, is captured by metrics of coherence in terms of certain systems properties (e.g., solution quality) [2].

Many mechanisms of coordination employ direct communication among the agents, especially, for agents informing each other about the intended actions and, eventually, negotiating and mutually adjusting their plans (plan revision) [8], [11]. However, communication among agents does not necessarily need to be perfect [3], [9]. Hence, an interesting research question is the following: How robust are mechanisms for coordinating plans of autonomous agents against erroneous communication of intended plans and, especially, which solution quality is achieved in the course of plan coordination that is affected by erroneous communication?
This paper intends to contribute to that research question and, for this, it employs an agent-based simulation based on the framework of NK fitness landscapes [4], [5]. In particular, the distributed systems studied consist of autonomous agents where each is responsible for searching for solutions of a certain sub-task; there is no central planning authority; though agents are not hostile against each other, each agent pursues its own objective; the agents communicate and, eventually, modify their plans (plan revision); the communication errors investigated are not intentionally (in order to achieve a certain private benefit) built in by the sending agents, but do occur accidentally. The simulation experiments control for different levels of communication errors and of task complexity which affects the coordination needs.

2 Outline of the Simulation Model

2.1 Distributed Problem and Task Assignment

The distributed systems simulated consist of $M$ agents indexed by $r = 1, ..., M$. The agents collaboratively search for superior solutions of an $N$-dimensional binary search problem which is partitioned into $M$ disjoint $N^r$-dimensional sub-problems. Each sub-problem is assigned to one agent $r$. In each time step $t$ of the search, each agent makes a plan regarding its partition of the overall problem. The coordination mode employed determines to which other agents $q \neq r$ agent $r$ communicates its plan and how the plans may be adjusted.

The $N$-dimensional binary search problem follows the framework of NK-fitness landscapes as originally introduced in the domain of evolutionary biology [4] and, since then, broadly employed (for an overview see [13]). From a more "technical" point of view NK landscapes are stochastically generated pseudo-boolean functions with $N$ bits, i.e., $F : \{0, 1\}^N \rightarrow R^+$. A major feature of NK fitness landscapes is that they allow to easily control for the complexity of the $N$-dimensional search problem as captured by parameter $K$ [1], [6]. In particular, in each time step a system of distributed search agents seeks for a superior configuration $d_t$ of an $N$-dimensional binary problem, i.e. $d_t = (d_{1t}, ..., d_{Nt})$ with $d_{it} \in \{0, 1\}$, $i = 1, ...N$, of $2^N$ different binary vectors possible. Each of the two states $d_{it} \in \{0, 1\}$ contributes with $C_{it}$ to overall system’s performance $V(d_t)$. In line with the NK framework, $C_{it}$ is randomly drawn from a uniform distribution with $0 \leq C_{it} \leq 1$. The parameter $K$ (with $0 \leq K \leq N - 1$) reflects the number of those choices $d_{jt}$, $j \neq i$ which also affect the performance contribution $C_{it}$ of choice $d_{it}$. Hence, contribution $C_{it}$ may not only depend on the single choice $d_{it}$ but also on $K$ other choices:

$$C_{it} = f_i(d_{it}; d_{i_1t}, ..., d_{i_Kt}),$$  \hspace{1cm} (1)

with $\{i_1, ..., i_K\} \subset \{1, ..., i - 1, i + 1, ..., N\}$.

In case of no interactions among choices, $K$ equals 0, and $K$ is $N - 1$ for maximum interactions where each single choice $i$ affects the performance contribution of each other binary choice $j \neq i$. The overall performance $V_t$ achieved in