

# Multi-Agent Dependence by Dependence Graphs

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## ABSTRACT

In this paper, we present an abstract structure called *dependence graph*, an extension of the notion of dependence network, as proposed in [16]. While this latter can be applied to express a set of dependence relations of a single agent, this new structure can be applied to the multi-agent case. It can be used, therefore, for the study of emerging social structures, such as groups and collectives, and may form a knowledge base for managing complexity in both competitive and organisational or other cooperative contexts. We analyze several properties of this structure, relating them to some corresponding social phenomena regarding group formation and cohesiveness.

## Categories and Subject Descriptors

I.2.11 [Artificial Intelligence]: Distributed Artificial Intelligence – *multiagent systems*.

## General Terms

Theory

## Keywords

Groups, teams, organizations and societies, group dynamics, formalisms for agents and MAS, self-organizing systems, emergent organization.

## 1. INTRODUCTION

This paper provides a formal model of multi-agent structures emerging from an aggregate of agents endowed with different goals and actions.

In [16], a notion of dependence network is proposed to represent the pattern of relationships holding between any given agent, on one hand, and one or more other agents on the other. In multi-agent systems, however, dependence relationships are *decentralised* structures, in which no agent involved is assigned a privileged role. As dependence networks are inadequate for representing decentralised structures, we propose instead a *graph* formalism to represent multi-agent dependence.

This new structure allows for the study of emerging social structures, such as groups and collectives, from simple aggregates of

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heterogeneous agents. Rather than situations in which tasks are already assigned and commitments made, we aim to model multi-agent interdependencies among different agents' goals and actions, and to build up a tool for predicting and simulating their emergence. This may form a knowledge base for managing multi-agent activity in both competitive and organisational or other cooperative contexts.

The paper is organized as follows. We discuss the importance of this work in the next section. In the third section, the original dependence theory proposed in [16] and some contributions [7] are summarized. In the fourth section, we present the formal description of dependence graphs. We use this notion in the fifth section, to illustrate how the dependence theory can be extended to include multi-agent dependence, with a special reference to group and collective phenomena. In the final section, some conclusions are drawn and ideas for future work are outlined.

## 2. MOTIVATION

The emergence and representation of social structures is a matter of growing concern in the (Multi) Agent Systems field [12] [13] [1]. This is so for different but interrelated reasons.

First, the emergence of groups, leadership and other social formations are receiving growing attention for designing and implementing robust open multi-agent systems [14]. Secondly, an efficient task distribution and execution is increasingly found to depend on dynamic, adaptive (self-) organised activity [2] [9] [8]. Thirdly, organisational practice is shown [4] to depend more on complex interrelationships among individuals and the environment rather than upon an explicit hierarchical organisational design (cf. the PCANS model [11]). We are only too aware of the huge body of literature on theories, methods and techniques for exploring organisational structures, and for evaluating their performance (for a thorough analysis and a taxonomy, see [4]). Far from providing still another method or technique, we intend to propose a new perspective on the study of emerging organisational structure based upon systems of heterogeneous agents.

## 3. DEPENDENCE THEORY

The work presented in this paper proceeds from the assumption that heterogeneous agents endowed with goals, beliefs, able to perform actions and situated in a common world are involved in more or less complex and dynamic networks of relationships. In current agent systems, agents are often conceived of and designed as autonomous. However, they are not completely autonomous: agents may have goals that exceed or differ from their capacities to reach them. In particular, in teamwork, agents' autonomy is intrinsically limited [6].

More generally, socially situated agents may depend on one another to achieve their *own* goals. In terms of the dependence theory, an