A Novel Development Methodology for Cooperative, Distributed Multi-agent Systems

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Abstract

The multi-agent systems (MaS) typology can be divided into “independent” and “cooperative” or closed and open respectively. Independent MaS embraces a set of agents linked together by predefined protocols that operate in a closed central control system. The closed system does not include or perform MaS dynamic behaviour; rather, it mainly performs agent team formation processes and promotes agents’ cooperation at runtime. This type of MaS is appropriate for application within fixed procedures that operate in one system boundary. In contrast, the cooperative MaS is an emergent system that has the potential to dynamically, at runtime, search in an open distributed computational environment and subsequently form a team of appropriate agents to achieve the defined goal. The agent cooperation behaviour is a key strength of MaS, which is characterised by agents’ autonomy.

This thesis investigates existing multi-agent system development methodologies: Prometheus, Gaia, MaSE, PASSI and Tropos. The results indicate that these methodologies are engineering an independent MaS focusing on the agent’s internal structure or system architecture through interaction protocols. However, the cooperative MaS development processes are minimally realised in these methodologies and the agent cooperation process is not implicitly addressed.

Further, the research aims to enhance MaS development methodology by proposing a novel development methodology for multi-agent systems (DMMAS) that can guide software practitioners in developing cooperative MaS with the ability to function in large-scale, open, distributed, incremental, heterogeneous systems. It is motivated by distributed architecture for problem solving in domains including military logistics, healthcare, transportation and travel agency systems. The research attempts to transition existing MaS from independent concepts to cooperative concepts.

To model agent autonomous behaviour, the research proposes a new organisational multi-agent systems architecture supported by an ontology-based search model and the agent cooperation, through dynamic team formation process is built on agent
adoptive strategy and Share Plan cooperation theory as an important characteristic of DMMAS.

The research has been conducted using design science in information system research method, and the case study research approach. For proof of the concept the research applied DMMAS development methodology on a real world case study “Travel Agency System (TAS)” which served as the motivating problem for the research work. The results are evaluated using a benchmark approach to compare DMMAS performance with the five existing MaS development methodologies.

This thesis makes four main contributions: first, it enhances the agent-based system by providing a new development methodology with an attempt to develop the multi-agent systems current state of the art from independent to cooperative. Secondly, the research presents new multi-agent systems architecture and a methodology on how to design and develop open distributed multi-agent systems. Thirdly, the research proposes how ontology analysis and design can be incorporated in software engineering practice. The research explains how ontology concepts, objects and relationships are identified to build the agent systems domain. Finally, the research introduces a new agent functionality ontology schema for a search to replace the agent name keyword based conventional search. The functionality based ontology approach utilises descriptor based semantics.

The proposed DMMAS design methodology is evaluated against software engineering principles and its strengths and inadequacies investigated. The research achievements are summarised and emerging research questions are outlined for future work.
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Dedication

To my family:

My wife: Anissa Al-Rowaie
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Yours truly, love and patience, yours constant encouragement and support provided a solid result. Being away from you was a tough time, all what I have done was for a better life.

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List of Acronyms

The following acronyms and abbreviations of standards phrases are used throughout the thesis:

ARPA  Advance Research Project Agency
AbSE  Agent-based Software Engineering
AbS   Agent-based System
AOSE  Agent-Oriented Software Engineering
AOS   Agent-Oriented Software
AI    Artificial Intelligence
BDI   Belief, Desire, and Intention agent architecture
DARPA Defence Advance Research Projects Agency
DFI   Design Fabricator Interpreter
DMMAS Development Methodology for Multi-agent Systems
DAI   Distributed Artificial Intelligence
DPS   Distributed Problem Solving
ERD   Entity Relationship Diagram
EVO   Evolutionary Delivery
SXML  Extensible Markup Language Schema
XML   Extensible Markup Language
EP    Extreme Programming
FIPA  Foundation for intelligent physical agents (FIPA)
HERM  High Entity Relationship Diagram
IS    Information System
JVM   Java Virtual Machine
JAD   Joint Application Development
KIF   Knowledge Interchange Formalism
KQML  Knowledge Query Manipulation Language
KSE   Knowledge Sharing Effort
MaS   Multi-agent Systems
NII National Information Infrastructure
OMT Object Modelling Technique
OOSE Object-oriented Software Engineering
OWL Ontology Web Language
PTA Planned Team Activity
PASSI Process for Agent Societies Specification and Implementation
Pa Professional-agent
PDT Prometheus Development Tools
RAD Rapid Application Development
RDFS Resources Definition Framework Schema
RDF Resources Definition Framework
SP Shared Plans Theory
Sa Skill-agent
SDM Software Development Methodology
SAT Speech Act Theory
SQL Structured Query Language
SDLC System Development Life Cycle
TFP Team Formation Process
TAS Travel Agency System
DOD United States Department of Defence
W3C World Wide Web