Towards an Adaptive Approach for Distributed Resource Allocation in a Multi-agent System for Solving Dynamic Vehicle Routing Problems

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Introduction. The existing problem of continuous planning in transportation logistics requires the solving of dynamic Vehicle Routing Problems (dynamic VRPs) which is an NP-complete optimization problem. The task of continuous planning assumes the existence of individual commit times for orders to be released for execution with specific commitment strategies and is similar to the problem of maintaining a guaranteed response time in real-time systems that, in a dynamic environment, applies additional restrictions on planning algorithms. This paper describes the developed multi-agent platform for solving the dynamic multi-vehicle pickup and delivery problem with soft time windows (dynamic m-PDPSTW) that supports goal-driven behavior of autonomous agents with a multi-objective decision-making model. Further research on the design of adaptive mechanisms for run-time feedback-directed adjustment of scheduling algorithms through learning and experience of applied decision options is outlined.

The market-based method for distributed dynamic resource allocation. The authors’ multi-agent approach to continuous planning in complex uncertain environments implements the concept of the dynamic distributed resource allocation (Modi et al. 2002) whereby decision making is carried out by means of asynchronous quasi-parallel processes of negotiation between the agents of resources and the agents of orders which are working distributively in a virtual marketplace over all the agents of the complex shared ontology object. Goal-driven behavior of autonomous agents is supported by the developed multi-objective decision-making model based on individual goals, criteria, and preference functions defined in the virtual marketplace ontology and methods of agent self-appraisal and decision-making strategies (priority of criteria, value superposition, and homeostasis).

In the implemented framework for agent knowledge representation, based on Prof. Marvin Minsky’s concept of frames, each autonomous agent in the virtual marketplace has its individual knowledge, agent memory with a dynamic decision-making table, experience of applied decision options, and reality representation of the world model (a shared ontological scene of reality) in an individual ontological scene and has its own perception via sensors and facades (Chevelev et al. 2006).

The presented process of self-organization in such a multi-agent system is based on the constant search to maintain a dynamic balance among the interests of all participants in the interaction by means of an economically decentralized method of agent behavioral coordination. The microeconomic model defines violation functions of agent preferences with personal accounts for agents and reflects individual expenses and profits for all agents at any moment of distributed decision-making process. Furthermore, this microeconomic model provides the basis for decentralized mechanisms for controlling emergent behavior and stabilizing of agent swarms.

Control methods of self-organization in complex environments. Conducted experiments on agent microeconomic parameters demonstrates that the complex system of interacting autonomous agents is characterized by the opportunity of the existence of several stable equilibria (attractors), by the unpredictable nonlinear processes of transitions between them, and by the emergence of resonating and oscillatory properties in the system. Special attention was given to the simulated processes of the significant internal reconfiguration of the agent system in response to the smallest external signals (a catastrophe) – trifling alterations on the agent local level led to a large-scale schedule reconstruction. Effective control mechanisms for self-organization need to be developed to make multi-agent systems more effective in solving dynamic VRPs with a view to achieving practical levels of performance for continuous planning in complex environments with higher levels of uncertainty, such as multi-modal logistics with multiple, competing companies. The developed mechanisms provide control methods for achieving both of the contending objectives: the transition of the multi-agent system toward the global quasi-optimal state while avoiding undesirable local attractors and the stabilization of agent activity and limitation of schedule reconstruction for maintaining a guaranteed response time for orders to be scheduled and released for execution according to their individual commitment times.

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Due to distributed decision-making process of autonomous agents based on locally available information in their ontological scenes, the dynamic optimization process can converge to local minima. The following centralized and distributed control methods were developed to guide the process of self-organization in the multi-agent system toward a desirable global quasi-optimal state. The swap allocation algorithm, with a dynamic and adaptive swap level, allows the opportunity to increase the length of the "ripple-effect" and to make decisions decreasing the system value within a "confidence credit" range. The identification algorithm of agent bottlenecks and the targeted agent pro-activity provide the ability to climb up from local optima.

The following two approaches to trigger the agent pro-activity are investigated: the centralized Yellow Pages service and distributed direct observation by agents of changes in their ontological scenes (agent image scenes). The centralized method of direct procurement by the network agent was developed for the focused investment and distribution of virtual money among agents, and the distributed microeconomic method of dissipative taxation (a tax on agent life in the virtual marketplace) was implemented for the cyclic re-allocation of agents from relatively unprofitable regions of the system ("thermal death" with recovery of virtual money from dissipated agents for re-allocation) based on Prof. Prigogine's theory of dissipative non-equilibrium systems.

A guaranteed time for orders to be scheduled and released for execution is achieved by the centralized and distributed control methods of the process of self-organization in the multi-agent system: the commit-time driven prioritization of agents in the time-demand queue of the agent dispatcher, the microeconomic methods of compensation and taxation on agent transactions for limiting negotiation chains and the length of the "ripple-effect", and the self-limitation of agent activity in achieving specific satisfaction levels depending on the chosen agent strategy.

Learning a multi-agent behavior. The described distributed market-based coordination mechanism and control techniques are originally sensitive to environmental variations and provide a continual schedule quality improvement trading off planning time and schedule quality. Nevertheless, a set of pre-defined mechanisms is inadequate for agents to effectively respond to all possible environmental dynamics. The problem of developing adaptive mechanisms for run-time feedback-directed adjustment of scheduling algorithms is addressed by applying machine learning and evolutionary computational techniques (Carchrae and Beck 2005). To address this problem, we have been investigating decentralized partially observable Markov decision processes (DEC-POMDPs), a technique for modeling of agent decision making under uncertainty, and reinforcement learning (RL) algorithms (Claus and Boutilier 1998). A subject of particular interest for us is the development of a near real-time knowledge management support engine based on agent-based continuous unsupervised learning to work concurrently with the scheduling component. A real-time knowledge management support engine for adaptive agent reasoning, currently being developed, is based on continual knowledge acquisition, the detection of the operating context (agent associative memory) for dynamically selecting appropriate goal-driven behavioral models of autonomous agents depending on various environmental patterns, and on knowledge derivation, adjustment and evolution of agent strategies through learning and experience of applied decision options. Accordingly, rather than merely changing the behavioral models of agents to more appropriate ones if an applied strategy does not work, we need to recognize various areas of a problem domain and determine the corresponding sets of agent strategies appropriate to the certain areas. Near real-time automatic clustering of ontology scenes is applied for the recognition of appropriate agent strategies to the areas, and a possibility to such the recognition is defined by means of the magnitude of error in the application of a certain strategy to the area of a problem domain.

The adaptive closed-loop control system, currently being designed and developed, is based on a learning analytical framework that provides a stochastic estimation model of the current state of dynamic systems for analyzing circular feedback loops from the use of specific planning and control techniques for dynamically selecting appropriate ones on different development stages of a multi-agent system with a view to achieving better schedule quality and organizational performance metrics. The defined framework functionality is the bidirectional cyclic approach to the adaptation of centralized planning methods based on the analysis of outcomes of decentralized control methods. Thus, defined or deduced rules for decentralized control methods can form the basis for the development or adjustment of centralized methods.

References


