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DES-BASED REINFORCEMENT LEARNING FOR THE OPTIMIZATION OF THE SCHEDULING PROBLEMS OF MANUFACTURING SYSTEMS

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ABSTRACT

Discrete event simulation is an effective method for environment modeling for solving scheduling problems in manufacturing systems through reinforcement learning. In this study, four characteristics (reliability, rapidity, interoperability, and cost-effectiveness) that a discrete event simulation environment should have to apply reinforcement learning to the scheduling problems are specified. Then, environment development framework based on SimPy, an open-source DES that satisfies these characteristics is proposed. Finally, successful industrial cases using this framework are introduced.

1 INTRODUCTION

With the development of deep artificial neural networks, reinforcement learning, which has a specialty in optimizing sequential decision-making, is becoming an important field of artificial intelligence research. Reinforcement learning agent performs learning by interacting with the environment in which the agent's decision-making is applied to. The learning performance depends on the algorithm but is also greatly influenced by the environment modeling. The environment for reinforcement learning is modeled in various forms depending on the type of problem, and there are many research that use control engines or game engines. Reinforcement learning can also be applied to the intelligentization of manufacturing systems and discrete event simulation is an effective approach for modeling scheduling problems of the manufacturing system. This paper specifies four characteristics (reliability, rapidity, interoperability, and cost-effectiveness) that reinforcement learning environment for a manufacturing system based on DES should have for applying its scheduling to the industrial case, and the open source SimPy is selected as the modeling method that satisfies these four characteristics. In addition, a framework to integrate reinforcement learning algorithm and DES-based environment is developed.

2 FRAMEWORK FOR MODELING SIMPY

In this study, SimPy, developed in a Python environment, is introduced for DES-based reinforcement learning. There are four main reasons for adopting SimPy. The first reason is reliability. The reliability is validated through the comparison with the COTS (commercial off-the-shelf) DES tools on various queueing models. Meanwhile, SimPy is operated on Python which is interpreter programming language. Although Python is not as fast as compile programming language such as C++, C, this study secures rapidity of computation by utilizing NumPy. In addition, SimPy has shown excellent interoperability with machine learning packages whose main operating programming language is Python. Lastly, SimPy has cost-effectiveness because its license type is MIT which is a permissive free software license.

Additional classes such as Job, Operation, Machine, Source are developed because SimPy alone has a limitation to model entity movement between process networks. Simulation component is a collection of these classes. Adapter component extracts system attributes from the input data and preprocesses them into appropriate data type. Modeler component models environment object by the system attributes. Data collecting component gathers the system object's current information (state and action) and that information is transferred to agent through the interface channel. This framework is shown in Figure 1. The environment (right below of Figure 1) which interacts with reinforcement learning agent(right upper of Figure 1) (e.g. the agent's algorithms are DQN, A3C, PPO, etc) is modeled with DES (left of Figure 1) based on SimPy. The proposed framework is applied to the scheduling problems of manufacturing system.

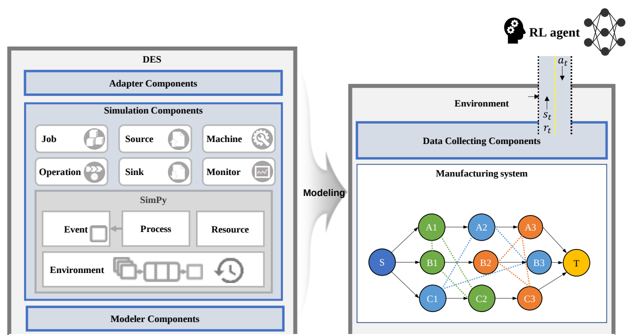

Figure 1 Reinforcement learning framework with DES

3 INDUSTRIAL CASES WITH PROPOSED FRAMEWORK

The proposed framework is applied to the industry's manufacturing scheduling problem. In all cases, the scheduling results using our framework showed equal or better performance comparing with algorithms, those have been known to be best for each case.

			Case1 (Cho, Nam et al. 2022)	**Case2** (Oh, Cho et al. 2022)	**Case3**	**Case4** (Cho, Oh et al. 2022)
Target problem			Unit assembly line	Flexible jobshop	Section steel shop	Post-launching process
Type			Flowshop	Flexible jobshop	Parallel machine shop	Flexible jobshop
Scheduling problem			Sequencing	Machine-job allocation	Machine-job allocation	Quay assignment
Objective			Minimizing makespan	Minimizing makespan	Minimizing weighted tardiness	Minimizing ship movements
Reinforcement learning algorithm			Proximal policy optimization	Implicit quantile networks	Proximal policy optimization	Deep recurrent Q learning
Data Transfer	**Env → RL**	**State**	❿ Processing time	❿ Waiting operations ❿ Machine setup ❿ Action history	❿ Line setup ❿ Tardiness level ❿ Remaining time	❿ Launching plan ❿ Preemption ❿ Availability
		reward	❿ Makespan	❿ Makespan	❿ Tardiness ❿ setup cost	❿ Movement
	RL → Env	**Action**	❿ Block sequence	❿ Operation	❿ Routing	❿ Quay
Result (improvement ratio comparing with state-of -the-art methods)			-0.01% (NEH)	1.75% (PPO)	25% (ATC)	12% (Heuristic)

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