Proceedings of the 3rd International Conference on Signal Processing and Machine Learning
DOI: 10.54254/2755-2721/6/20230530

Design and implementation of an intelligent generation method of simulation scenario based on knowledge graph

Jing An[1], Xue chao Zhang[1], Wei Liu[2] and Xian wei Zhu[2]

[1]Joint Logistics College of NDU, Beijing, China, 100000
[2]China Electronic Engineering Design Institute, Beijing, China, 100000

anj21_2000@sina.com

Abstract. An intelligent generation method of simulation scenario based on KG(knowledge graph) is designed and implemented. The KG is constructed by linking multi-source simulation model entities with global features based on RL(reinforcement learning). An entity alignment algorithm suitable for simulation model matching and a script generation method based on DOM are designed to realize intelligent generation of simulation scenarios. Finally, taking the "multi-dimension projection" action as an example, the simulation scenario is generated and the simulation system is driven to run according to the scheduled action sequence, which verifies the effectiveness of this method.

Keywords: simulation scenario, KG (Knowledge graph), RL (Reinforcement learning), entity alignment.

1. Introduction

With the increasing complexity of war, simulation system has been widely used in operational theory innovation, operational scheme design optimization, operational capability evaluation, as well as various exercises and training and equipment acquisition activities [1-5]. As the basic support for initializing and driving the effective operation of simulation system, the quality of simulation scenario directly affects the system operation efficiency and the authenticity of simulation results [6]. However, due to the differences in simulation levels (platform level, aggregation level), simulation modes (man in the loop, man out of the loop), simulation models, etc. of the simulation system, the requirements for simulation scenarios and scenario scripts that can be driven to run are not completely consistent. Therefore, the development of simulation scenarios is generally characterized by strong professionalism, high customization requirements and poor mobility. Aiming at these problems, an intelligent generation method of simulation scenario based on KG is proposed. This method constructs KG through entity link of multi-source simulation model, and studies the application of simulation model. The entity alignment method of type matching can improve the reusability of simulation system model and the matching degree of data, improve the speed and accuracy of simulation scenario generation, and ensure that the simulation experiment driven by simulation scenario is feasible and reliable.

In this method, the key technologies to be solved include: First, the formal description of simulation scenarios. Different from military scenario, simulation scenario is used to drive simulation system operation. It should be expressed as structured and formal scenario data, and ensure that it can be identified, understood and used by simulation system. The second is the construction of KG. To support the mapping and matching of simulation scenarios, the KG framework should be built according to the element requirements of simulation scenarios, and the common simulation system model entities should be effectively linked. The third is the selection of entity alignment algorithm. In different simulation deduction systems, the same entity may correspond to different simulation models or have different model attributes. In order to improve the speed and accuracy of matching, it is necessary to select an effective entity alignment algorithm.

2. Definition and formal description of simulation scenario

Simulation scenario is the setting of initial battlefield situation, forces of warring parties, weapons and equipment, combat operations, engagement rules, simulation rules, etc. On the basis of military scenario, facing simulation simulation system, according to the purpose of simulation experiment, boundary conditions, experiment mode, simulation system requirements, etc. As the basis of simulation experiments, simulation scenarios provide various data sets and scripts required for the initialization, drive and operation of the simulation system, including structured and formalized simulation scenario data such as simulation entities, task models, rule models, which are recorded as multidimensional Euclidean space (entities, tasks, rules), and are formally described as follows:

$$\overrightarrow{\mathbf{SS}}=\left\{\overrightarrow{\mathbf{Agent}},\ \overrightarrow{\mathbf{Task}},\ \overrightarrow{\mathbf{Rule}}\right\} \tag{1}$$

- $\overrightarrow{\mathrm{Agent}}=\left\{\overrightarrow{\mathrm{Agent}_1},\ \overrightarrow{\mathrm{Agent}_2},\ \ldots\ldots,\ \overrightarrow{\mathrm{Agent}_N}\right\}$ (N is the entity dimension) represents the collection of various simulation entities in the scenario data, including: environment, forces of all parties, weapons and equipment and other aggregated entities and platform entities. $\overrightarrow{\mathrm{Agent}_{\mathrm{i},\ \mathrm{i}\in\mathrm{N}}}=\{\mathrm{chara}_1,\ \mathrm{chara}_2,\ \ldots\ldots,\ \mathrm{chara}_\mathrm{M}\}\mathrm{chara}_{\mathrm{j},\ \mathrm{j}\in\mathrm{M}}$ (M is the dimension of entity attribute) represents a simulation entity, which is the attribute of the entity, such as name, owner, quantity, type, combat technical indicators, deployment and related tactical parameters.
- $\overrightarrow{\mathrm{Task}}=\left\{\overrightarrow{\mathrm{Task}_1},\ \overrightarrow{\mathrm{Task}_2},\ \ldots\ldots,\ \overrightarrow{\mathrm{Task}_\mathrm{L}}\right\}$ (L is the combat task dimension) represents the combat task set in the scenario data. $\overrightarrow{\mathrm{Task}_{\mathrm{i},\ \mathrm{i}\in\mathrm{L}}}=\left\{\mathrm{taskname},\ \overrightarrow{\mathrm{Action}},\ \mathrm{actionseq}\right\}$ represents a combat mission. Taskname indicates the task name; $\overrightarrow{\mathrm{Action}}=\left\{\overrightarrow{\mathrm{Action}_1},\ \overrightarrow{\mathrm{Action}_2},\ \ldots\ldots,\ \overrightarrow{\mathrm{Action}_\mathrm{K}}\right\}$ (K is the action dimension) indicates that the entity is a set of actions to complete the task, and $\overrightarrow{\mathrm{Action}_{\mathrm{i},\mathrm{i}\in\mathrm{K}}}=\left\{\mathrm{agent},\ \mathrm{condition},\ \overrightarrow{\mathrm{status}_{\mathrm{begin}}},\ \overrightarrow{\mathrm{status}_{\mathrm{end}}},\ \overrightarrow{\mathrm{description}}\right\}$ represents a single action, which consists of the action execution entity agent, the action initiating condition condition, the starting state $\overrightarrow{\mathrm{status}_{\mathrm{begin}}}=\{\mathrm{begin}_{\mathrm{time}},\mathrm{begin}_{\mathrm{position}},\mathrm{begin}_{\mathrm{action}}\}$ (starting time, starting position, starting state of action), the ending state $\overrightarrow{\mathrm{status}_{\mathrm{end}}}=\{\mathrm{end}_{\mathrm{time}},\mathrm{end}_{\mathrm{position}},\mathrm{end}_{\mathrm{action}}\}$ (ending time, ending position, ending state of action), and the action process description $\overrightarrow{\mathrm{description}}=\{\mathrm{action}_{\mathrm{area}},\ \mathrm{action}_{\mathrm{way}},\ \mathrm{action}_{\mathrm{target}},\ \mathrm{action}_{\mathrm{time}},\ \mathrm{action}_{\mathrm{effect}}\}$ (action area, action route, action target, action duration, and expected effect); actionseq indicates the event flow for executing actions, including sequence, concurrency, and circulation.
- $\overrightarrow{\mathrm{Rule}}=\left\{\mathrm{rule}_{interaction},\ \mathrm{rule}_{seq},\ \mathrm{rule}_{\mathrm{pre}},\ \mathrm{rule}_{\mathrm{trigger}},\ \mathrm{rule}_{\mathrm{random}}\right\}$ represents a set of rules in scenario data, including interaction rules $\mathrm{rule}_{interaction}$, timing rules rule_{seq}, priority rules $\mathrm{rule}_{\mathrm{pre}}$, trigger rules $\mathrm{rule}_{\mathrm{trigger}}$, random rules $\mathrm{rule}_{\mathrm{random}}$, etc.

3. Construction of KG

As a symbolic expression of knowledge features, KG can accurately represent the correlation between entities and features [7]. The construction process is as follows: on the basis of determining the core concept set of the domain, through the concept modeling, relationship modeling and attribute modeling of ontology, establish the core concept hierarchy and relationship, and complete the construction of the knowledge map framework; Based on this framework, the existing simulation

DOI: 10.54254/2755-2721/6/20230530

system and other model libraries are linked to improve the reusability of simulation models and complete the combined expression of knowledge features.

3.1. Domain knowledge ontology modeling

There are many top-level concepts in the operational field, including combat power, weapons and equipment, combat operations, battlefield environment, etc. The core concept set of the field needs to be selected according to the construction of the KG. For example, the construction goal of the KG in this paper is to support the mapping and matching of simulation scenario data, so the selected core concept set is scenario entities $\overrightarrow{\text{Agent}}$ (including combat forces and weapons), tasks $\overrightarrow{\text{Task}}$, and rules $\overrightarrow{\text{Rule}}$. According to operational rules and regulations, define the exact definition of core concepts, determine the hierarchical relationship structure (some hierarchical relationship descriptions are shown in the table 1), define the underlying attributes of the ontology, complete the conceptual modeling, relationship modeling, attribute modeling of the ontology, and build the basic framework of the knowledge map.

Table 1. Ontology hierarchy relation table (partial).

Serial No	Relationship Description	meaning
1	isA	the relationship between upper and lower levels of ontology
2	isSynonyms	Synonyms between ontologies
3	hasEquipment	the entity mounts/assembles weapons and equipment
4	hasTask	the entity performs operational tasks
5	isOperatedBy	operational tasks/actions are performed by entities
6	hasPart	the task contains subtasks/sub actions
7	isPartOf	sub actions/sub tasks constituting tasks
8	Parallel	the parallel relationship between tasks/actions
9	pre_ drive	the pre relationship between tasks/actions
10	after_ drive	the post relationship between tasks/actions
11	sameOperator	the task/action is performed by the same entity

3.2. Multi source simulation model entity link

The global feature linking method is used to integrate the multi-source simulation model data such as the big data equipment attribute data model of the whole military equipment, the open model library of the simulation system, and link them to the KG framework constructed in the previous section.

Global feature linking method is based on RL global feature extraction network and NNs(neural networks) for similarity calculation. Due to space limitation, the training process of the network will not be described here, and the network framework and application will be emphasized. The basic idea of entity linking is as follows:

- Through the global feature extraction network framework based on RL, features are extracted from the global information of the entity/indication to be linked. The global feature extraction network framework based on RL is described as follows:

State space $\boldsymbol{w_i}$: it is composed of the current feature and the selected feature. When selecting the feature x_i of the entity/indicator, the state is represented as a continuous feature vector $F(w_i) = \{x_i, w_{i-1}, s\}$, in which the vector x_i representing the current feature, The vector w_{i-1} representing the selected feature set, s representing the entity/indication to be linked.

Action policy $\boldsymbol{y_i}$: 0 indicates that the accuracy of the current feature to the entity link has not been improved, and 1 indicates that it has been improved. Determined by the policy function $\pi_\Theta(w_i, y_i)$.

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Reward function **r**： it is the evaluation of whether the currently selected feature can improve the entity link accuracy. It is defined as$r(w_i|S) = \Delta s$, Δs represents the difference between the feature weight of the entity relationship mixed feature and the entity feature in the classifier.

Policy function$\pi_\Theta(w_i, y_i)$：

$\pi_\Theta(w_i, y_i) = P_\Theta(y_i|w_i) = y_i\sigma(W * F(w_i) + b) + (1 - y_i)(1 - \sigma(W * F(w_i) + b))$ Where, $F(w_i)$is the eigenvector, $\sigma(\cdot)$is the sigmoid activation function with super parameters $\Theta = \{W, b\}$.

- After obtaining the features of the entity/reference item to be linked, they are cascaded with the features of the candidate entity in the hidden layer, input into the two-layer neural network, and use the sigmoid activation function to obtain the similarity score $sim(m, e)$ between the entity/reference item m and the feature e of the candidate entity

The loss function of the NNs adopts cross entropy error $\mathrm{L}(s,t) = t\log(s) + (1-t)\log(1-s)$. Where, s is the calculated similarity score $sim(m,e)$, and t indicates whether the entity is true.

- The ranking score of [entities to be linked/reference items, candidate entities] is obtained through weighted calculation. The calculation formula is $r(m, e) = \alpha p(e|m) + \beta sim(m, e)$. Wherein, $sim(m, e)$refers to similarity score, $p(e|m)$refers to prior probability, α and β refers to the weight coefficients of similarity and prior probability, respectively, $\alpha + \beta = 1$.
- Sort each candidate entity by $r(m, e)$ and complete the link of entity/reference item.

4. Simulation scenario matching mapping based on knowledge map entity alignment

4.1. Entity alignment

Based on the above knowledge map, entities, tasks and rules are matched to the simulation model with the highest similarity in the simulation system model base through entity alignment technology. Considering that name features and structure features depict entities from two different aspects: semantics [8-10] and structure [11-12], combining them can provide more comprehensive clues to entity alignment. Therefore, this paper chooses the method of combining entity name feature and entity structure feature.

- The entity name feature vector is expressed by the average word embedding, which is concise and universal, and can express semantic information without special training corpus. It is recorded as $D_s(e_1, e_2)$.
- The entity structure feature vector is captured by the graph convolutional neural network (GCN) to generate the entity adjacent structure information, which is recorded as$D_n(e_1, e_2)$.

There are many mature research on the generation methods of the two eigenvectors, and this paper will not expand. Combining the two features, the distance between two entities $e_1\hat{I}G_1$ and $e_2\hat{I}G_2$ can be described as: $D(e_1, e_2) = \alpha D_s(e_1, e_2) + (1 - \alpha)D_n(e_1, e_2)$, where α is a super parameter that adjusts the weight of entity name feature and entity structure feature. Obviously, this distance determines the matching degree between two entities. The smaller the value, the higher the entity matching degree.

4.2. Script generation

Use XML DOM technology to generate simulation scenario run script. Specific processes include:

- Build the object node of XML simulation script according to the scenario standard template of the simulation simulation platform;
- Insert the data item by item into the object node by locating the instanced data $\overrightarrow{\mathrm{SS}} = \{\overrightarrow{\mathrm{Agent}}$， $\overrightarrow{\mathrm{Task}}$， $\overrightarrow{\mathrm{Rule}}\}$
- Repeat step1 and 2 until all nodes insert data, and generate simulation scenario running scripts that can drive deduction.

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5. Verification and analysis of simulation scenario generation example

With the " multi-dimension projection " action as the background, generate simulation scenarios to verify whether the simulation system can be driven to run according to the scheduled action sequence.

- The scenario data is formally described as follows:

Table 2. Formal description of simulation scenario (maritime navigation operation).

Serial No	Formal description	meaning
1	Taskname	Maritime navigation
2	$\overrightarrow{Action}$	{rendezvous, formation, ferry}
3	Agent	Joint operation cluster
4	Condition	Arrive at the sea meeting area
5	$\overrightarrow{status_{begin}}$	
6	$begin_{time}$	Expressed in D-XX minutes, accurate to minutes
7	$begin_{position}$	Sea junction area
8	$begin_{action}$	Complete the rendezvous formation
9	$\overrightarrow{status_{end}}$	
10	end_{time}	Expressed in D-XX minutes, accurate to minutes
11	$end_{position}$	Tactical deployment line
12	end_{action}	Prepare for transfer and wave making by flashing
13	$\overrightarrow{description}$	
14	$action_{area}$	Navigational sea area
15	$action_{way}$	Maritime rendezvous area to tactical deployment line
16	$action_{target}$	
17	$action_{time}$	The time required by the superior to complete the task
18	$action_{effect}$	Complete the ferry and reach the tactical deployment line
19	actionseq	

- Based on the constructed KG (omitted), the entity alignment algorithm combining name features and structure features is used to instantiate the simulation scenario and map it to the executable simulation scenario running script of the simulation system (CMO Steam version 1.04 is selected). Some matching results are shown in the following table.

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Table 3. Simulation scenario instantiation matching results (partial).

Serial No	CMO system model	Scenario entity
1	Stinger MANPADS	A combat force
2	F-CK-1D Hsiung Ying [Ching Kuo MLU]	IDF fighter
3	AH-64E Apache Guardian	AH64 Apache helicopter
4	E-2K Hawkeye 2000E	E-2K
……		……
97	Atilgan SAM [M113, Quad Stinger]	Defense Company 2

- Import the generated simulation scenario script into the CMO system, and conduct simulation deduction in the way that people are not in the loop. The deduction process is as follows.

Table 4. Simulation process.

Serial No	Simulation time (h)	actions	Screenshot of simulation system
1	0	The combat force is launched	
2	2	Amphibious transport formation ferry	
3	4	Air transport formation takes off	
4	4.5	Offshore formation unloading	
5	5	Gathering of forces on the island	

It can be seen from the running results of the simulation system that the simulation scenario generated in this paper can drive the simulation system to deduce according to the predetermined action sequence.

6. Conclusion

In this paper, an intelligent generation method of simulation scenario based on KG is designed and implemented. Firstly, based on reinforcement learning global feature extraction network and NNs for similarity calculation, the method realizes the link of mainstream simulation model entities, and constructs a KG. The entity alignment algorithm combining name features and structure features is adopted to achieve accurate matching of simulation scenario entities and quickly generate simulation scenarios. Finally, the " multi-dimension projection " is selected as an example to generate a simulation scenario. The scenario is run based on the CMO simulation system, and the simulation process is consistent with the actual scheduled action, which verifies the effectiveness of the method.

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