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Digital twin system framework and information model for industry chain based on industrial Internet

Key words: Industry chain; Digital twin; Industrial Internet; Knowledge graph; Graph neural network

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Motivation

- The industrial Internet contains massive multi-source heterogeneous industry chain data. However, there are few general methods for mining industry chain knowledge from a large volume of expert knowledge, public databases, and enterprise manufacturing data.
- Knowledge of the industry chain includes structured, semi-structured, and unstructured information resources. This leads to the lack of a unified structured expression of industry chain knowledge and the inefficiency of data processing.
- Industry chain knowledge is characterized by strong professionalism and complex relationships, and the hidden relationships in the industry chain knowledge need to be further explored.

Main idea

- A construction framework for the industry chain digital twin (DT) system is proposed for real-time analysis of the state, robustness, and industry chain capacity feasibility decisions.
- A knowledge graph (KG) based industry chain information model is designed to extract industry chain knowledge from heterogeneous, multi-source industrial Internet data.
- A bidirectional encoder representations from Transformers (BERT) based multi-head selection model is proposed for joint entity–relation extraction of the industry chain from the industry chain data to obtain the original KG.
- A relation completion model based on a relational graph convolutional network (R-GCN) and a GraphSAGE is proposed, which considers both semantic information and graph structure information of KG.

Framework

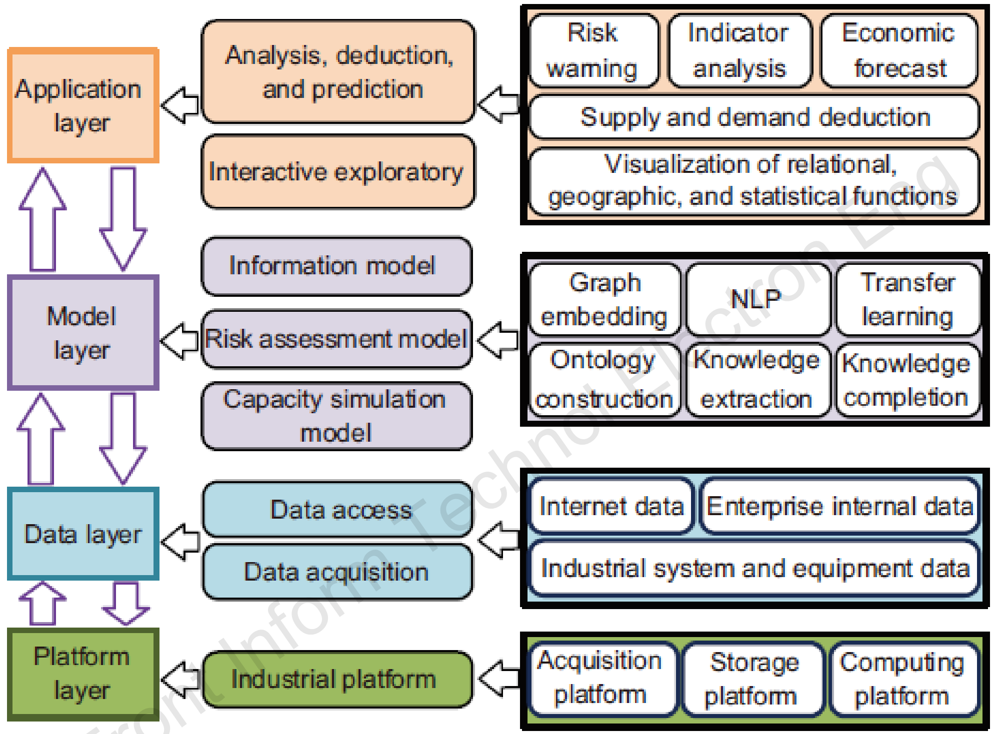

Fig. 3 Digital twin based industry chain analysis technology framework (NLP: natural language processing)

The framework includes four layers. The platform layer is constructed based on the industrial Internet. In the data layer, data transmission, data processing, and data collection technologies are used to form a complete industrial data collection system. In the model layer, three models are established to form an algorithmic support for the industry chain DT system. The application layer provides an interactive exploration interface for users.

Framework

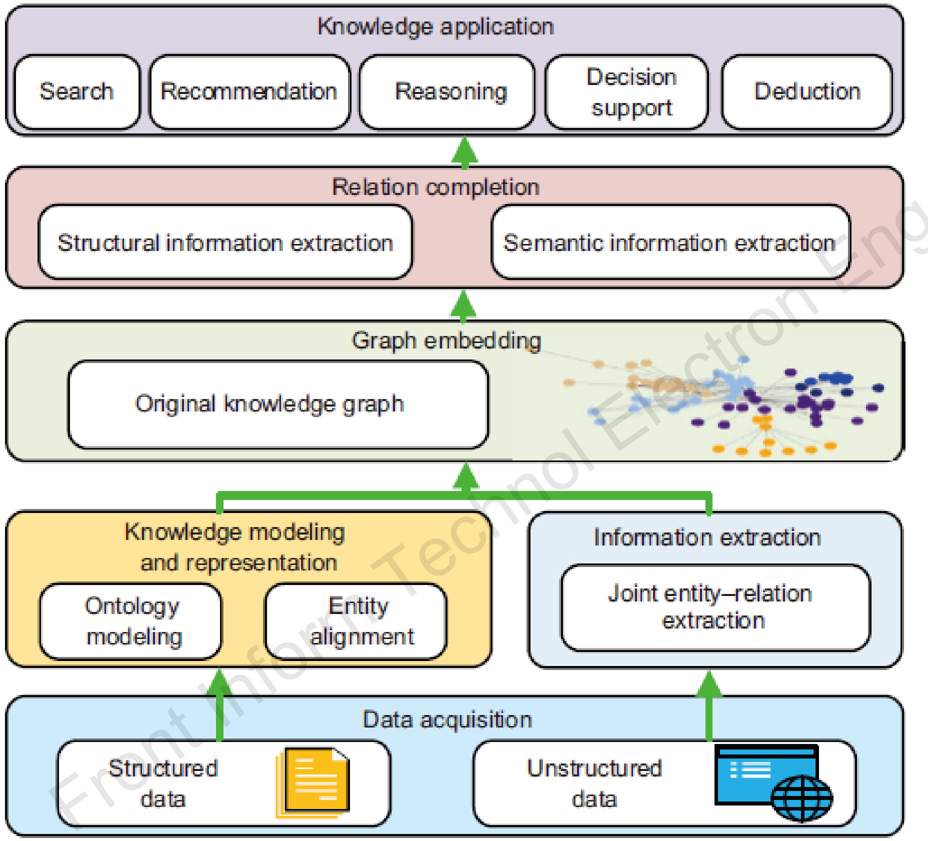

Fig. 4 Framework of industry chain information model construction

1. Industry chain data are collected and the KG ontology is constructed;
2. Entity alignment of triples is performed, and the structured data are stored in the graph database;
3. Joint entity–relation extraction of semi-structured and unstructured data is carried out;
4. Knowledge completion technology is used to supplement and improve the KG.

Method

A joint entity–relation extraction method based on BERT multi-head selection model and the relationship completion model based on a graph neural network is proposed.

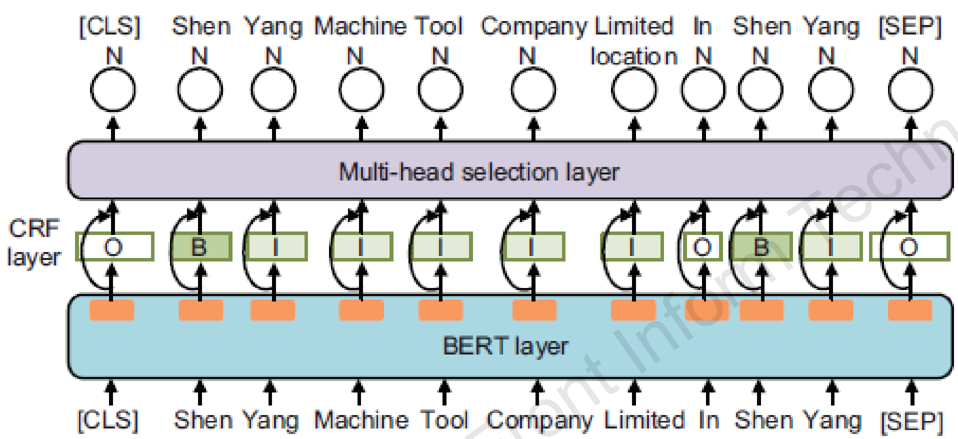

Fig. 6 BERT-based multi-head selection model for joint entity–relation extraction

BERT can output a high-level semantic representation. The sequence boundary position is learned through the CRF. The interaction between entities and relations is enhanced through the multi-head selection.

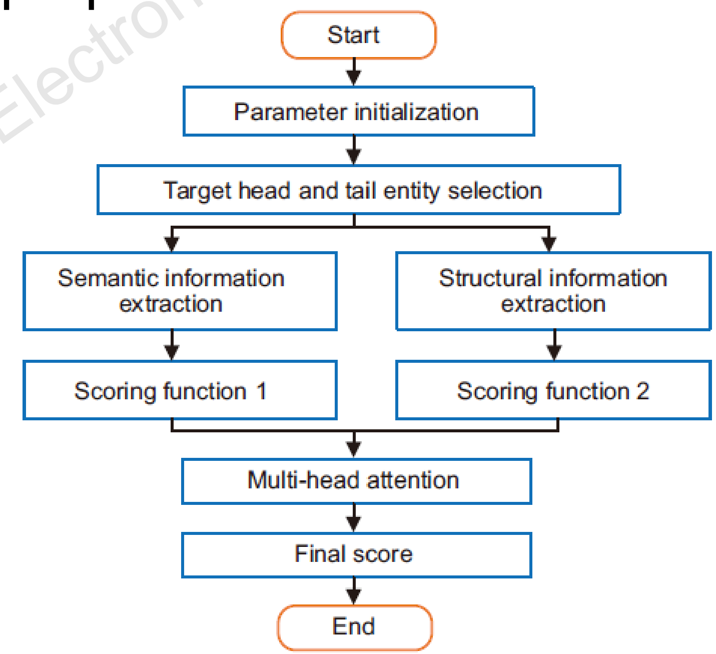

Fig. 7 Knowledge graph completion based on the semantic and structural information of the graph

R-GCN is used to obtain semantic information, and GraphSAGE is used to obtain the structural information.

Results

Table 3 Comparison of the entity–relation extraction on dataset *B*

Model	*P* (%)	*R* (%)	*F* (%)
LSTM-CRF	77.88	78.47	76.66
BiLSTM-CRF	79.39	80.28	77.24
BERT	82.02	82.12	80.03
BERT-CRF	82.23	82.76	80.16
BERT-based multi-head selection	**82.44**	**82.95**	**80.66**

Best results are in bold

Table 5 Comparison of the relation completion on dataset *B*

Model	MRR	Hit@1	Hit@3	Hit@10
TransE	0.290	0.128	0.268	0.525
DistMult	0.241	0.184	0.331	0.534
ComplEx	0.294	0.261	0.314	0.526
ConvE	0.325	0.197	0.421	0.520
RotatE	0.314	0.156	0.315	0.522
R-GCN	0.259	0.166	0.271	0.452
A2N	0.308	0.223	0.347	0.511
CompGCN	0.349	0.236	0.440	0.592
Ours	**0.381**	**0.282**	**0.451**	**0.621**

Best results are in bold, and the second-best results are with the underline

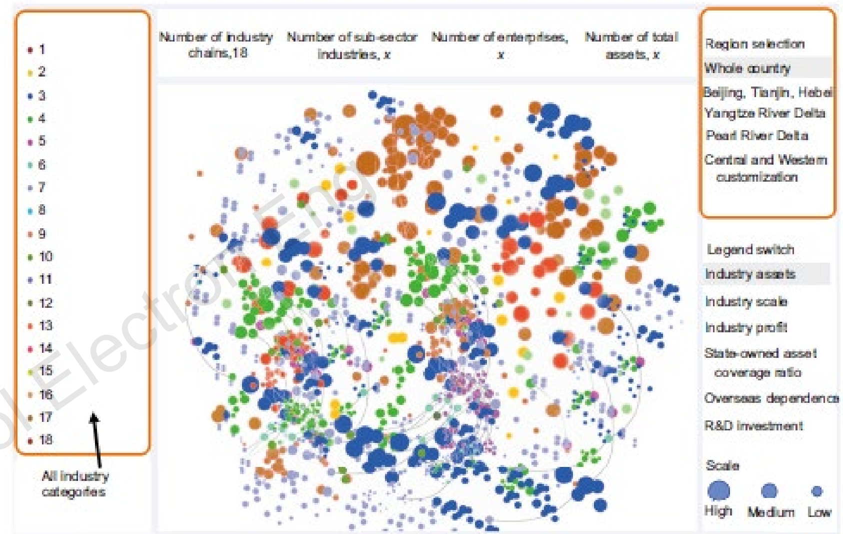

Fig. 9 Industry panorama of the basic machinery field

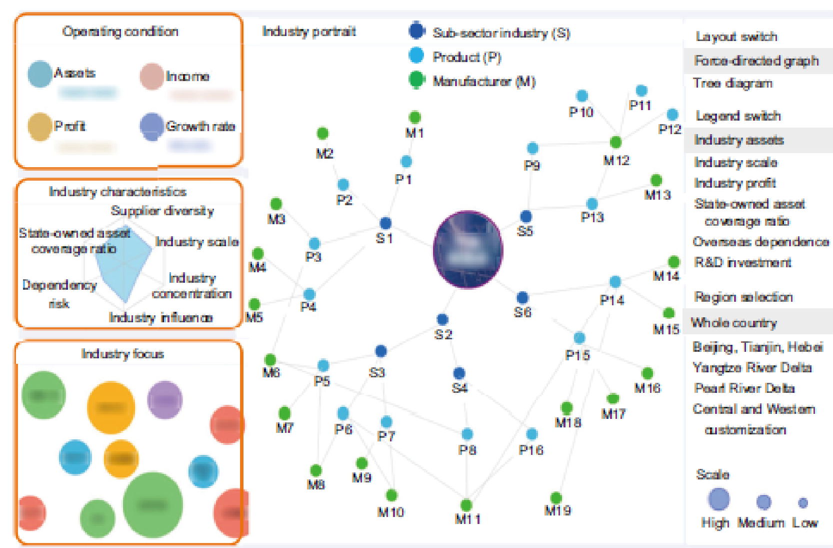

Fig. 11 Industry chain portrait

Conclusions

To improve the ability to collaboratively innovate, avoid risk ability, and comprehensively govern each link of the industrial Internet, this paper proposed an industrial chain DT system framework and an industrial chain information model based on KG. (1) The construction process of the industrial chain DT system framework supported by the industrial Internet was presented. (2) A KG-based industry chain information model construction method was proposed. (3) Based on the data of 18 industrial chains, an industrial chain information model in the field of basic machinery was established.

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