

Muhao Chen

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Research Interests

Natural Language Understanding and Knowledge Acquisition.

EDUCATION

University of California, Los Angeles, USA

Ph.D., Department of Computer Science

2014.9-2019.6

Dissertation: Multi-relational Representation Learning and Knowledge Acquisition

Advisor: Carlo Zaniolo, Distinguished Professor of Computer Science, N.E. Friedmann Chair in Knowledge Science

Collaborators:

- Kai-Wei Chang, Assistant Professor of Computer Science
- Wei Wang, Leonard Kleinrock Chair Professor of Computer Science
- Yizhou Sun, Associate Professor of Computer Science
- Alex Bui, Professor of Radiology Sciences

Fudan University, Shanghai, China

B.S. in Computer Science

2010.9-2014.6

Advisor: X. Sean Wang

PUBLICATIONS

*Indicating equal contributions. ✉Indicating contact authors of journal publications.

Tutorials

1. **Muhao Chen**, Hongming Zhang, Qiang Ning, Manling Li, Heng Ji, Kathleen McKeown, Dan Roth. Event-centric Natural Language Processing. In **ACL**, 2021.
2. **Muhao Chen**, Hongming Zhang, Qiang Ning, Manling Li, Heng Ji, Dan Roth. Event-centric Natural Language Understanding. In **AAAI**, 2021.
3. **Muhao Chen**, Kai-Wei Chang, Dan Roth. Recent Advances in Transferable Representation Learning. In **AAAI**, 2020.

Refereed Publication in Conference Proceedings

4. Fangyu Liu, **Muhao Chen**, Dan Roth, Nigel Collier. Visual Pivoting for (Unsupervised) Entity Alignment. In *the 35th AAAI Conference on Artificial Intelligence (AAAI)*, 2021.
5. Cunchao Zhu, **Muhao Chen**, Changjun Fan, Guangquan Cheng, Yan Zhang. Learning from History: Modeling Temporal Knowledge Graphs with Sequential Copy-Generator Networks. In *the 35th AAAI Conference on Artificial Intelligence (AAAI)*, 2021.
6. **Muhao Chen**, Weijia Shi, Ben Zhou, Dan Roth. Cross-lingual Entity Alignment with Incidental Supervision. In *the 16th Conference of the European Chapter of the Association for Computational Linguistics (EACL)*, 2021.
7. Xuelu Chen*, Michael Boratko*, **Muhao Chen**, Shib Sankar Dasgupta, Xiang Li, Andrew McCallum. Probabilistic Box Embeddings for Uncertain Knowledge Graph Reasoning. In *the 19th Annual Conference of the North American Chapter of the Association for Computational Linguistics (NAACL)*, 2021.
8. Fei Wang, Kexuan Sun, **Muhao Chen**, Jay Pujara, Pedro Szekely. Retrieving Complex Tables with Multi-Granular Graph Representation Learning. In *Proceedings of the 44th ACM SIGIR Conference on Research and Development in Information Retrieval (SIGIR)*, 2021.
9. **Muhao Chen**, Hongming Zhang, Haoyu Wang, Dan Roth. “What Are You Trying to Do?” Semantic Typing of Event Processes. In *Proceedings of the 24th SIGNLL Conference on Computational Natural Language Learning (CoNLL)*, 2020. **Best Paper Nomination**

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10. Zequn Sun, **Muhao Chen**, Wei Hu, Chengming Wang. Knowledge Association with Hyperbolic Representation Learning of Knowledge Graphs. In *Proceedings of the 25th Conference on Empirical Methods in Natural Language Processing (EMNLP)* 2020.
11. Haoyu Wang, **Muhao Chen**, Hongming Zhang, Dan Roth. Joint Constrained Learning for Event-Event Relation Extraction. In *Proceedings of the 25th Conference on Empirical Methods in Natural Language Processing (EMNLP)*, 2020.
12. Hongming Zhang, **Muhao Chen**, Haoyu Wang, Y. Song, Dan Roth. Analogous Process Structure Induction for Sub-event Sequence Prediction. In *Proceedings of the 25th Conference on Empirical Methods in Natural Language Processing (EMNLP)*, 2020.
13. Xuelu Chen, **Muhao Chen**, Changjun Fan, Ankith Uppunda, Yizhou Sun, Carlo Zaniolo. Multilingual Knowledge Graph Completion via Ensemble Knowledge Transfer. In *Proceedings of the 25th Conference on Empirical Methods in Natural Language Processing (EMNLP) - Findings*, 2020.
14. Zequn Sun, Chengming Wang, Wei Hu, **Muhao Chen**, Jian Dai, Wei Zhang, Yuzhong Qu. Knowledge Graph Alignment Network with Gated Multi-hop Neighborhood Aggregation. In *the 34th AAAI Conference on Artificial Intelligence (AAAI)*, 2020.
15. Changping Meng, **Muhao Chen**, Jie Mao, Jennifer Neville. ReadNet: A Hierarchical Transformer Framework for Readability Analysis. In *the 42nd European Conference on Information Retrieval (ECIR)*, 2020.
16. Junheng Hao, Chelsea J. T. Ju, **Muhao Chen**, Yizhou Sun, Carlo Zaniolo, Wei Wang. Bio-JOIE: Joint Representation Learning of Biological Knowledge Bases. In *the 11th ACM Conference on Bioinform., Comput. Bio. and Biomed. (ACM BCB)*, 2020 (**Best Student Paper Award**, ~0.8%)
17. Tianran Zhang, **Muhao Chen**, Alex Bui. Diagnostic Prediction with Sequence-of-sets Representation Learning for Clinical Events. In *Proceedings of the 18th International Conference on Artificial Intelligence in Medicine (AIME)*, 2020
18. **Muhao Chen**, Yingtao Tian, Haochen Chen, Kai-Wei Chang, Steve Skiena, Carlo Zaniolo. Learning to Represent Bilingual Dictionaries. In *Proceedings of the 23rd SIGNLL Conference on Computational Natural Language Learning (CoNLL)*, 2019
19. Junheng Hao, **Muhao Chen**, Wenchao Yu, Yizhou Sun, Wei Wang. Universal Representation Learning of Knowledge Bases by Jointly Embedding Ontological Concepts and Instances. In *Proceedings of the 25th ACM SIGKDD Conference on Knowledge Discovery and Data Mining (KDD)*, 2019.
20. Xuelu Chen, **Muhao Chen**, Weijia Shi, Yizhou Sun, Carlo Zaniolo. Uncertain Knowledge Graphs Embeddings. In *the 33rd International Conference on Artificial Intelligence (AAAI)*, 2019.
21. **Muhao Chen**^{*}, Weijia Shi^{*}, Pei Zhou, Kai-Wei Chang. Retrofitting Contextualized Word Embeddings with Paraphrases. In *Proceedings of the 24th Conference on Empirical Methods in Natural Language Processing (EMNLP)*, 2019.
22. Pei Zhou, Weijia Shi, Jieyu Zhao, Kuan-Hao Huang, **Muhao Chen**, Ryan Cotterell, Kai-Wei Chang. Examining Gender Bias in Languages with Grammatical Gender. In *Proceedings of the 24th Conference on Empirical Methods in Natural Language Processing (EMNLP)*, 2019.
23. **Muhao Chen**, Chris Quirk. Embedding Edge-attributed Relational Hierarchies. In *Proceedings of the 42nd ACM SIGIR Conference on Research and Development in Information Retrieval (SIGIR)*, 2019.
24. Qingheng Zhang, Zequn Sun, Wei Hu, **Muhao Chen**, Lingbing Guo, Yuzhong Qu. Multi-view Knowledge Graph Embedding for Entity Alignment. In *Proceedings of the 28th International Joint Conference on Artificial Intelligence (IJCAI)*, 2019. Also in **ISWC** 2020 Invited Sister Conference Track.
25. Zequn Sun, Jiacheng Huang, Wei Hu, **Muhao Chen**, Yuzhong Qu. TransEdge: Translating Relation-contextualized Embeddings for Knowledge Graphs. In *the 18th International Semantic Web Conference (ISWC)*, 2019.
26. Haochen Chen, Syed Fahad Sultan, Yingtao Tian, **Muhao Chen**, Steven Skiena. Fast and Accurate Network Embeddings via Very Sparse Random Projection. In *Proceedings of the 28th ACM International Conference on Information and Knowledge Management (CIKM)*, 2019.
27. Changjun Fan, Yuhui Ding, Li Zeng, **Muhao Chen**, Yizhou Sun and Zhong Liu. Learning to Identify High Betweenness Centrality Nodes from Scratch: A Novel Graph Neural Network Approach. In *Proceedings of the 28th ACM International Conference on Information and Knowledge Management (CIKM)*, 2019.
28. **Muhao Chen**, Changping Meng, Gang Huang, Carlo Zaniolo. Learning to Differentiate Between Main-articles and Sub-articles in Wikipedia. In *IEEE International Conference on Big Data (BigData)*, 2019.
29. Yingtao Tian, Haochen Chen, Bryan Perozzi, **Muhao Chen**, Xiaofei Sun, Steven Skiena. Social Relation Inference via Label Propagation. In *the 41st European Conference on Information Retrieval (ECIR)*, 2019.

30. Qi Zhao, **Muhao Chen**, Pengyuan Du, Tuan Le, Mario Gerla. Towards Efficient Cellular Traffic Offloading via Dynamic MPTCP Path Configuration with SDN. In *IEEE International Conference on Computing, Networking and Communications (ICNC)*, 2019.
31. **Muhao Chen**, Gang Huang, Changping Meng, Carlo Zaniolo. Neural Article Pair Modeling for Wikipedia Sub-article Matching. In *the 29th European Conference on Machine Learning (ECML)*, 2018 (**Plenary Presentation**, ~1.7% acceptance rate)
32. **Muhao Chen**, Yingtao Tian, Kai-Wei Chang, Steven Skiena, Carlo Zaniolo. Co-training Embeddings of Knowledge Graphs and Entity Descriptions for Cross-lingual Entity Alignment. In *the 27th International Joint Conference on Artificial Intelligence (IJCAI)*, 2018.
33. **Muhao Chen**, Yingtao Tian, Xuelu Chen, Zijun Xue, Carlo Zaniolo. On2Vec: Embedding-based Relation Prediction for Ontology Population. In *Proceedings of the 17th SIAM International Conference on Data Mining (SDM)*. SIAM, 2018
34. Haochen Chen, Xiaofei Sun, Yingtao Tian, Bryan Perozzi, **Muhao Chen** and Steven Skiena. Enhanced Network Embeddings via Exploiting Edge Labels. In *the 27th ACM Conference on Information and Knowledge Management (CIKM)*. ACM 2018.
35. Pengyuan Du, Seunghyun Yoo, Qi Zhao, **Muhao Chen**, Mario Gerla. Towards Opportunistic Resource Sharing in Mobile Social Networks - an Evolutionary Game Theoretic Approach. In *Proceedings of the 19th ACM International Symposium on Mobile Ad Hoc Networking and Computing (MobiHoc)*, ACM 2018.
36. **Muhao Chen**, Qi Zhao, Pengyuan Du, Carlo Zaniolo, Mario Gerla. Demand-driven Cache Allocation Based on Context-aware Collaborative Filtering. In *Proceedings of the 19th ACM International Symposium on Mobile Ad Hoc Networking and Computing (MobiHoc)*, ACM 2018.
37. **Muhao Chen**, Yingtao Tian, Mohan Yang, Carlo Zaniolo. Multilingual Knowledge Graph Embeddings for Cross-lingual Knowledge Alignment. In *Proceedings of the 26th International Joint Conference on Artificial Intelligence (IJCAI)*. 2017.
38. **Muhao Chen**, Carlo Zaniolo. Learning Multi-faceted Knowledge Graph Embeddings for Natural Language Processing. In *Proceedings of the 26th International Joint Conference on Artificial Intelligence (IJCAI)*. 2017 (Extended abstract)
39. **Muhao Chen**, Shi Gao, X. Sean Wang. Converting Spatiotemporal Data Among Heterogeneous Granularity Systems. In *Proceedings of the 25th IEEE International Conference on Fuzzy Systems (FUZZ-IEEE)*. IEEE, 2016. Shorter version in *Proceedings of the 31st ACM SIGAPP Symposium on Applied Computing (SAC)*. ACM, 2016.

Refereed Journal Publication

40. Jyun-Yu Jiang, Chelsea J.-T. Ju, Junheng Hao, **Muhao Chen**, Wei Wang. Circular RNA Prediction based on Junction Encoders and Deep Interaction among Splice Sites. To appear in *Bioinformatics*, Oxford University Press, 2021. Proceedings of **ISMB/ECCB**, 2021.
41. Guangyu Zhou*, **Muhao Chen**[✉], Chelsea J. T. Ju*, Zheng Wang, Jyun-Yu Jiang, Wei Wang[✉]. Mutation effect estimation on protein-protein interactions using deep contextualized representation learning. *NAR Genom. Bioinform*, vol. 2 (2). Oxford University Press. 2020.
42. Zequn Sun, Qingheng Zhang, Wei Hu[✉], Chengming Wang, **Muhao Chen**, Chengkai Li, Yuzhong Qu. A Benchmarking Study of Embedding-based Entity Alignment for Knowledge Graphs. *Proceedings of the VLDB Endowment (PVLDB)*, vol. 13. ACM. 2020
43. **Muhao Chen**[✉], Chelsea J. T. Ju*, Guangyu Zhou, Tianran Zhang, Kai-Wei Chang, Carlo Zaniolo, Wei Wang. Multifaceted Protein-Protein Interaction Prediction Based on Siamese Residual RCNN. *Bioinformatics*, vol. 35 (14) Oxford University Press. Proceedings of **ISMB/ECCB**, 2019.
44. Carlo Zaniolo[✉], Shi Gao, Maurizio Atzori, **Muhao Chen**, Jiaqi Gu. User-Friendly Temporal Queries on Historical Knowledge Bases. *Information and Computation*, Vol. 259 (3). Elsevier, 2018.

Refereed Workshop and System Demonstration Papers

45. Weijia Shi, **Muhao Chen**, Yingtao Tian, Kai-Wei Chang. Learning Bilingual Word Embeddings Using Lexical Definitions. In *Proceedings of ACL Workshop on Representation Learning for NLP (RepL4NLP)*, 2019.
46. Zubo Deng, Pei Zhou, Weijia Shi, **Muhao Chen**, Kai-Wei Chang. Computational Analysis of French-origin Reborrowing Process for English Loanwords. In *ICDM Workshop on Multilingual Cognitive Services (ICDMW)*, 2019
47. Changjun Fan, Yizhou Sun, Li Zeng, Yang-Yu Liu, **Muhao Chen**, Zhong Liu. Dismantle Large Networks through Deep Reinforcement Learning. In *ICLR Workshops*, 2019.
48. Pei Zhou, **Muhao Chen**, Kai-Wei Chang, Carlo Zaniolo. Quantification and Analysis of Scientific Language Variation by Research Fields. In *Proceedings of the ICDM Workshops (ICDMW)*, 2018.

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49. **Muhao Chen**, Tao Zhou, Pei Zhou, Carlo Zaniolo. Multi-graph Affinity Embeddings for Multilingual Knowledge Graphs. **Contributed talk** in the *6th Workshop on Automated Knowledge Base Construction at NIPS (AKBC)*. 2017.
50. Tao Zhou, **Muhao Chen**, Demetri Terzopoulos, Jie Yu. Attention-based Natural Language Person Retrieval. In *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition Workshops (CVPRW)*. IEEE, 2017.
51. Shi Gao, **Muhao Chen**, Maurizio Atzori, Carlo Zaniolo. SPARQL^T and its User-Friendly Interface for Managing and Querying the History of Knowledge Bases. In *the 14th International Semantic Web Conference (ISWC)*, 2015 (demo).

PRESENTATIONS

Invited talks, colloquia and tutorials

1. Event-Centric Natural Language Understanding. *Half-day Tutorial at ACL*. Aug, 2021. (Scheduled)
2. Understanding Event Processes in Natural Language. *Invited talk, IBM Research Almaden*. San Jose. May, 2021 (Scheduled)
3. Understanding Event Processes in Natural Language. *Invited talk, CS Research Colloquium, UCSB*. April, 2021
4. Understanding Event Processes in Natural Language. *Invited talk, NLP Seminar, The Ohio State University*. April, 2021
5. Understanding Event Processes in Natural Language. *Invited talk, Frontier Topics in Vision and Language, Arizona State University*. Mar, 2021.
6. Event-Centric Natural Language Understanding. *Half-day Tutorial at AAAI*. Feb, 2021.
7. Understanding Event Processes in Natural Language. *Invited talk at Language Technology Seminar, University of Cambridge*. Nov 2020
8. Understanding Event Processes in Natural Language. *Invited talk at Machine Learning and Big Data Seminar, UCLA*. Nov 2020
9. Knowledge Acquisition with Transferable Representation Learning. *CS Research Colloquium, USC*. Nov 2020
10. Event-Centric Commonsense Understanding. *CKG Lunch Talk, USC ISI*. Aug 2020
11. Event Schema Instantiation as Knowledge Graph Alignment. *PI meeting (KAISOS), DARPA*. June 2020.
12. Recent Advances in Transferable Representation Learning. *Half-day tutorial at AAAI*. NYC, NY, Feb 2020.
13. Multi-relational Knowledge Acquisition with Transferable Representation Learning. *AI Seminar, USC ISI*. Los Angeles, Jan 2020.
14. Multi-relational Knowledge Acquisition with Transferable Representation Learning. *IBM Research Almaden*. San Jose, Jan 2020.
15. Multi-relational Knowledge Acquisition with Transferable Representation Learning. *Invited talk at FDSiF, Fudan Univ., Shanghai, China*. Dec 2019.
16. Multi-relational representation learning and knowledge acquisition. *Invited talk at SNAP Seminar, Stanford University*. Jan 2019
17. Multi-relational representation learning and knowledge acquisition. *Machine Learning and Big Data Seminar, UCLA*. Jan 2019
18. Neural Article Pair Modeling for Wikipedia Sub-article Matching. *Google Search Intelligence Seminar Talk*. Sept 2017
19. Reasoning Across Multiple Spatiotemporal Granularity Systems. *Invited talk at Teradata Labs, El Segundo, CA, USA*. Mar 2015

Conference talks

20. Cross-lingual Entity Alignment with Incidental Supervision. *Conference talk at EACL*. April 2021
21. “What Are You Trying To Do?” Semantic Typing of Event Processes. *Conference talk at CoNLL*. Nov 2020
22. Retrofitting contextualized word embeddings with paraphrases. *Conference talk at EMNLP, Hong Kong, China*. Nov 2019
23. Cross-lingual Dependency Parsing with Unlabeled Auxiliary Languages. *Conference talk at CoNLL, Hong Kong, China*. Nov 2019
24. Neural Article Pair Modeling for Wikipedia Sub-article Matching. *Plenary talk at ECML, Dublin, Ireland*. Sept 2018
25. Co-training Embeddings of Knowledge Graphs and Entity Descriptions for Cross-lingual Entity Alignment. *Conference talk at IJCAI, Stockholm, Sweden*. July 2018
26. On2Vec: Embedding-based Relation Prediction for Ontology Population. *Conference talk at SDM, San Diego, CA, USA*. May 2018
27. Multilingual Knowledge Graph Embeddings for Cross-lingual Knowledge Alignment. *Contributed talk at AKBC, Longbeach, CA, USA*. Dec 2017

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28. Multilingual Knowledge Graph Embeddings for Cross-lingual Knowledge Alignment. *Conference talk at IJCAI. Melbourne, Australia.* Aug 2017
29. Converting Spatiotemporal Data Among Heterogeneous Granularity Systems. *Conference talk at FUZZ-IEEE. Vancouver, Canada.* Aug 2016

PROFESSIONAL EXPERIENCE

University of Southern California

2020.8-date

- **Assistant Research Professor**, Department of Computer Science
- **Staff Researcher**, AI Division of the Information Science Institute

University of Pennsylvania, Philadelphia, PA (CogCompGroup)

2019.8-2020.7

- **Postdoctoral Fellow**, *Hosted by Dan Roth, Eduardo D. Glandt Distinguished Professor of Computer and Information Science*
- *DARPA KAIROS and DARPA BETTER Programs*

Microsoft Research, Redmond, WA (NLP Group)

2018.6-2018.9

- **Research Intern**, *Embedding Edge-attributed Relational Hierarchies.* [22]

Google, Mountain View, CA (Google Knowledge Graph)

2017.6~2017.9

- **Research Intern**, *Neural Article Pair Modeling for Large-scale Sub-article Relation Extraction.* [30,27,14]

Google, Mountain View, CA (Procella Real-time Data Infrastructure)

2016.6~2016.9

- **System SDE Intern**, *Dynamic Shard-partitioning for Large-scale Windowed Event Streams.*

Teradata Labs, Los Angeles, CA (Optimizer Group)

2015.6~2015.9

- **R&D Intern**, *Multi-task Learning for Cost-based Database Optimizers.*

SELECTED AWARDS

SIGBio ACM-BCB Best Student Paper Award 2020

UCLA Dissertation Fellowship. 2018-2019

Google Research & Travel Support Archimedes Program. 2018

NSF Travel Grants. 2016, 2017, 2018, 2019

Research Grant of the National University Student Innovation Program. Ministry of Education of China. 2014

Tung OOCL Scholarships. Tung's Foundation of Hong Kong & The Oriental Overseas Container Line. 2012, 2013

Wang-Dao Fellowship. President of Fudan University. 2013

EMC Scholarship. EMC Inc. 2013

Chun-Tsung Fellowship. Hui-Chun Chin and Tsung-Dao Lee Chinese Undergraduate Research Endowment. 2012

TEACHING AND MENTORING EXPERIENCE

PhD Committee Members

Minh Pham, USC PhD Student in Computer Science. Committee Chair: Craig Knoblock

Xuelu (Shirley) Chen, UCLA PhD Student in Computer Science. Committee Chair: Carlo Zaniolo

Mentoring (Publications by undergraduate and master's mentees are highlighted)

Eric (Ehsan) Qasemi, USC PhD Student in Computer Science. **Research mentor**

2020.11-date

Wenxuan Zhou, USC PhD Student in Computer Science. **Research mentor**

2020.10-date

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Fei Wang, USC MS Student in Computer Science. Research mentor (First-author publication in SIGIR'21)	2020.9-date
Leshang Chen, UPenn PhD Student in Computer and Information Science. Research mentor	2020.2-date
Haoyu Wang, UPenn MS Student in Computer and Information Science. Research mentor (First-author publication in EMNLP'20, co-authored another two EMNLP'20 and CoNLL'20 papers)	2019.9-2020.7
Tianran Zhang, UCLA PhD student in Bioengineering. Research mentor	2019.6-date
Junheng Hao, UCLA PhD student in Computer Science. Research mentor	2017.10-2019.9
Xuelu (Shirley) Chen, UCLA PhD student in Computer Science. Research mentor	2017.10-2020.11
Pei Zhou, UCLA undergraduate student (Now PhD student at USC CS). Research mentor (First-author publications in EMNLP'19 and ICDMW'18. Coauthored paper in AKBC'18)	2019.12-2019.6
Weijia Shi, UCLA undergraduate student (Now PhD student at UW CSE). Research mentor (First-author publications in EMNLP'19 and RepL4NLP'19. Coauthored paper in AAAI'19)	2018.6-2019.12
Ankith Uppunda. UCLA undergraduate student. Research mentor . (Published in Findings of EMNLP 2020)	2019.3-2019.6.
Zhubo Deng, UCLA undergraduate student. Research mentor (First-author publication in ICDMW'19).	2019.1-2019.6
Xiaoshuang Wei, UCLA MS student in Computer Science (Now software engineer at Google). Thesis mentor	2016.10-2017.3

Teaching

Teaching assistant (2015.9-2016.6), associate (2016.9-2017.6), fellow (2017.9-2018.6) at UCLA (Data Structures and Algorithms; Introduction to Computer Science).

ACADEMIC SERVICES

Organization Committee:

2021: AAAI (Senior PC), IJCAI (Senior PC)

2019: IEEE AIKE (Doctoral Consortium Co-chair)

PC Member:

2021: ACL, EACL, NAACL, WSDM, WWW.

2020: AAAI, AACL-IJCNLP, AKBC, COLING, EMNLP, IJCAI, ISWC, KDD, SIGIR, WSDM, *SEM.

2019: AAAI, AKBC, NAACL, ACL, EMNLP-IJCNLP, BigData, NLPCC, WISE, ICSC.

2018: AAAI, EMNLP, BigData, NLPCC, SoCal NLP.

Journal Reviewer: TPAMI, TNNLS, TKDD, TOIS, W3J, PLOS Computational Biology, Clinical and Translational Medicine, Comput. & Struct. Biotechnol., TKDE, TII, BMC Genomics, BMC Medical Genomics, GeoInformatica, Evolutionary Intelligence, Frontiers of Computer Science, Information Sciences.