Classification of Edge-dependent Labels of Nodes in Hypergraphs

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Code and Data: *https://github.com/young917/EdgeDependentNodeLabel*

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KAIST AI
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Summary

- **Novel Problem: Classification of edge-dependent node labels**
- **Effective Model: A novel hypergraph neural network WHATsNET** based on two ideas:
  - **WithInATT:** An attention module where the edge-dependent embedding of each node is computed by attending to the other nodes within each hyperedge
  - **WithinOrderPE:** An edge-dependent positional encoding defined by the relative order of node centrality within each hyperedge
- **Extensive Experiments:**
  - **Superiority: WHATsNET performs significantly and consistently better** than ten competitors on six real-world hypergraphs
  - **Usefulness**: WHATsNET is demonstrated **useful in three applications**: (a) ranking aggregation, (b) node clustering, and (c) product return prediction

Problem Definition: Edge-Dependent Node Classification

- **Examples of Edge-Dependent Node Classification:**
- **(a) Co-Authorship**

Authors (Nodes)

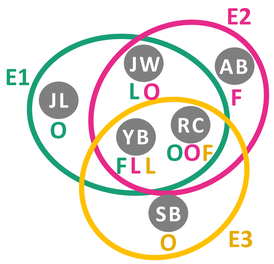
Y Bengio	(YB)	J Weston	(JW)
J Louradour	(JL)	A Bordes	(AB)
R Collobert	(RC)	S Bengio	(SB)

Publications (Hyperedges)

E1: Curriculum learning
Y Bengio, J Louradour, R Collobert, J Weston – ICML'09

E2: Learning structured embeddings of knowledge bases
A Bordes, J Weston, R Collobert, Y Bengio – AAAI'11

E3: A parallel mixture of SVMs for very large scale
R Collobert, S Bengio, Y Bengio – NIPS'01



Labels: First, Last, or Others based on the positions in the author list of each publication

- **(b) Email**

People (Nodes)

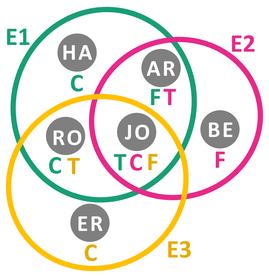
Joan@enron.com	(JO)	arnold@enron.com	(AR)
harry@enron.com	(HA)	ben@enron.com	(BE)
robert@enron.com	(RO)	eric@enron.com	(ER)

Emails (Hyperedges)

Email	
To	Joan@enron.com
CC	harry@enron.com, robert@enron.com
From	arnold@enron.com
TITLE : Today's meeting	

Email	
To	arnold@enron.com
CC	Joan@enron.com
From	ben@enron.com
TITLE : Project Issue	

Email	
To	robert@enron.com
CC	eric@enron.com
From	joan@enron.com
TITLE : Discussion	



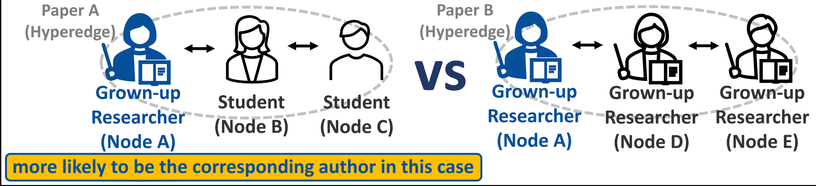
Labels: To, From, or CCs based on the roles (senders, receivers, and the CCed) in each email

- **Formal Problem Definition:**
  - **Given:** (a) A hypergraph $\mathcal{G} = (\mathcal{V}, \mathcal{E})$: a node set $\mathcal{V}$ and a hyperedge set $\mathcal{E}$
    (b) Edge-dependent node labels in some hyperedges $\mathcal{E}' \subset \mathcal{E}$:
    $y_{v,e}, \forall v \in e, \forall e \in \mathcal{E}'$
    (c) (Optionally) a node feature matrix X
  - **Aim to**: accurately predict the unknown edge-dependent node labels in $\mathcal{E} \backslash \mathcal{E}'$:
    $y_{v,e}, \forall v \in e, \forall e \in \mathcal{E} \backslash \mathcal{E}'$

- **Desirable Properties as a Benchmark Task for Hypergraph Neural Networks**
  - It evaluates the capability of capturing properties unique to hypergraphs
  - Existing hypergraph neural networks exhibit limited performance in this task
  - The predictive outputs can directly be applied to various applications

WithInATT: Attention to Other Nodes Within Hyperedges

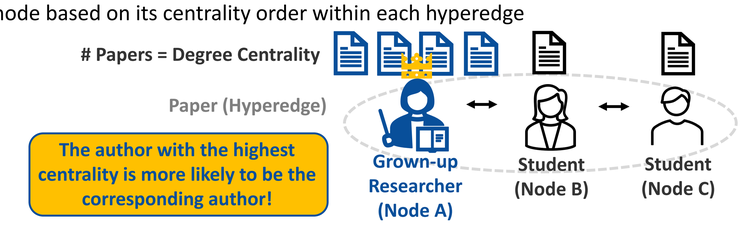
- **Motivation:** The edge-dependent label of each node is shaped by its relation to the other nodes within the same hyperedge.
- **Details: WithInATT** computes the **edge-dependent embedding** of each node by **attending** to the other nodes within each hyperedge



more likely to be the corresponding author in this case

WithinOrderPE: Using Centrality for Positional Encoding

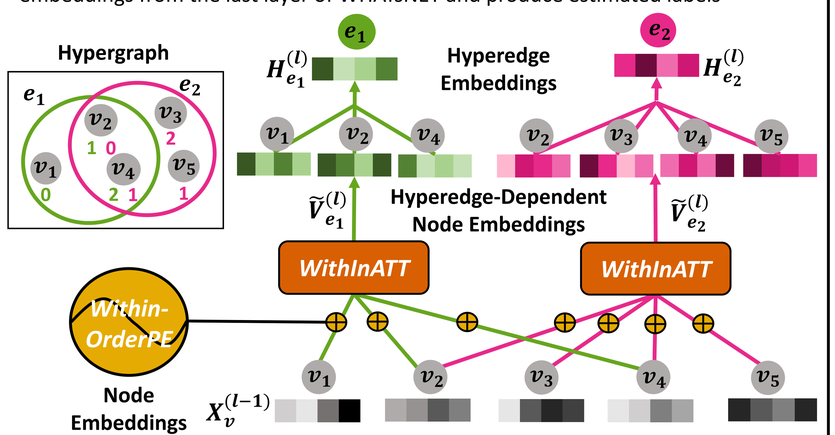
- **Motivation:** The edge-dependent label of each node is closely related to its relative centrality (e.g., degree centrality) within each hyperedge
- **Details: WithinOrderPE** provides the **edge-dependent positional encoding** of each node based on its centrality order within each hyperedge



The author with the highest centrality is more likely to be the corresponding author!

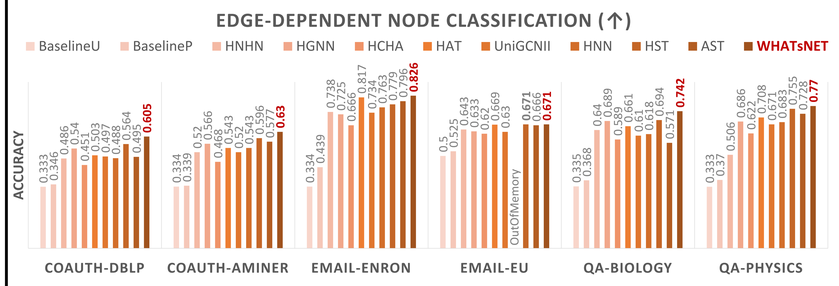
Proposed Model: WHATsNET (Within-Hyperedge Attention Transformer Network)

- **Two message passing steps** in each layer:
  - (1) Updating hyperedge embeddings by aggregating embeddings of incident nodes
  - (2) Updating node embeddings by aggregating embeddings of incident hyperedges
- In each step:
  - (1) Input embeddings of nodes (or hyperedges) are augmented by **WithinOrderPE**
  - (2) **WithInATT** generates hyperedge-dependent node (or node-dependent hyperedge) embeddings
  - (3) They are aggregated into hyperedge (or node) embeddings
- **Predict** edge-dependent node labels:
  - A single-layer perceptron classifier takes the concatenated node and hyperedge embeddings from the last layer of WHATsNET and produce estimated labels

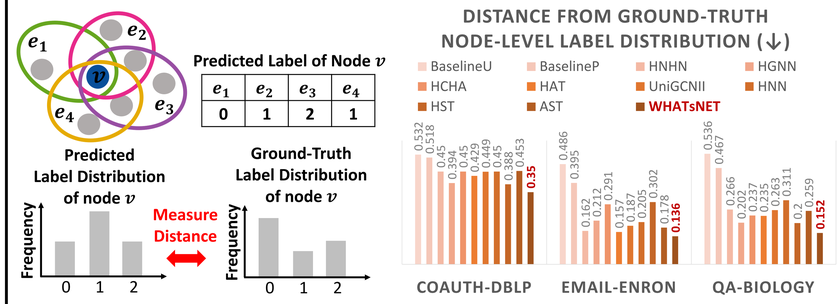


Experimental Results

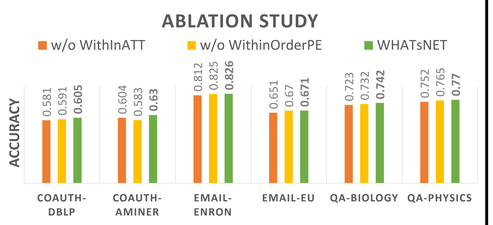
- **Q1:** Does WHATsNet accurately predict the edge-dependent labels of nodes?
- WHATsNET consistently outperforms 10 competitors in classifying edge-dependent node labels across all 6 datasets



- **Q2:** Does WHATsNet classify the same node differently depending on hyperedges?
- We investigate the distribution of edge-dependent labels of each node
- The outputs of WHATsNet preserve well the distribution



- **Q3:** Does each component contribute to the performance?
- Both WithinATT and WithinOrderPE lead to better performance



- **Q4:** Is WHATsNet useful in downstream tasks?
- Edge-dependent labels produced by WHATsNet consistently enhance the performance in three downstream tasks, compared to using no labels