Representation Learning in Hierarchical Collaboration Networks for Team Performance Prediction

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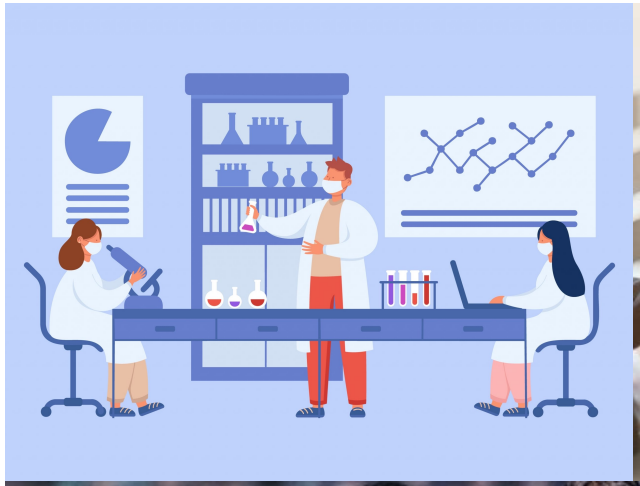
What is Collaboration?

- Important component of teamwork
- Can boost work productivity and improve team performance by putting together individuals' disciplines, expertise, and background
- Example
  - Academic collaboration
  - Business collaboration
  - Sports collaboration



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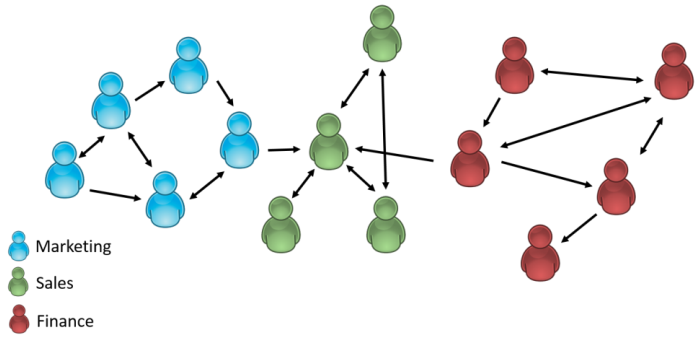
Team Performance Prediction in Collaboration Networks

- Understanding collaboration patterns associated with team performance helps decision-making
  - Example: Sports team lineup decision, hire for a project team
- View collaborations from the network perspective
- Existing studies that predict team performance on collaboration networks
  - Use average structural centrality of team members as features
  - Use dynamics of historical team performance as features
- Limitations of existing works
  - Manual feature engineering is required to represent the whole team
  - Individual team members are treated as equally important

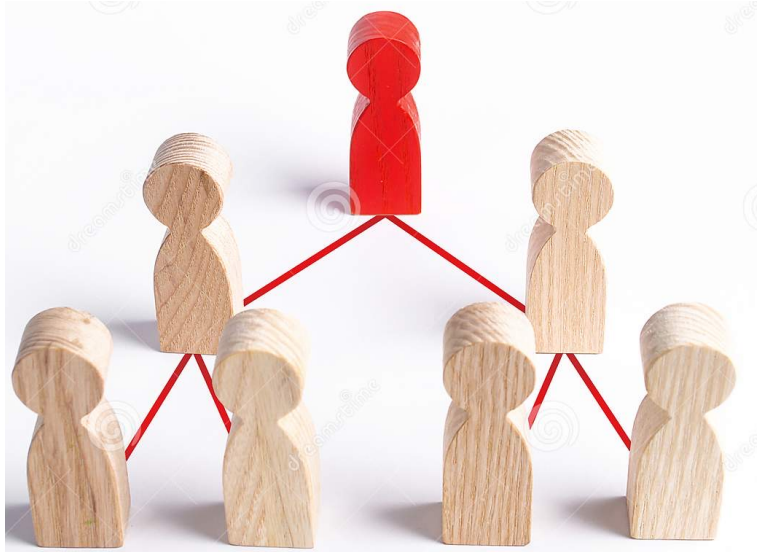


https://www.smartsheet.com/collaboration-networks

Our Work

- Contributions:
  - Captures hierarchical relationships among team members
  - Preserve team members' characteristics and collaboration structures in a team
  - Predict future team performance

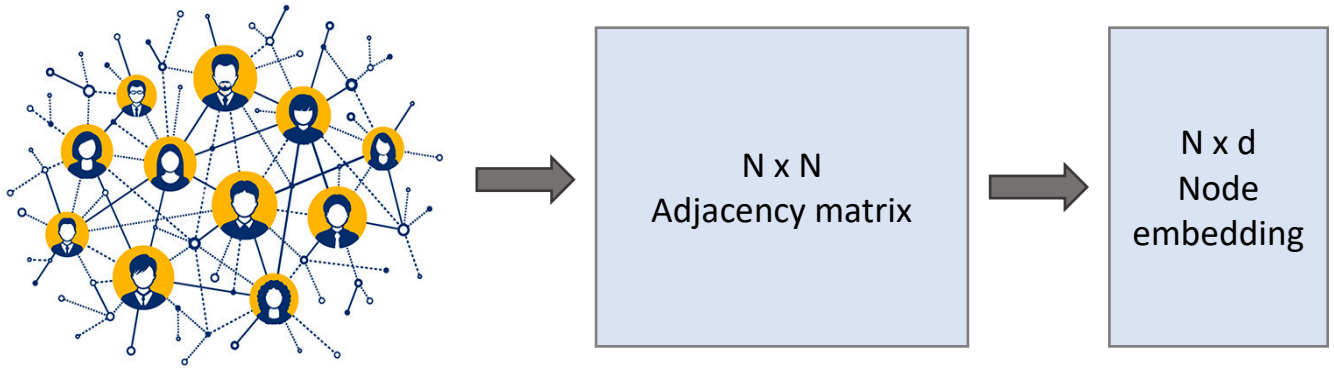
- Adopted network embedding to learns representations of teams



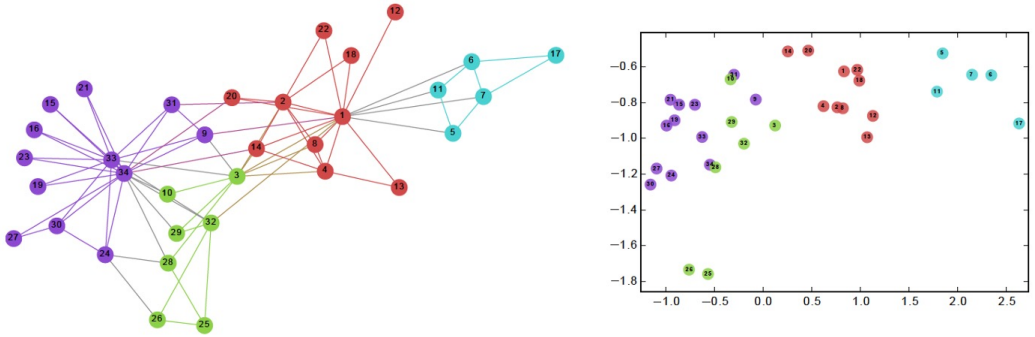
https://www.dreamstime.com/hierarchical-system-company-organization-leadership-teamwork-feedback-team-cooperation-collaboration-image159601780

What is Network Embedding?

- Network embedding is representing a network as vector representations

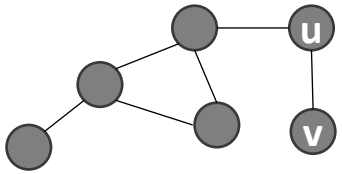


- Node embeddings preserve nodes' structural property in a network



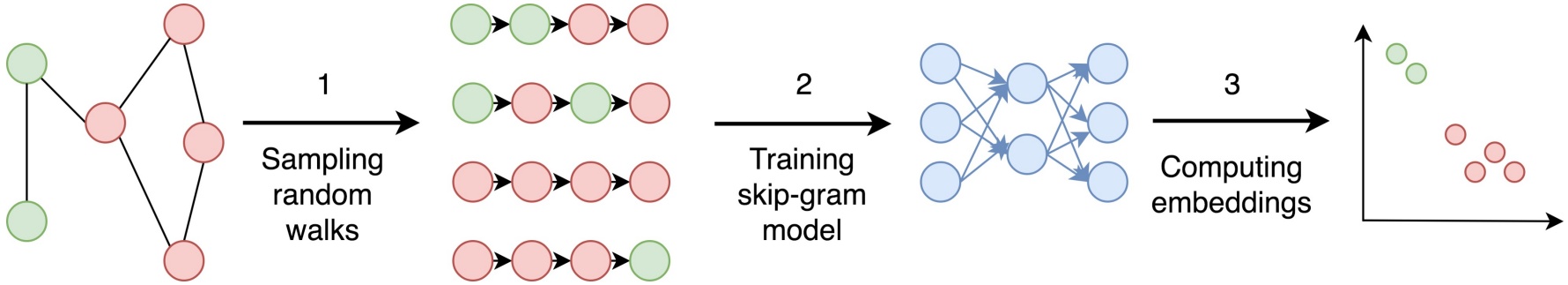
What is Network Embedding?

- Two approaches of node embeddings
  - Unsupervised embedding approach
    - Preserve the latent information of nodes (node closeness, node attribute similarity, etc.)



Objective function: Maximize similarity(u, v)

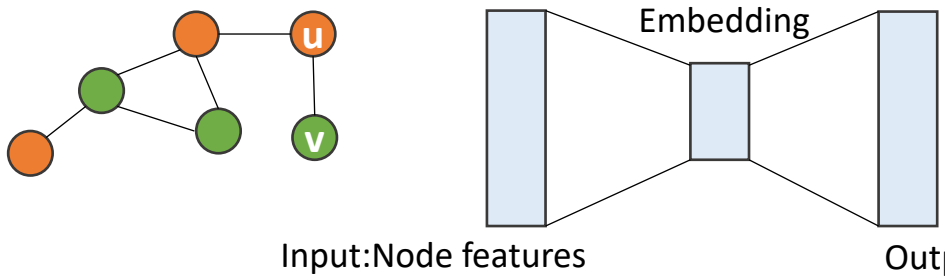
- DeepWalk (Perozzi et al., 2014)



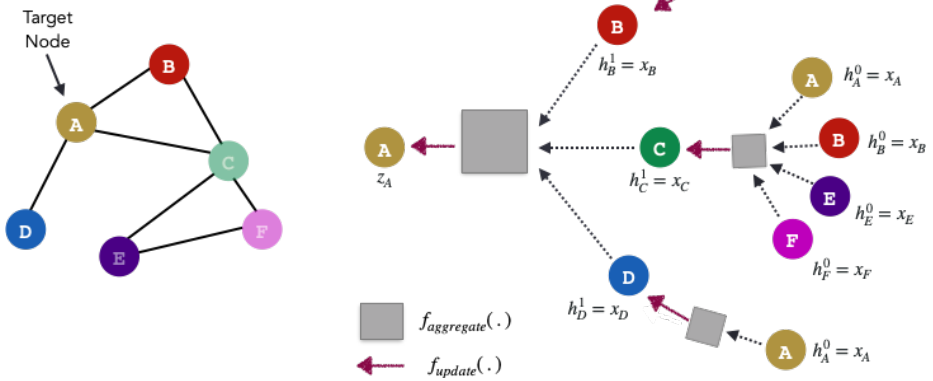
Perozzi, B., Al-Rfou, R., & Skiena, S. (2014, August). Deepwalk: Online learning of social representations. In *Proceedings of the 20th ACM SIGKDD international conference on Knowledge discovery and data mining* (pp. 701-710).

What is Network Embedding?

- Two approaches of node embeddings
  - Supervised embedding approach
    - Node labels guide the training, such that model learns similar representations for similar nodes
    - Deep learning architectures are applied (CNN, attention mechanism, etc.)



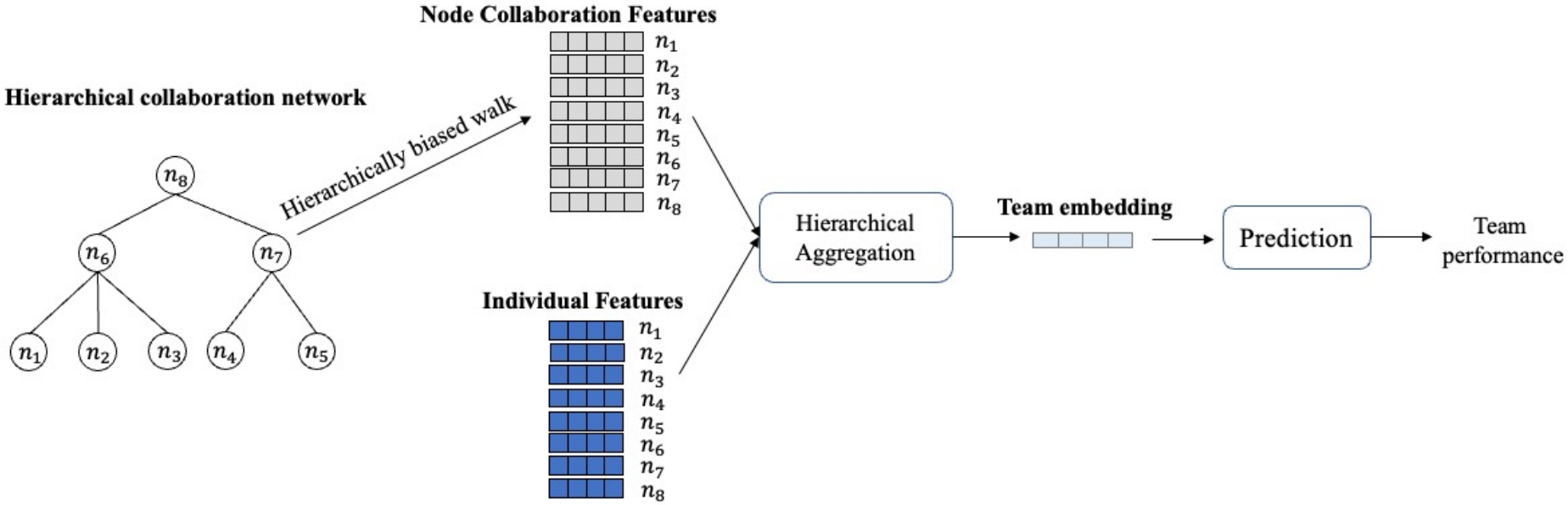
- GraphSAGE (Hamilton et al., 2017)



Hamilton, W. L., Ying, R., & Leskovec, J. (2017, December). Inductive representation learning on large graphs. In *Proceedings of the 31st International Conference on Neural Information Processing Systems* (pp. 1025-1035).

Overview of model

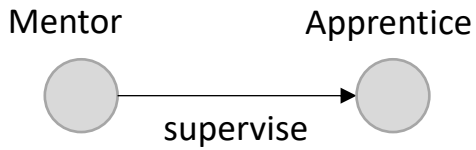
1) Construct a hierarchical collaboration network based on the hierarchical relationship among team members
2) Generate node features of the hierarchical collaboration network
3) Aggregate node features in the same team in a hierarchical way and use an end-to-end learning architecture to learn team representations
4) Predict team performance using the team embedding



Hierarchical Collaboration Networks

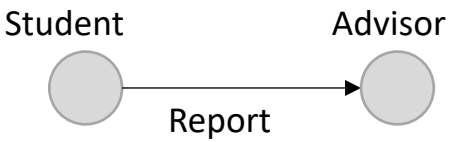
- Nodes: individual team members (e.g., scholars, sports players)
- Three types of edges: hierarchical collaboration relationship
  - Supervision edges: from a member at a higher level to another member directly under

    EX)



  - Reporting edges: opposite of supervision edges

    EX)



  - Peer edges: colleagues working for the same supervisor (no direction)

    EX)

Node Feature Construction

(1) Individual features

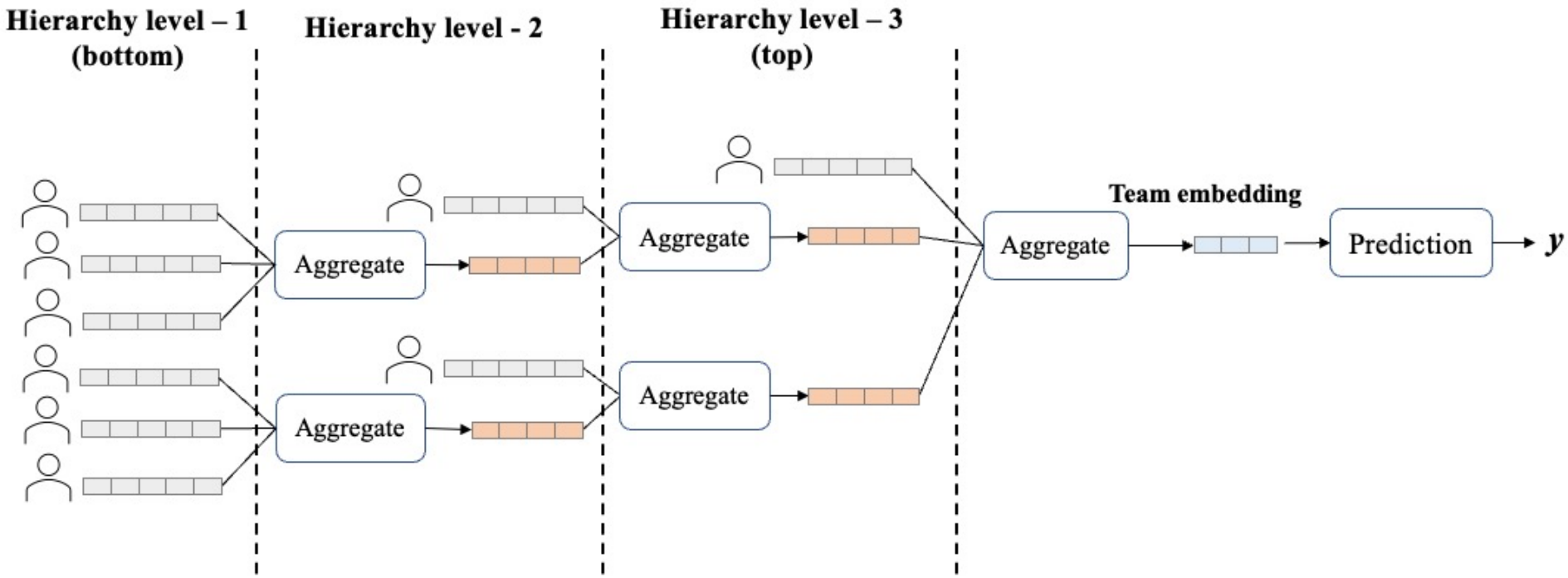
- Expertise, skills, or previous performance

(2) Collaboration features

- Historical collaboration from team members' previous experience
- Learned by variating DeepWalk approach
- Random walk is biased to give different probabilities for traversing supervision, reporting, and peer ties

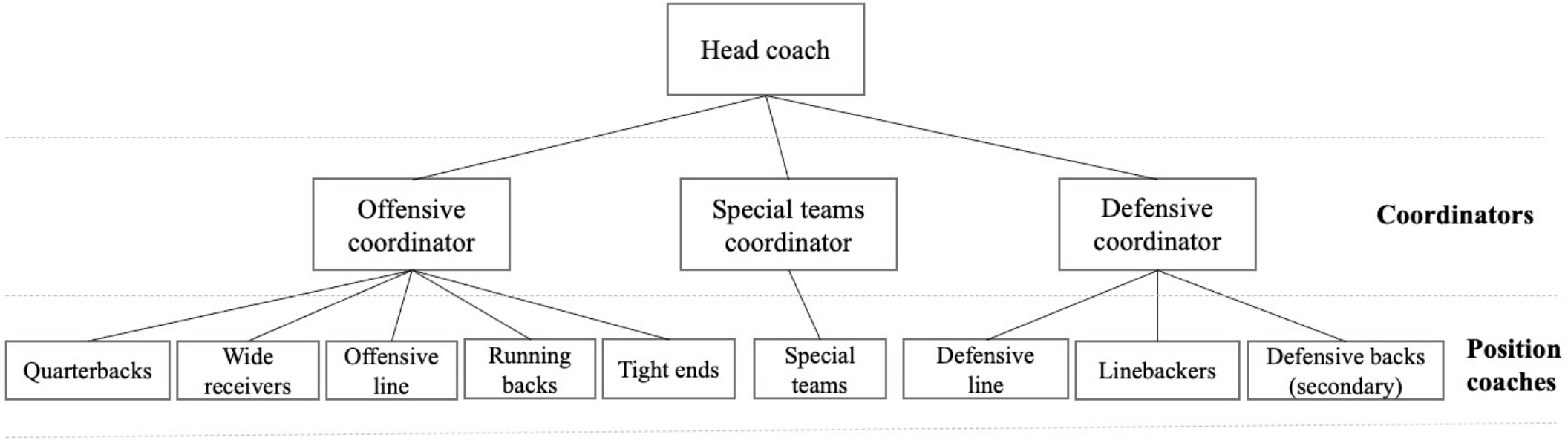
Hierarchical Node Feature Aggregation

- Team embedding is learned by aggregating team members' node features
- Hierarchically aggregate node features in a bottom-up fashion
- Aggregation in each level might be mean, fully-connected layers, or attention mechanism



Experiments - Data

- National Football League (NFL) coach collaboration between 2002 and 2019
- Three levels of hierarchical command structure



Experiments – Design

- Prediction outcome:
  - team failure in each season (failed to win 50% of regular season games / head coach fired)
- Dataset split
  - Training: 2002-2015 (14 years)
  - Validation: 2016-2017 (2 years)
  - Test: 2018-2019 (2 years)
- Experimented on three feature sets
  - Feature set 1: Individual features
  - Feature set 2: Individual features + Collaboration features (non-hierarchical DeepWalk)
  - Feature set 3: Individual features + Collaboration features (hierarchical walk)
- Baseline model: non-hierarchical aggregation of coaches

Results

- Evaluated with AUC metric of prediction performance
- Using hierarchical collaboration features as node features performs the best
- Hierarchical aggregation for team embedding performs the best

	Non-hierarchical aggregation	Hierarchical aggregation
Feature set 1	0.572	0.631
Feature set 2 (DeepWalk)	0.585	0.597
Feature set 3 (Hierarchical walk)	0.600	**0.653**

Summary

- This work proposed a graph representation learning model designed for teams with hierarchical structures
- Two contributions:
  - Leveraged hierarchically biased walk for learning previous hierarchical collaboration patterns
  - Used end-to-end team embedding model that aggregates node features in a hierarchical way
- Future works:
  - Use data from another domain for generalizability
  - Robustness check
  - Give edge weights to hierarchical collaboration networks for considering recency and frequency of ties