# Inductive Learning of Concept Representations from Library-Scale Bibliographic Corpora

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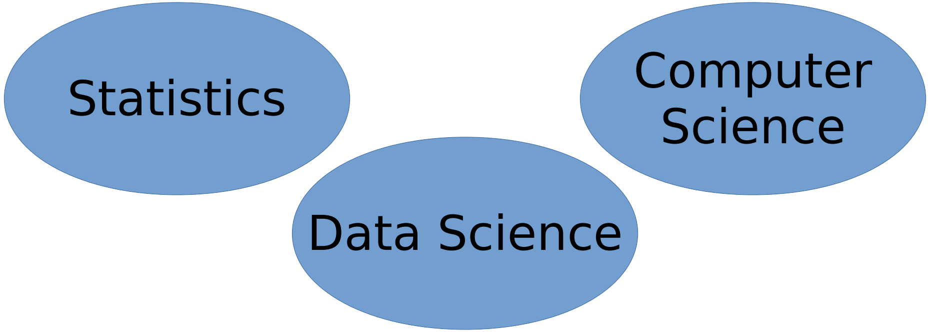
# Outline

1) Motivation: **analyses of research dynamics**
2) Problem statement: **learning concept similarity from graph data**
3) Approach: **unsupervised training objective for graph neural nets**
4) Quantitative and (small-scale) qualitative evaluation

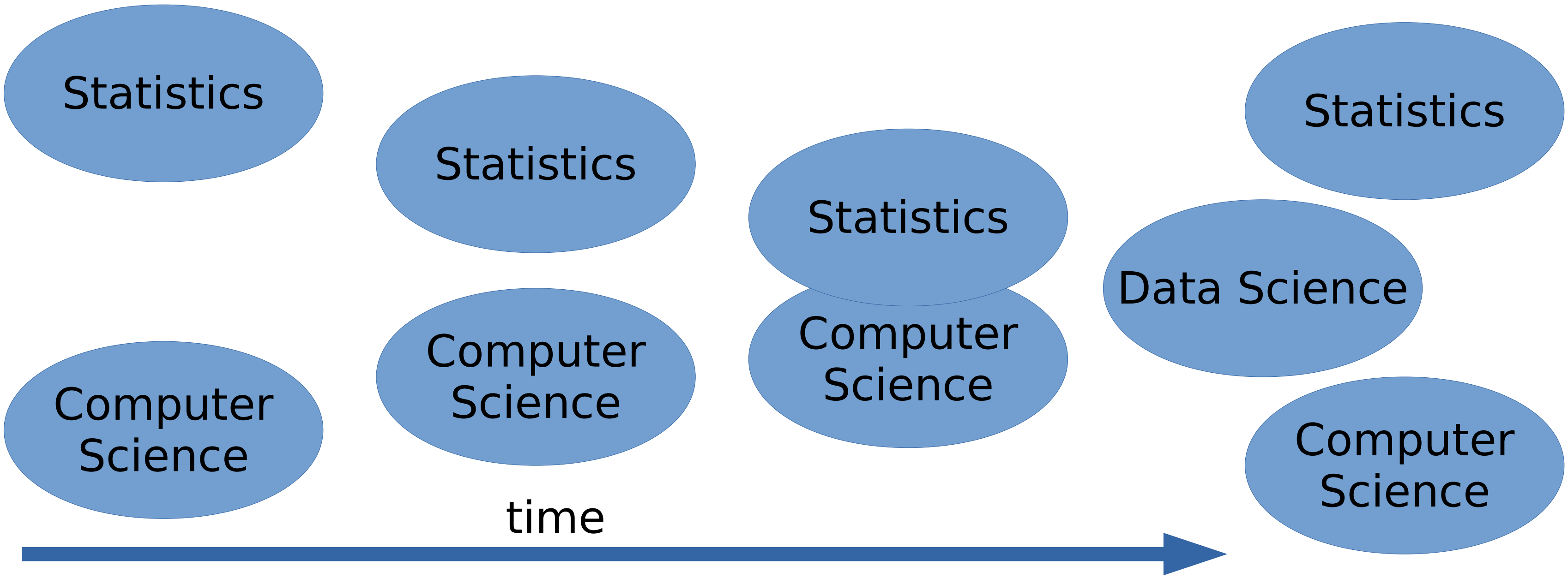
# Motivation

- Digital libraries accumulate a large amount of bibliographic data
- Include valuable annotations with controlled vocabularies (concept hierarchies)
- Used for multi-label classification
- Used for information retrieval
- Used for recommender systems
- What about analyses of research dynamics?

# Motivation



# Motivation: Research Dynamics



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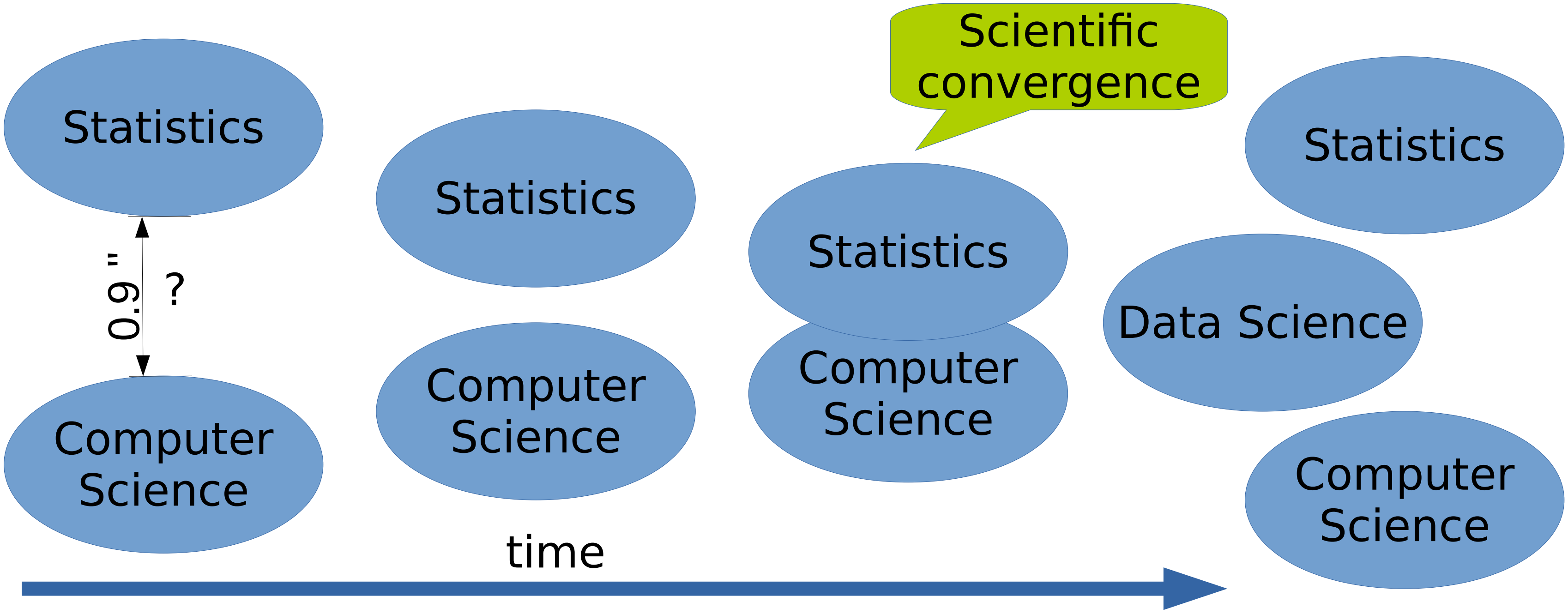
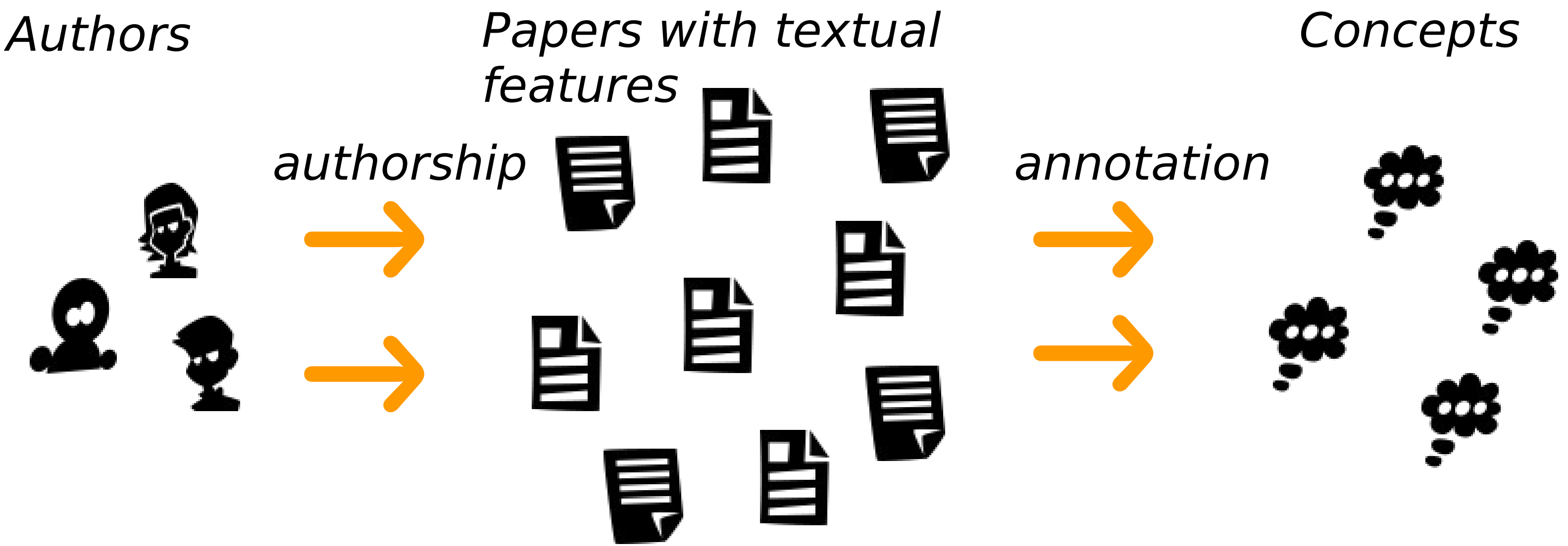


# How to identify scientific convergence?

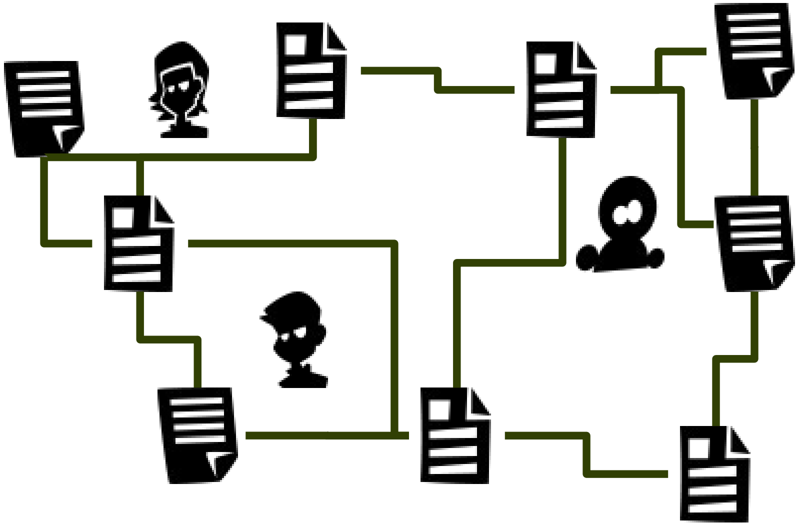
- Decreasing distance over time
- $\frac{d_{t+1}(a,b)}{d_t(a,b)} < 1$ for t in [$t_{start}$,..., $t_{end}$], distance metric d, arbitrary concepts a, b
- Metric learning in pairwise concept space
- Replace d(a, b) by $d^{euclidean}$( f(a), f(b) ), where f maps concept to vectors
- **This paper:** *We can learn function* f *from data*

# Bibliographic Data



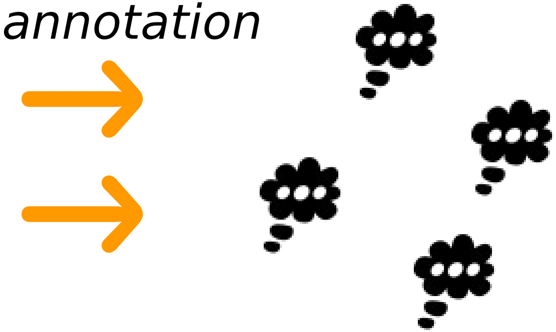
# Bibliographic Data

*Coauthorship edges between Papers*



*Concepts*

*annotation*



# Problem Statement

## Learning Concept Representations

**Given:**

- a graph (V, E)
- V consists of paper nodes P and concept nodes C
- E consists of co-authorship and annotation edges
- Papers P have textual features (e.g. their title)
- Concepts C have no features

**Desired output:** *Meaningful* and *useful* vector representations for concepts C

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Induced similarity corresponds to human judgments

useful for downstream tasks

# Transductive vs Inductive Learning

**Transductive Learning**

- Look-up table for node representations
- Need further training whenever new nodes/edges appear
- Approaches: DeepWalk (Perozzi et al., KDD 2014), node2vec (Grover & Lescovec, SIGKDD 2016), TransE, (Bordes et al., NeurIPS 2013), … (many more)

**Inductive Learning**

Valuable for dynamic graphs

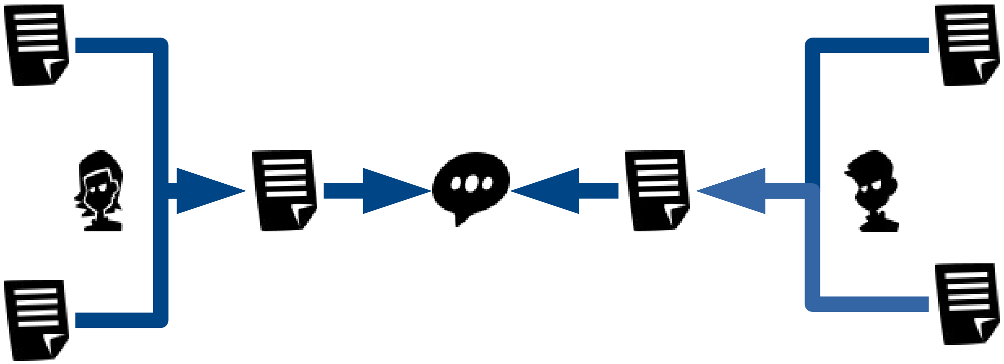
- Node representations solely induced by node features
- *Capable of dealing with unseen nodes/edges without retraining*
- Approaches: GCN (Kipf & Welling, ICLR 2017), GraphSAGE (Hamilton et al., NeurIPS 2017), … (many more)

# Graph Convolution (Kipf & Welling 2017)

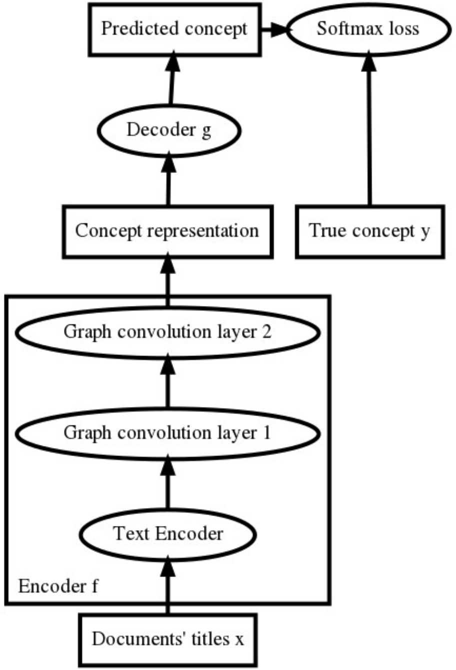
$$h_i^{(l+1)} = \sigma\left(\sum_{j \in \mathcal{N}(i)} \frac{1}{c_{ij}} W^{(l)} h_j^{(l)} + b^{(l)}\right)$$

**From layer l to l+1**

1) Transform via parameters W, b
2) Aggregate neighbor representations
3) Nonlinear activation



# Reconstruction-based Training



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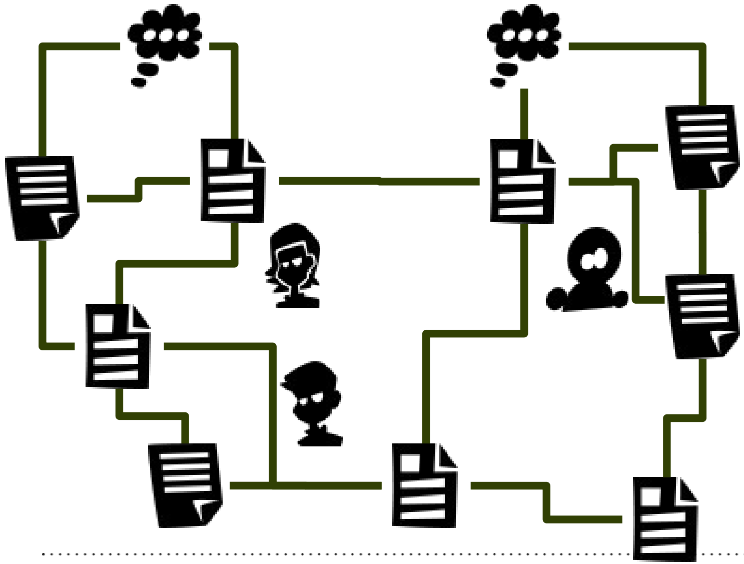

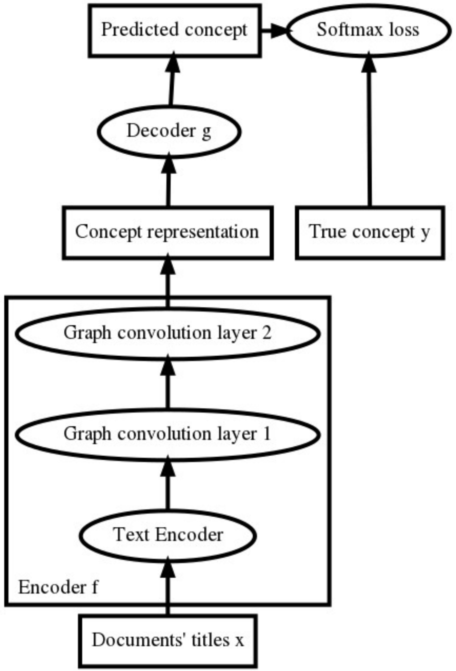

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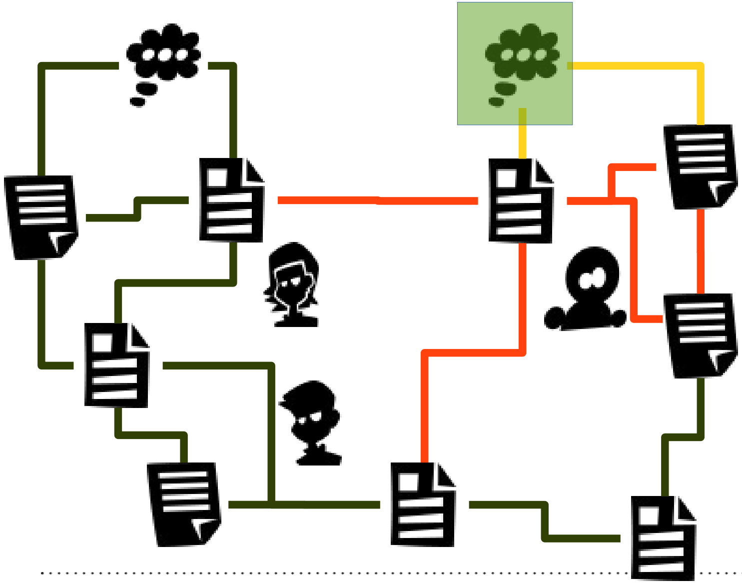

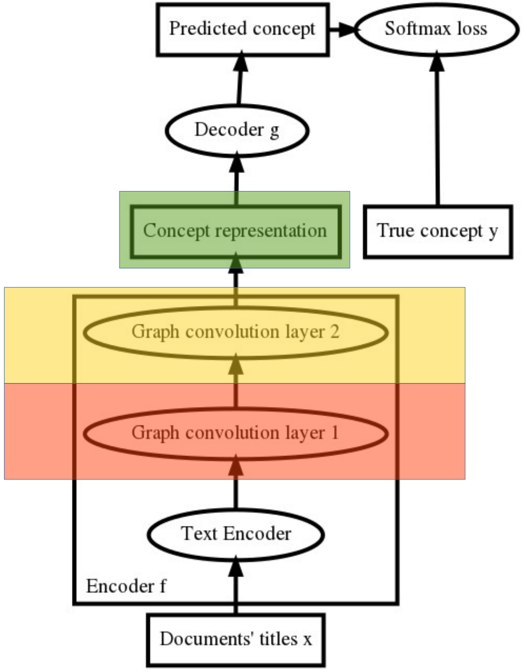

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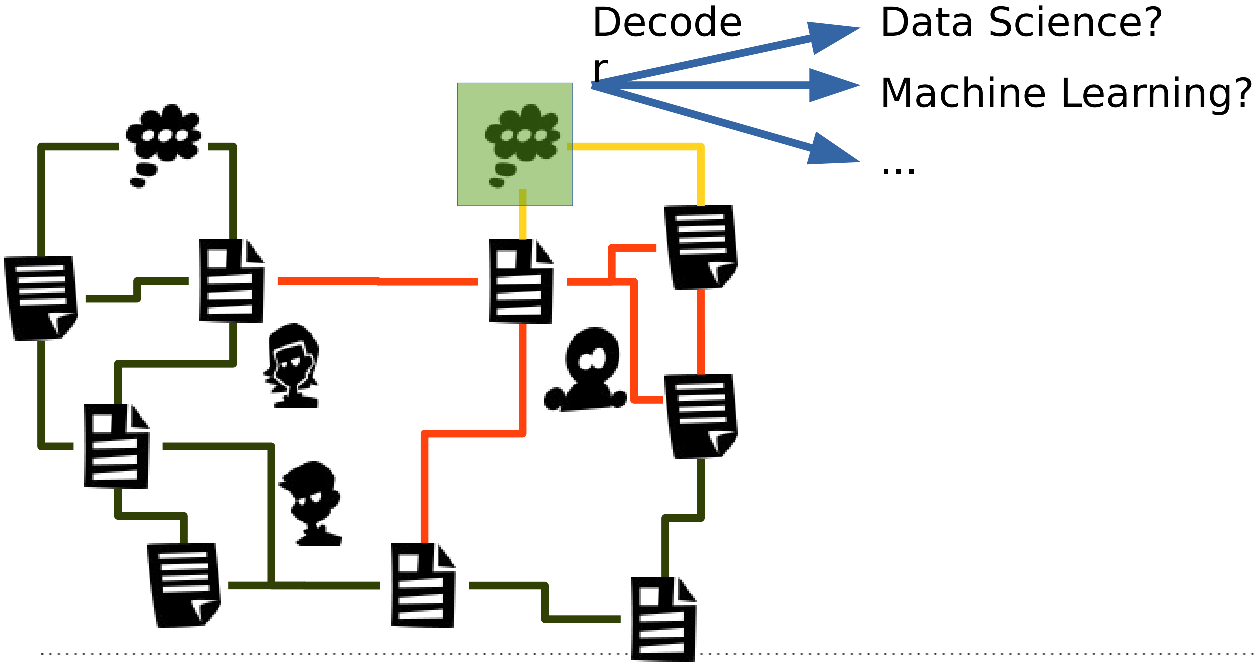
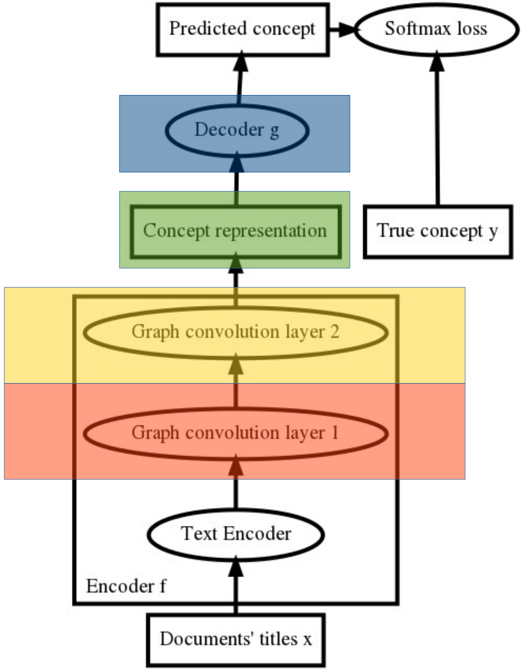


# Experiments

- 2.1M English research papers from economics and business economics domain
- 5,688 concepts from Standardthesaurus Wirtschaft (http://zbw.eu/stw)
- Quantitative Evaluation
  - Subset of 3,113 concepts, which belong to only one of 7 subthesauri
  - Downstream tasks: clustering and classification
- Qualitative Evaluation:
  - Nearest concept queries
  - Linear operations in latent space

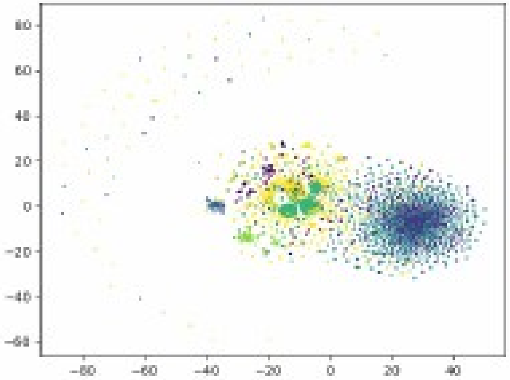
# Results: Clustering with k-Means

| Model | S | CH | H | C | V | ARI |
|---|---|---|---|---|---|---|
| Random | 0.0062 | 13.83 | 0.0032 | 0.0030 | 0.0031 | 0.0000 |
| Random (L2) | 0.0062 | 13.92 | 0.0033 | 0.0031 | 0.0032 | 0.0001 |
| LSA | -0.0207 | 53.45 | 0.0030 | 0.0071 | 0.0042 | -0.0041 |
| LSA (L2) | **0.1284** | 96.44 | 0.0022 | 0.0025 | 0.0023 | -0.0009 |
| DeepWalk | 0.0194 | 124.80 | 0.2165 | 0.2496 | 0.2318 | 0.1852 |
| DeepWalk (L2) | 0.0670 | 131.18 | **0.2930** | **0.2810** | **0.2869** | **0.1981** |
| GCN | 0.0667 | 171.13 | 0.1845 | 0.1761 | 0.1802 | 0.1178 |
| GCN (L2) | 0.0823 | **193.64** | 0.1992 | 0.1891 | 0.1940 | 0.1423 |

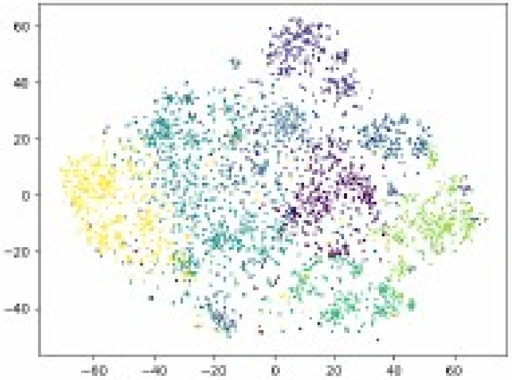


Avg. of 100 k-Means runs

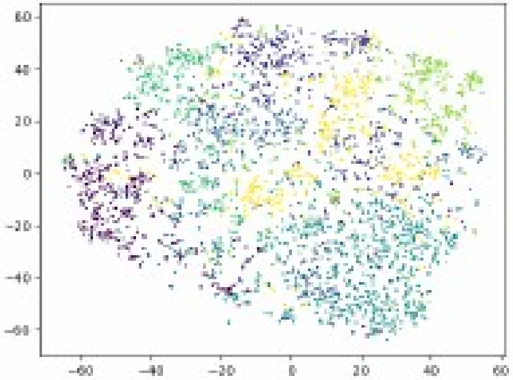
# t-SNE Visualization




LSA




DeepWalk




GCN

# Results: Classification with linear SVMs

| Model | Norm | Accuracy |
|---|---|---:|
| LSA | None | 0.2345 (SD: 0.00) |
| LSA | Unit L2 | 0.2181 (SD: 0.02) |
| DeepWalk | None | 0.6625 (SD: 0.04) |
| DeepWalk | Unit L2 | 0.6708 (SD: 0.03) |
| GCN | None | **0.6813 (SD: 0.03)** |
| GCN | Unit L2 | 0.6496 (SD: 0.03) |

Avg. and SD of 10-fold CV

# Nearest Concept Queries 1/4

Textual descriptions are never shown to the models

Query: *Economic growth*

| LSA | DeepWalk | GCN |
|---|---|---|
| Management information system | Economic adjustment | Stages of growth model |
| Tobacco | Economic policy | Growth policy |
| Internet Usage | Growth policy | Resource wealth |
| Eurobond | Economic development | Kuznets curve |
| Automobile engine | Economic reform | Export-led growth |

# Nearest Concept Queries 2/4

Query: *Tax*

| LSA | DeepWalk | GCN |
|---|---|---|
| Rehabilitation hospital | Fiscal administration | Tax policy |
| Abortion | Tax system | Tax system |
| Biodiversity | Tax policy | Tax reform |
| Financial statement analysis | Sales tax | Taxation procedure |
| Association agreement | Tax reform | Tax burden |

# Nearest Concept Queries 3/4

Query: *Germany*

| LSA | DeepWalk | GCN |
|---|---|---|
| Debt crisis | Italy | East Germany |
| Mesoeconomics | France | Austria |
| Population policy | Comparison | West Germany |
| Complaint management | Netherlands | Lower Saxony |
| Unemployment theory | Austria | Western Europe |

# Nearest Concept Queries 4/4

Query: *Vehicle*

| LSA | DeepWalk | GCN |
|---|---|---|
| Pigouvian tax | Transport research | Sustainable mobility |
| Cargo shipping | Transport economics | Passenger transport |
| Cyclical unemployment | Waste treatment | Freight transport |
| Wage subsidy | Battery | Major electrical appliances |
| Financial Statement analysis | Microsystems | Traffic |

# Linear relationship queries 1/2

Query: $Tax + Theory$

| LSA | DeepWalk | GCN |
|---|---|---|
| Tax | Tax | Theory of taxation |
| Theory | Theory of taxation | Theory |
| Financial statement analysis | Tax system | Second best |
| Nursing profession | Capital income | Optimal taxation |
| Rehabilitation hospital | Public economics | Welfare economics |

# Linear relationship queries 2/2

Query: *Economic growth* + *Theory*

| LSA | DeepWalk | GCN |
|---|---|---|
| Economic growth | Economic growth | Growth theory |
| Banking services | Growth theory | Neoclassical growth model |
| Producer cooperative | Economic model | Unbalanced growth |
| Licence | Theory | Balanced growth |
| Laboratory | Endogenous growth model | Functional income distribution |

# Conclusion & Limitations

- DeepWalk works well despite using only structural features (confirms orig. paper)
- GCNs can be used for **inductive** representation learning
- Learned GCN representations are comparably meaningful & useful as DeepWalk‘s
- **Limitations:**
    - No ground truth for pairwise concept similarity
    - Only one dataset, but large-scale!

# Next steps

- Add more structure (concept hierarchy, journals, institutions, ...)
- Use publication years for truly dynamic research analyses
- Create a ground truth for pairwise concept similarity


**Github:** lgalke/INFORMATIK2019-concept-representation-learning

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- Icons used in this presentation: https://mariodelvalle.github.io/CaptainIconWeb/ [CC BY-SA]