

Graph Learning

Topic Preview

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Microsoft



Research

Graph Learning at **OSDI/ATC '21**

Two exciting sessions on graphs / learning on graphs

- **ATC: Wednesday July 14**
 - **Track 2: Searching for Tracks: Graphs**
 - From 10:30am to 12:00noon
- **OSDI: Friday July 16**
 - **Graph Embeddings and Neural Networks**
 - From 10:15am to 11:30am

All the times listed are in **Pacific Daylight Time (PDT)**

Graph Learning

=

Machine Learning

+

Graph-structured Inputs

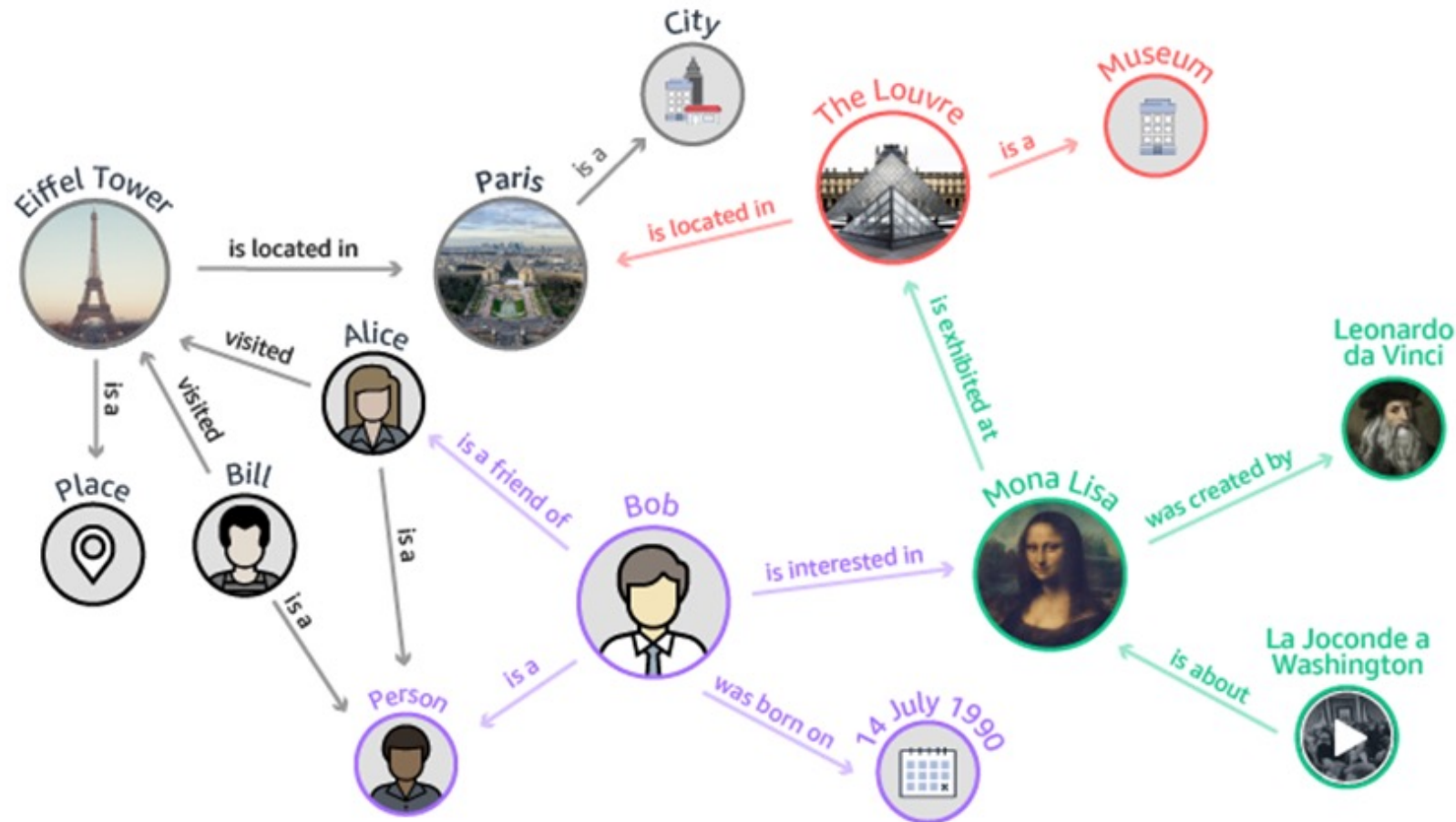
Why Learn on **Graphs**?

Many real-world datasets are graphs!



Why Learn on **Graphs**?

Many real-world datasets are graphs!



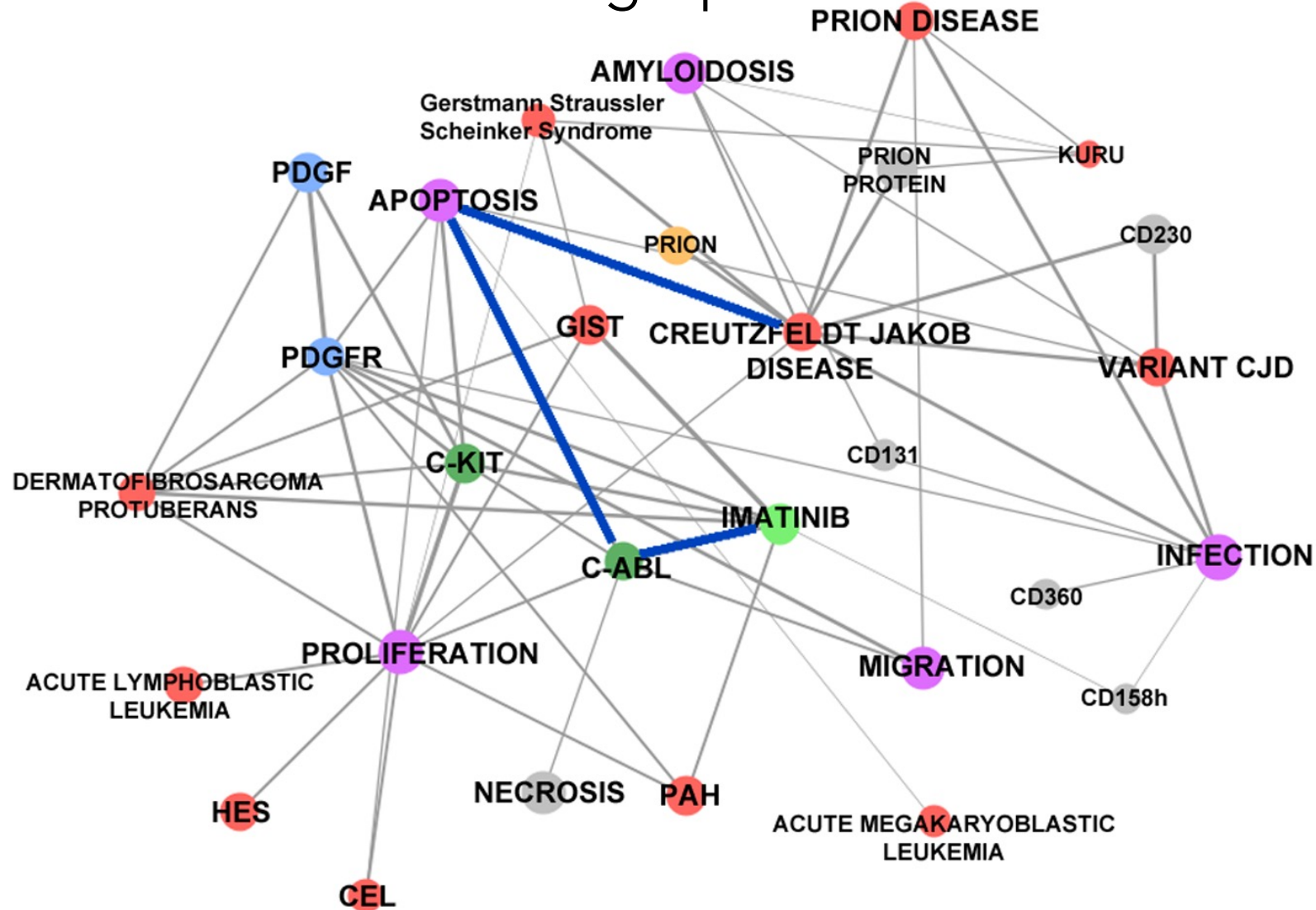
Why Learn on **Graphs**?

Many real-world datasets are graphs!



Why Learn on **Graphs**?

Many real-world datasets are graphs!



Graphs can capture the
rich & complex relationships
in the data in these domains

Graph learning can provide
significant performance boost!

Why Learn on **Graphs**?

Significant impact in a **wide variety** of domains

Chemistry

Discover chemical structures

Vision

Zero shot classification

NLP

Text classification, machine translation

Biology

Disease classification, side effect prediction

Physics

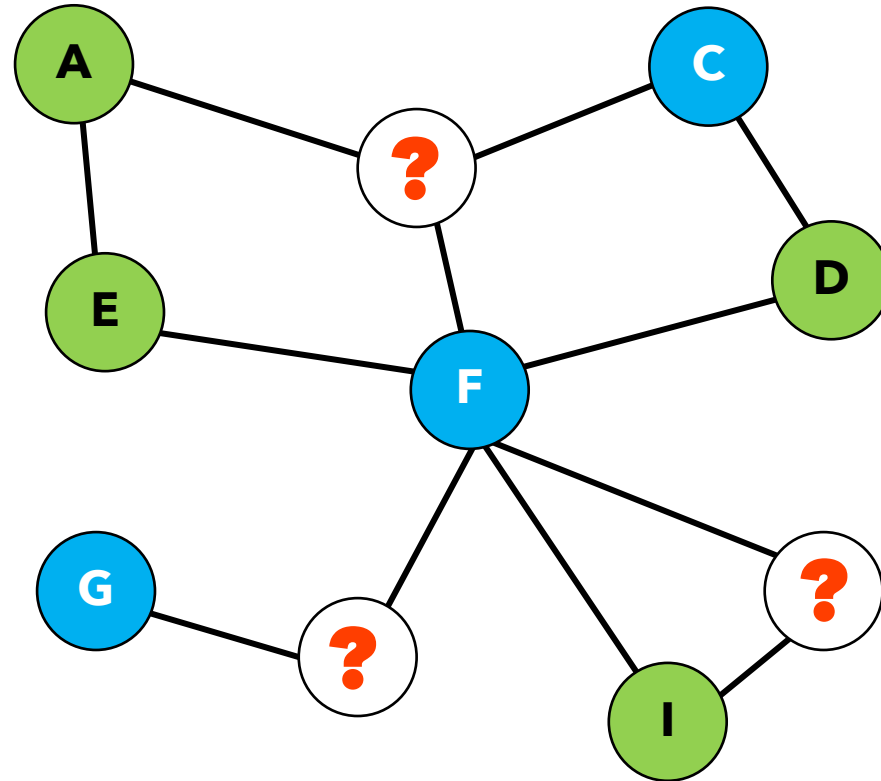
Particle simulation, interaction networks

Many others

Program synthesis, knowledge graphs

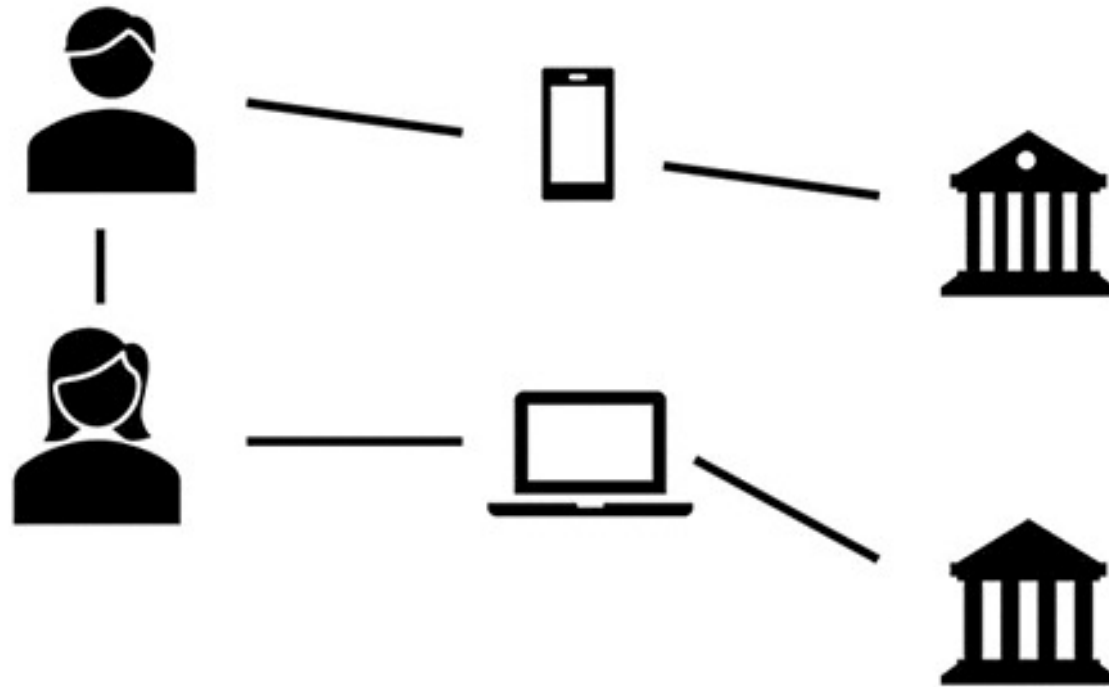
Graph Learning: **Node Classification**

Predict labels for **new** or previously **unknown** nodes



Input Graph

Graph Learning: **Node Classification**



Graph Learning: **Node Classification**

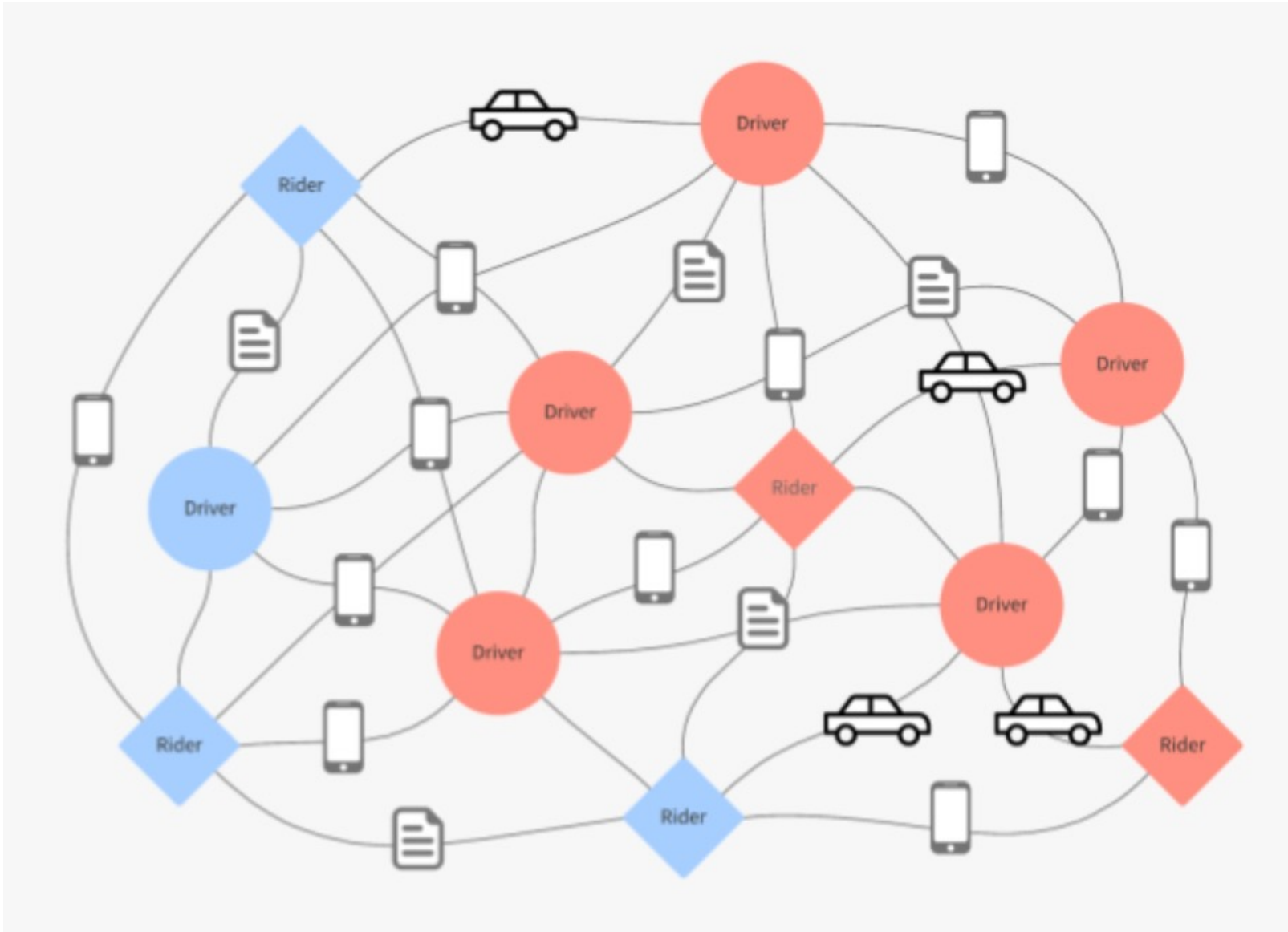
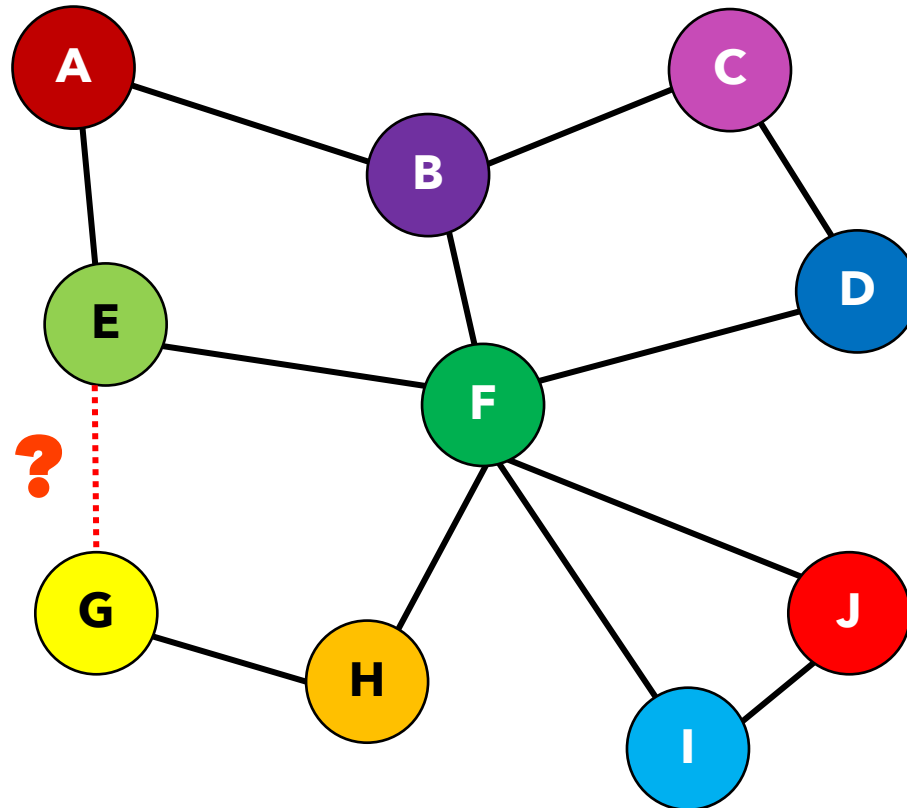


Image courtesy: Uber

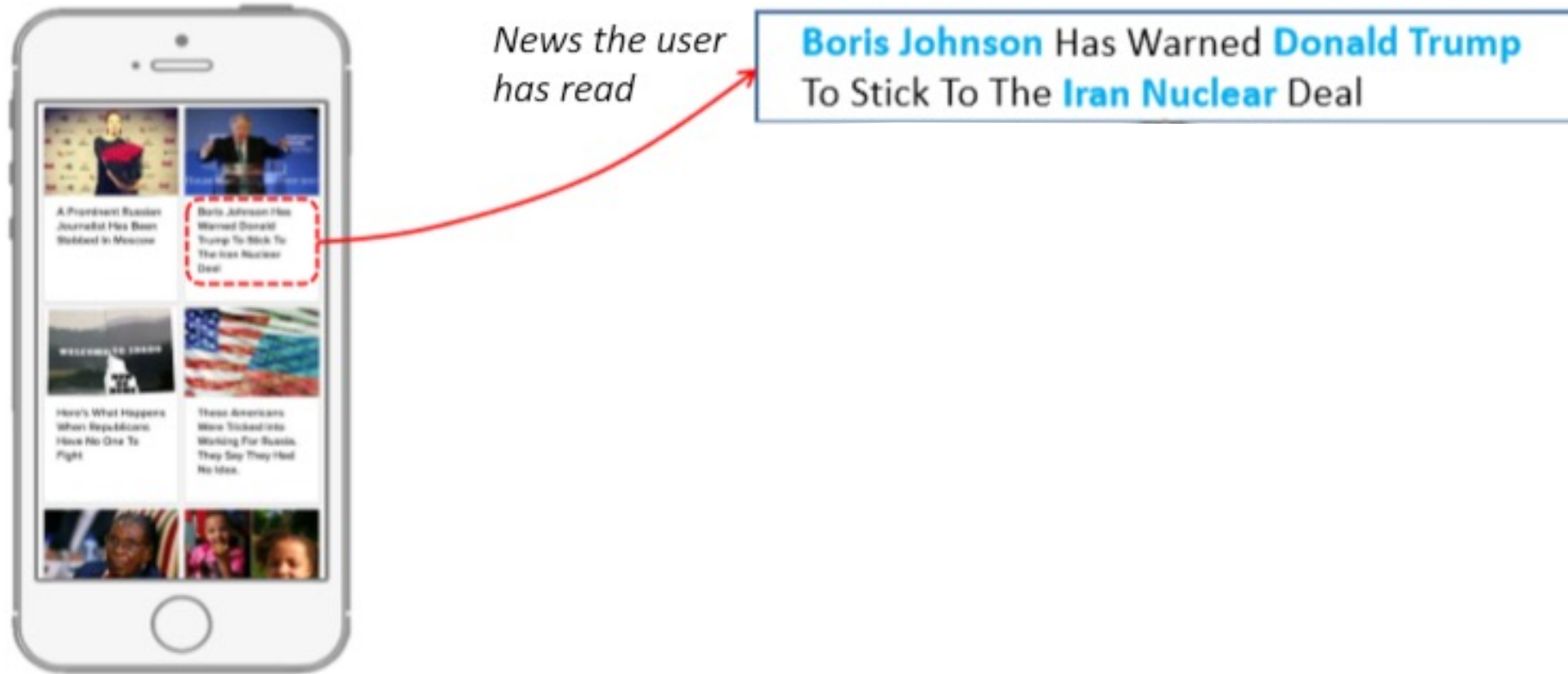
Graph Learning: **Edge Prediction**

Predict existence of **link** between existing nodes

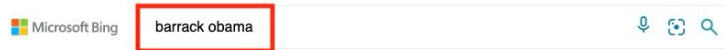


Input Graph

Graph Learning: **Edge Prediction**



Graph Learning: Edge Prediction



Including results for **barrack obama**.
Do you want results only for **barrack obama**?

Barack Obama - Wikipedia
https://en.wikipedia.org/wiki/Barack_Obama

Barack Hussein Obama II is an American politician and attorney who served as the 44th president of the United States from 2009 to 2017. A member of the Democratic Party, Obama was the first African-American president of the United States. He previously served as a U.S. senator from Illinois from 2005 to 2008 and as an Illinois state senator from 1997 to 2004. Obama was born in ... +



< **Early life and career** Presidential campaigns Presidency (2009–2017) >

Obama was born on August 4, 1961, at Kapiolani Medical Center for Women and Children in Honolulu, Hawaii. He is the only president born outside the contiguous 48 states. He was born to an American mother of European descent and an African father. His mother, Ann Dunham (1942–1995), was born in Wichita, Kansas; she was mostly of English descent, with some German... +

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News about Barack Obama
<bing.com/news>



Sasha Obama's Close Friend Maisy Biden 'Was Like the LeBron' of Their School League, Barack Says

Barack Obama told Dax Shepard on the latest episode of his podcast that his younger daughter ...

YAHOO!News · 7h



Barack Obama stresses protecting voting rights to avoid 'further' ...

CNN on MSN.com · 4d



Historians rank Trump near the bottom of U.S. presidents as Obama rises into ...

USA Today on MSN... · 2d



Celtics' Jaylen Brown meets with former President Barack Obama

Boston.com · 3d

See more news about Barack Obama

Opinions



Obama and the Broken Nation He Made Come Of Age



Barack Obama
44th President of the United States



American politician and attorney who served as the 44th president of the United States from 2009 to 2017. A member of the Democratic Party, Obama was the first African-American president of the United States.

barackobama.com



SPOUSE
Michelle Obama
Since 1992

BORN
Aug 04, 1961
Honolulu, HI

AGE
59
HEIGHT
6' 1"
1.85 m

You can't let your failures define you.
You have to let your failures teach you.

Obama was the **first** sitting U. S. president to speak to the British Parliament.



Time Magazine named him **"Person of the Year"** for 2008. He won this title again in 2012.



Obama's last full day in office, he announced 330 commutations for nonviolent drug offenders.

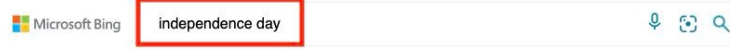
He led a **rather ascetic life** and read works of literature and philosophy by William Shakespeare, Friedrich Nietzsche, Toni Morrison, and others.

1990

Obama was elected the first African American editor of the Harvard Law Review.

1996

Obama was elected to the Illinois Senate.



Independence Day (United States) - Wikipedia
[https://en.wikipedia.org/wiki/Independence_Day_\(United_States\)](https://en.wikipedia.org/wiki/Independence_Day_(United_States))

Independence Day (colloquially the Fourth of July or **July 4**) is a federal holiday in the United States commemorating the Declaration of Independence of the United States, on **July 4, 1776**. The Continental Congress declared that the thirteen American colonies were no longer subject (and subordinate) to the monarch of Britain, King George III, and were now united, free, and ind... +



< **Background** Observation Customs Celebration gallery N >

During the American Revolution, the legal separation of the thirteen colonies from Great Britain in 1776 actually occurred on July 2, when the Second Continental Congress voted to approve a resolution of independence that had been proposed in June by Richard Henry Lee of Virginia declaring the United States independent from Great Britain's rule. After voting for indepen... +

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News about Independence Day
<bing.com/news>



Independence Day

See where the stars of the hit disaster film are, 25 years after the film's July 3, 1996 premiere The ...

People · 4h



"You Can't Actually Blow Up the White House": An Oral History of ...

The Hollywood Repo... · 5h



25 thoughts I had while watching 'Independence Day' for the first time

Air Force Times · 2h



Hot Independence Day Weekend Ahead

StarTribune · 4h

See more news about Independence Day

Images of Independence Day
<bing.com/images>



Fourth of July, 2021



A Capitol Fourth (from Washington, DC—watch on PBS)

Macy's 4th of July Fireworks (from New York City—watch on NBC)

Biden plans 1,000-strong Fourth of July gathering at White House to mark Covid progress (Yahoo News)

Fourth of July BBQ recipes (Bing)

America quiz (Bing)



A federal holiday in the United States commemorating the Declaration of Independence of the United States, on July 4, 1776.



DATE
Celebrated on July 4

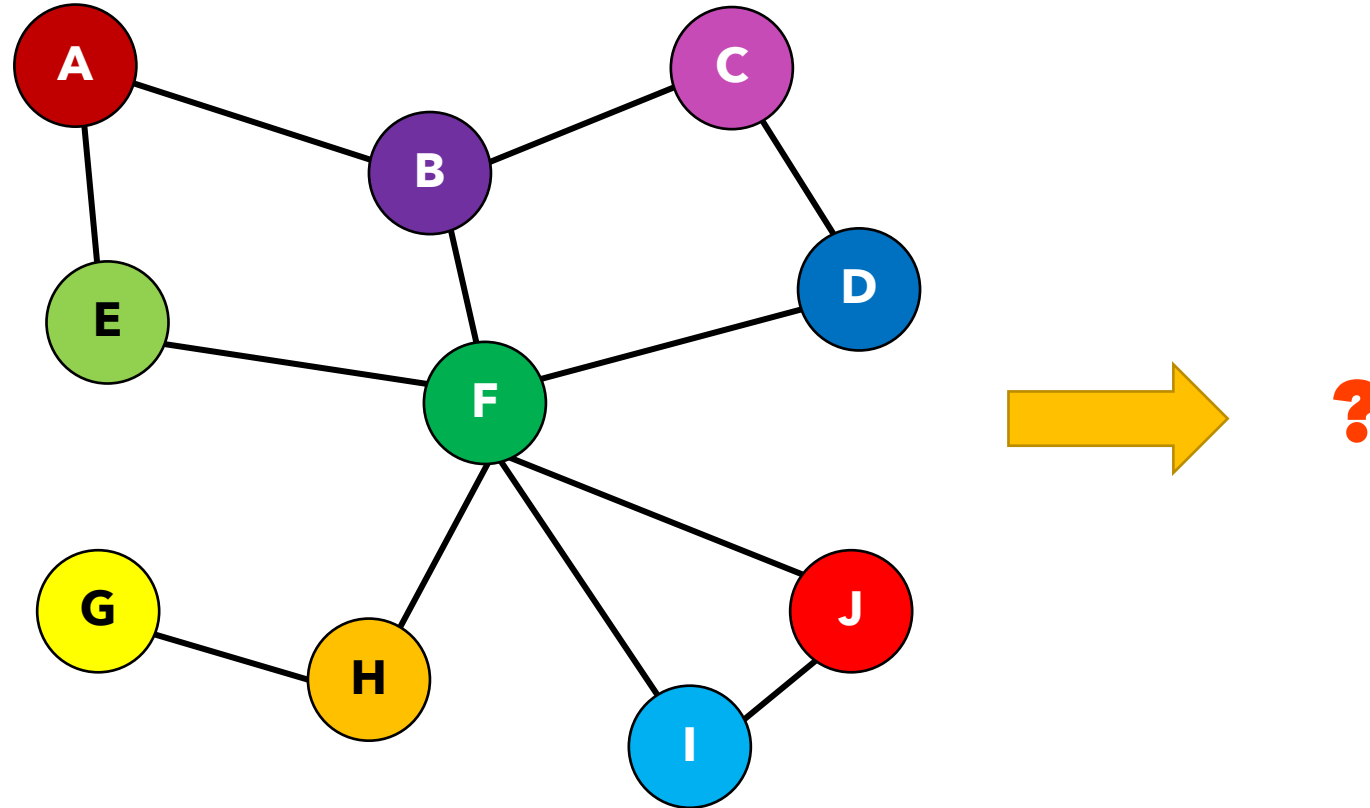
Every 4th of July **the Liberty Bell** in Philadelphia is tapped – although not actually rung – 13 times in honour of the original 13 American colonies.

In 1938, Congress changed Independence Day to a **paid federal holiday**.



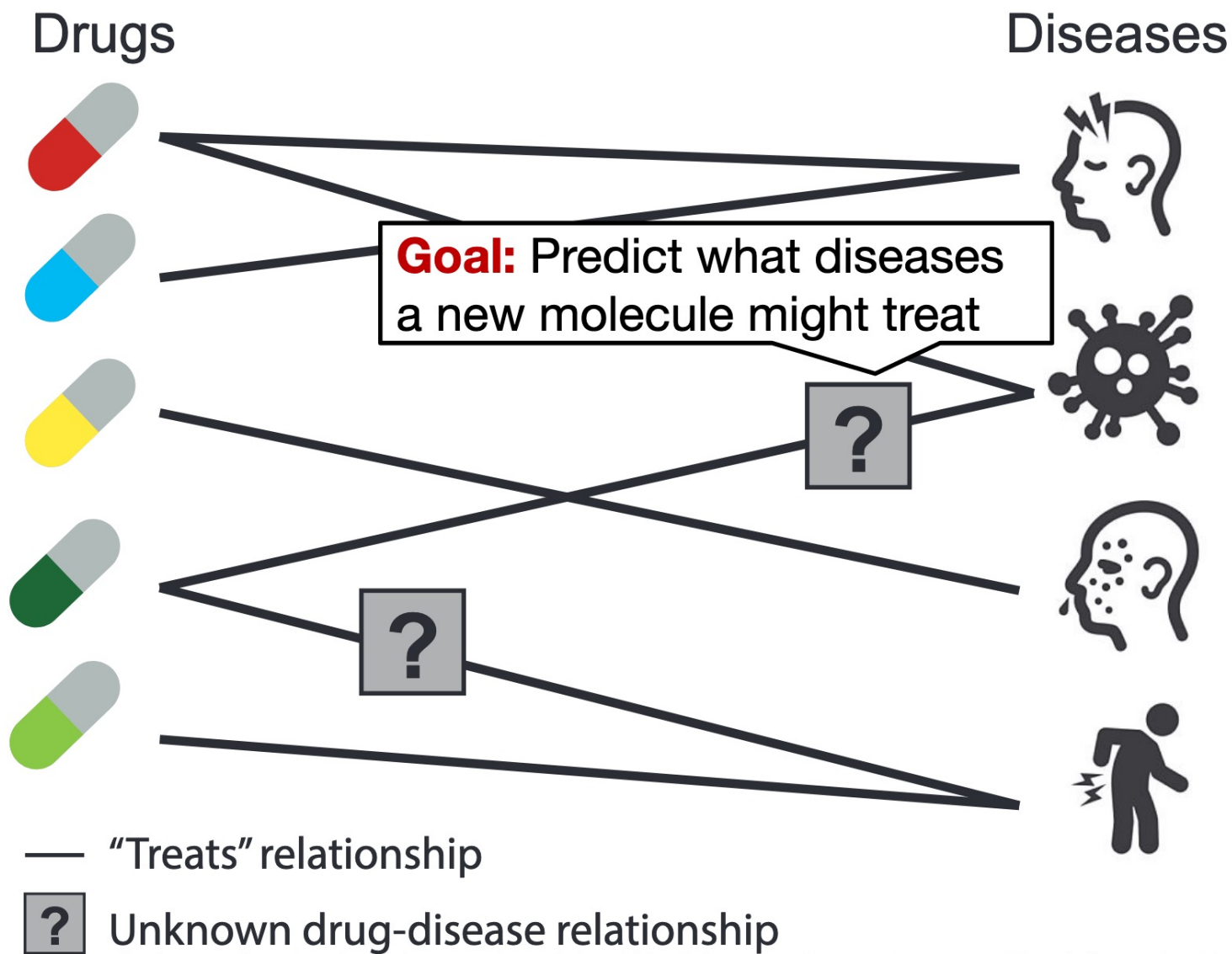
Graph Learning: **Graph Classification**

Predict label for a **graph** or **subgraph**



Input Graph

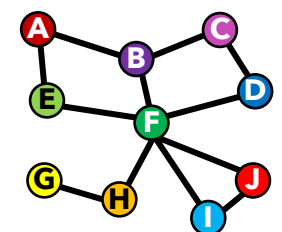
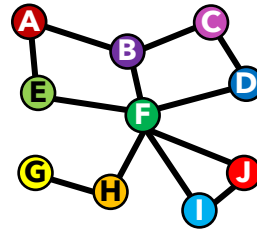
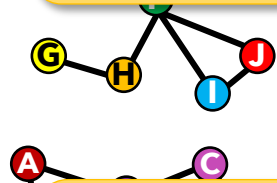
Graph **Classification**



Graph Learning

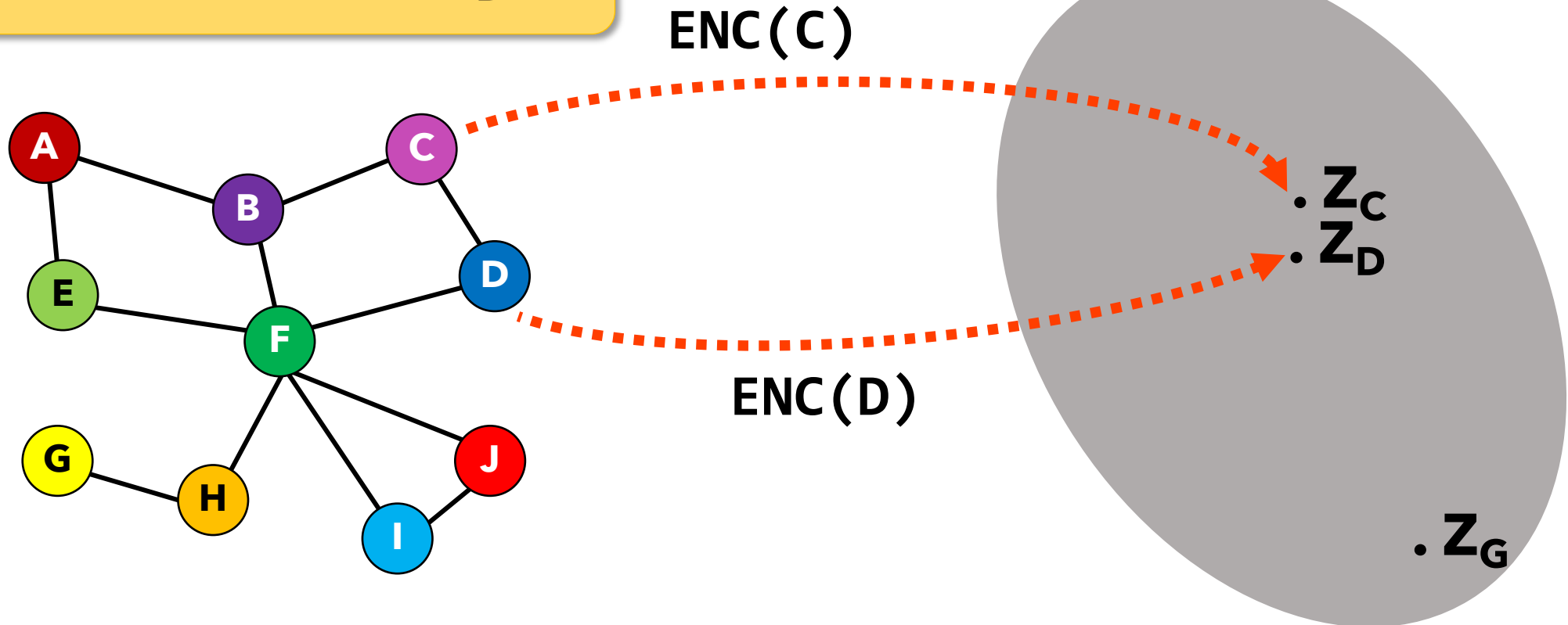
Graph Representation Learning

Task agnostic feature (embedding) learning



Graph **Embeddings**

$$\text{similarity}(C, D) \cong Z_D^T Z_C$$



Input Graph

Embedding Space

Shallow **Encoding**

Encoder: simple **embedding lookup**

embedding vector for a
specific node

embedding
matrix

Goal: Maximize $\mathbf{Z}_D^T \mathbf{Z}_C$ for similar pairs (C,D)

$\mathbf{Z} =$

dimension/size
of embeddings

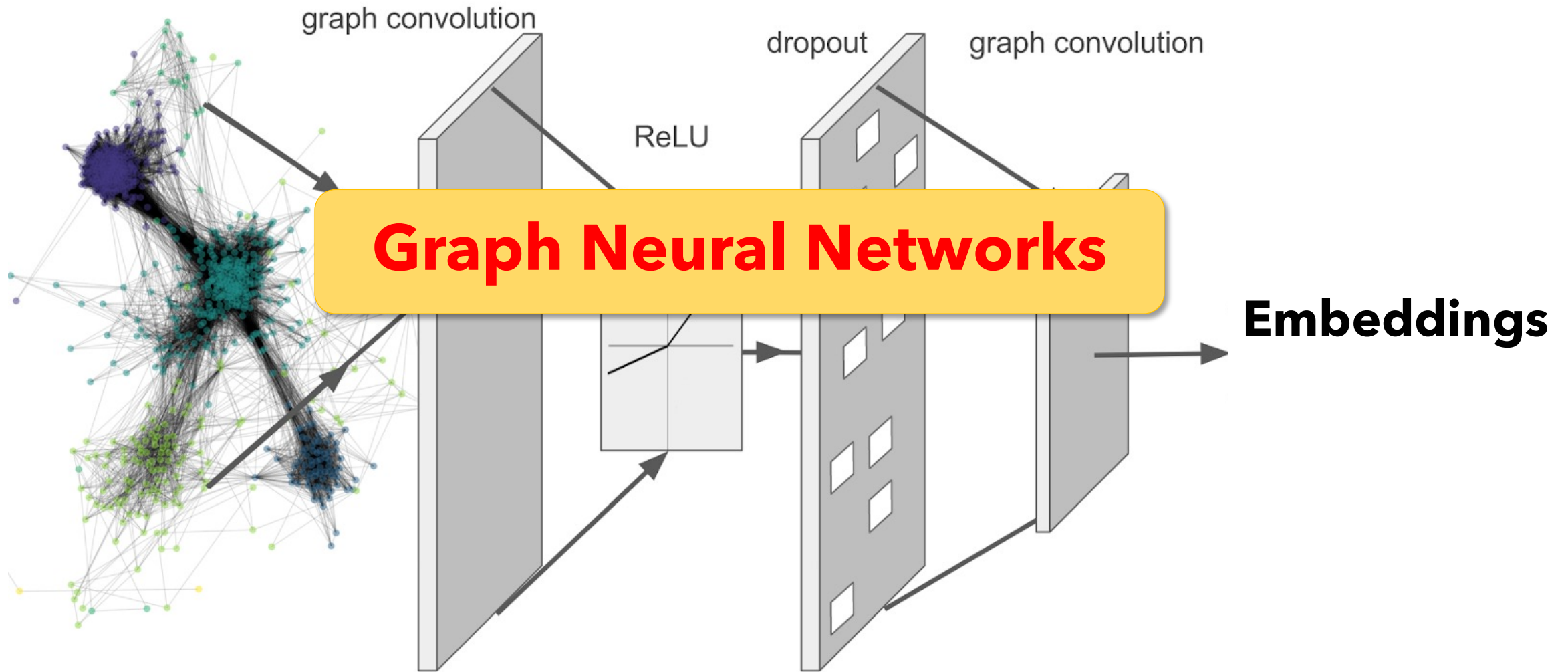
one column per node

Shallow **Encoding**

- Simple approach
 - **Many proposals:** DeepWalk, node2vec, DistMult, ComplEx, ...
 - Techniques differ in how **similarity** is defined
- Every node gets a **unique** embedding vector
 - Nothing shared across nodes
- **Transductive:** cannot generate embeddings for nodes not present at training
- Does not incorporate node features

Deep **Encoding**

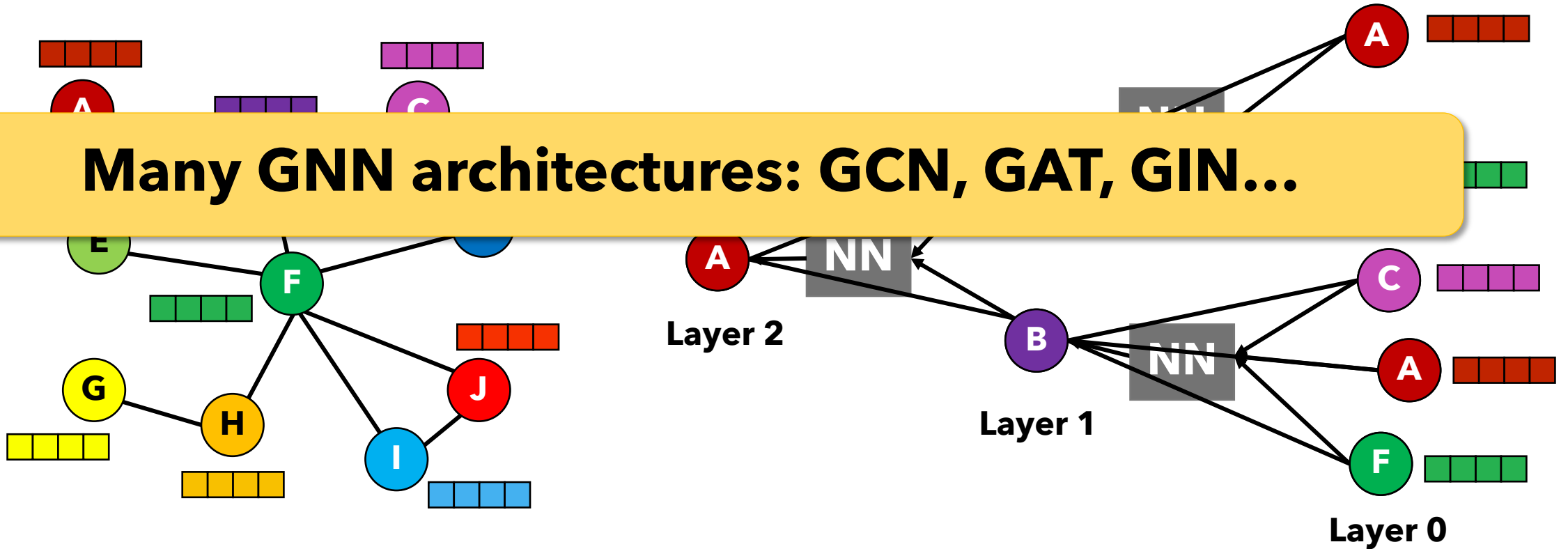
Encoder: **multiple** layers of non-linear **transformations** on the graph



Deep **Encoding**

Graph Structure: What (to propagate?)

Neural Network: How (information is transformed)



Input Graph

2 2-hop neighborhood of A A

Deep **Encoding**

$$h_v^0 = x_v$$

Initial 0-th layer embeddings = node features

$$h_v^{(l+1)} = \sigma \left(\overset{\text{Trainable weight matrices}}{\mathbf{W}_l} \sum_{u \in N(v)} \frac{h_u^{(l)}}{|N(v)|} + \overset{\text{Embedding of } v \text{ at layer } l}{\mathbf{B}_l} h_v^{(l)} \right), \forall l \in \{0, \dots, L-1\}$$

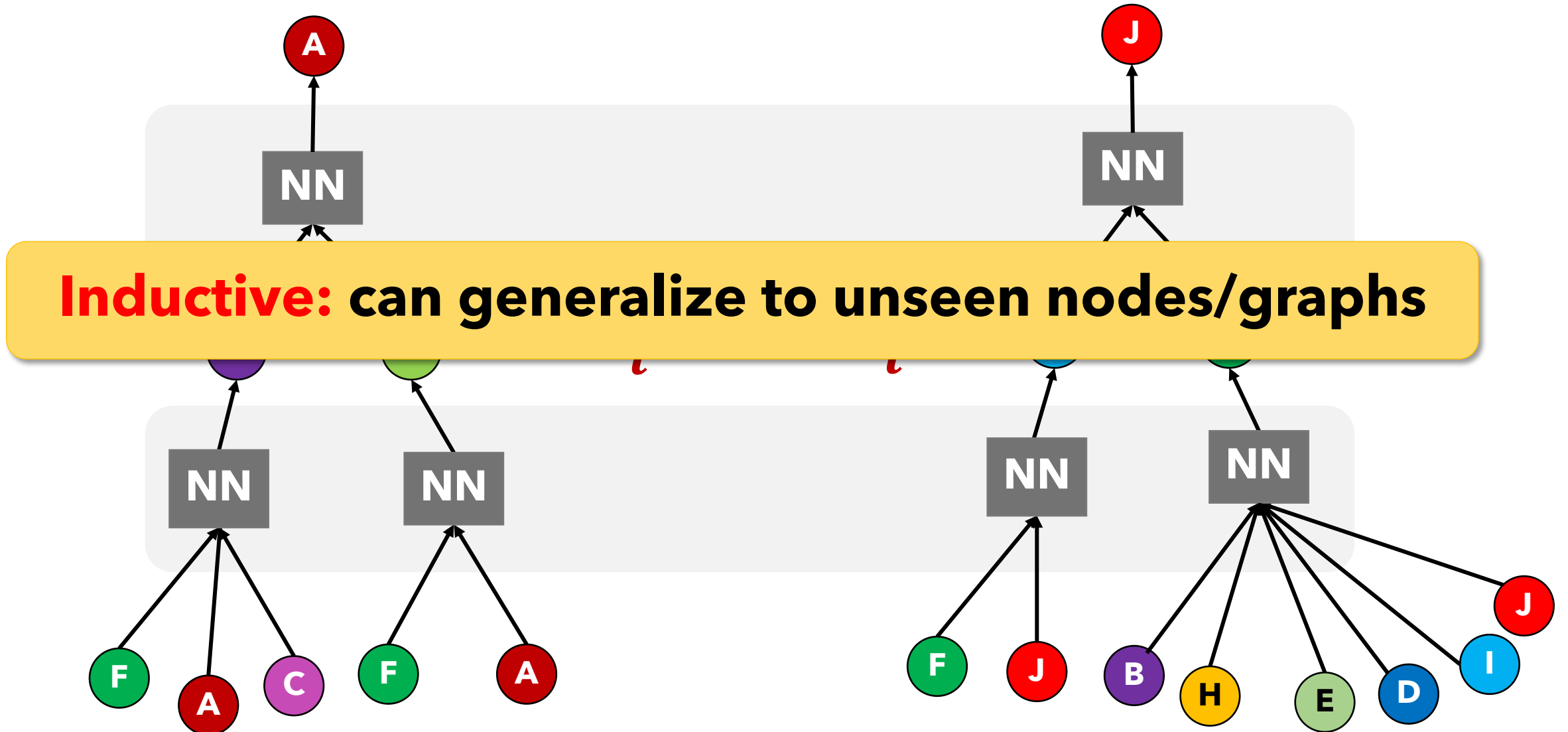
Non-linearity
(e.g., ReLU)

Average of neighbor's
previous layer embeddings

$$z_v = h_v^{(L)}$$

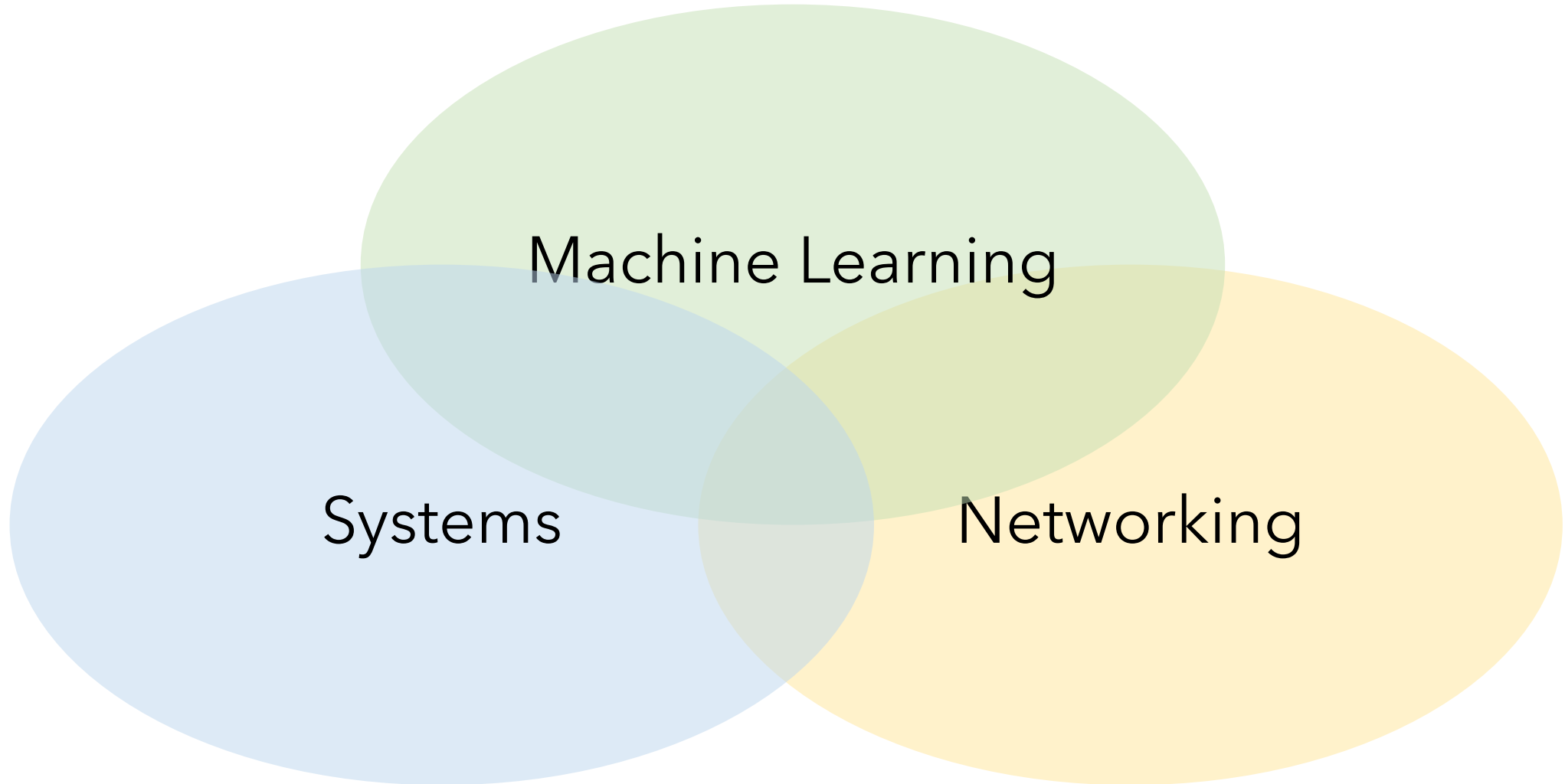
Embedding after L layers

Deep **Encoding**



Graph Learning **Research**

Active area of research



Graph Learning: **Trends**

Large Graphs

Billions of nodes,
trillions of edges

Hundreds or
thousands of features

New Models

DistMult, ComplEx, GCN,
GAT, GIN, ...

More **sophisticated**,
complex architectures

Graph Learning: **Systems Challenges**

- **Scalability**

- How do we learn on **massive datasets**?
- How do we handle dynamicity?

- **Efficiency**

- Deep learning is **resource hungry**.
- How do improve resource utilization and reduce cost?

- **Security**

- Many domains have **sensitive data** (e.g., financial networks, healthcare)
- How do we ensure robustness?

Graph Learning @ ATC '21

Wednesday, July 14
Track 2: 10:30 am - 12 noon

Deep Encoders
Scalability
Data movement

Graph learning techniques **move** large amounts of **data from storage to host memory**, incurring significant latency and power usage

A **graph learning accelerator inside storage** can provide **an order of magnitude** speedup!

GLIST: Towards In-Storage Graph Learning

Cangyuan Li ^{1,2}, Ying Wang ^{1,2}, Cheng Liu ^{1,2}, Shengwen Liang ^{1,2}, Huawei Li ^{1,2,3}, Xiaowei Li ^{1,2}
SKLCA, Institute of Computing Technology, Chinese Academy of Sciences, Beijing, China ¹
University of Chinese Academy of Sciences, Beijing, China ²
Peng Cheng Laboratory, Shenzhen, China ³

Graph learning training needs **expensive GPUs** incurring high cost

Decomposing the training pipeline into fine-grained tasks allows training on a **combination of serverless threads and cheap CPUs faster than using GPUs!**

Dorylus: Affordable, Scalable, and Accurate GNN Training with Distributed CPU Servers and Serverless Threads

John Thorpe^{†♣} Yifan Qiao^{†♣} Jonathan Eyolfson[†] Shen Teng[†] Guanzhou Hu^{†‡} Zhihao Jia[§]
Jinliang Wei^{*} Keval Vora[♭] Ravi Netravali[♯] Miryung Kim[†] Guoqing Harry Xu[†]
UCLA[†] University of Wisconsin[†] CMU[§] Google Brain^{} Simon Fraser[♭] Princeton University[♯]*

Deep Encoders
Efficiency
Cost

**Friday, July 16
10:15 - 11:30 am PDT**

**Graph Learning @
OSDI '21**

One-size-fit-all optimizations do not work for emerging graph learning architectures, resulting in **poor performance**

Run-time that **adapts to the given workload and graph learning architecture** can improve performance **up to 4x!**

GNNAdvisor: An Adaptive and Efficient Runtime System for GNN Acceleration on GPUs

Yuke Wang, Boyuan Feng, Gushu Li, Shuangchen Li, Lei Deng, Yuan Xie, and Yufei Ding
University of California, Santa Barbara

Deep Encoders
Efficiency
Resource Utilization

Friday, July 16
10:15 - 11:30 am PDT

Graph Learning @
OSDI '21

Existing systems are bottlenecked by **data movement**, resulting in **inefficient** training and **poor performance**

Minimizing disk access by caching and data ordering and interleaving data movement with computation enables training of **billion edge graphs** on a **single** machine!

Marius: Learning Massive Graph Embeddings on a Single Machine

Jason Mohoney, Roger Waleffe, Henry Xu*, Theodoros Rekatsinas, Shivaram Venkataraman
University of Wisconsin-Madison

Shallow Encoders
Efficiency
Data movement

Friday, July 16
10:15 - 11:30 am PDT

Graph Learning @
OSDI '21

Existing distributed graph learning systems are bottlenecked by **communication**, resulting in **poor scalability**

A **hybrid training** approach can significantly **reduce** the need for communication, gracefully scale to **multiple billion edge graphs** and speed up training by up to **7x**!

P^3 : Distributed Deep Graph Learning at Scale

Swapnil Gandhi*
Microsoft Research

Anand Padmanabha Iyer
Microsoft Research

Deep Encoders
Scalability
Communication

Friday, July 16
10:15 - 11:30 am PDT

Graph Learning @
OSDI '21

Graph Learning **Summary**

- Emerging field with **active** research
 - Inter-disciplinary: machine learning, systems and networking
 - Tremendous impact in many domains
- Significant opportunities for systems researchers
 - Increasing interest in the industry
 - Many open systems challenges
- Do checkout the papers in this year's ATC and OSDI!

Acknowledgements: Content based on Prof. Jure Leskovec's CS224W course at Stanford and Prof. William Hamilton's "*Graph Representation Learning*" book.