Lecture#1: Introduction to Knowledge Graphs and their Real-World Applications

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Knowledge Discovery with Knowledge Graphs: From Structural Embeddings to Generative Reasoning (KnowKG), KDD 2026 Tutorial

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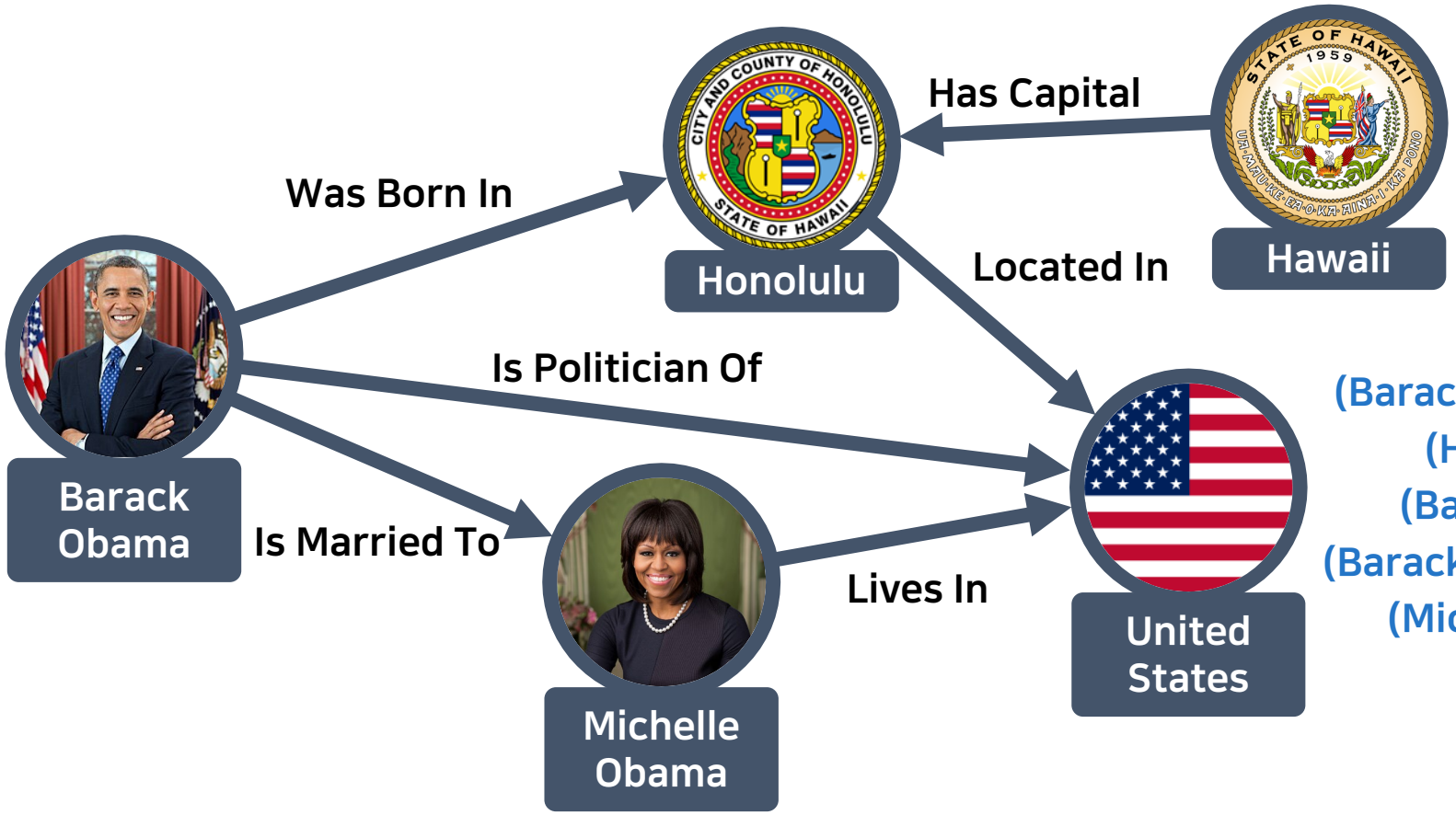
01 Knowledge Graphs

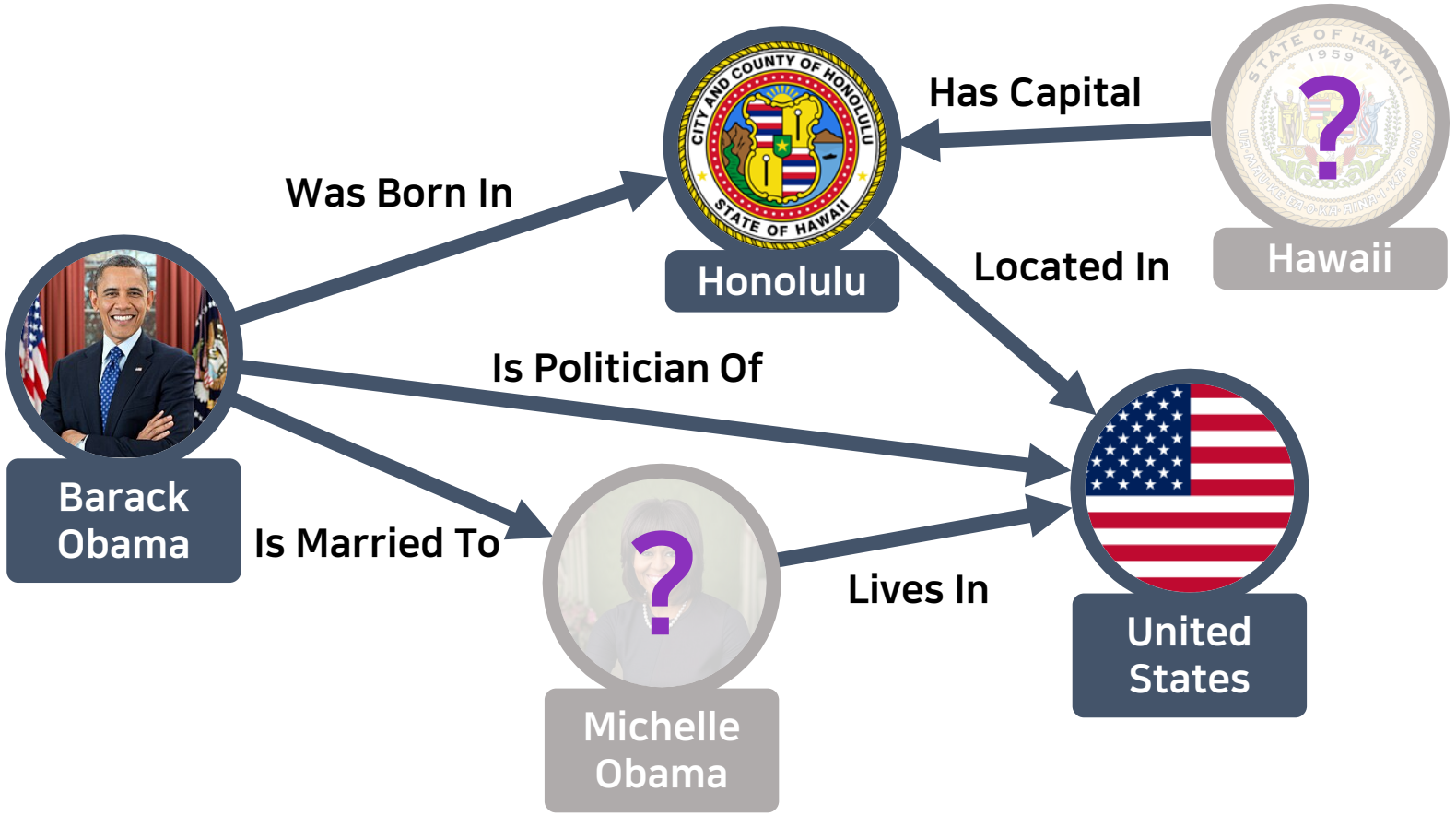
- Graphical Representation of Human Knowledge
  - Each fact is represented by a triplet (head entity, relation, tail entity)



(Barack Obama, is politician of, United States)
(Honolulu, located in, United States)
(Barack Obama, was born in, Honolulu)
(Barack Obama, is married to, Michelle Obama)
(Michelle Obama, lives in, United States)
(Hawaii, has capital, Honolulu)

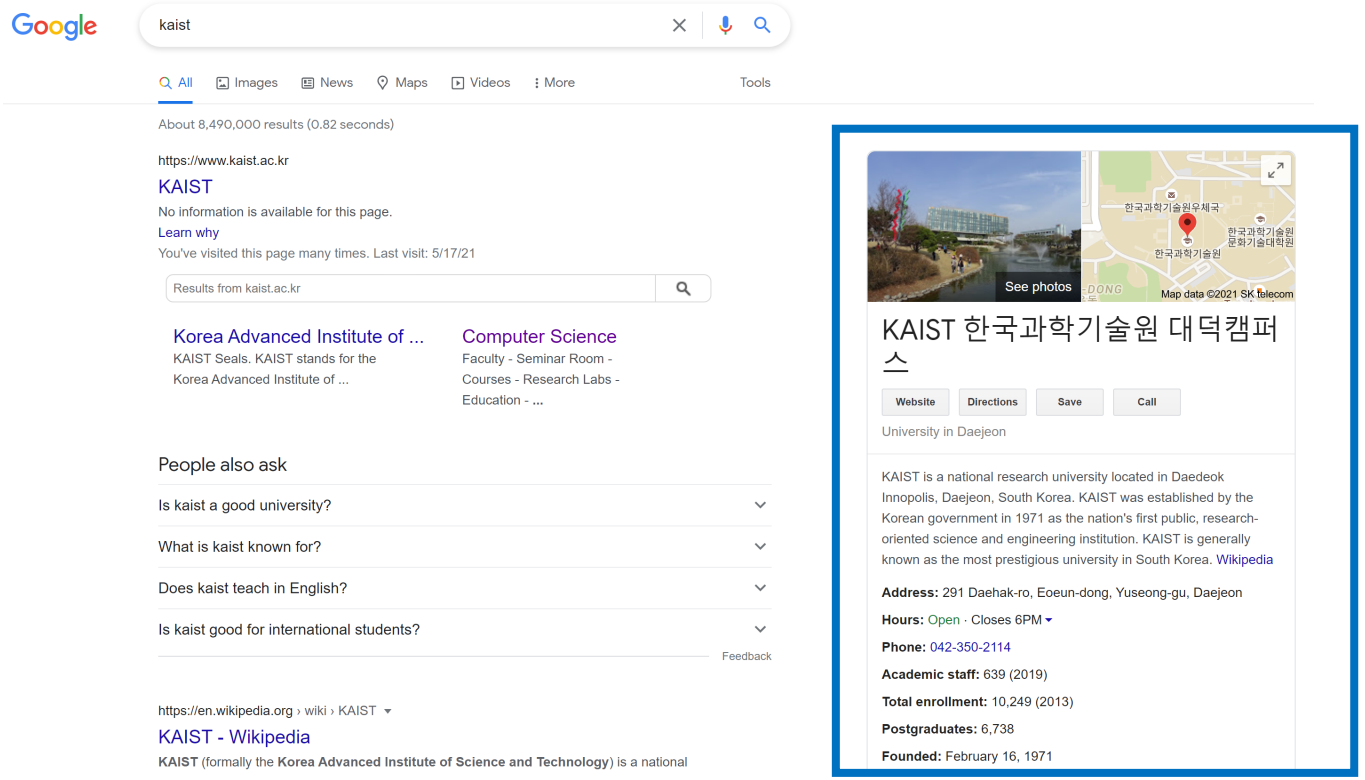
01 Knowledge Graph Completion

- Given a head entity and a relation, predict the tail entity.
- Given a tail entity and a relation, predict the head entity.



01 Examples of Knowledge Graphs

- Google’s search engine
  - An infobox next to the search results is created based on knowledge graphs



Infobox

01 Examples of Knowledge Graphs

- Google's search engine
  - Knowledge graphs are embedded in the search engine
- Microsoft's knowledge mining API
  - Used for the Bing search engine, QnA pair mining, processing LinkedIn data
- Meta's heterogeneous graphs
  - Analyze connections between people, events, ideas, and news
- Amazon's product networks
  - Utilize relationships between users, products, and their metadata
- IBM's knowledge graphs
  - Provide a framework to develop internal knowledge graphs
- Palantir's ontology
  - Build business-level ontology for real-world organization management

01 Examples of Knowledge Graphs in NVIDIA

- Use cases of knowledge graphs across various domains
  - Healthcare: Enable advanced decision making by mapping medical knowledge into graphs
  - Recommender Systems: Deliver personalized experiences by linking preferences with content
  - Finance: Detect frauds by analyzing transaction graphs and identifying hidden relationships

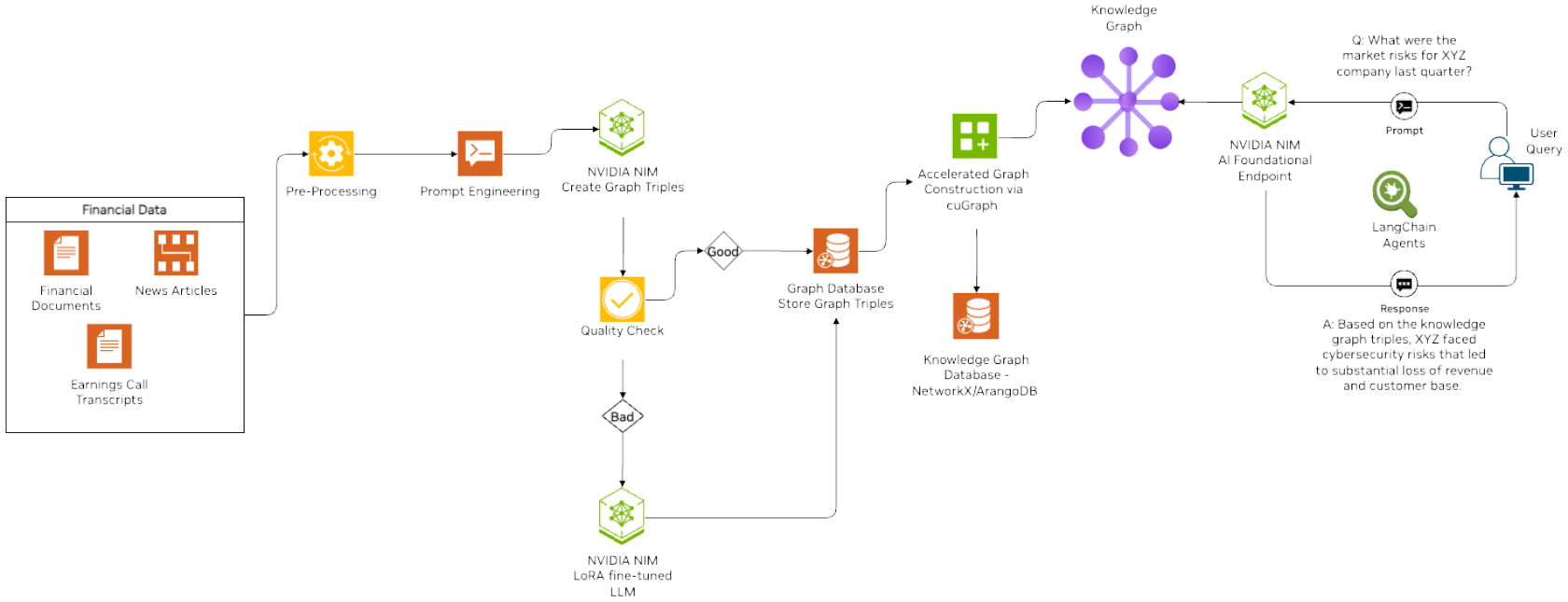


Image: https://developer.nvidia.com/blog/insights-techniques-and-evaluation-for-llm-driven-knowledge-graphs/

01 Examples of Knowledge Graphs in SAMSUNG

- Samsung Smartphones
  - Provide personalized user experiences using the Personal Data Engine powered by knowledge graphs

Image: https://www.oxfordsemantic.tech/blog

01 Examples of Knowledge Graphs in Palantir

- Construct ontology that integrates the data, logic, action, and security of the enterprise

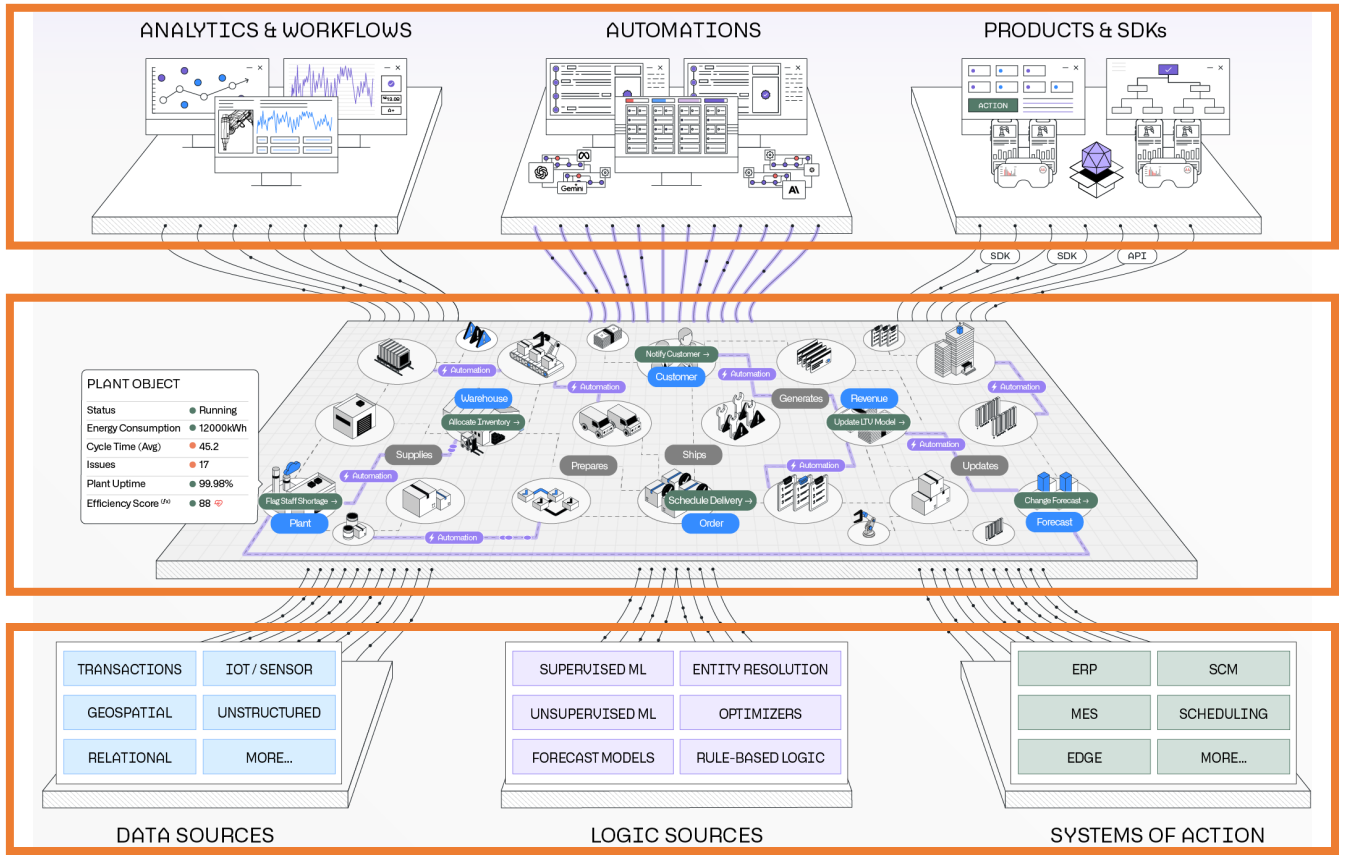
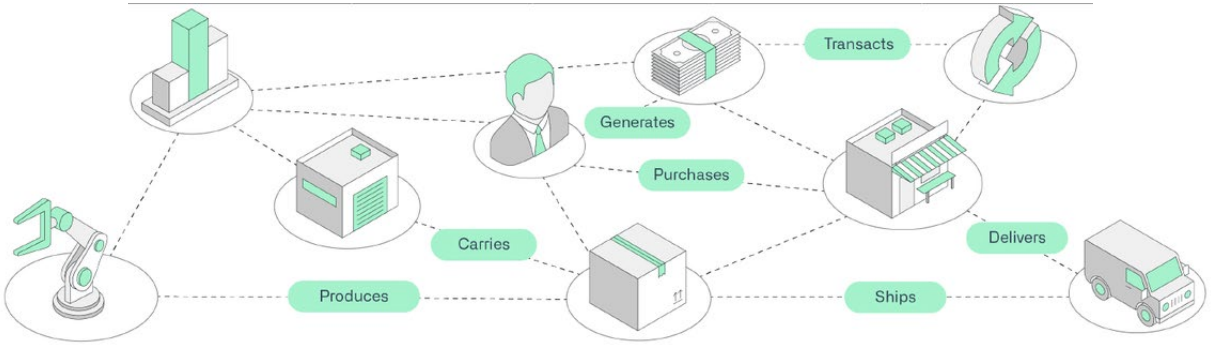


Image: https://www.palantir.com/docs/foundry/architecture-center/ontology-system

01 Examples of Knowledge Graphs in Palantir

- Palantir Ontology
  - Designed to represent the complex, interconnected decisions of an enterprise



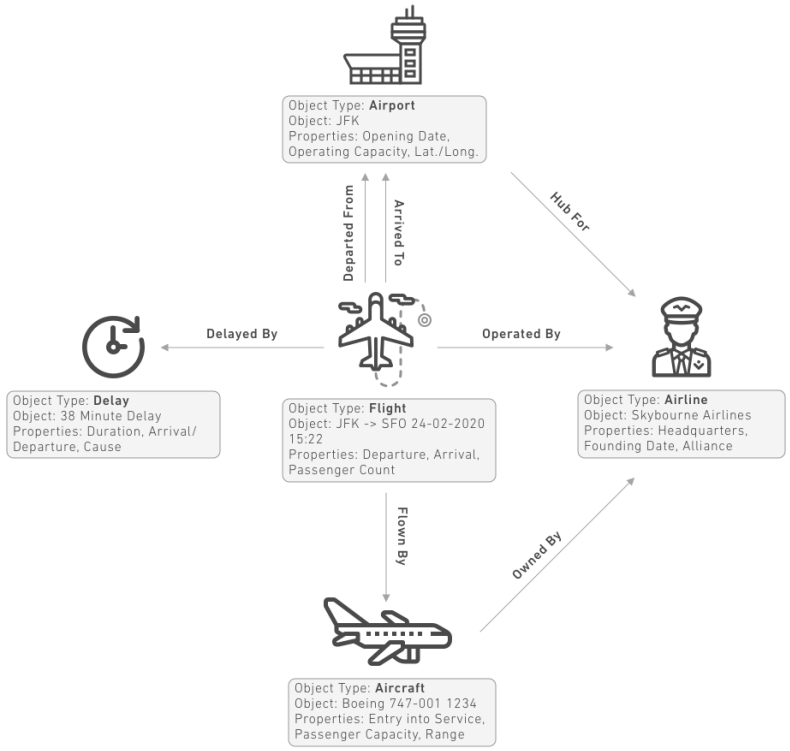
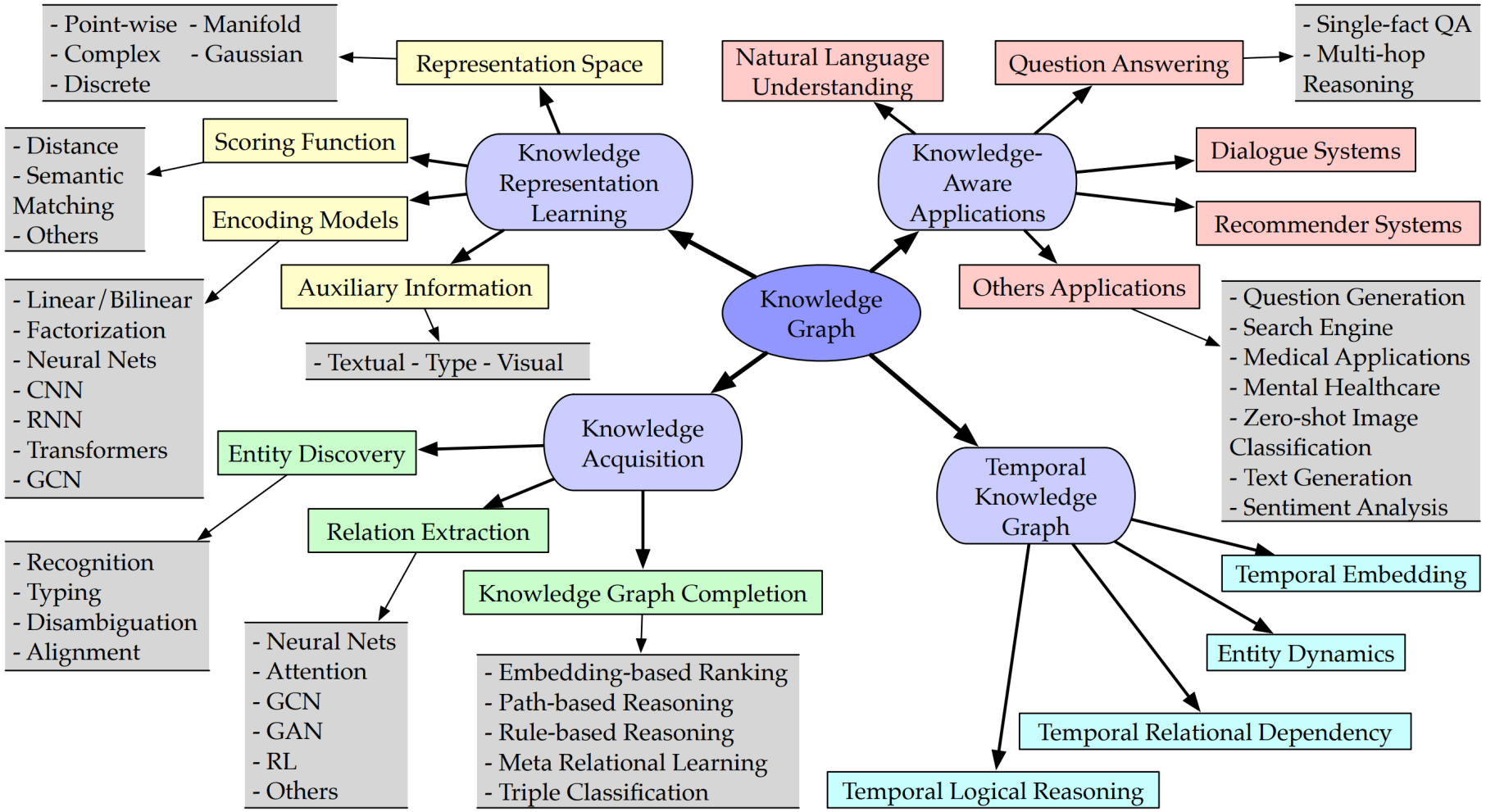


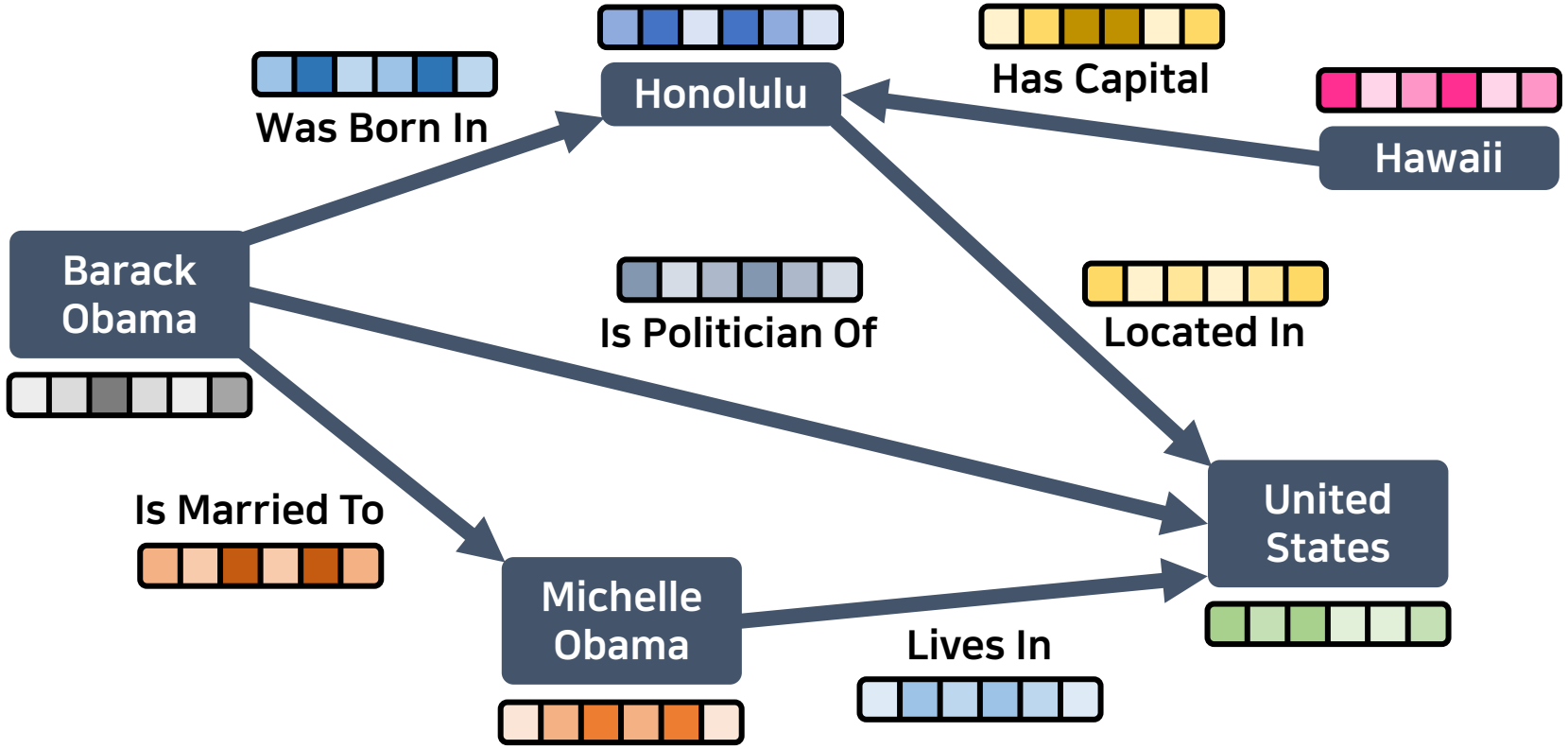
Image: https://www.palantir.com/docs/foundry/ontology/core-concepts/?ref=community.heartcount.io

01 Research on Knowledge Graphs



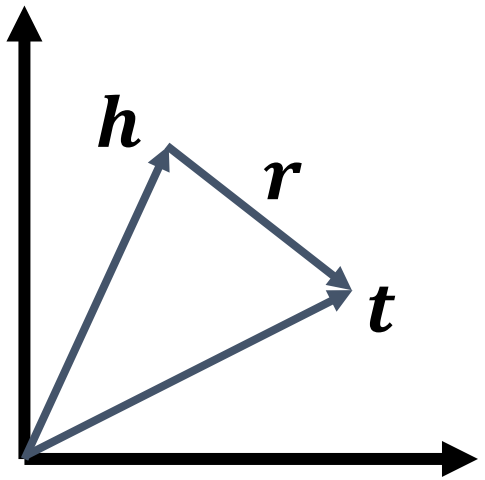
01 Knowledge Graph Embedding

- Represent the entities and relations in a low-dimensional feature space.
- Simplify the manipulation while preserving the inherent structure of the graph.

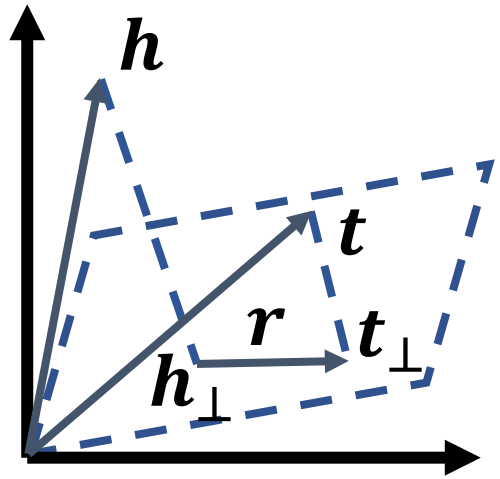


01 Knowledge Graph Embedding Models

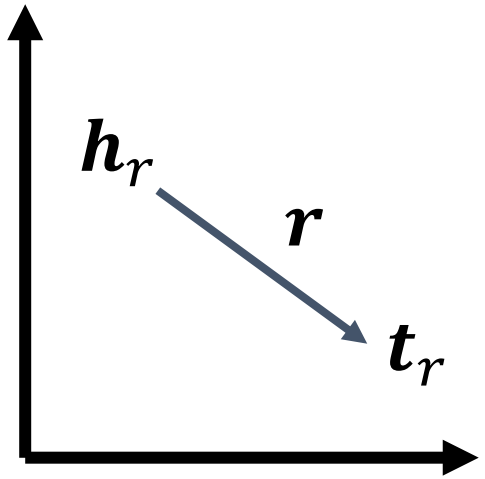
- Translational distance models
  - Use distance-based scoring functions.
  - Measure the plausibility of a fact as the distance between the two entities, usually after a translation carried out by the relation.
  - Examples: TransE, TransH, TransR, RotatE



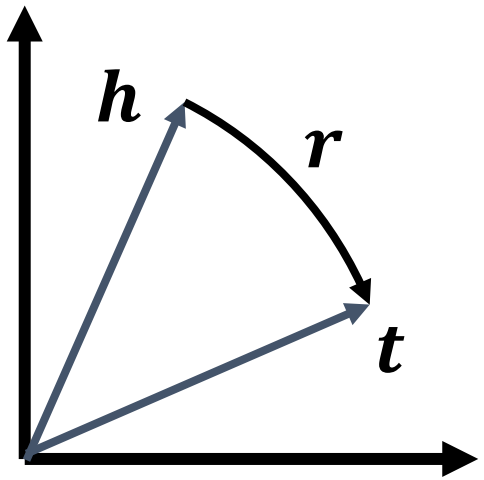
Entity and relation space



Entity and relation space



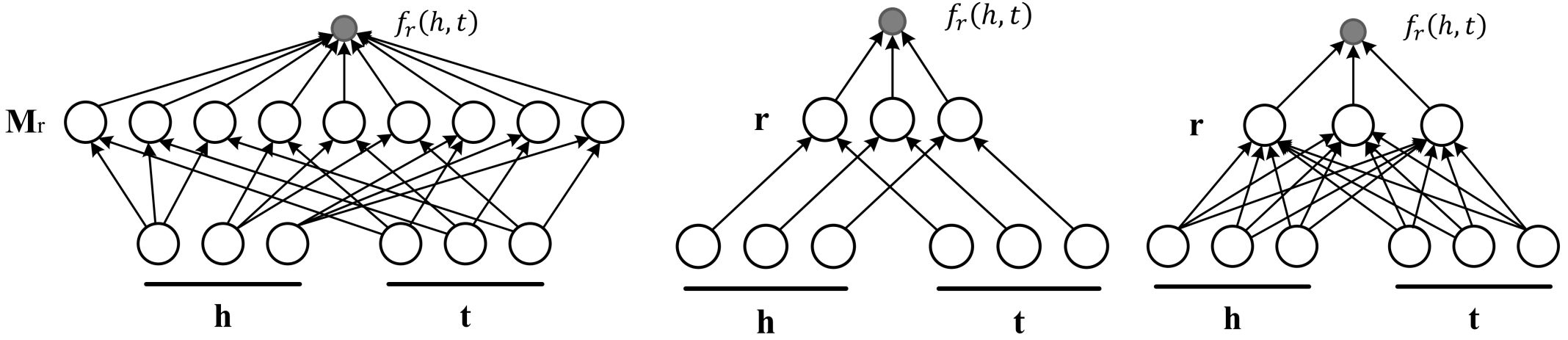
Relation space of r



Entity and relation space

01 Knowledge Graph Embedding Models

- Semantic matching models
  - Exploit similarity-based scoring functions.
  - Measure plausibility of facts by matching latent semantics of entities and relations embodied in their vector space representations.
  - Examples: RESCAL, DistMult, HolE

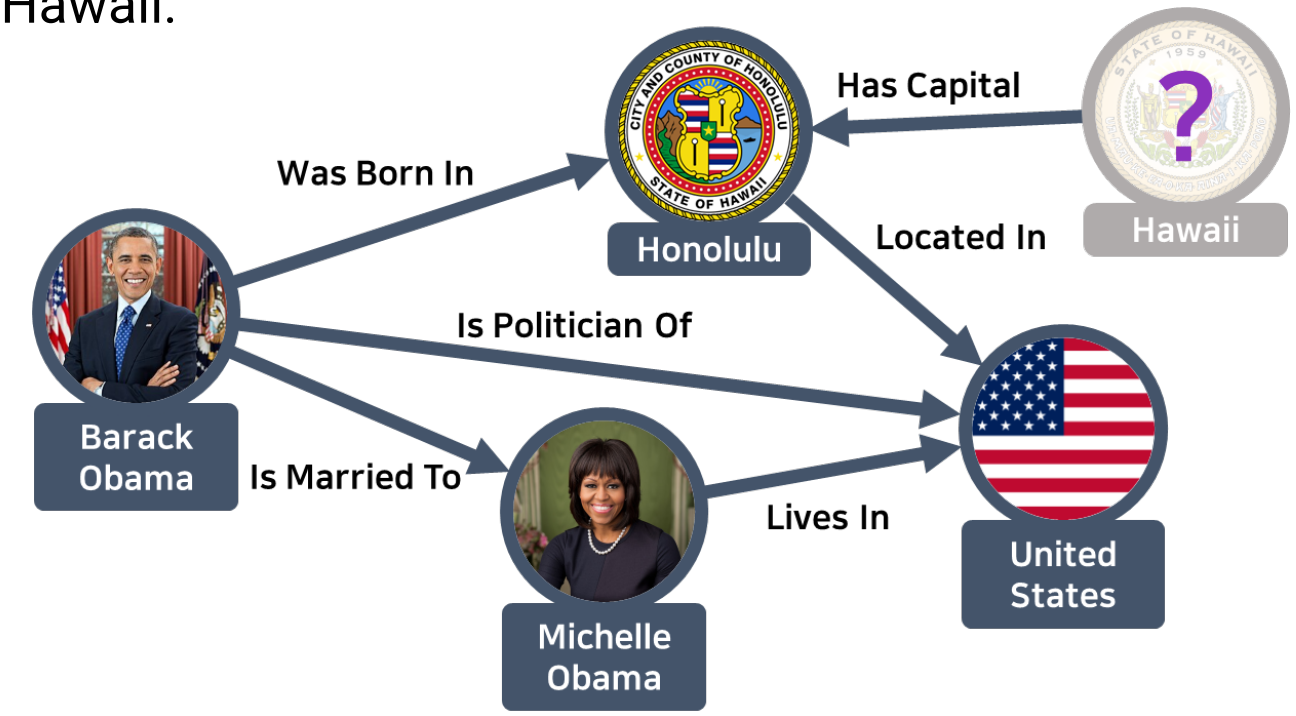


01 Training under Open World Assumption

- Knowledge graphs contain only true facts and non-observed facts can be either false or just missing.
- Negative Sampling: Generating negative training examples
  - Given a positive fact $(h, r, t) \in \mathcal{E}$, replace either h or t with a random entity
    $\mathcal{E}^- = \{(h', r, t) | h' \in \mathcal{V} \wedge h' \neq h \wedge (h, r, t) \in \mathcal{E}\} \cup \{(h, r, t') | t' \in \mathcal{V} \wedge t' \neq t \wedge (h, r, t) \in \mathcal{E}\}$
  - False negative examples:
    (JamesCameron, Gender, Male) → (AlfredHitchcock, Gender, Male)
  - To reduce such false-negative examples, set different probabilities for replacing the head and the tail.
    - Give more chance to replacing the head if the relation is 1-to-N and the tail if the relation is N-to-1

01 Link Prediction in Knowledge Graphs

- Assume that we learned embeddings using TransE.
- To solve (?, HasCapital, Honolulu), compute $f_r(h,t) = -\|\boldsymbol{h} + \boldsymbol{r} - \boldsymbol{t}\|$.
  - A ranked list: Hawaii, United States, Barack Obama, Michelle Obama
  - Predict ? to be Hawaii.



01 Evaluation of Link Prediction

- Record ranks of correct answers in the ordered lists.
  - Mean Rank (MR)
    - Compute the average of the ranks.
    - The lower the better
  - Mean Reciprocal Rank (MRR)
    - The average of reciprocal ranks.
    - The higher the better
  - Hit@N
    - The proportion of ranks no larger than N.
    - The higher the better

01 Evaluation of Link Prediction

[Problem 1] Answer: D

Rank	Entity
1	B
2	C
3	D
4	A
5	E
6	F
7	H
8	J
9	K
10	G
11	I
12	L
⋮	

[Problem 2] Answer: G

Rank	Entity
1	G
2	B
3	A
4	C
5	E
6	D
7	H
8	J
9	L
10	F
11	K
12	I
⋮	

[Problem 3] Answer: K

Rank	Entity
1	A
2	C
3	F
4	B
5	J
6	D
7	E
8	G
9	H
10	K
11	I
12	L
⋮	

[Problem 4] Answer: L

Rank	Entity
1	C
2	D
3	F
4	B
5	E
6	G
7	I
8	A
9	J
10	K
11	H
12	L
⋮	

MR=(3+1+10+12)/4=6.5, MRR=[1/3+1+1/10+1/12]/4=0.3792, Hit@10=3/4=0.75

03 References

- Some slides are made based on the following references.
  - Q. Wang et al., “Knowledge graph embedding: a survey of approaches and applications”, TKDE, 2017.
  - H. Cai et al., “A Comprehensive Survey of Graph Embedding: Problems, Techniques, and Applications”, TKDE, 2018.
  - S. Ji et al., “A Survey on knowledge graphs: representation, acquisition and applications”, TNNLS, 2021.