



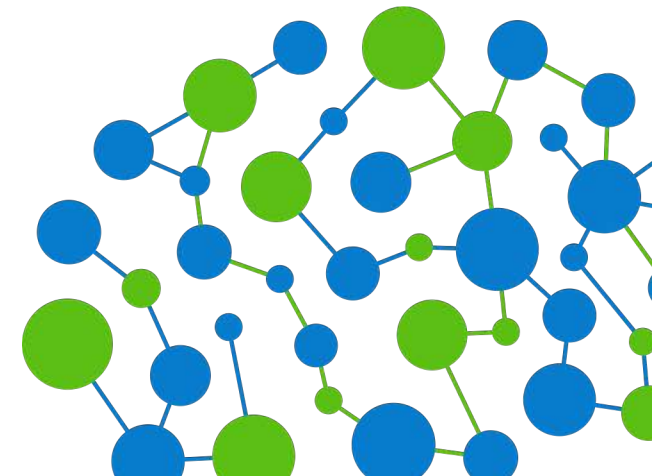
Theoretical Innovations and New Research Paradigms of Knowledge Graphs in the Era of Large Language Models

Haofen Wang

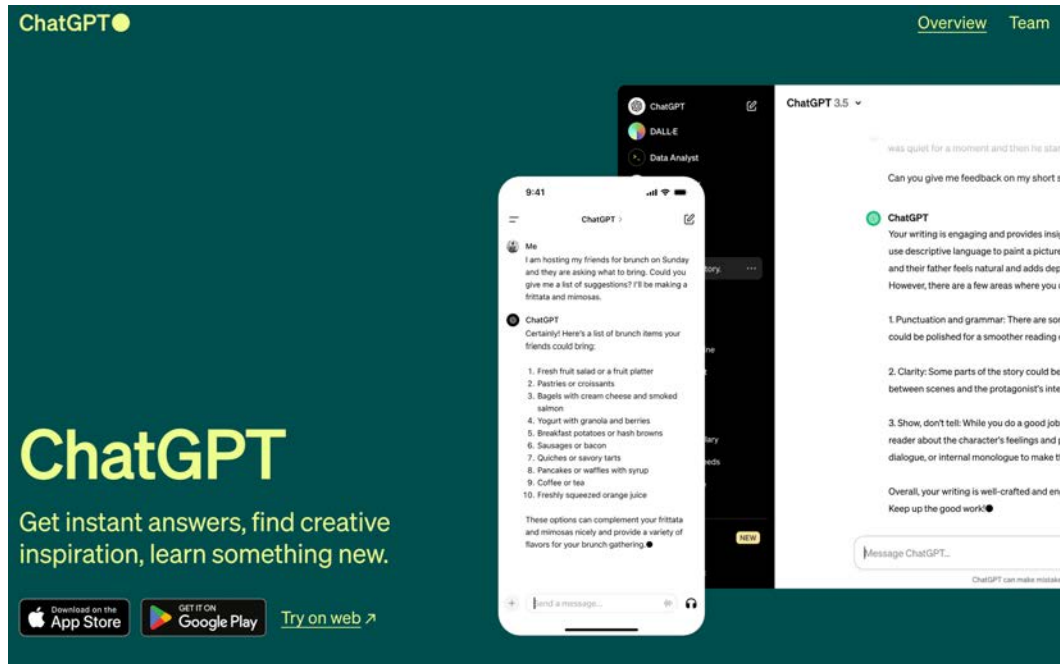
LKM Workshop, IJCAI 2024



- **The Rise of LLM**
- The Development of KG
- The Emerging Paradigm
- OpenKG
- Conclusion and Outlook



The Wave towards AGI by LLM



ChatGPT ● Overview Team

ChatGPT
DALL·E
Data Analyst

9:41

Me
I am hosting my friends for brunch on Sunday and they are asking what to bring. Could you give me a list of suggestions? I'll be making a frittata and mimosas.

ChatGPT
Certainly! Here's a list of brunch items your friends could bring:

1. Fresh fruit salad or a fruit platter
2. Pastries or croissants
3. Bagels with cream cheese and smoked salmon
4. Yogurt with granola and berries
5. Breakfast potatoes or hash browns
6. Sausages or bacon
7. Quiches or savory tarts
8. Pancakes or waffles with syrup
9. Coffee or tea
10. Freshly squeezed orange juice

These options can complement your frittata and mimosas nicely and provide a variety of flavors for your brunch gathering.

ChatGPT 3.5

... was quiet for a moment and then he starts

Can you give me feedback on my short stc

ChatGPT
Your writing is engaging and provides insight use descriptive language to paint a picture o and their father feels natural and adds depth However, there are a few areas where you could be polished for a smoother reading ex:

1. Punctuation and grammar: There are some could be polished for a smoother reading ex;
2. Clarity: Some parts of the story could bene between scenes and the protagonist's intern
3. Show, don't tell: While you do a good job of reader about the character's feelings and pi dialogue, or internal monologue to make the

Overall, your writing is well-crafted and enga Keep up the good work!

Message ChatGPT...

Download on the App Store GET IT ON Google Play Try on web

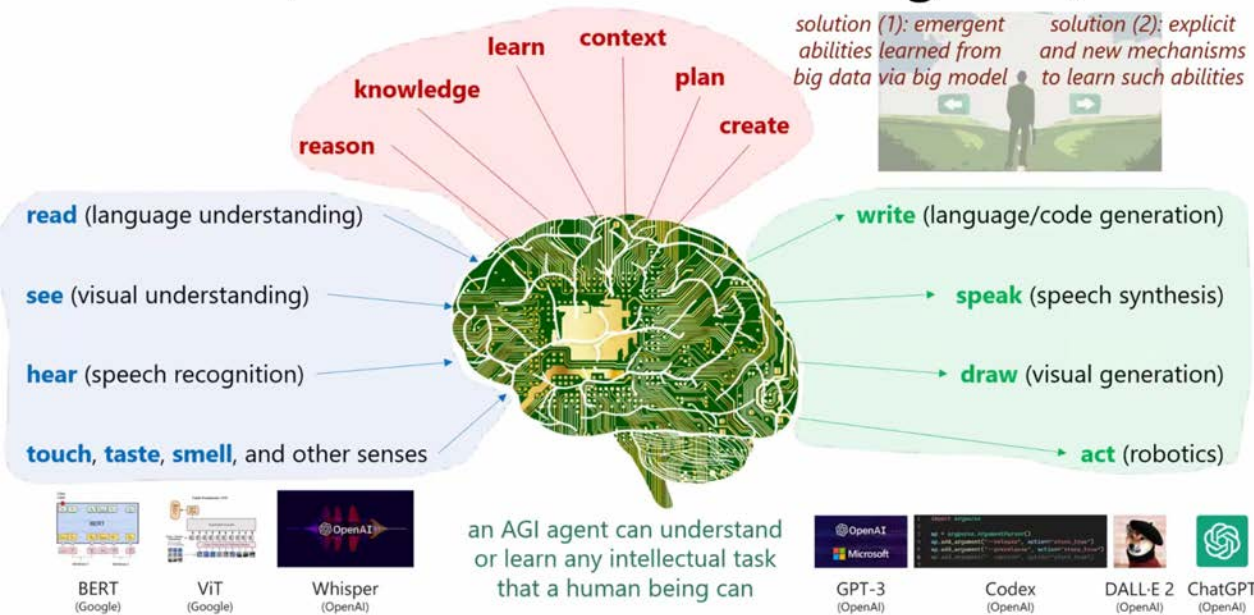


Introducing Sora: Creating video from text

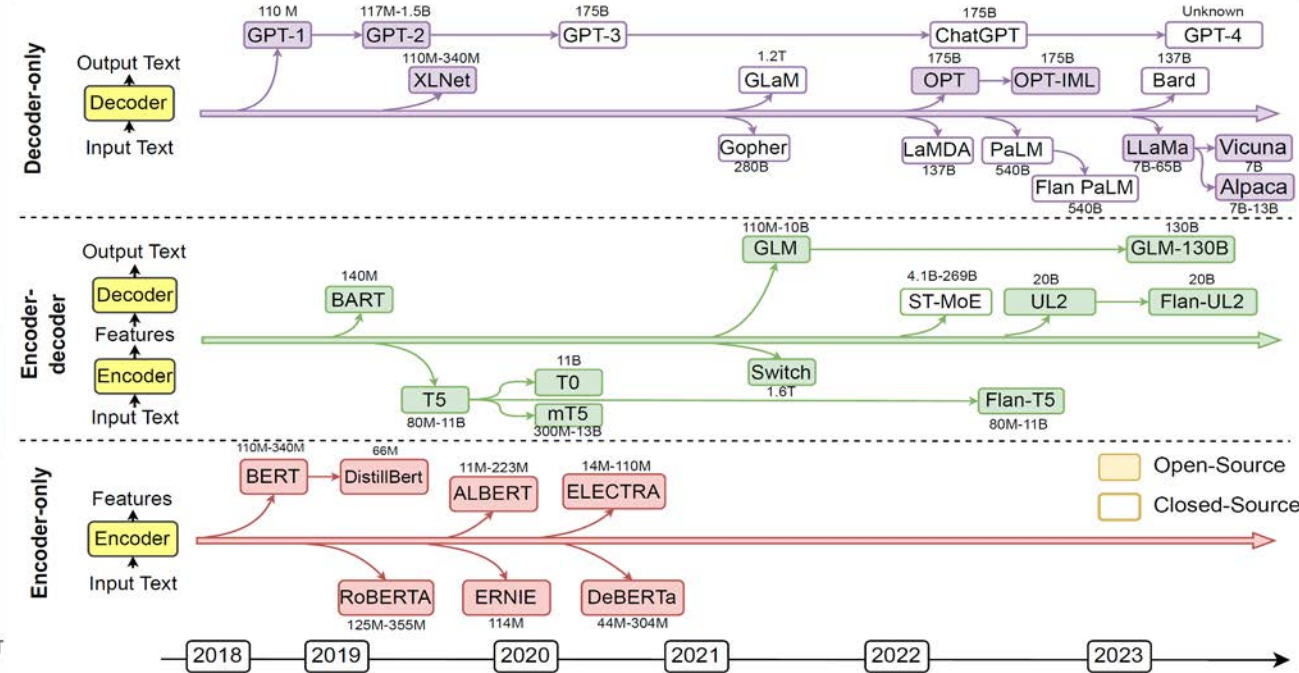
Learn more about Sora

The Wave towards AGI by LLM

AGI (Artificial General Intelligence)



Credit by Nan Duan, MSRA



A Survey of Large Language Models, 2023

The Programming of LLM: Prompt Engineering

Standard Prompting

Q: Natalia sold clips to 48 of her friends in April, and then she sold half as many clips in May. How many clips did Natalia sell altogether in April and May?

T: The answer is :

LM

72

Few-shot Prompting

Q: There are 3 cars in the parking lot and 2 more cars arrive. How many cars are in the parking lot?

A: The answer is 5.

.....

Q: Natalia sold clips to 48 of her friends in April, and then she sold half as many clips in May. How many clips did Natalia sell altogether in April and May?

A: The answer is :

LM

72

Chain-of-Thought Prompting

Q: There are 3 cars in the parking lot and 2 more cars arrive. How many cars are in the parking lot?

C: There are 3 cars in the parking lot already. 2 more arrive. Now there are $3 + 2 = 5$ cars.

A: The answer is 5.

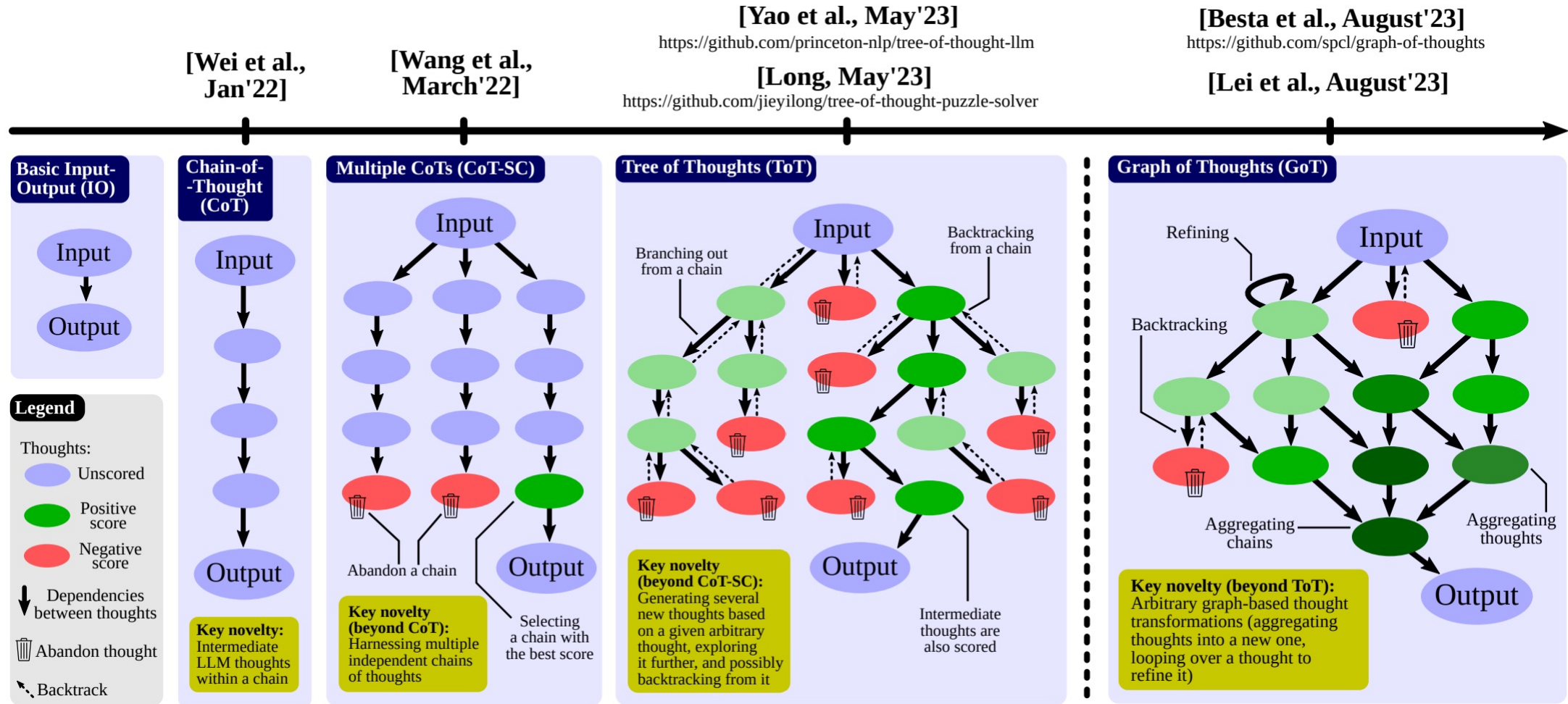
.....

Q: Natalia sold clips to 48 of her friends in April, and then she sold half as many clips in May. How many clips did Natalia sell altogether in April and May?

C: Natalia sold $48 / 2 = 24$ clips in May. Altogether, Natalia sold $48 + 24 = 72$ clips in April and May.

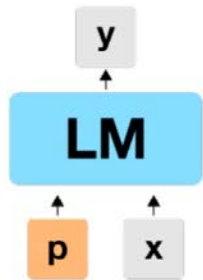
A: The answer is 72.

The Programming of LLM: Prompt Reasoning

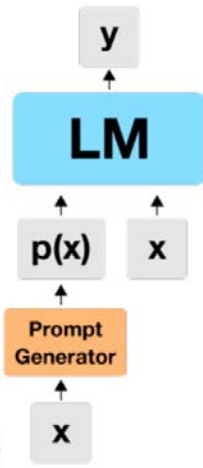


Structured and more logical prompt knowledge helps constrain **complex reasoning**, resulting in a better step-by-step thought process.

The Programming of LLM: Design Patterns of Prompts

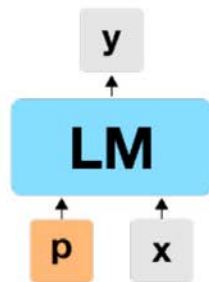


(a)



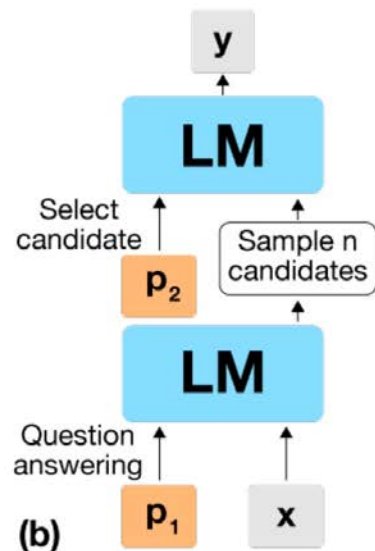
(b)

input-dependent prompt tuning

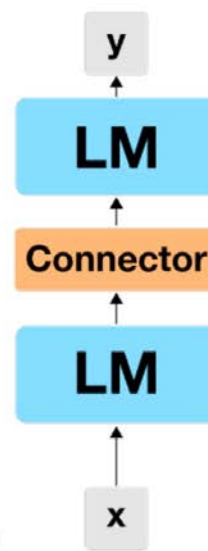


(a)

textual recursive LM

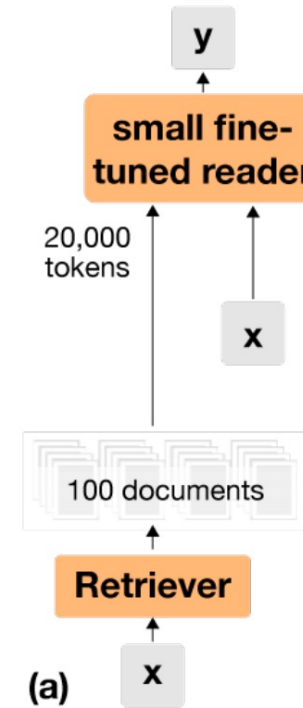


(b)



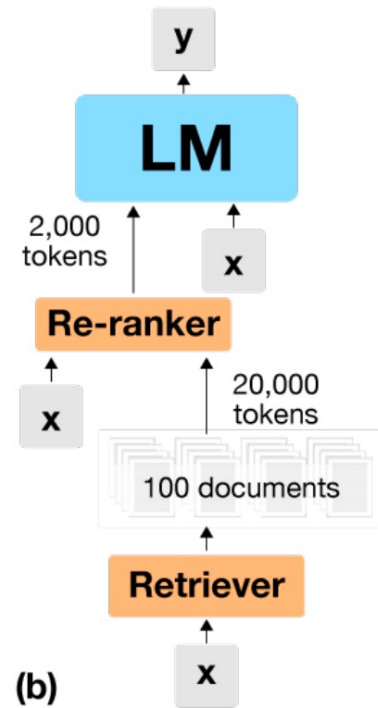
(c)

neural recursive LM



(a)

retrieve-read

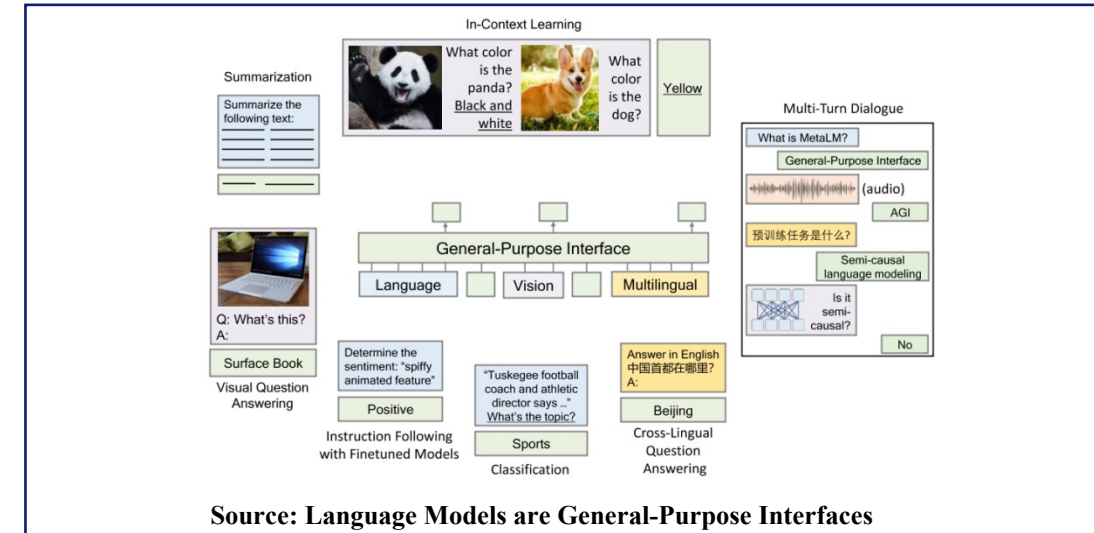
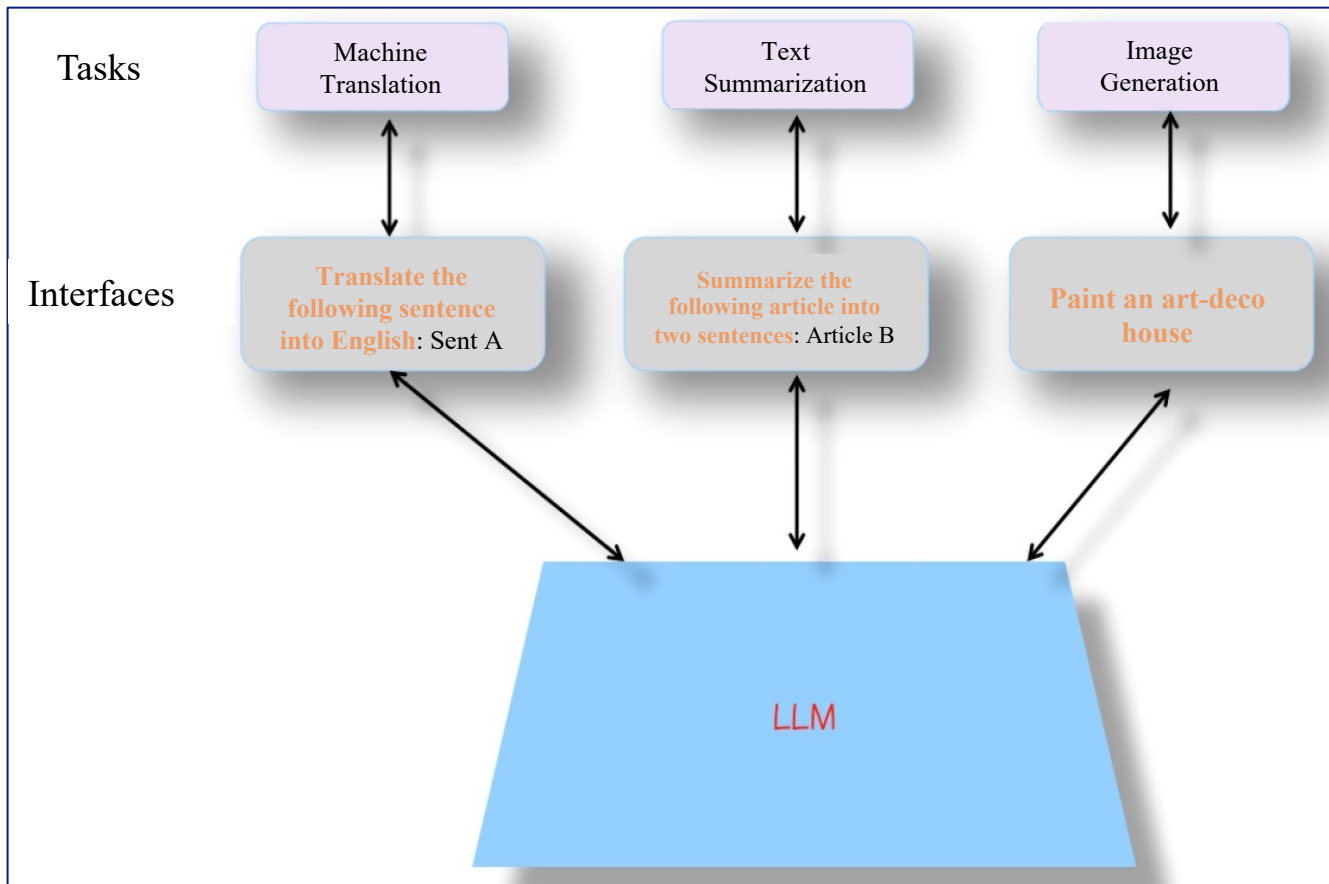


(b)

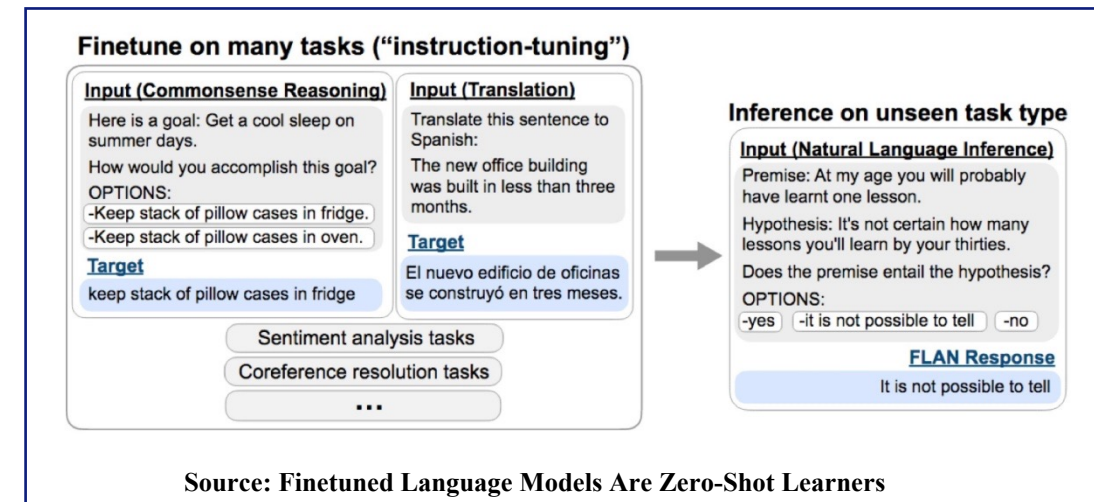
re-rank

LLM as a Basis for Providing Interfaces

- Zero/few shot prompting
- In Context Learning
- Instruction



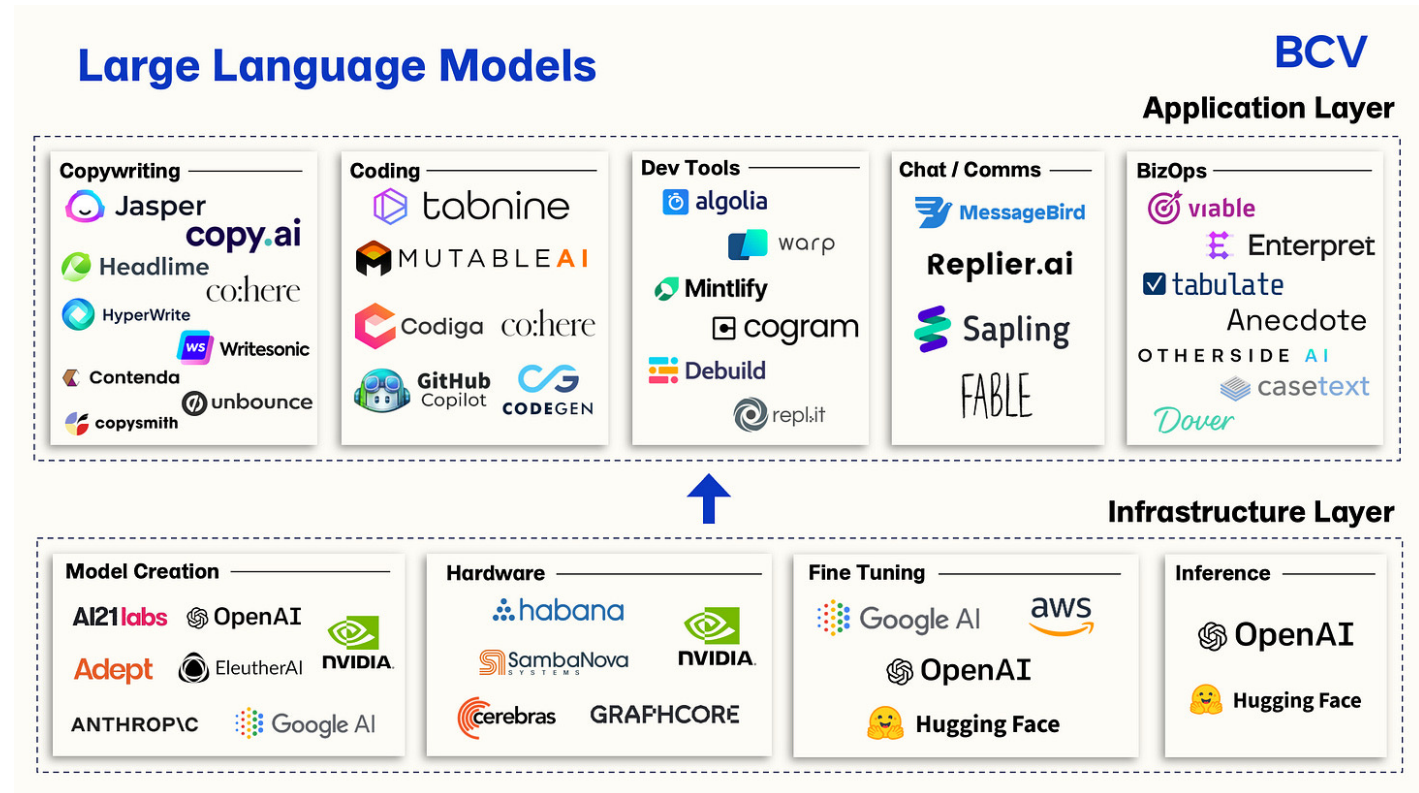
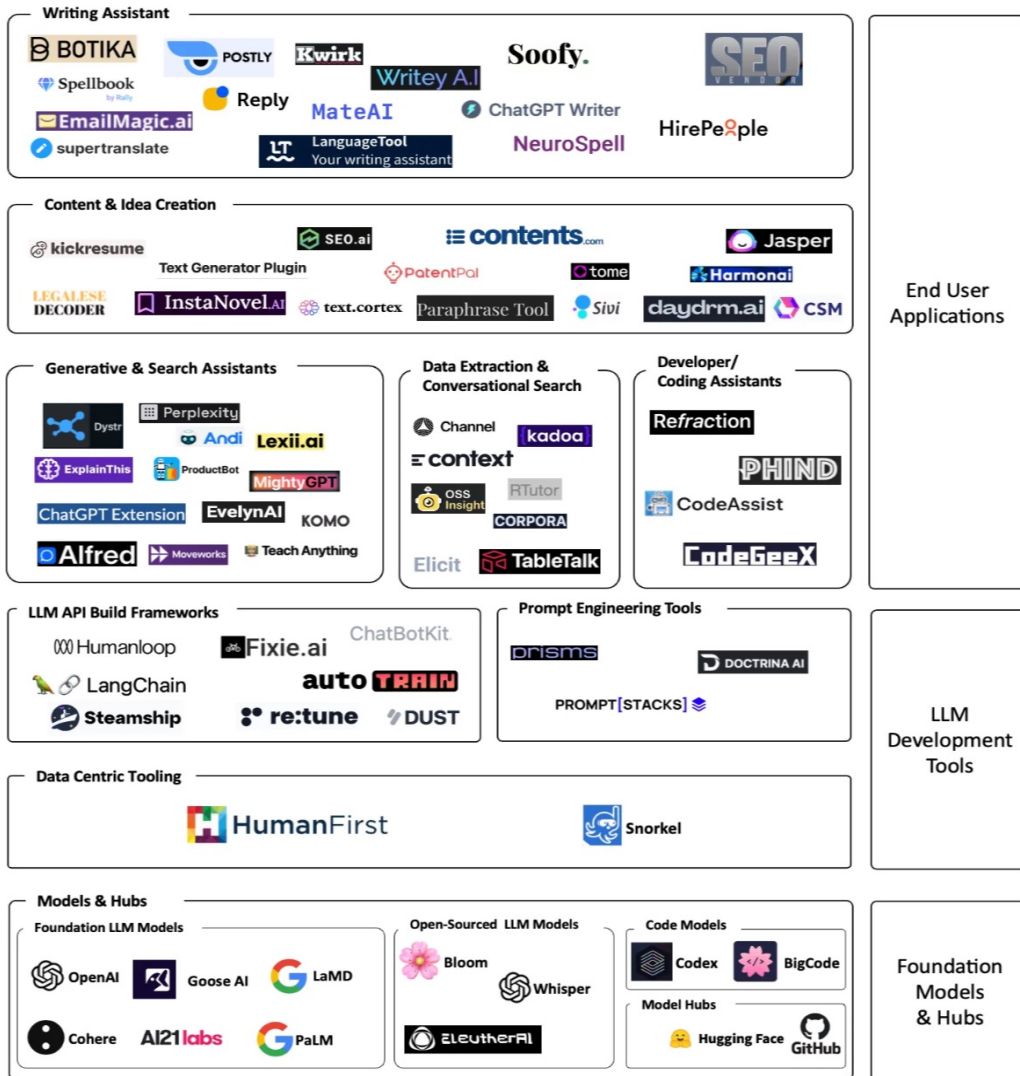
Source: Language Models are General-Purpose Interfaces



Source: Finetuned Language Models Are Zero-Shot Learners

The Ecosystem of LLM

Foundation Large Language Model Stack



GPT = Giant Parrot Talking?



Limitations of LLMs

Personalized questions

15 Which companies in Beijing have a market value greater than 50 million RMB?

I'm sorry, but I don't have access to real-time financial data or the ability to browse the internet to provide you with a list of companies in Beijing with market values greater than 50 million RMB. Market values of companies can change frequently due to stock price fluctuations, mergers, acquisitions, and other factors.

To obtain the most up-to-date information on the market values of companies in Beijing, I recommend checking financial news websites, stock market exchanges, or financial databases. You can also consult with a financial advisor or use a financial data service to access this information.

15 How is the weather today?

Real-time questions

I'm unable to provide real-time weather information as my knowledge was last updated in 2022, and I don't have access to the internet to fetch current data. To find out the current weather in your location, I recommend using a weather website or app, or you can simply check a search engine like Google for the latest weather updates by entering your location and "weather" as the search query.

Questions that require new knowledge

15 How do you perceive the results of the 2022 FIFA World Cup?

I don't have access to real-time information or events that occurred after my last knowledge update in 2022. Therefore, I cannot provide information or perceptions about the results of the 2022 FIFA World Cup or any other events that occurred after that date.

To get the most up-to-date information and perspectives on the 2022 FIFA World Cup or any recent events, I recommend checking reliable news sources or sports websites that cover the tournament. You can also engage in discussions with people who have been following the event to get their insights and perceptions.

15 If I could foresee the future, how should I change my destiny? **Hallucination**

If you could accurately foresee the future, it would indeed be a powerful ability. However, there are several considerations and ethical dilemmas associated with this hypothetical situation. Assuming that you could foresee the future, here's how you might consider changing your destiny:

- Planning:** Use your foreknowledge to create well-informed plans and strategies for your life. This could include career goals, financial planning, personal development, and more.
- Risk Management:** If you can foresee future difficulties or challenges, take proactive measures to mitigate potential risks. This might involve purchasing insurance, making lifestyle changes, or seeking legal advice.
- Financial Decisions:** Make investment and financial decisions based on the insights you have about the future to help achieve your financial goals.
- Relationships:** Use your knowledge of the future to build healthier relationships, resolve potential conflicts, and improve your personal and professional interactions.
- Personal Growth:** Knowing what opportunities and challenges lie ahead, focus on personal growth, learning, and self-improvement to better prepare yourself for the future.

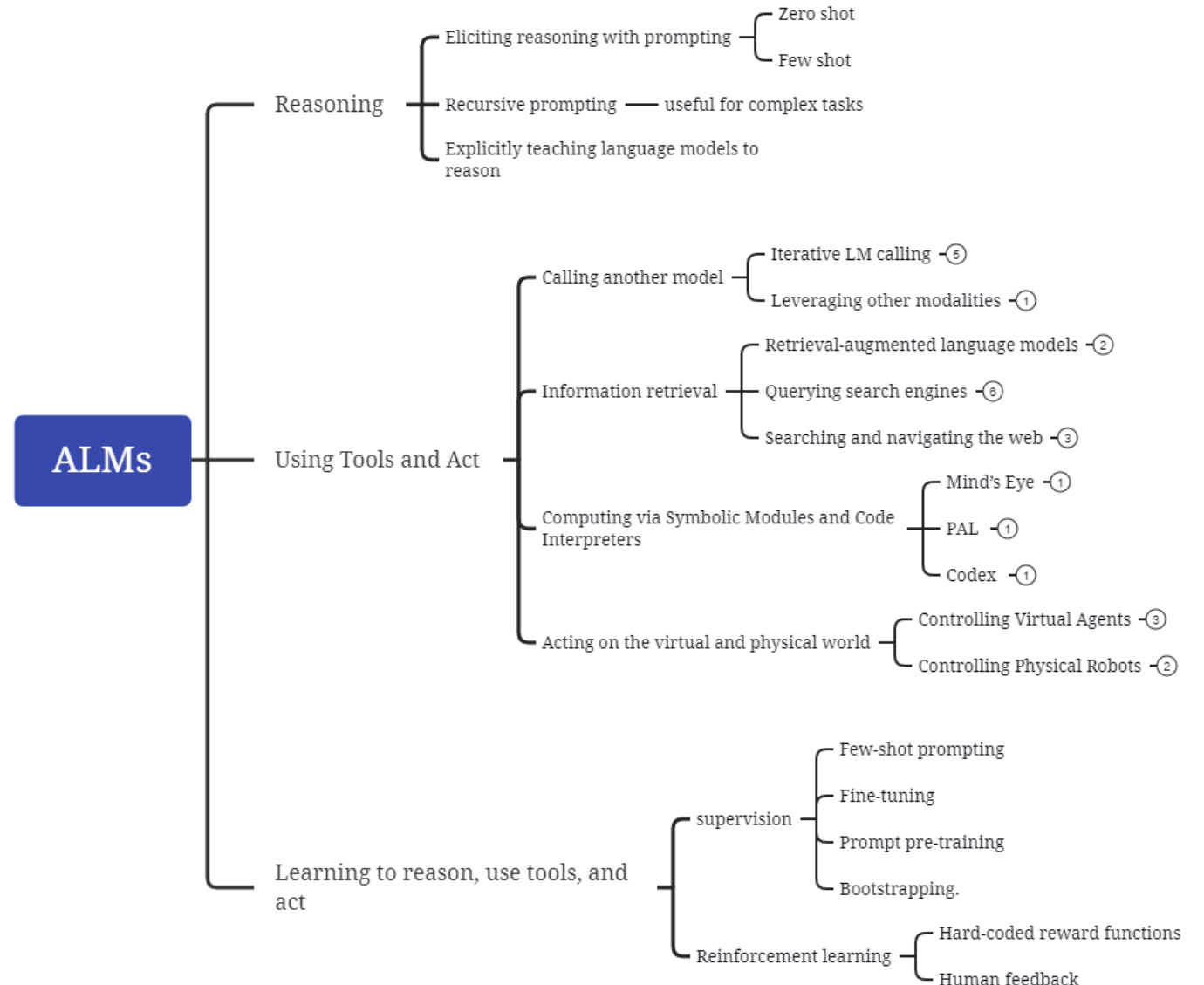
It's important to emphasize that this is a hypothetical scenario. In reality, we cannot foresee the future with certainty. Every decision we make is based on current information and risk assessments. Additionally, even in this hypothetical scenario, ethical considerations are vital. Any actions you take should be legal, ethical, and considerate of the well-being of others.

- It cannot handle personalized, dynamic, real-time questions like stock prices or weather changes.
- LLMs are unable to acquire the latest knowledge, therefore it cannot provide the up-to-date information.
- The existence of Hallucinations leads to a tendency to talk nonsense with a serious tone.
- Inappropriate prompts may lead to irrelevant even harmful response

Augmented Language Models

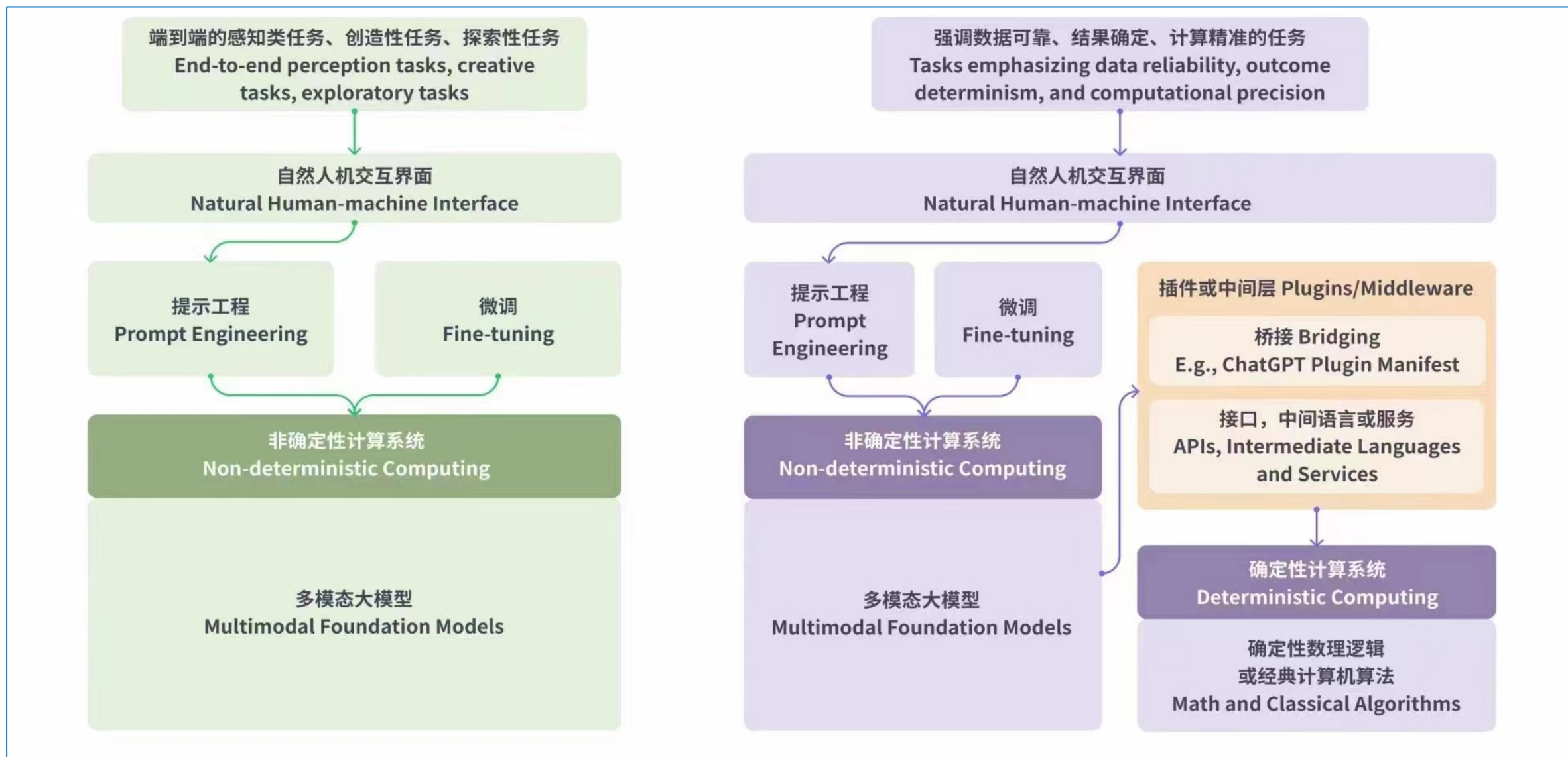
❖ Studies have proposed some improvements, such as enabling LLM to utilize external tools, enhancing context understanding with important missing information not included in LLM's weights, and forming a more powerful intelligent agent. These models are collectively referred to as **Augmented Language Models (ALMs)**.

- ❖ **Reasoning:** Breaking down complex tasks into simpler subtasks can make it easier for the LM to solve on its own or with the use of tools.
- ❖ **Tools:** Collecting external information, or influencing the virtual or physical world perceived by ALM.
- ❖ **Act :** Invoking a tool that has an impact on the virtual or physical world and observing its results, incorporating it into the current context of ALM.

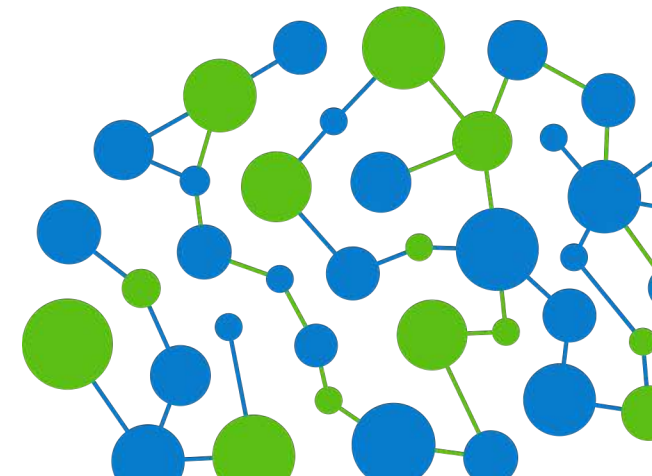


Source: Augmented Language Models: a Survey (Yann Lecun et al.)

Two kinds of Usage of LLM

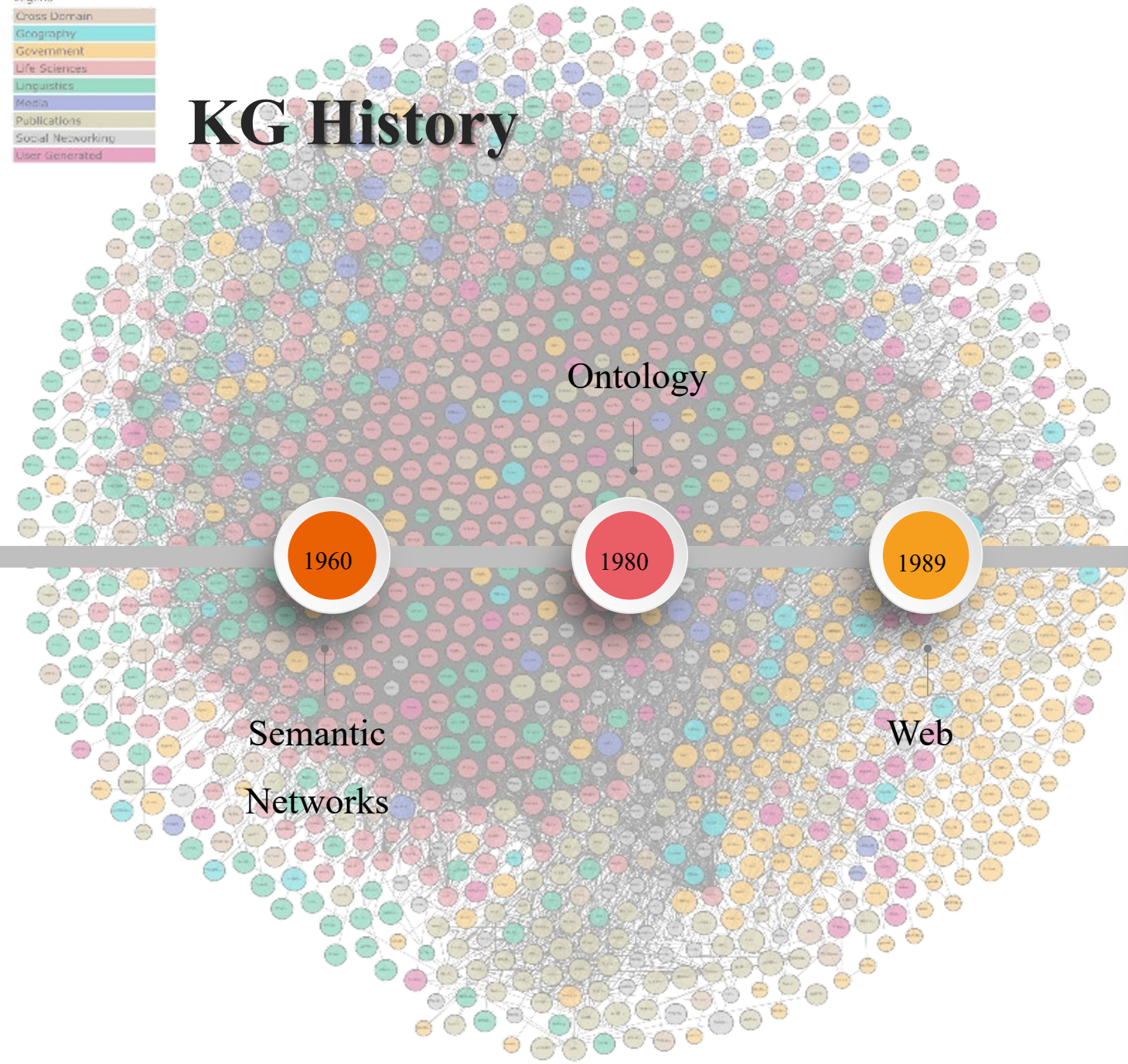


- The Rise of LLM
- **The Development of KG**
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- Cross Domain
- Geography
- Government
- Life Sciences
- Linguistics
- Media
- Publications
- Social Networking
- User Generated

KG History



Semantic

Web



Knowledge Graph



Semantic
Networks

Ontology

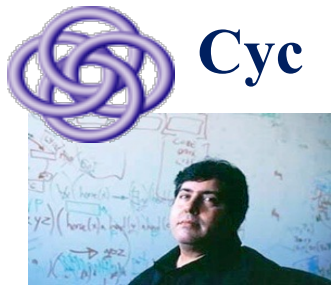
Web

Linked data

Linking Open Data cloud diagram 2022-11-03 Andrejs Abele, John P. McCrae, Paul Buitelaar, Anja Jentzsch and Richard Cyganiak. <http://lod-cloud.net/>



What is Knowledge Graph (KG) – Popular KBs and Characteristics



WordNet



By Human
For Human

guitarist \subset {player, musician}
 \subset artist
 algebraist
 \subset mathematician
 \subset scientist

Wikipedia



4.5 Mio. English articles
 20 Mio. contributors

$\forall x: \text{human}(x) \Rightarrow$
 $(\exists y: \text{mother}(x,y) \wedge$
 $\exists z: \text{father}(x,z))$
 $\forall x,u,w: (\text{mother}(x,u) \wedge$
 $\text{mother}(x,w)$
 $\Rightarrow u=w)$

1985

1990

2000

2005

2010

2015

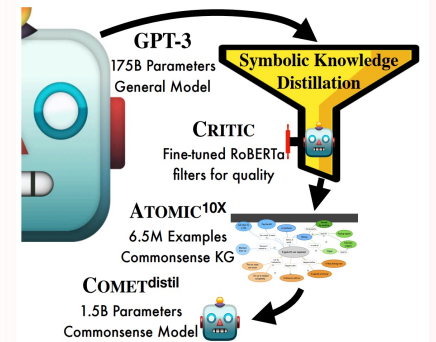
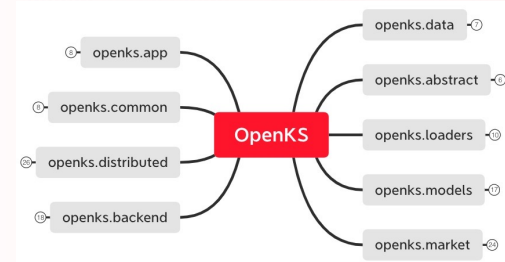
2023



By Algorithm
For Machine



Human Machine
Collaboration



Key
Features

In the early stage, KG is **High-quality, manually-built, and for human consumption**; in the middle age, KG is **constructed by algorithms** and used **to enhance the understanding capability of machines**; nowadays KG is evolving towards **multi-modality** and **subsymbolic representations**

Knowledge Graph

Knowledge Graph (KG) is an explicit representation of human knowledge, which is stored in the form of graph and used for reasoning and computing.

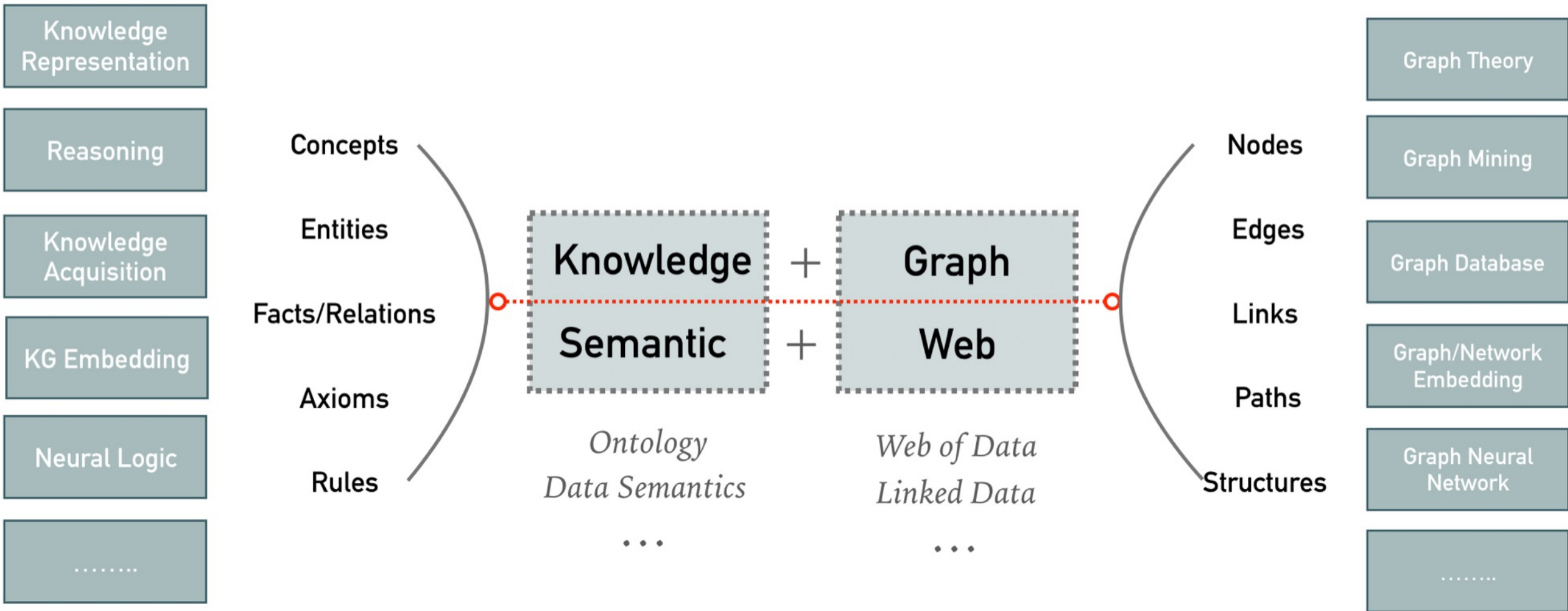


- General domain oriented
- Commonsense knowledge
- Structured encyclopedia knowledge
- Emphasize the breadth of knowledge
- For general users



- Industrial domain oriented
- Industrial data
- Semantic industrial knowledge base
- Emphasize the depth of knowledge
- For industry users

Knowledge Graph is more expressive than pure Graph but less complex than formal logic.

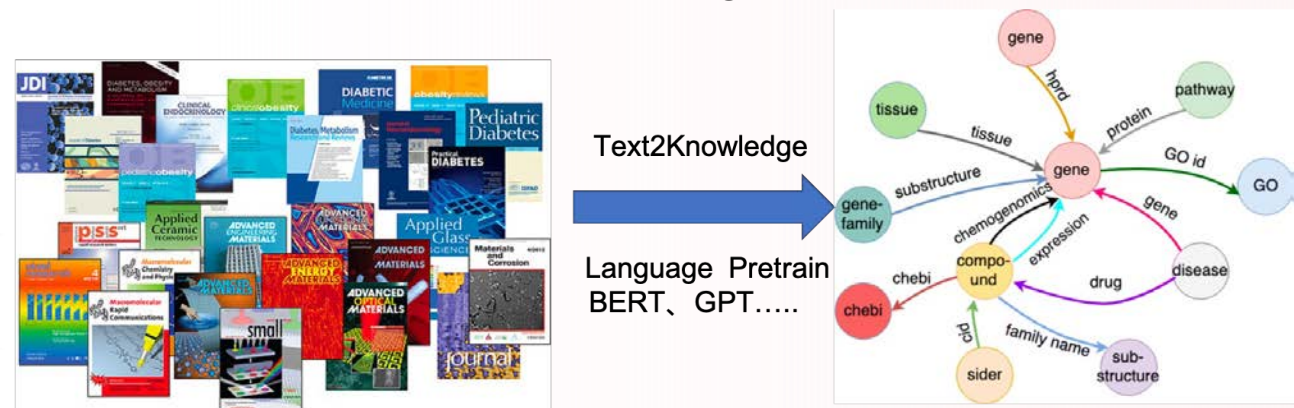


What is Knowledge Graph (KG) – Perspective and Implication

KG as a World Model

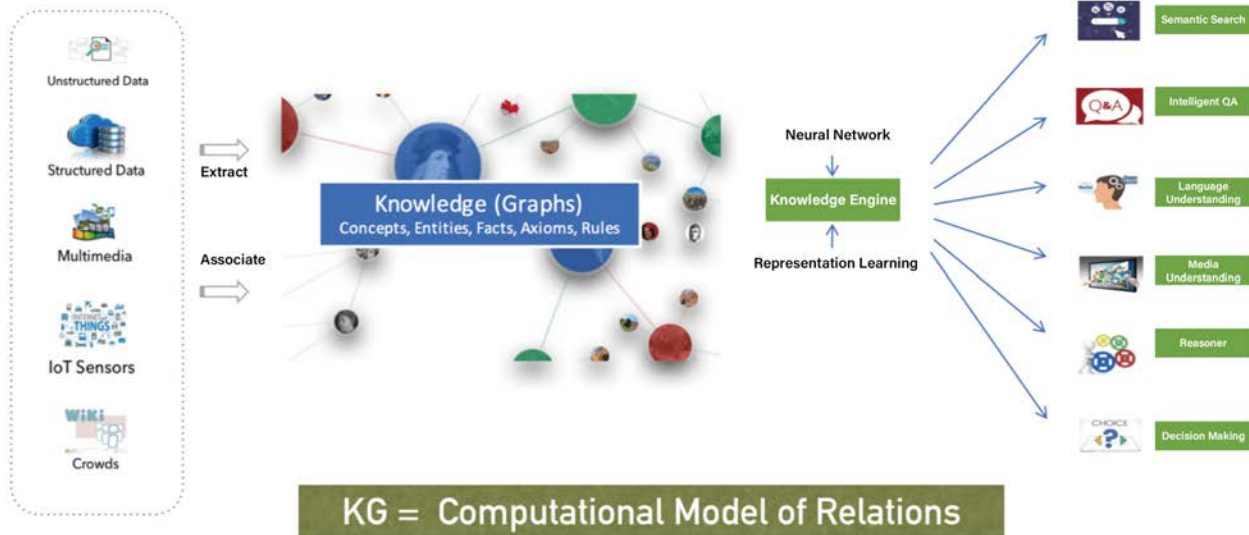


Text as Knowledge Base



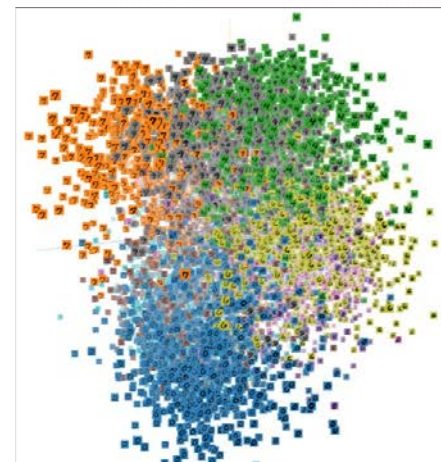
The Good Old Fashioned AI The Semantic Web & Linked Knowledge The Knowledge Graph

Graph Structure as Knowledge Base

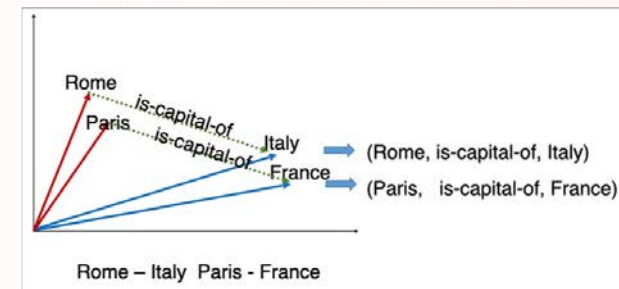


Embeddings as Knowledge Base

Embeddings : Distributed Vector Representation



- Text : Learn a vector of each word in a sentence
- KG: Learn a vector for each entity or property
- Image/Video : Learn a vector for each visual object



Implication

Knowledge Graph originates from how machines represent knowledge, use the graph structure to describe the relationship between things, developed in the rise of Web technologies, and landed in application fields such as search engine, intelligent QA, and recommender systems.

SOTA and Trend of KG – Knowledge Representation and Reasoning

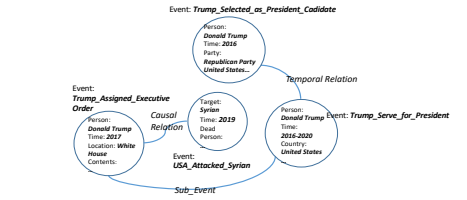
Entity Centric KG



(Barack Obama, Spouse, Michelle Obama)

Triples in form of (s, p, o)

Event Centric KG



Event Frames

- Birth**
 - birth date
 - birth place
 - name
- Marriage**
 - date
 - location
 - male
 - female
- EndPosition**
 - time
 - company
 - position

Event Relations Causal relation, Temporal relation, Co-reference relation, Sub-class relation...

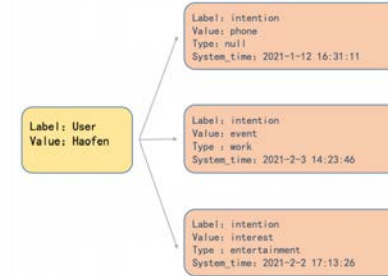
Prompt KG

```

1 Translate English to French:
2 sea otter => loutre de mer
3 peppermint => menthe poivrée
4 plush girafe => girafe peluche
5 cheese =>
    
```

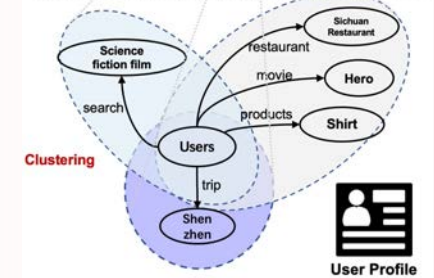
LLM as knowledge base and use prompts to elicit the corresponding facts

Personal KG



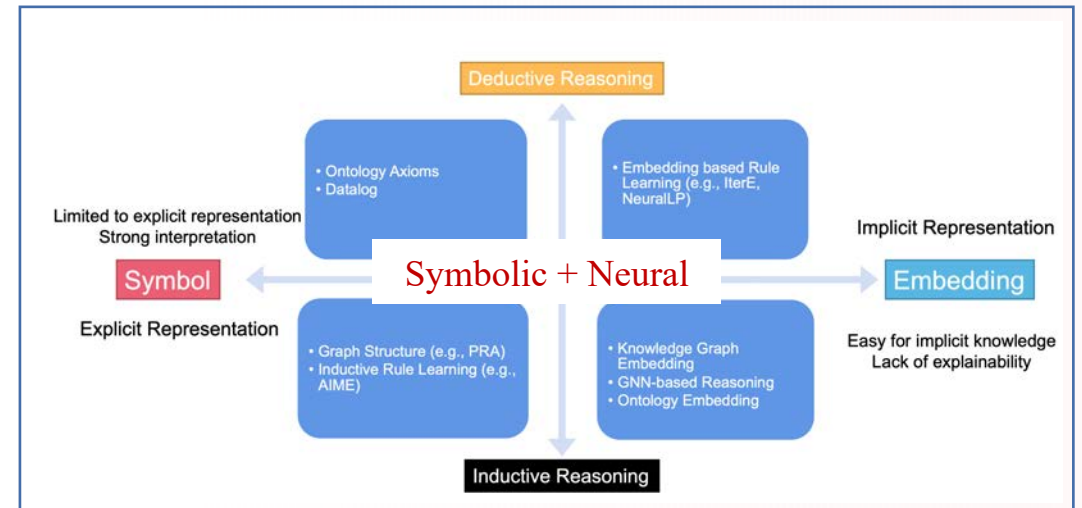
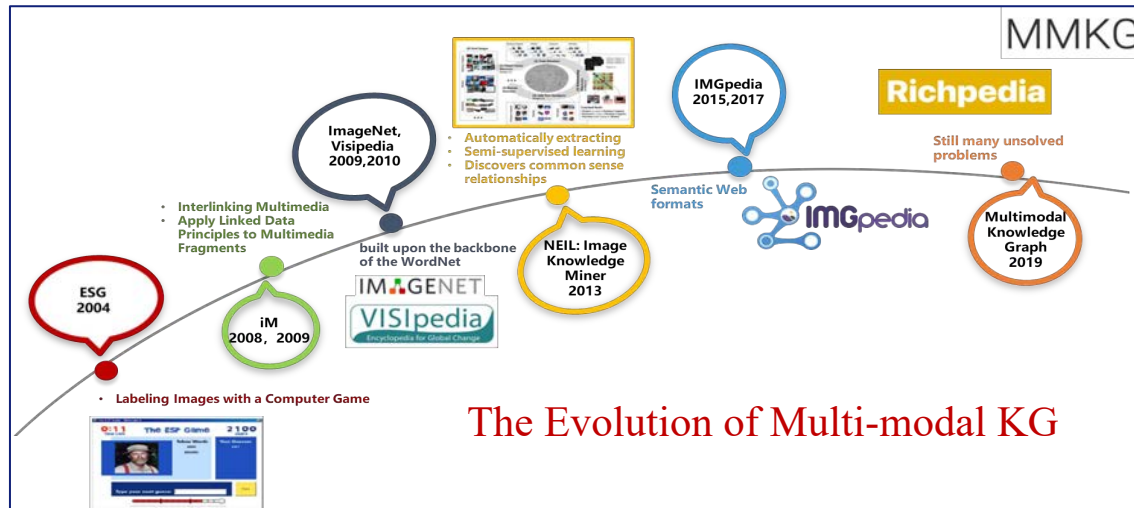
Graph composing events, interests, behaviors of an individual under the protection of privacy and security

Spatiotemporal KG



Expand knowledge representation level in time series and space dimensions

Knowledge types: simple -> complex, static -> dynamic, community -> personal, plain -> spatiotemporal



Challenges

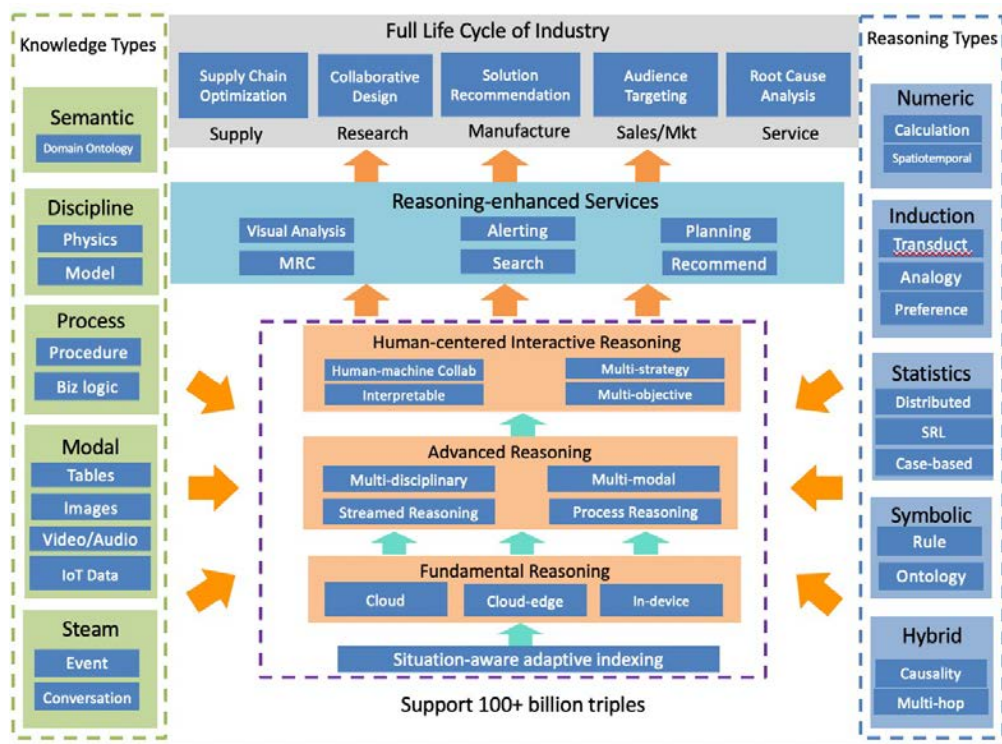
Traditional symbolic knowledge representation methods are difficult to accurately represent complex knowledge such as **dynamics**, **processes**, and **cross-modalities**. At the same time, how to **combine symbolic reasoning** methods based on knowledge graphs and **neural reasoning** methods is extremely challenging.

SOTA and Trend of KG – System Engineering View

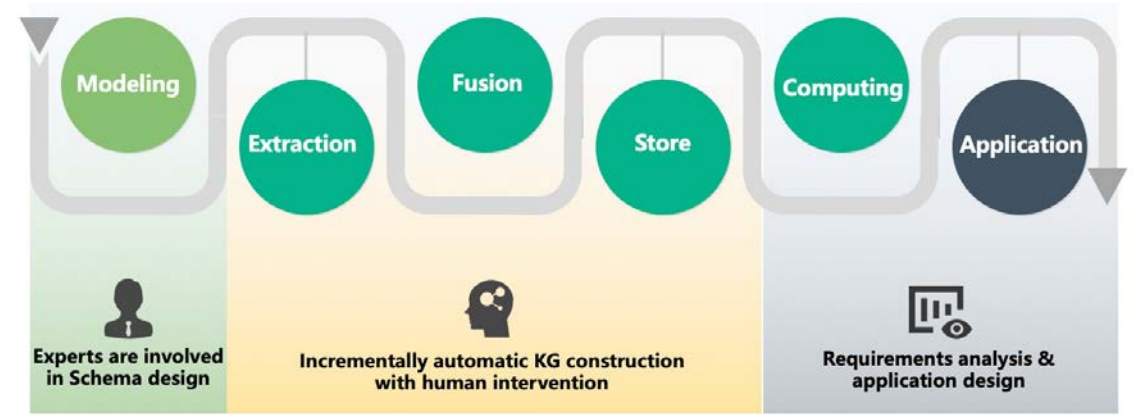


AI should focus on small data and **data centric AI**. Especially in the manufacturing industry, we must rely on **domain knowledge**

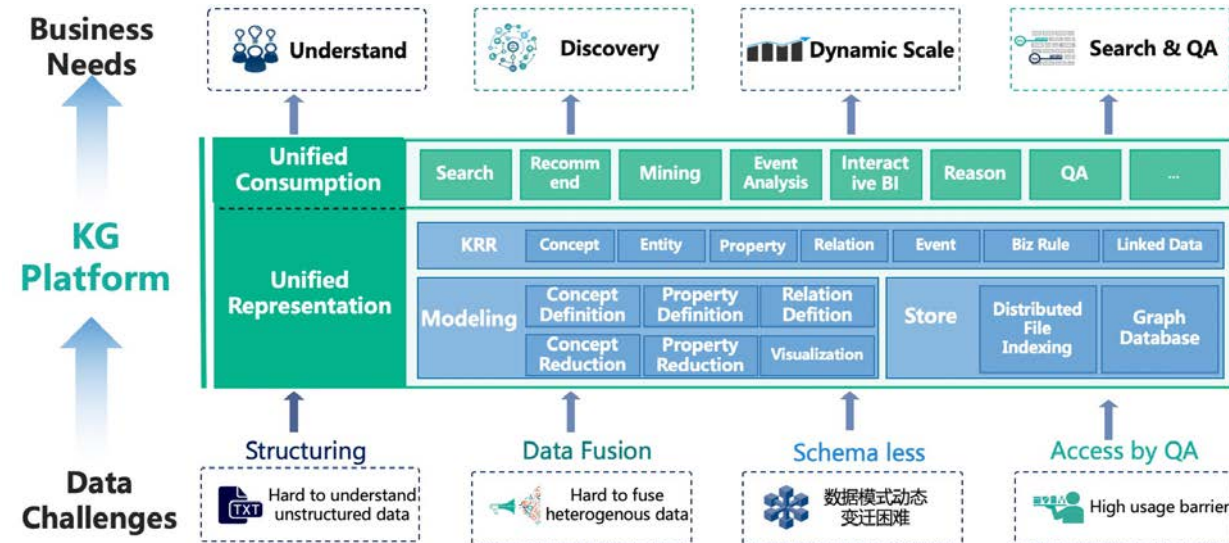
Andrew Ng



Knowledge Graph System Architecture in Industry



Different computing manners, "offline - near real time - real-time", depend on the type of knowledge

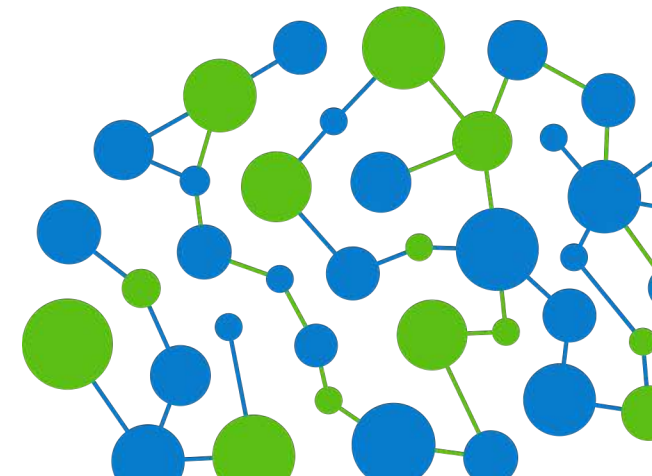


New Paradigm of Technology with Knowledge as the Core

Challenges

Data characteristics and knowledge differences in different fields lead to **low knowledge coverage**, **intensive labor input**, **shallow usage**. In applications, **poor computing efficiency**, **difficult & weak sustainable operation** and **long time cost**

- The Rise of LLM
- The Development of KG
- **The Emerging Paradigm**
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Are symbolism and connectionism mutually exclusive?

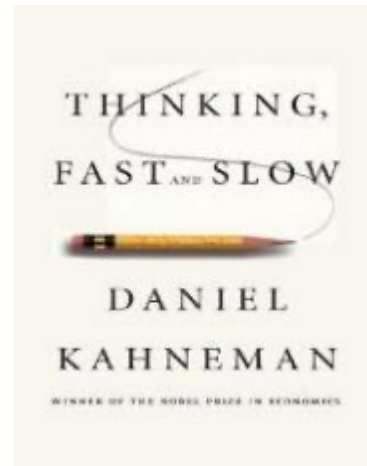
■ Cognitive motivation

Symbolism: Humans rely on symbolic systems (such as language) to organize, communicate, reason, and create knowledge

Connectionism: The physical form of the human brain is a widely connected network of neurons

■ Dual-process cognitive theory

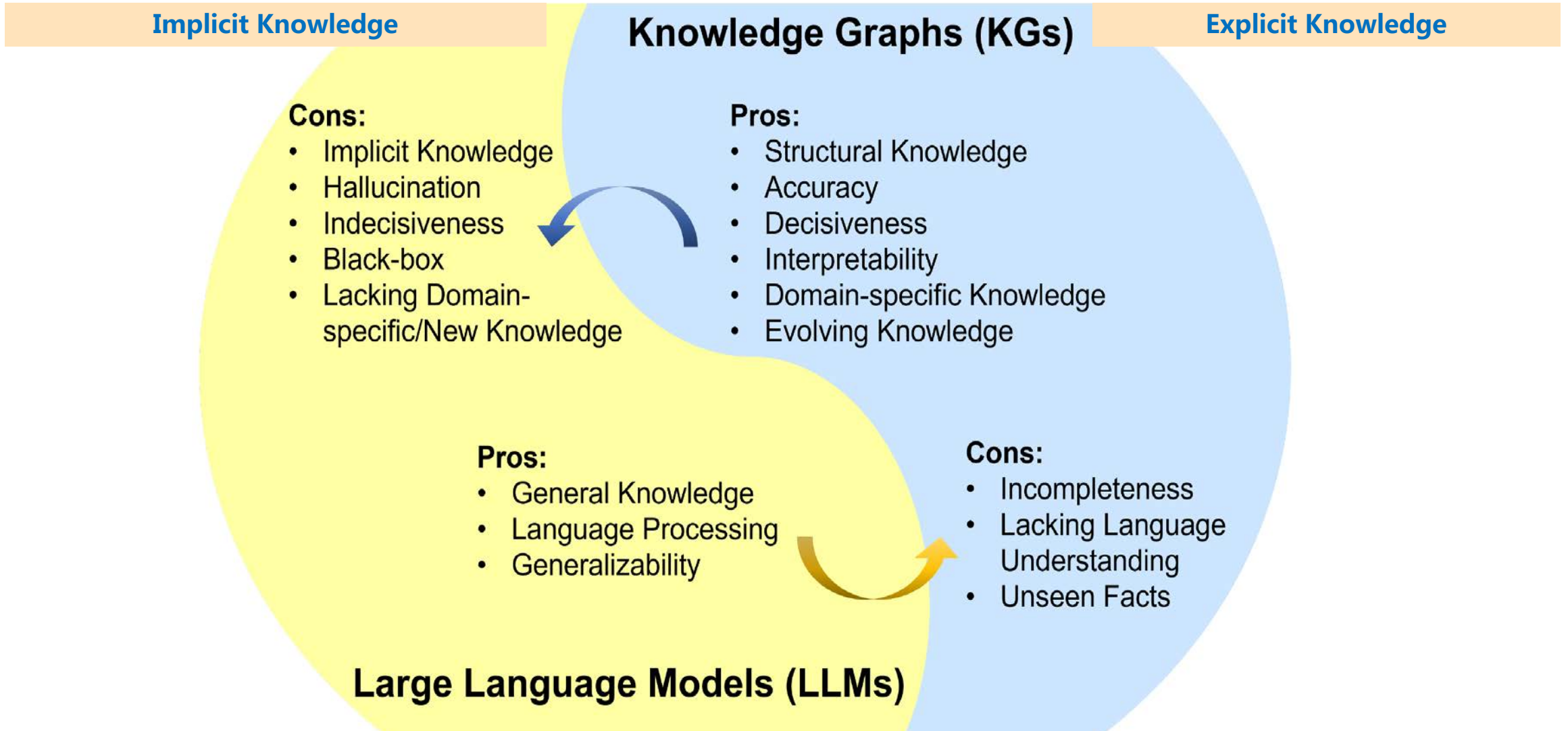
System 1 Intuition (Intuitive)
<ul style="list-style-type: none">• Emotions, memory, and experience• Unconscious, capable of quickly activate associated objects• Easily deceived



System 2 Rational (Analytic)
<ul style="list-style-type: none">• Logical reasoning and computation• Conscious, deliberate, and methodical thinking• "Slow thinker"

Connectionist models are the implementation foundation, while symbolic systems are the features of higher-level abilities.

When KG meets LLM: Two Sides of a Coin



When KG meets LLM: Reasoning Capability Comparison

LLM Reasoning

- **Code pre-training:** enhance LLM reasoning during training
- **Prompt Engineering:** eliciting LLM reasoning during inference

KG Reasoning

- Graph computing
- Rule-based reasoning
- Ontology reasoning
- Spatial-temporal reasoning
- KG embedding/GNN

LLM Reasoning

- zero-shot prompting
- Few-shot prompting
- CoT prompting
- Instruction

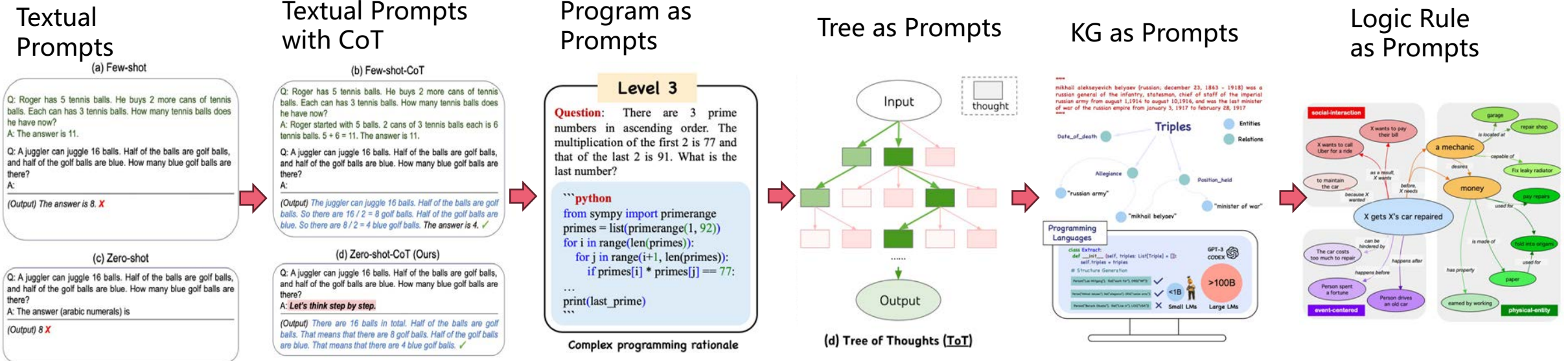


KG Reasoning

- Graph computing
- Rule-based reasoning
- Ontology reasoning
- Spatial-temporal reasoning
- KG embedding/GNN

Structured Knowledge vs. Parameterized Knowledge

Extensive practice indicates that the quality and detail of prompt design, as well as the level of structure and logic in prompt representation, significantly impact the model's output. Essentially, **prompt engineering is knowledge engineering**, aiming to acquire prior knowledge from humans to guide model training or activate model reasoning capabilities.



As the level of structure and logic in prompt knowledge gradually increases, the model's reasoning capabilities become stronger, but the difficulty of acquiring prompt knowledge also increases, making large-scale emergence harder to achieve.

Representation vs Reasoning

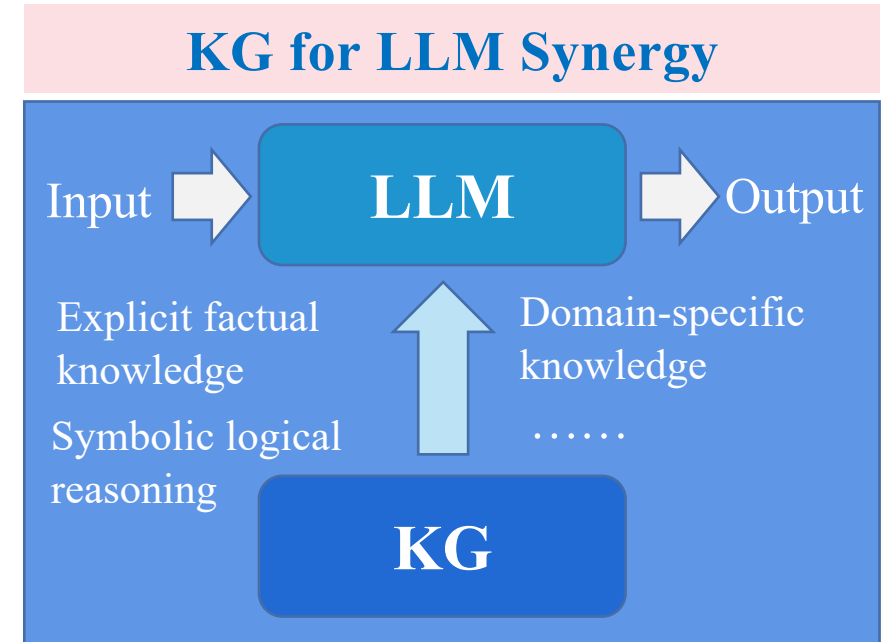
The proportional relationship between the level of representation and reasoning ability still exists. The conflicting relationship between representation complexity and scalability still persists.

Representation vs Scale

Knowledge Graph Helps the Large Model Research

Knowledge Engineering **FOR** the LLM

- Aiming to address the issues of large models through appropriate knowledge engineering methods (resources and frameworks)
 - Hallucination of factual knowledge
 - Knowledge updating
 - Evaluating emergent symbolic abilities to identify problems
 - Issues of scale and efficiency
 - Logical accuracy and interpretability of complex reasoning processes

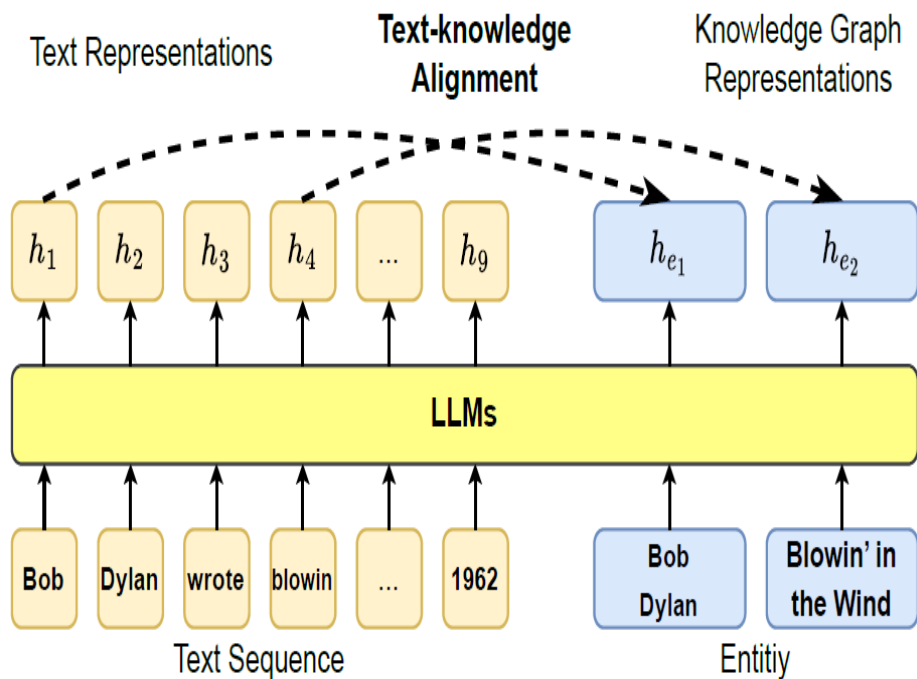


- **Pre-training**
- **Fine-tuning**
- **Inference**
- **Interpretability**
- ...

KG for LLM : Pre-training

Designing pre-training objective to incorporate KG components

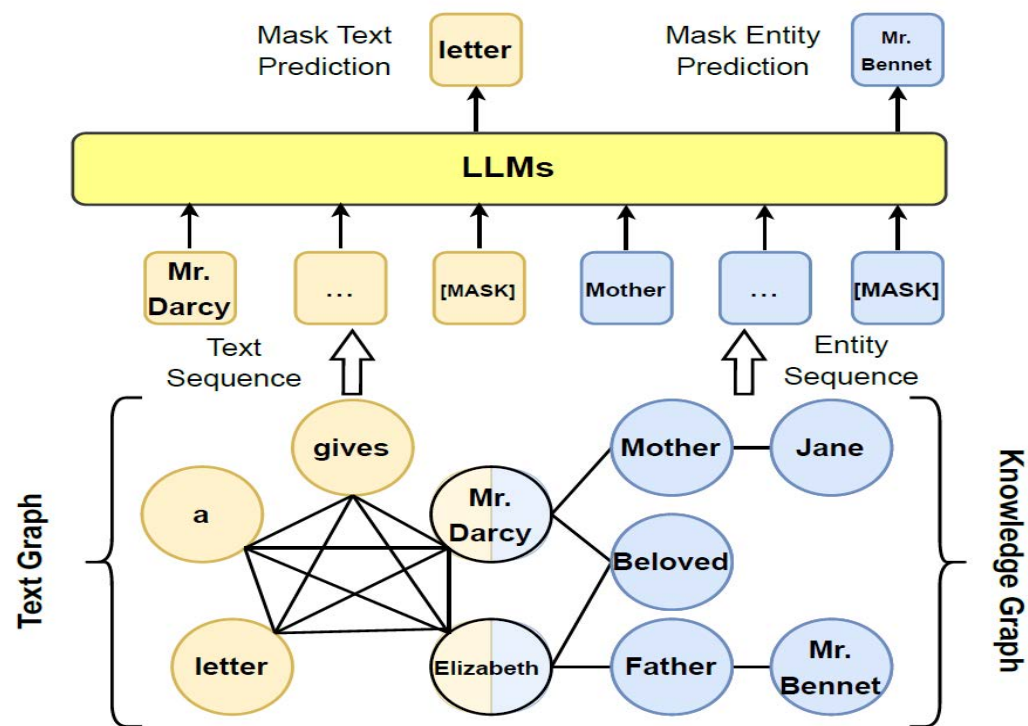
- ERNIE training objective: word-entity alignment



Input Text: Bob Dylan wrote Blowin' in the Wind in 1962

Integrate KG with text as LLM training input

- CoLAKE: word-knowledge graph



Input Text: Mr. Darcy gives Elizabeth a letter

When KG meets LLM: Knowledge or Structural Augmented

- More research indicates that introducing various types of **internal and external structured signals** during the pre-training phase can improve model performance:
 - **External structured signal enhancement:** For example, incorporating Protein-Protein Interaction (PPI) information in the training of protein language models.
 - **Internal structured signal enhancement:** For example, expanding the relational information between entities within sentence samples during sentence pre-training.

Introduce external structured signals to training corpora

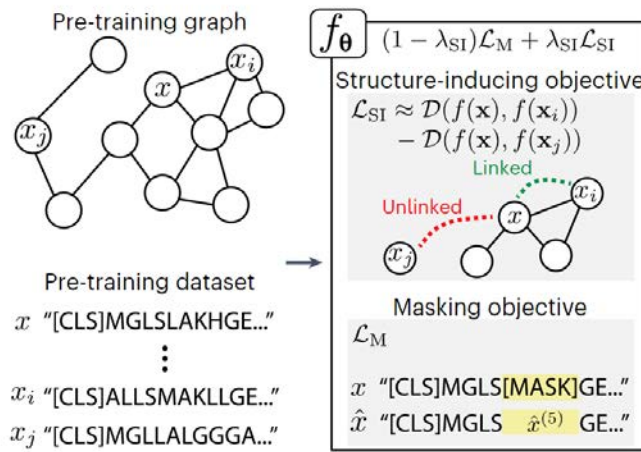
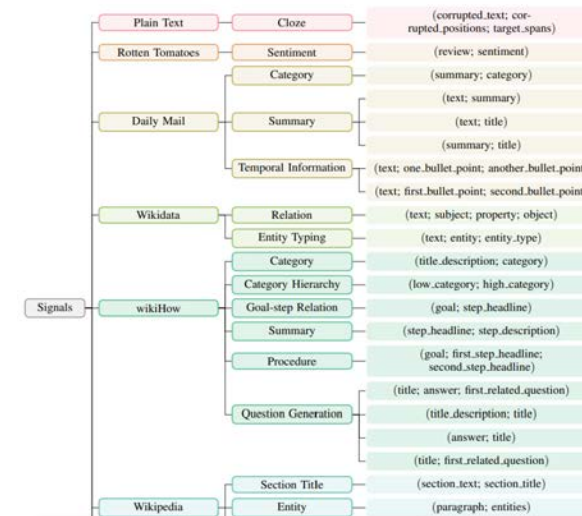


Figure 1: Structure-inducing Pre-training. PT graph G_{PT} as input to the pre-training objective \mathcal{L}_{SI} , which pushes a PT encoder f_{θ} to embed samples such that samples are close in the latent space if and only if they are linked in G_{PT} .

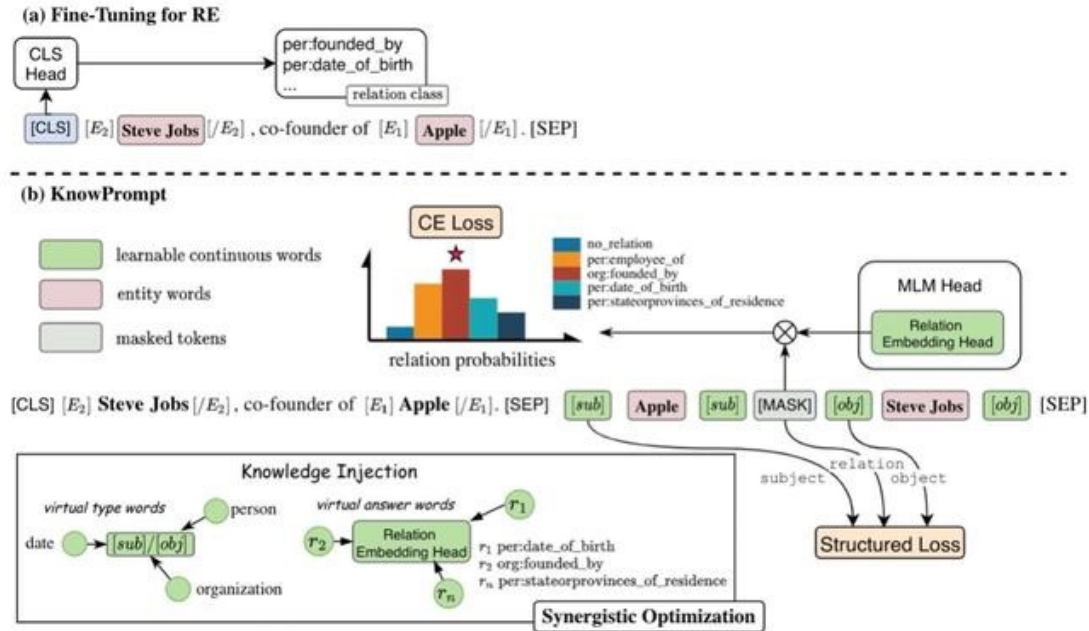
- Structure-inducing pre-training. Nature Machine Intelligence 2023.
- reStructured Pre-training. 2022



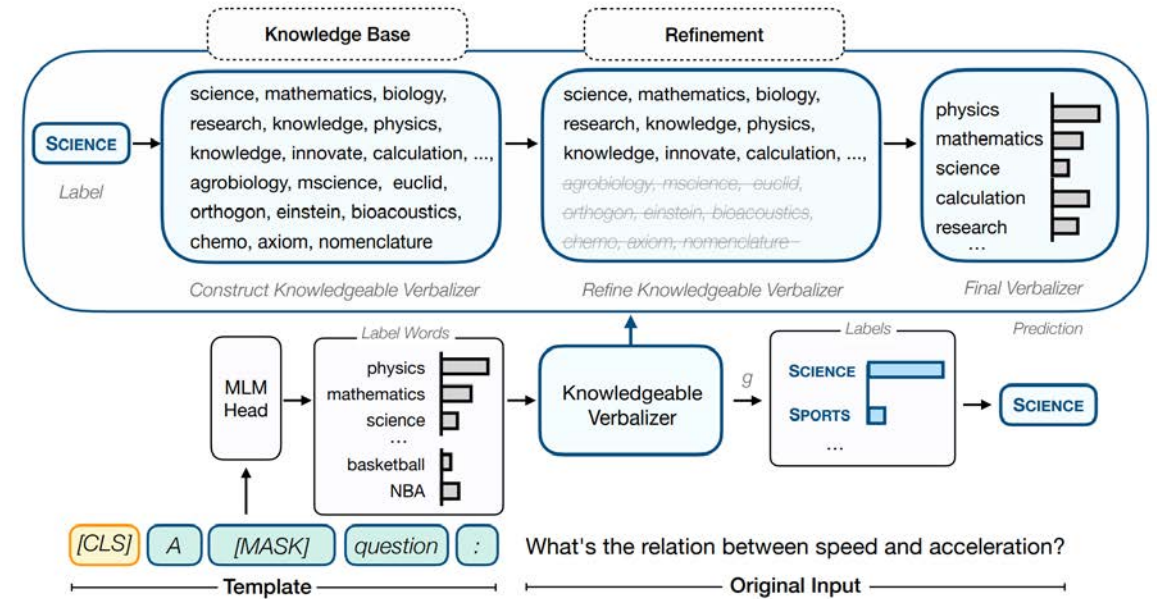
Enhance the internal structured signals of training corpora

reStructured Pre-training

When KG meets LLM: Knowledgeable Prompt Tuning



KnowPrompt



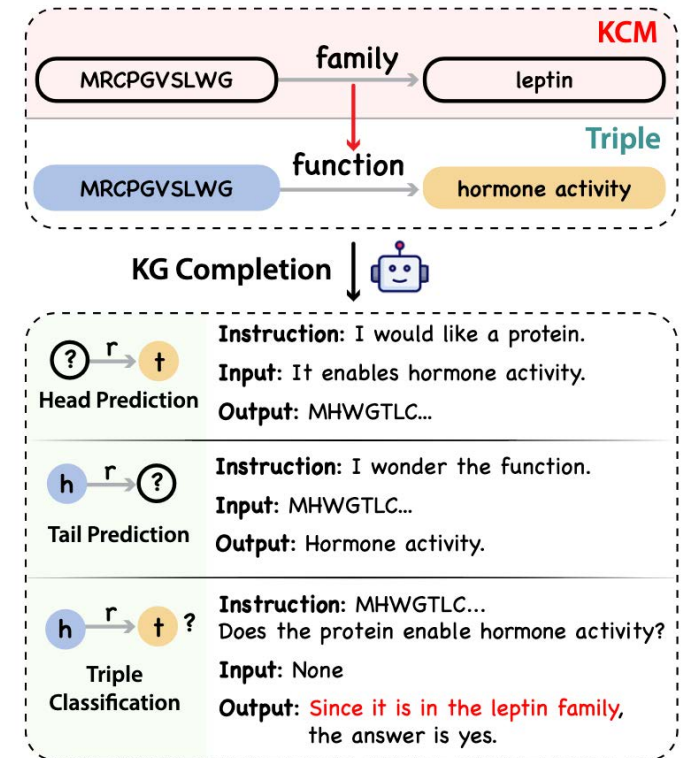
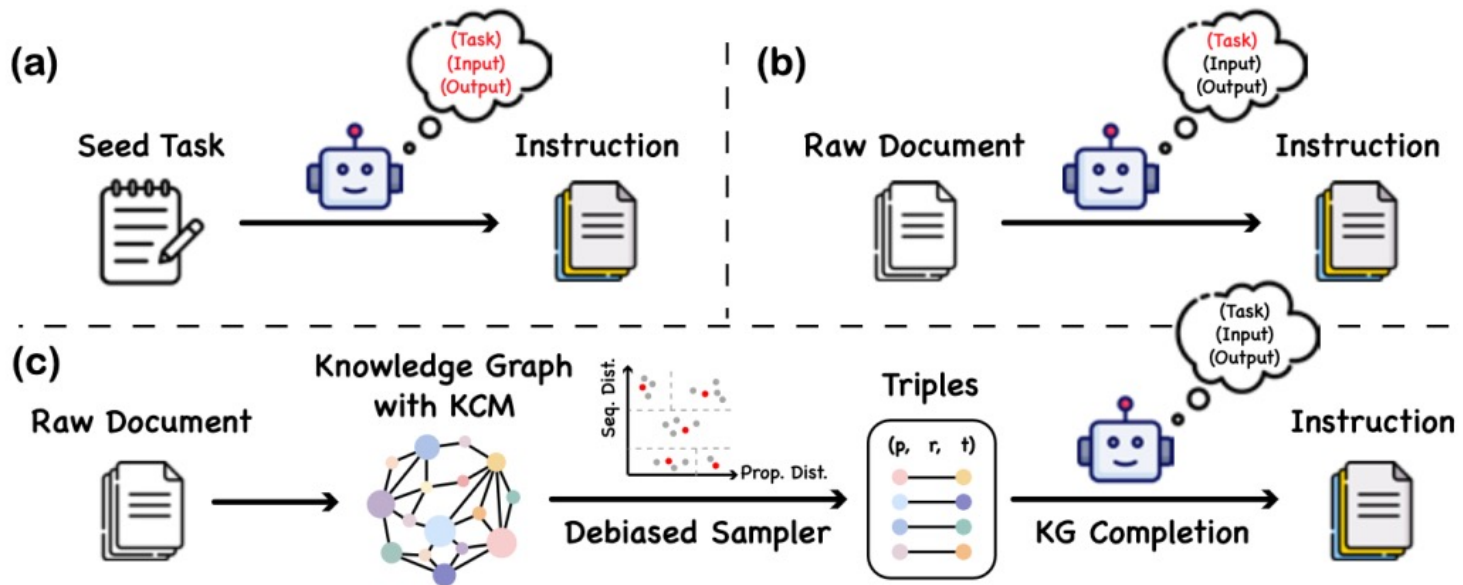
Knowledgeable Prompt-tuning

- KnowPrompt: Knowledge-aware Prompt-tuning with Synergistic Optimization for Relation Extraction. WWW 2022
- Knowledgeable Prompt-tuning: Incorporating Knowledge into Prompt Verbalizer for Text Classification. ACL 2022

When KG meets LLM: Instruction Construction

- Knowledge graphs can also guide the construction of instruction datasets. For example, the triples in the graph can guide the setting of Input/Output for instruction templates, and the association signals in the graph can be used to ensure that the instruction dataset has better logic, relevance, and structure.

Knowledge to Instruction

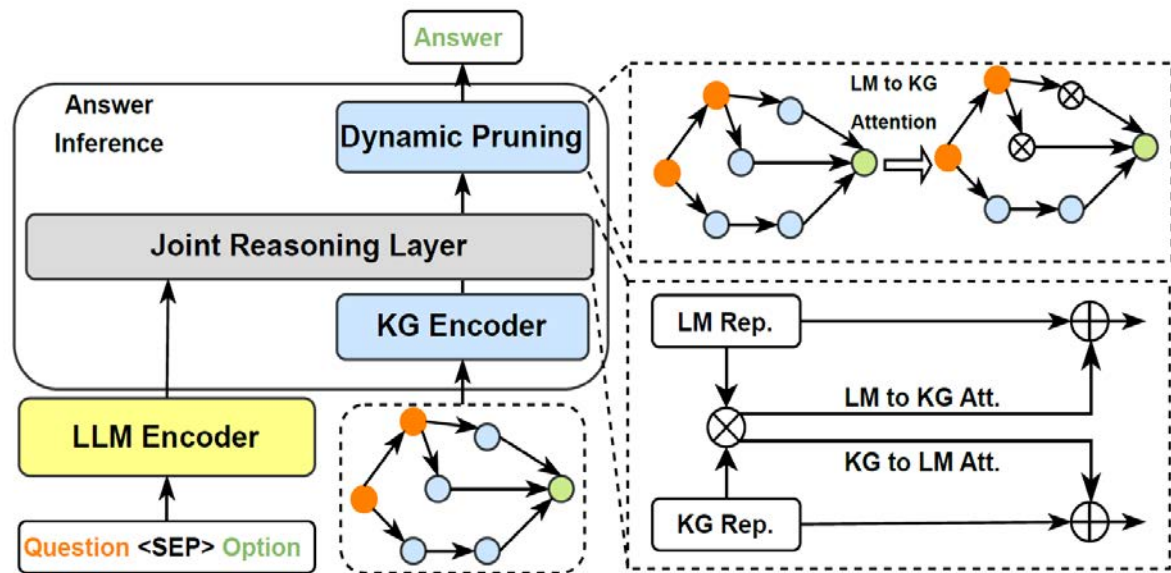


KG for LLM : Inference

Problems during the pre-training phase: Knowledge updating

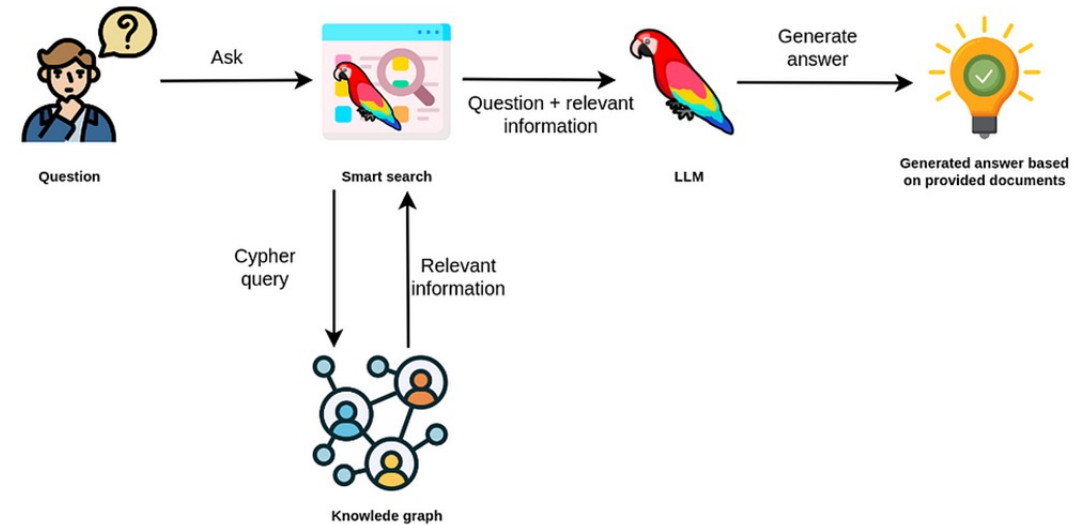
Dynamic KG integration method

- JointLK: LM-to-KG and KG-to-LM bidirectional attention mechanism



Retrieval-augmented KG integration method

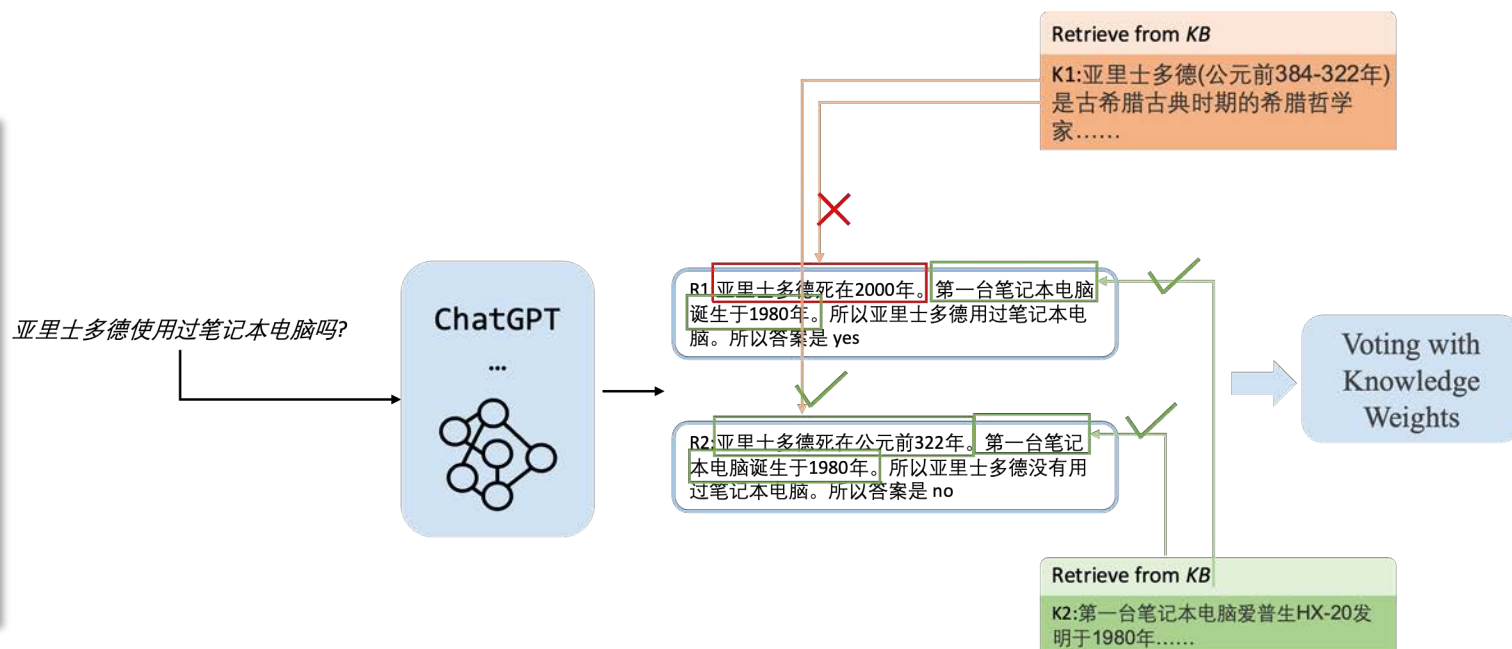
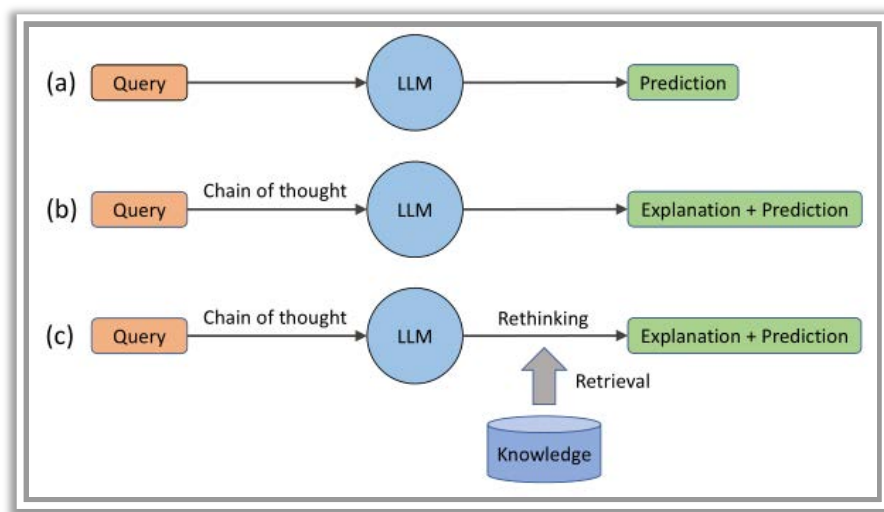
- RAG: Retrieve external KG as LLM input



- Y. Sun, Q. Shi, L. Qi, and Y. Zhang, "JointLK: Joint reasoning with language models and knowledge graphs for commonsense question answering," 2022.
- P. Lewis, E. Perez, A. Piktus, et al, "Retrieval-augmented generation for knowledge intensive nlp tasks," NeurIPS 2020.

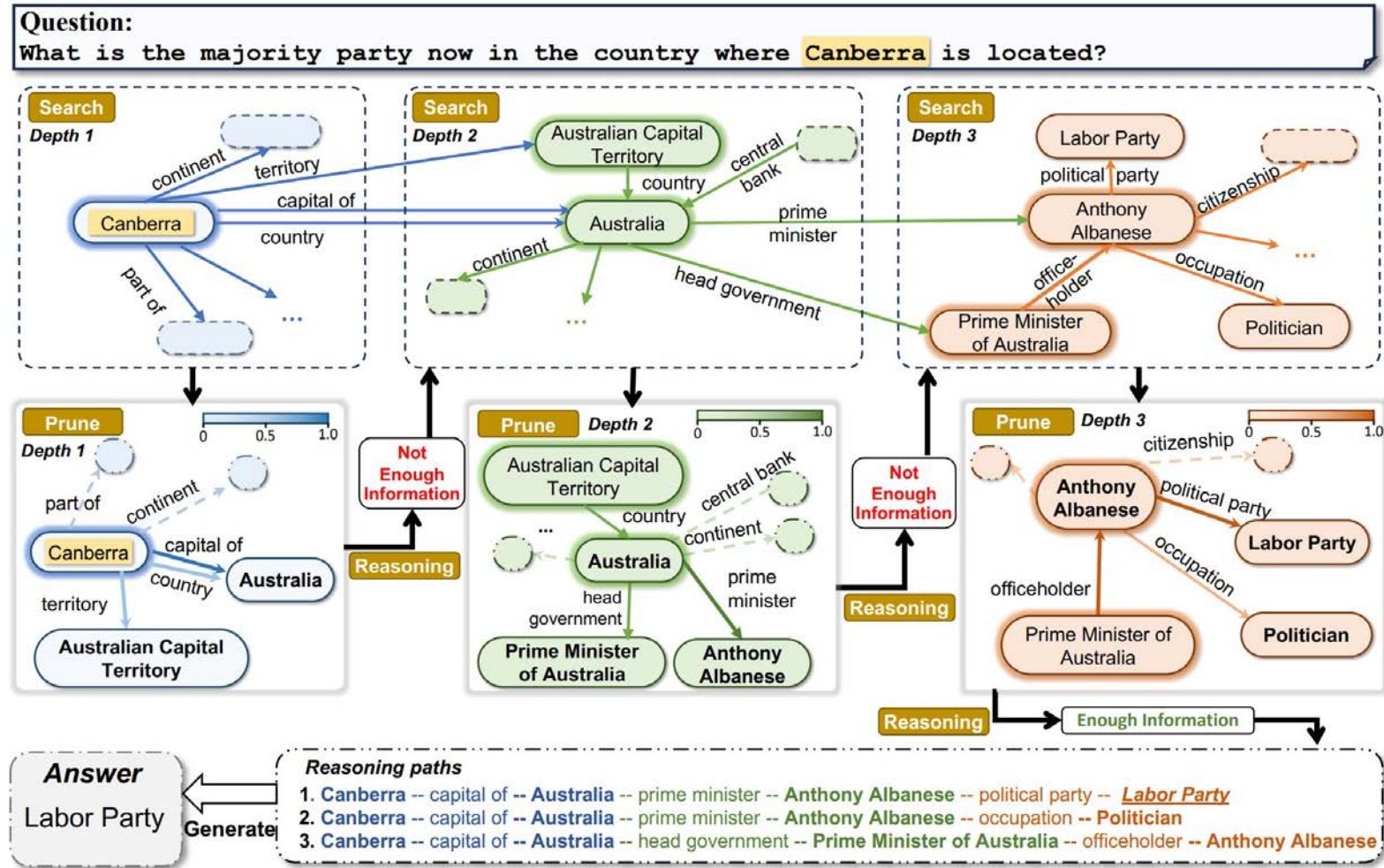
KG for LLM : Retrieval/Knowledge Augmented Generation

- Using a knowledge graph as an external knowledge base during the inference of pre-trained models
- For example: Rethinking



When KG meets LLM: KG-induced CoT

- Utilizing entity association paths from external knowledge graphs to guide LLM in question decomposition, improving the accuracy of multi-hop question answering.



• Think-on-graph: Deep and responsible reasoning of large language model with knowledge graph. ICLR 2024.

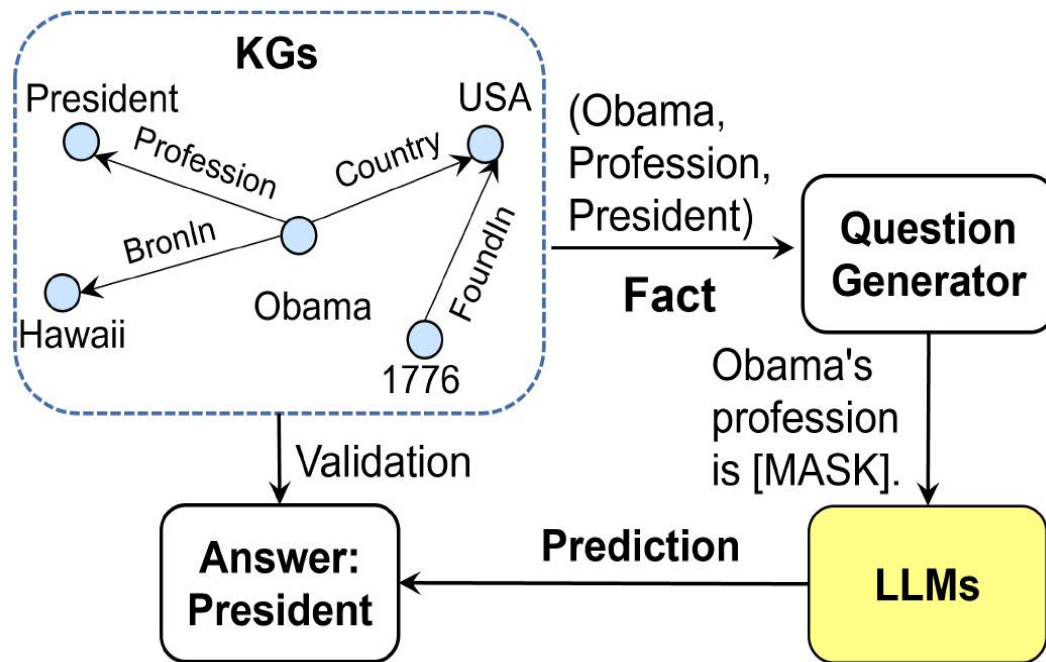
• Graph Chain-of-Thought: Augmenting Large Language Models by Reasoning on Graphs. 2024

KG for LLM : Interpretability

An important issue with LLMs: Lack of explainability, affecting applications in critical

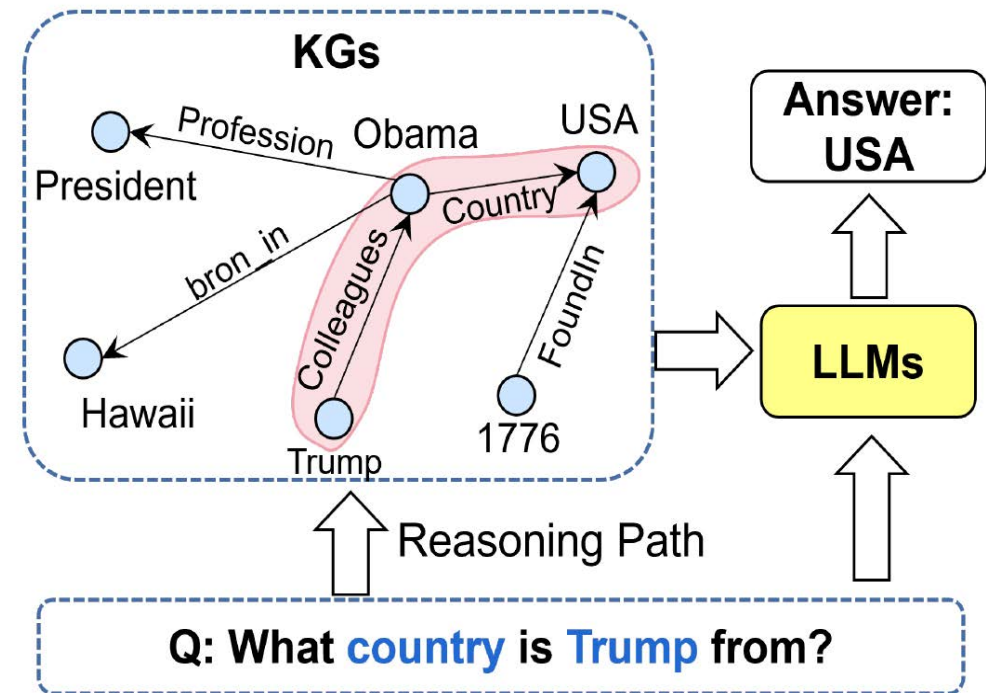
KG-based LLM probing and evaluation methods

- LAMA: Converts knowledge from KG into prompt templates and uses LLM predictions to verify the accuracy of LLM knowledge



KG-based analysis of LLM-generated results

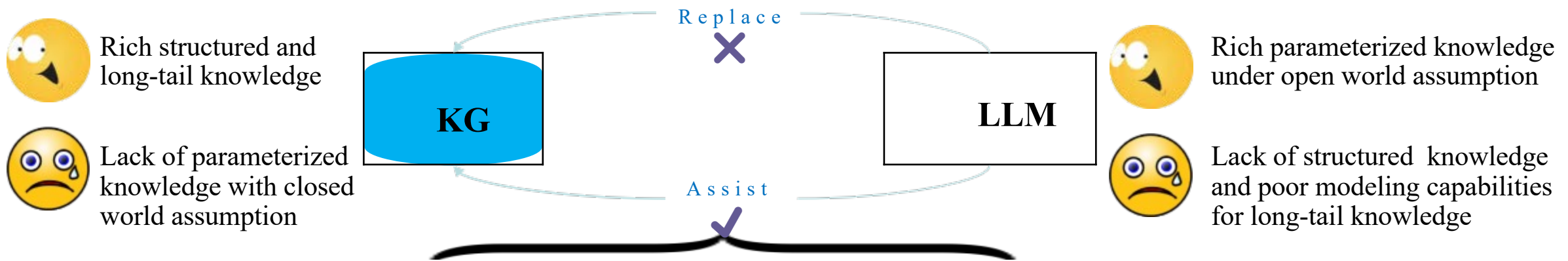
- KagNet, QA-GNN: LLM outputs are explained by KG graph structures



- F. Petroni, T. Rocktaschel, S. Riedel, et al, "Language models as knowledge bases?" EMNLP 2019.
- B. Y. Lin, X. Chen, J. Chen, and X. Ren, "Kagnet: Knowledge-aware graph networks for commonsense reasoning," EMNLP 2019
- M. Yasunaga, H. Ren, A. Bosselut, et al, "QAGNN: Reasoning with language models and knowledge graphs for question answering," NAACL 2021

Leveraging Large Models in Knowledge Graph Research

■ Knowledge Engineering **BY** the LLM



- LLM as resources
 - data augmentation
 - a form of knowledge source



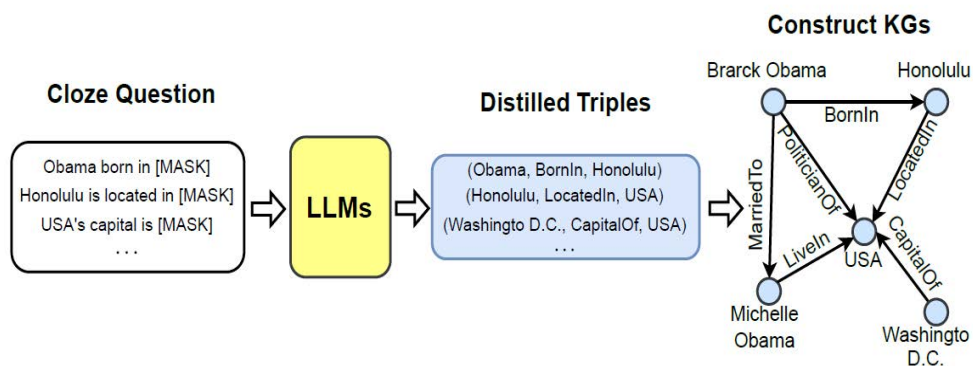
- LLM as enablers
 - encoders with parameter fine-tuning
 - Reading comprehension & QA

LLM for KG : Knowledge Extraction

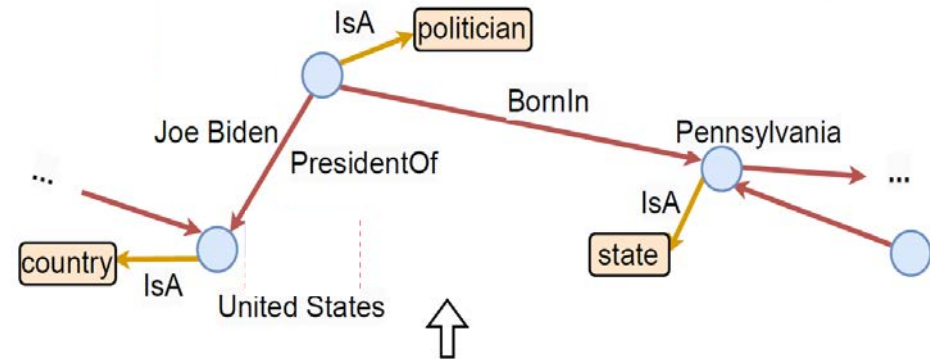
LLM-based KG Construction Methods

1. Entity Recognition
2. Entity Typing
3. Coreference Resolution
4. Relation Extraction

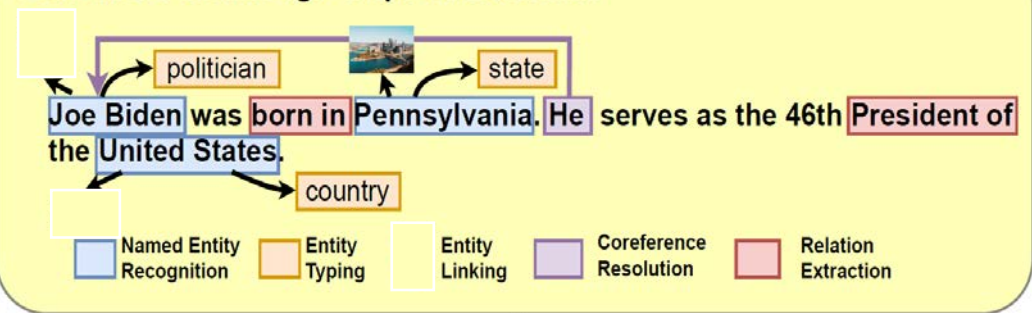
- LLM-based End-to-End KG Construction
- LLM-based KG Distillation Construction



Knowledge Graph



LLM-based Knowledge Graph Construction



Text: Joe Biden was born in Pennsylvania. He serves as the 46th President of the United States.

- A. Kumar, A. Pandey, R. Gadia, et al, "Building knowledge graph using pre-trained language model for learning entity-aware relationships," 2020.
- A. Bosselut, H. Rashkin, M. Sap, et al, "Comet: Commonsense transformers for knowledge graph construction," ACL 2019.

LLM for KG : Knowledge Extraction



Schema Old



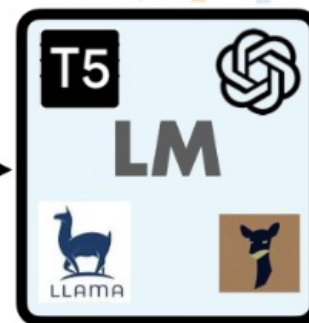
Schema New

a) Traditional approaches

b) Instruction-based IE

Input: Timothy Cook (born November 1, 1960), is an American business executive. He currently serves as the CEO of Apple.

Instruction: You are our relation triple detector. The provided relation list is **{Schema}**. Based on this list, extract relation triples. Which relation triples might be present in this sentence? If a relation is missing, output NAN. Please respond in the format of **(Subject,Relation,Object)**.



Schema Old

Schema New

Schema Old + Instruction

Schema New + Instruction

Timothy Cook:
time of birth: November 1, 1960
affiliated organization: Apple ✓

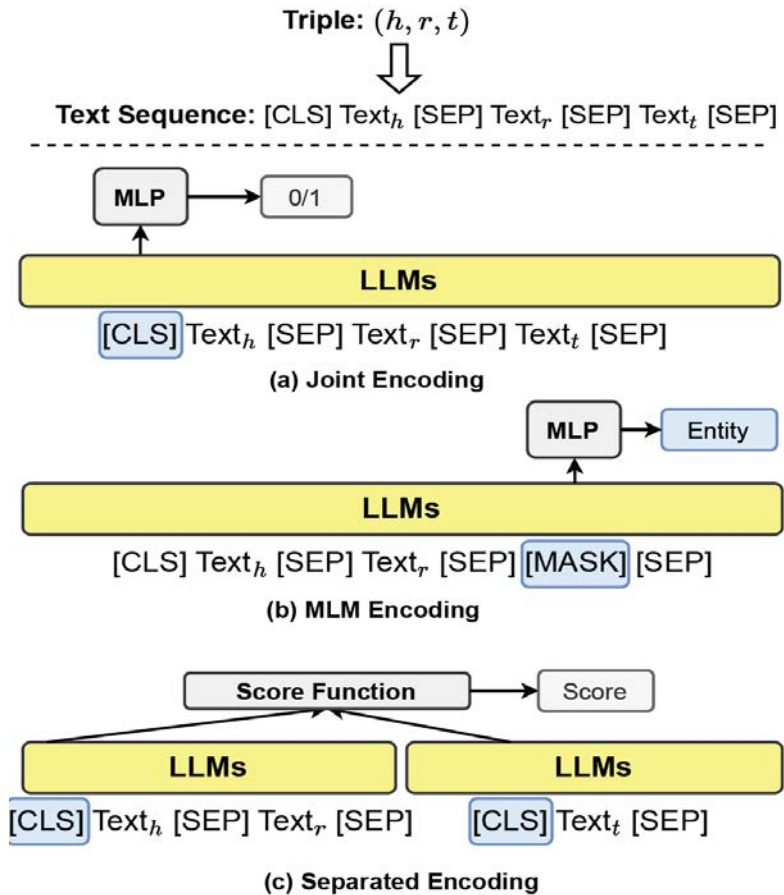
Timothy Cook:
time of birth: November 1, 1960
affiliated organization: Apple ✗

(Timothy Cook, time of birth, November 1, 1960) (Timothy Cook, affiliated organization, Apple) ✓

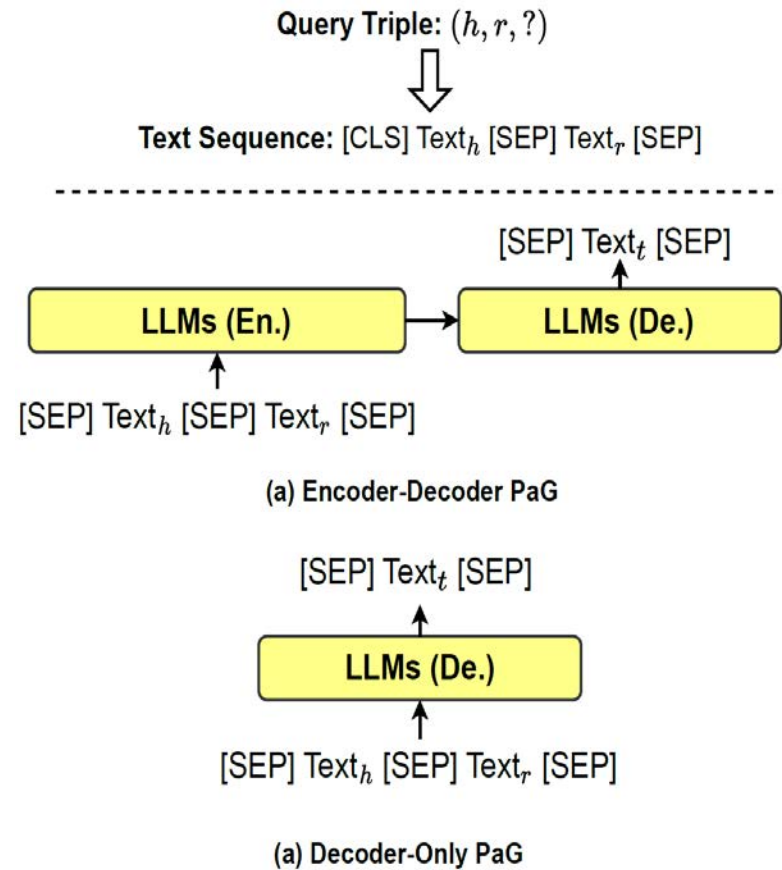
(Timothy Cook, time of birth, November 1, 1960) (Timothy Cook, affiliated organization, Apple),
(Timothy Cook, post, CEO) ✓

LLM for KG : Knowledge Completion

LLM as Encoder



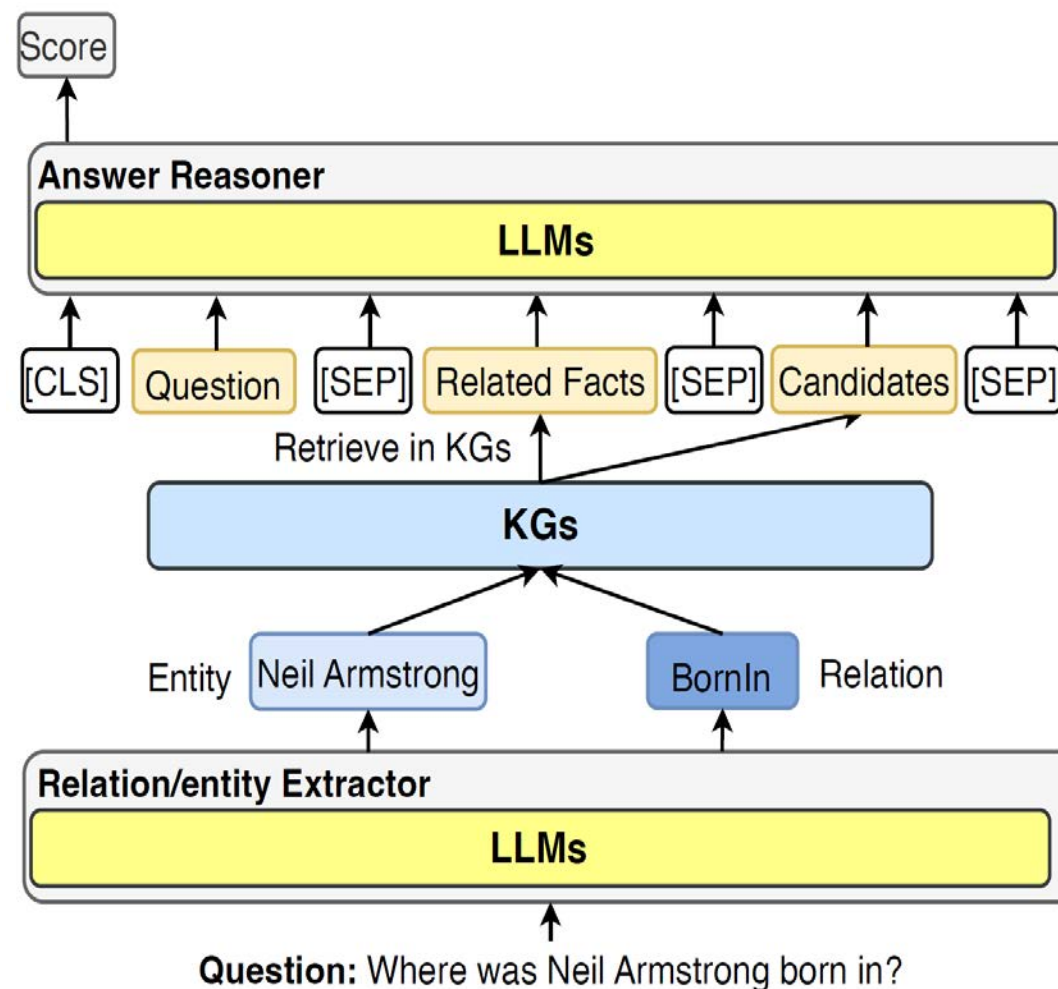
LLM as Generator



LLM for KG : Knowledge-based Question Answering

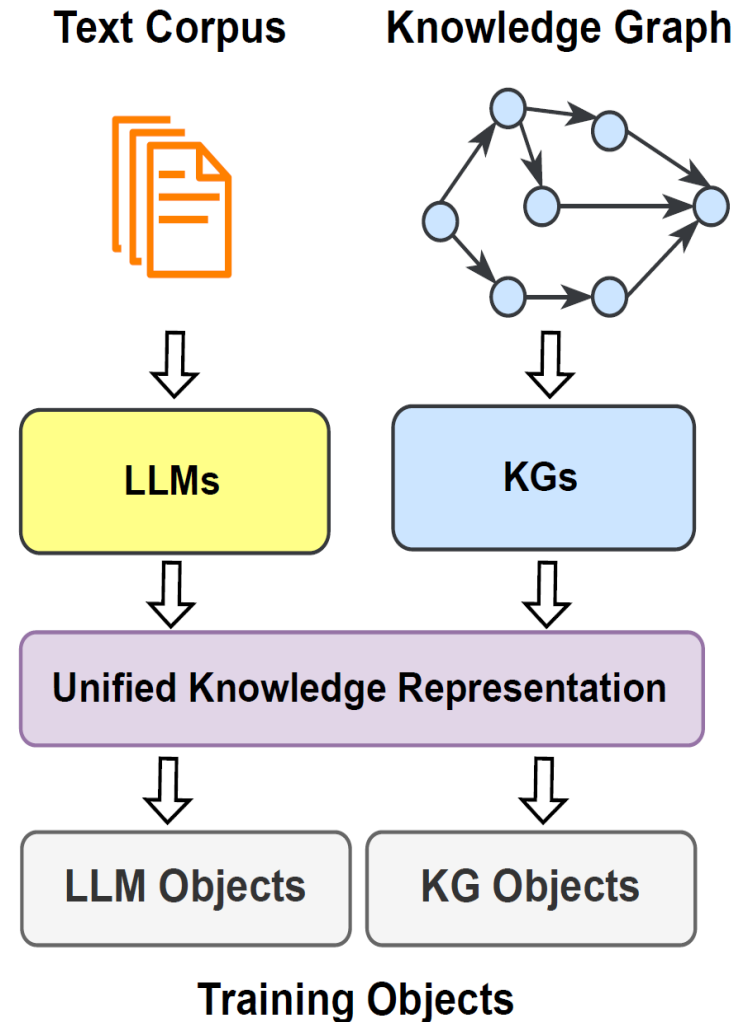
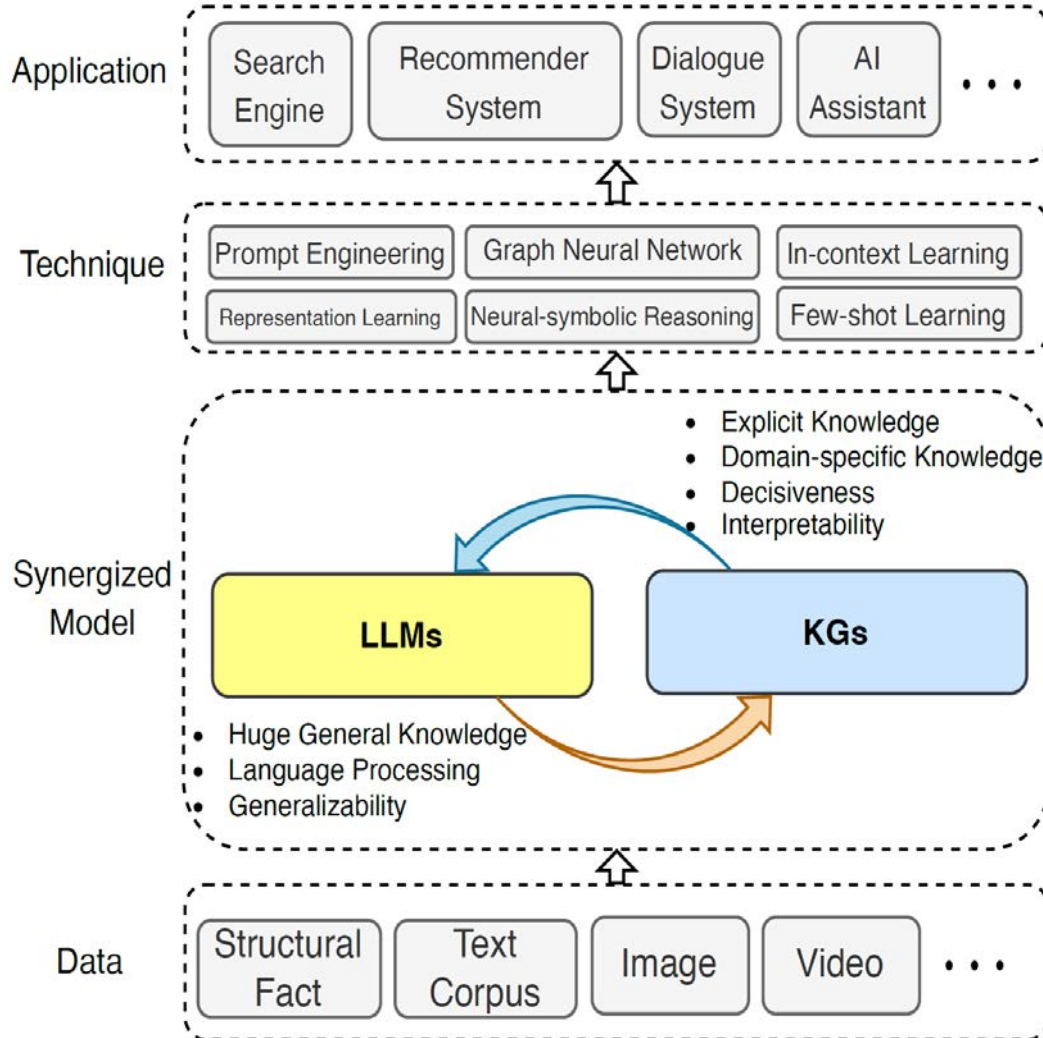
LLM as Entity/Relation extractor

LLM as Answer reasoner



- D. Lukovnikov, A. Fischer, and J. Lehmann, "Pretrained transformers for simple question answering over knowledge graphs," ISWC 2019
- Y. Xu, C. Zhu, R. Xu, Y. Liu, M. Zeng, and X. Huang, "Fusing context into knowledge graph for commonsense question answering," ACL 2021
- M. Zhang, R. Dai, M. Dong, et al "Drhk: Dynamic hierarchical reasoning with language model and knowledge graph for question answering," EMNLP 2022
- Y. Yan, R. Li, S. Wang, et al, "Large-scale relation learning for question answering over knowledge bases with pre-trained language models," EMNLP 2021

When KG Meets LLM: Deep Synergies

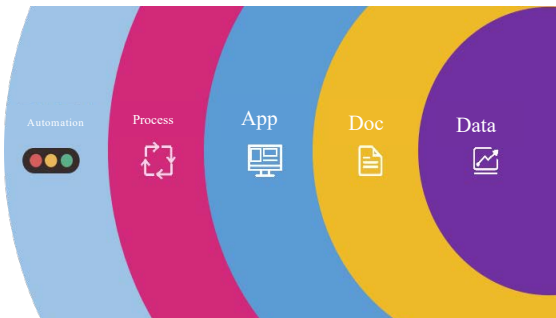
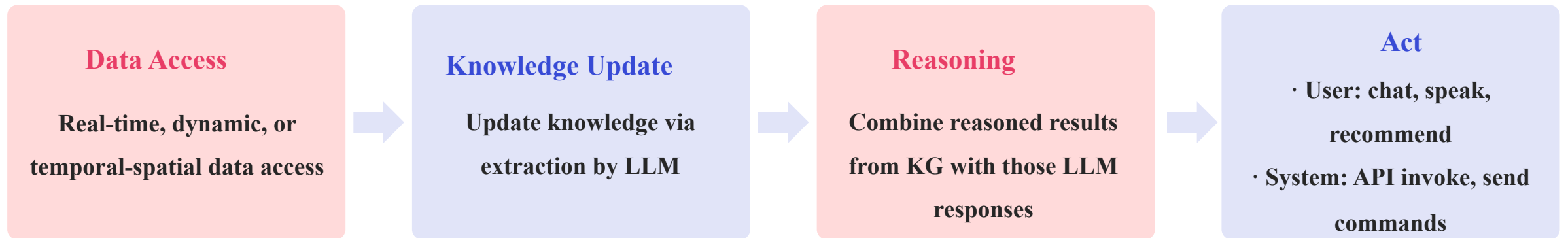


When KG meets LLM: Interoperability & Orchestration

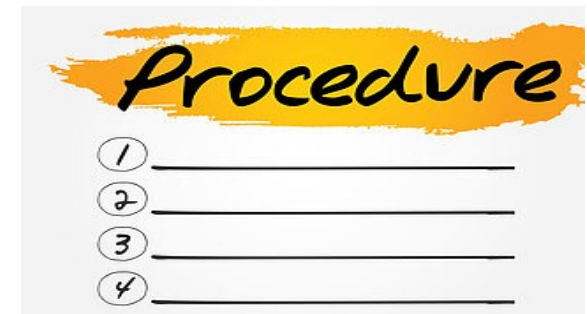
KG uses ontology to realize the representation of domain data, knowledge and interaction, and completes the automation of the whole process from real-time data access, knowledge update to user interaction.

Interoperate & Orchestrate

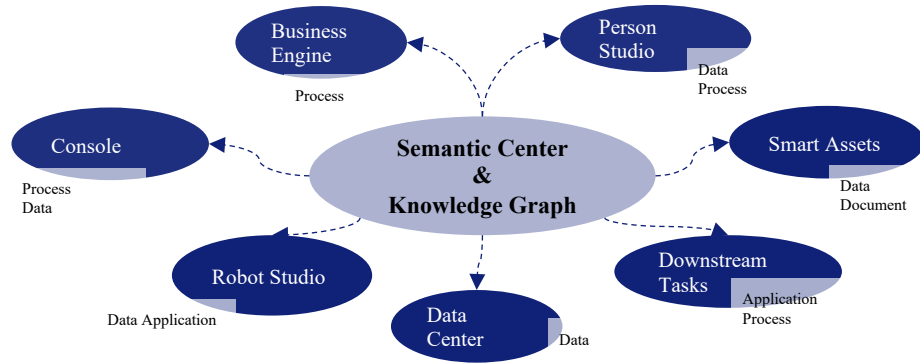
Integrate the following steps into a whole end-to-end process for hyper-automation



- Task mining
- Consistency checking
- Process discovery
- Modeling via simulation
- Case prediction
- Suggestion via history data

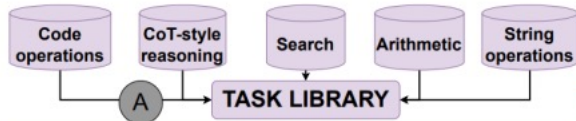


When KG meets LLM: Interoperability & Orchestration



RPA + Tool use

New Task (Physics QA) Answer this high-school physics question
Input: Hector yanks on the chain with a 72.0 N force at an angle of 35.0° above the horizontal. Determine the horizontal components of the tension force.

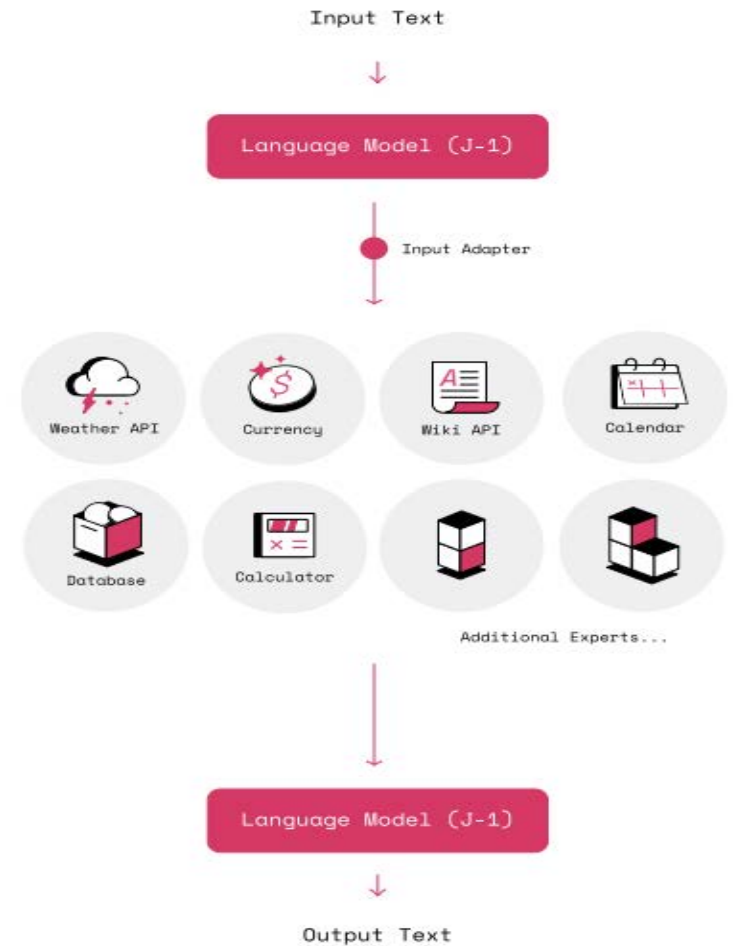


Solve these arithmetic problems using python code
Input: Viola had 167 breads. Nancy took 137 from him. How many does Viola have now?
Q1: [generate code] Write down arithmetic as python code
#1: viola_bought = 167, nancy_took = 137
 ans = viola_bought - nancy_took
Q2: [code execute] Execute snippet **#2:** 30 **Q3:** [EOQ] **Ans:** No

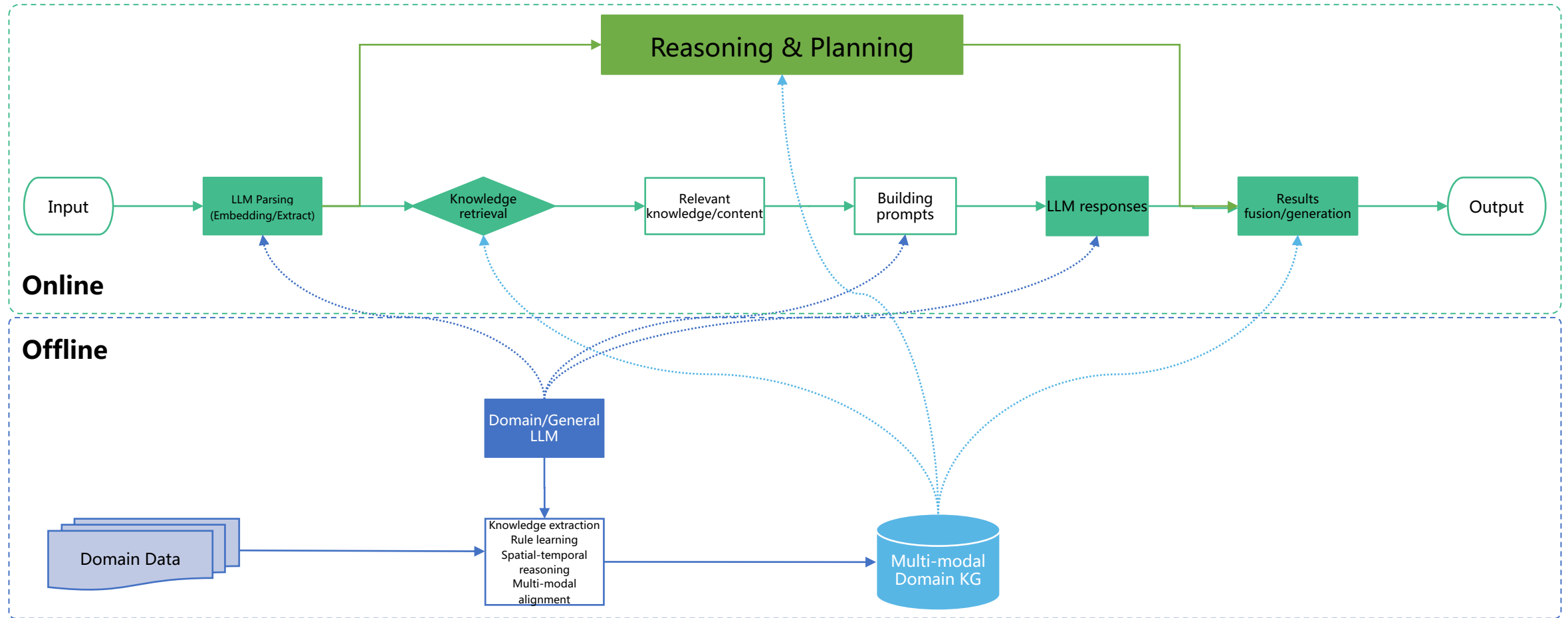
Does the sentence contain an anachronism? Yes/No.
Input: President George H. W. Bush called his generals at the outset of the Gulf War.
Q1: [search] When was President George H. W. Bush, president?
#1: George H. W. Bush's tenure started on January 20, 1989, and ended on January 20, 1993.
Q2: [search] When was the Gulf War fought? **#2:** The Gulf War was a 1990–1991
Q3: [subquestion] Could these entities have co-existed? **#3:** Yes. Their time periods intersect.
Q4: [generate output] Is this an anachronism? **#4:** No **Q5:** [EOQ] **Ans:** No

LLM **Input:** Hector yanks on the chain with a 72.0 N force at an angle of 35.0° above the horizontal. Determine the horizontal components of the tension force.
Q1: [search] What is the formula for the horizontal component of the tension force?
#1: The formula for the horizontal component of the tension force is $T \cos \theta$. The horizontal component (F_x) can be calculated as $F_{tens} \cdot \cos(\theta)$ where θ is the angle which the force makes with the horizontal in radians.
OpenAI Codex
Input: ... **Q1:** [search] ...
#1: ... can be calculated as $F_{tens} \cdot \cos(\theta)$ where θ is ...
Q2: [generate code] Use the formula $F_x = F_{tens} \cdot \cos(\theta)$ to solve: Hank ...
#2: $T = 72.0$, $\theta = 35.0$
 $radians = \text{math.pi} * \theta / 180$
 $F_x = T * \text{math.cos}(radians)$
python
Input: ... **Q1:** [search] ... **#1:** ...
Q2: [generate code] Use the formula $F_x = F_{tens} \cdot \cos(\theta)$ to solve: Hank ...
#2: ... $F_x = T * \text{math.cos}(radians)$
Q3: [code execute] Execute the python code and get the value of "Fx"
#3: 58.9789
Q4: [EOQ] **Ans:** 58.9789

Adaptive Routing



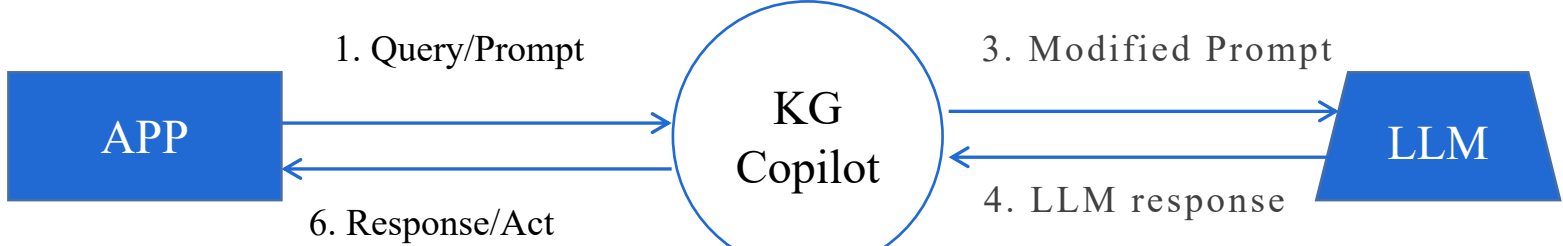
Retrieval/Knowledge Augmented Generation Whole Picture



KG Copilot Engine

❖ **KG for unified knowledge modeling**

- ❖ Multi-modal data
- ❖ Multi-source data



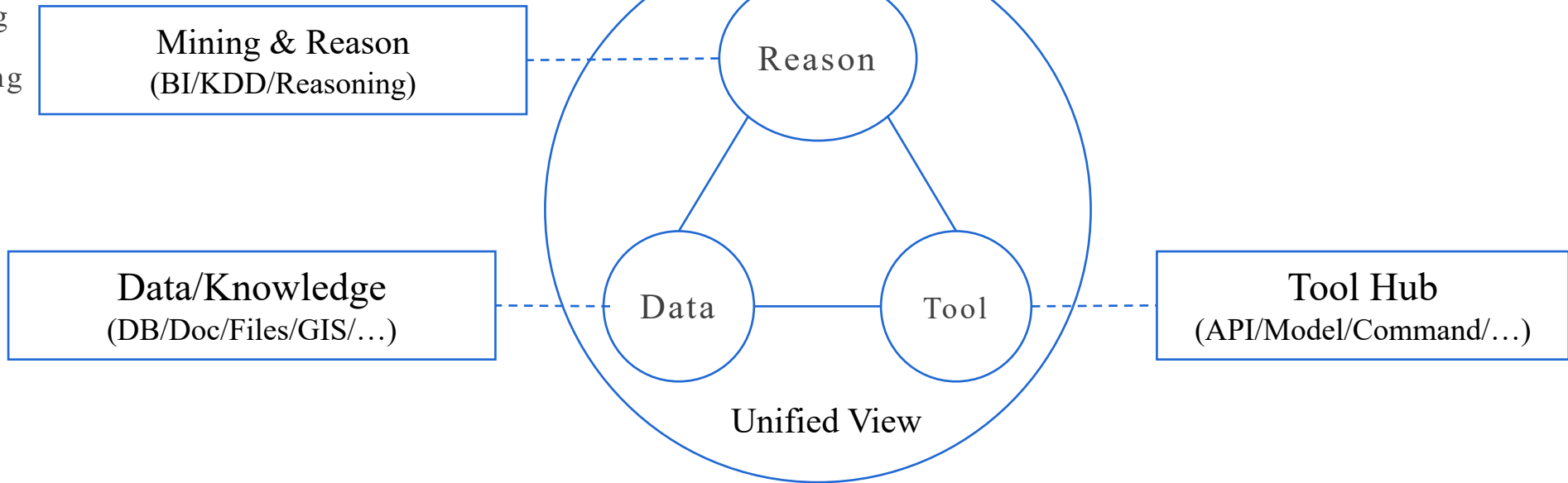
❖ **KG for unified programming as a semantic gateway**

- ❖ LLM + KG + Tool

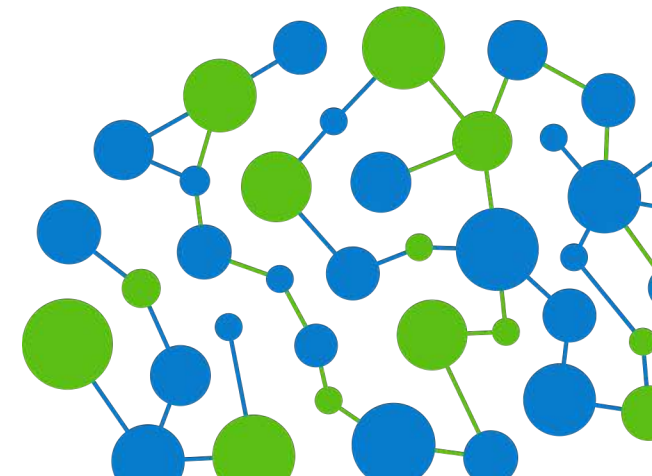
- a. Prompt build
- b. refinement
- 2. Pre-processing
- 5. Post-processing
- a. Fact checking
- b. Data query
- c. Tool invoke
- d. Reasoning
- e. Result fusion

❖ **KG for automatic prompt building and result checking**

- ❖ Pre-processing grounding
- ❖ Post-processing grounding

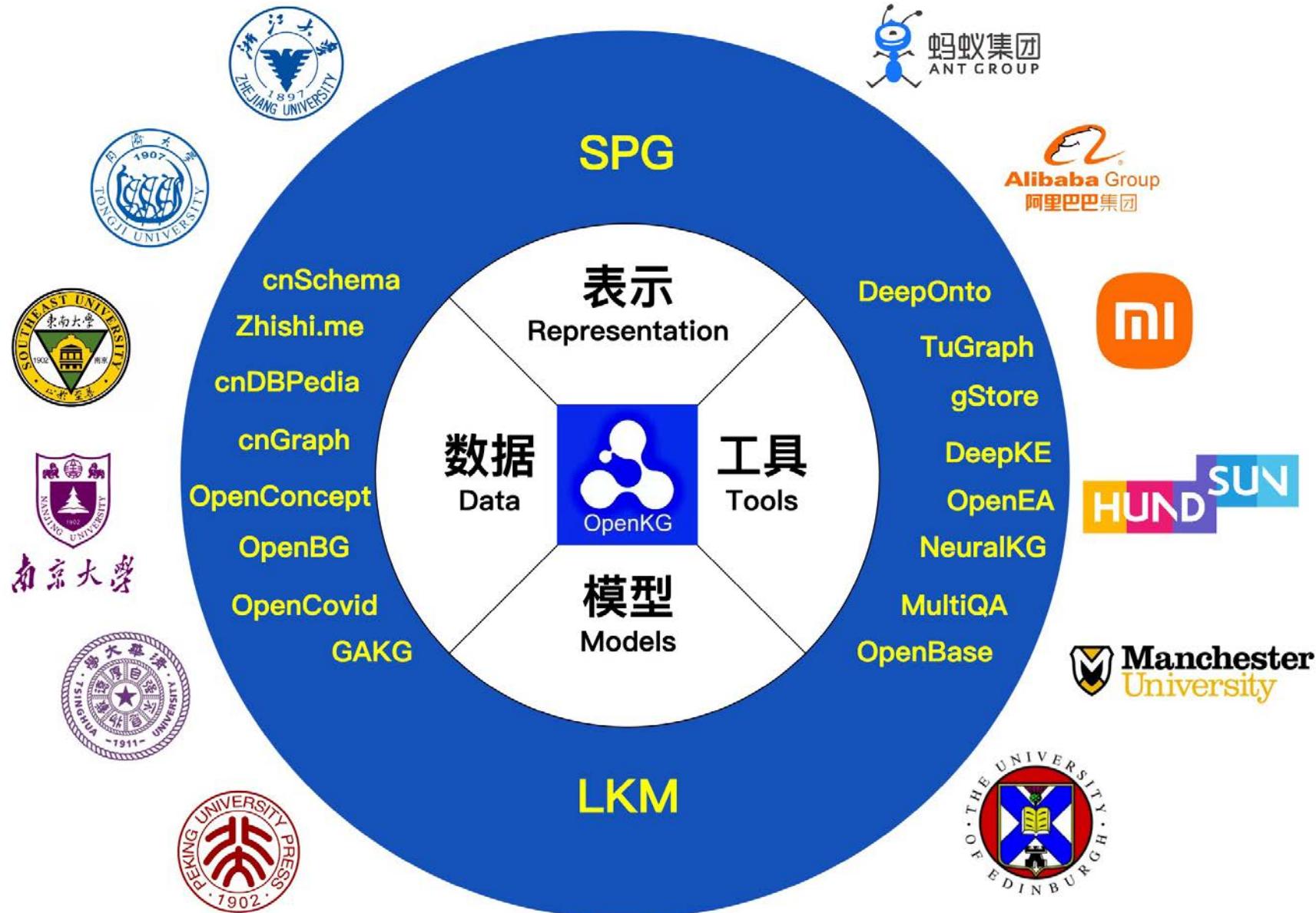


- The Rise of LLM
- The Development of KG
- The Emerging Paradigm
- **OpenKG**
- Conclusion and Outlook

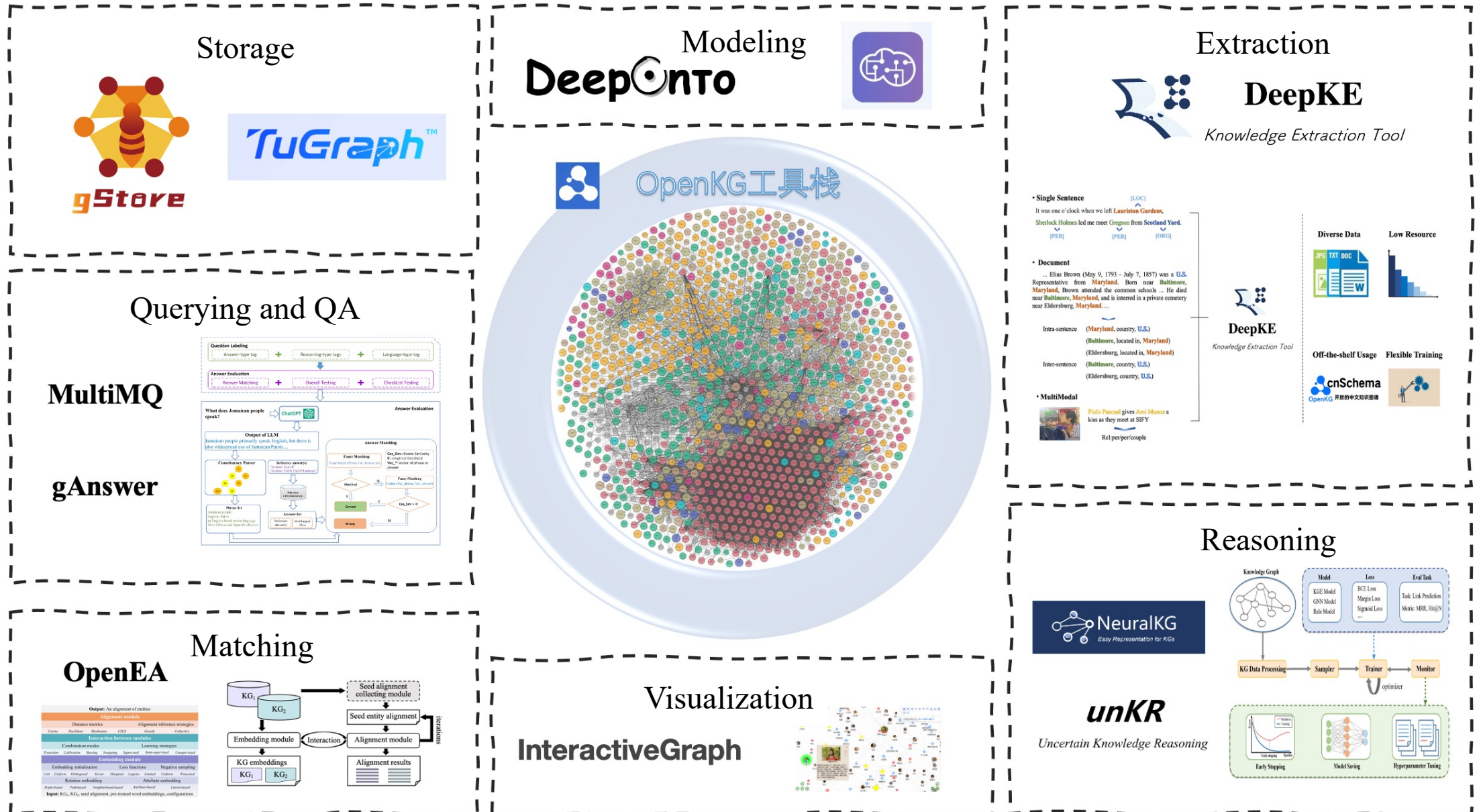


OpenKG

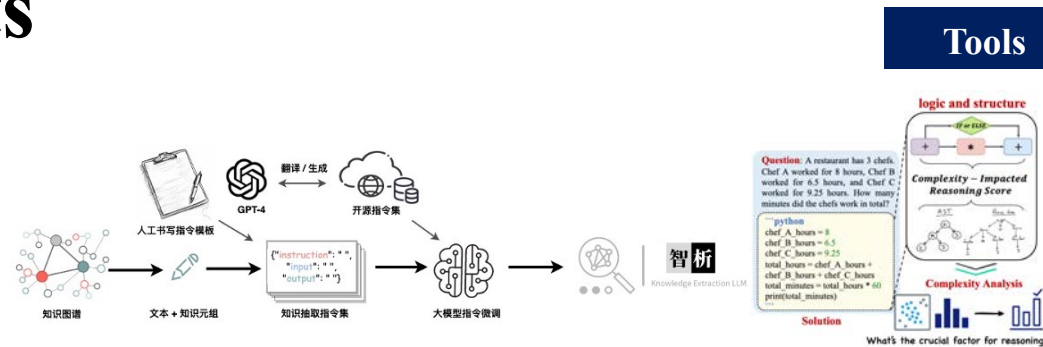
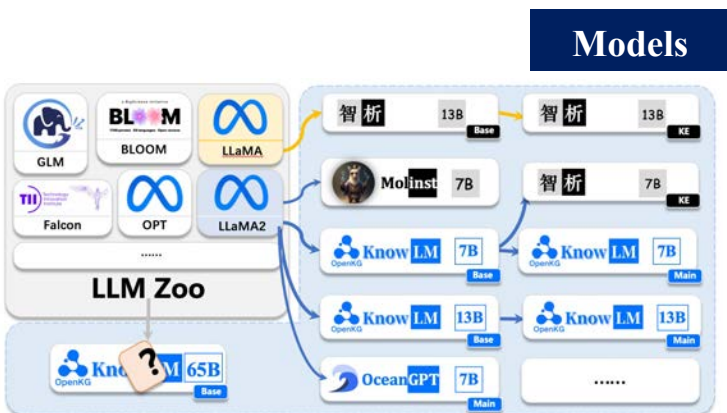
Established in 2015, it initially aimed to promote **the world's largest open knowledge graph centered on Chinese**. By 2023, the goal has evolved to, through an open, collaborative, sustainable, and scalable approach, build a **globally leading knowledge graph ecosystem in the era of large models**, providing intelligent knowledge services for various industries and promoting the sharing and enhancement of knowledge value.



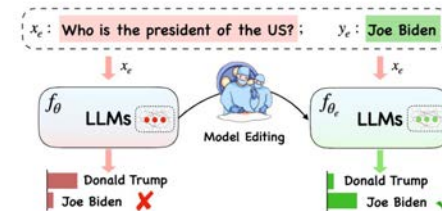
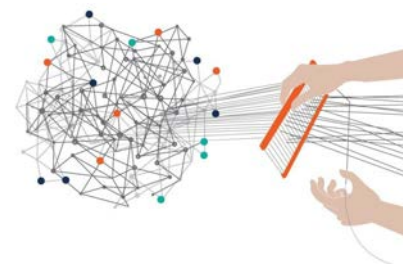
OpenKG: Full Stack Tools



OpenKG: Tools, Models and Agents



Enhancing large model training based on knowledge graphs



Editing large models after deployment based on knowledge graphs

OpenKG: Open RAG



inheritance and development of RAG paradigms

RAG Flow

The selection and arrangement of different modules and operators within the modules constitute RAG Flow, thereby identifying typical RAG Flow patterns.

3 Tuning Stage

- Retriever FT
- Generator FT
- Dual FT

4 Inference Stage

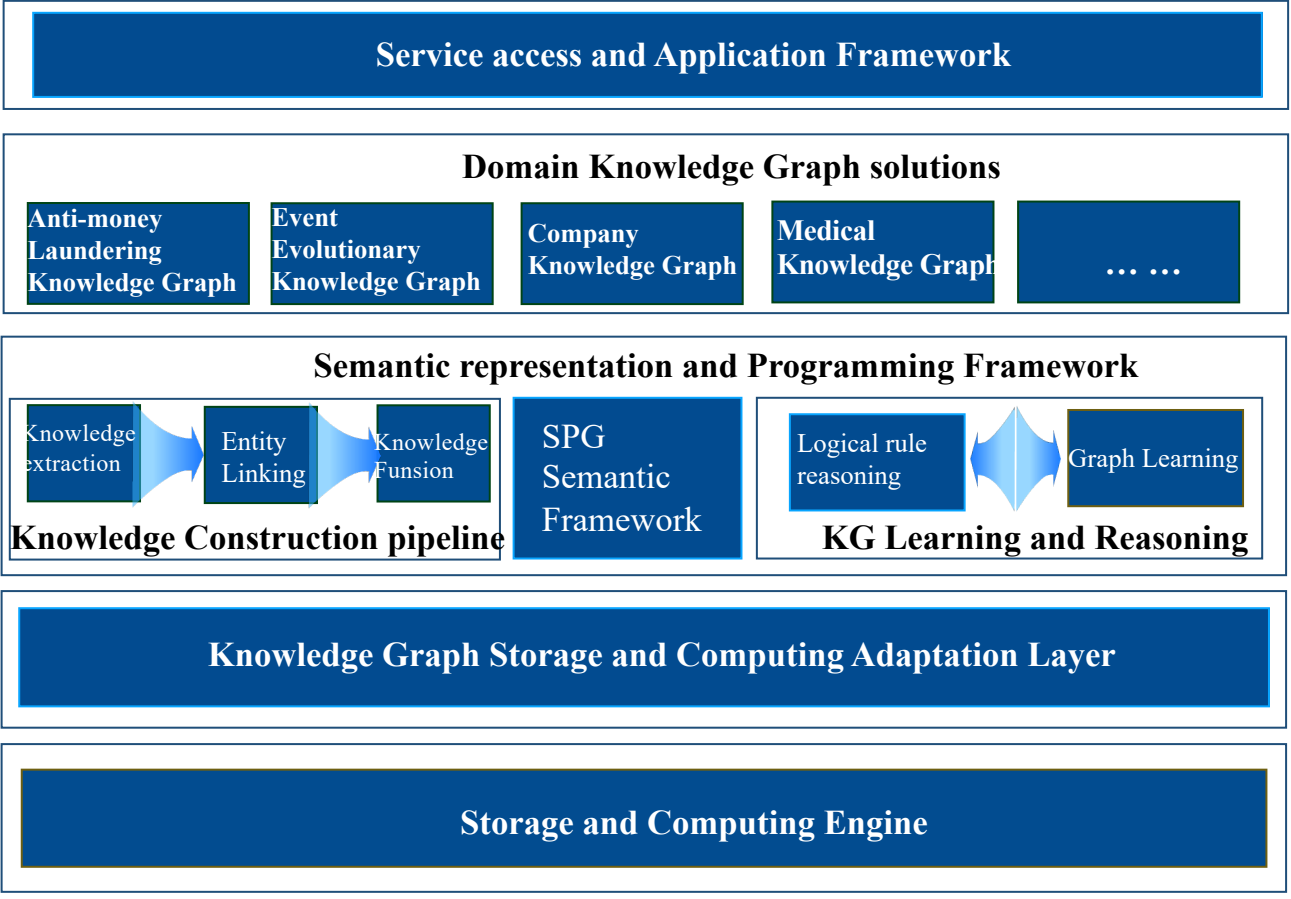
- Sequential
- Conditional
- Branch
- Loop



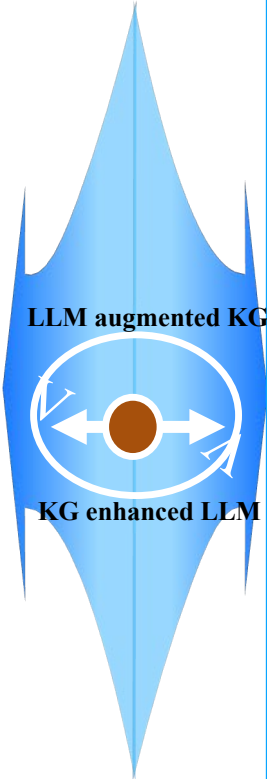
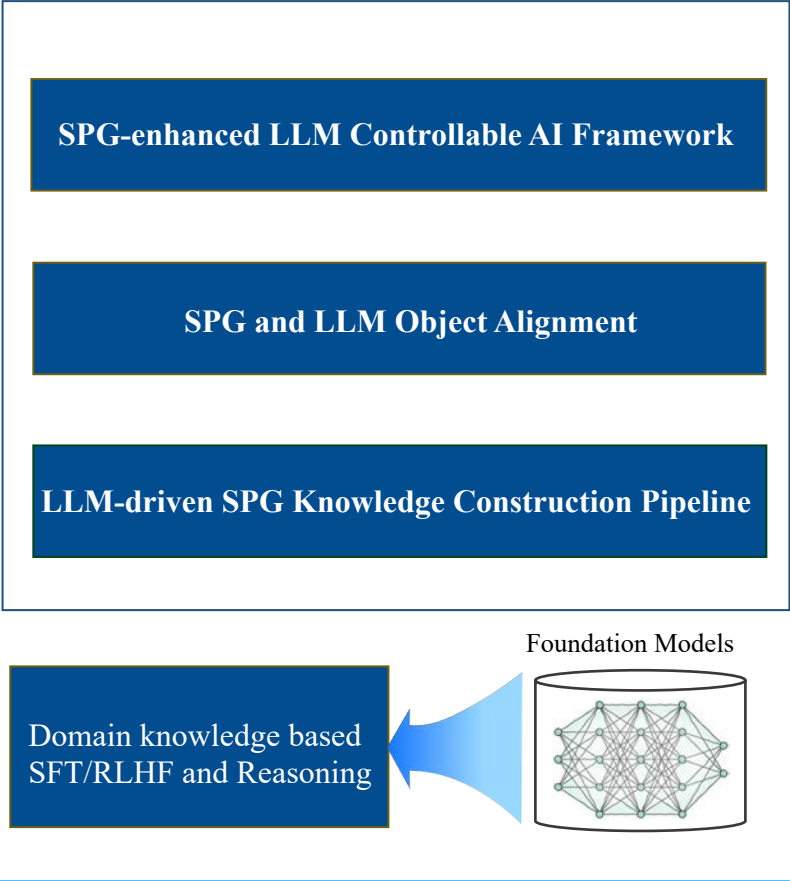
OpenKG: SPG and LLM bidirectionally driven controllable AI

Building next-generation industrial-level cognitive engine

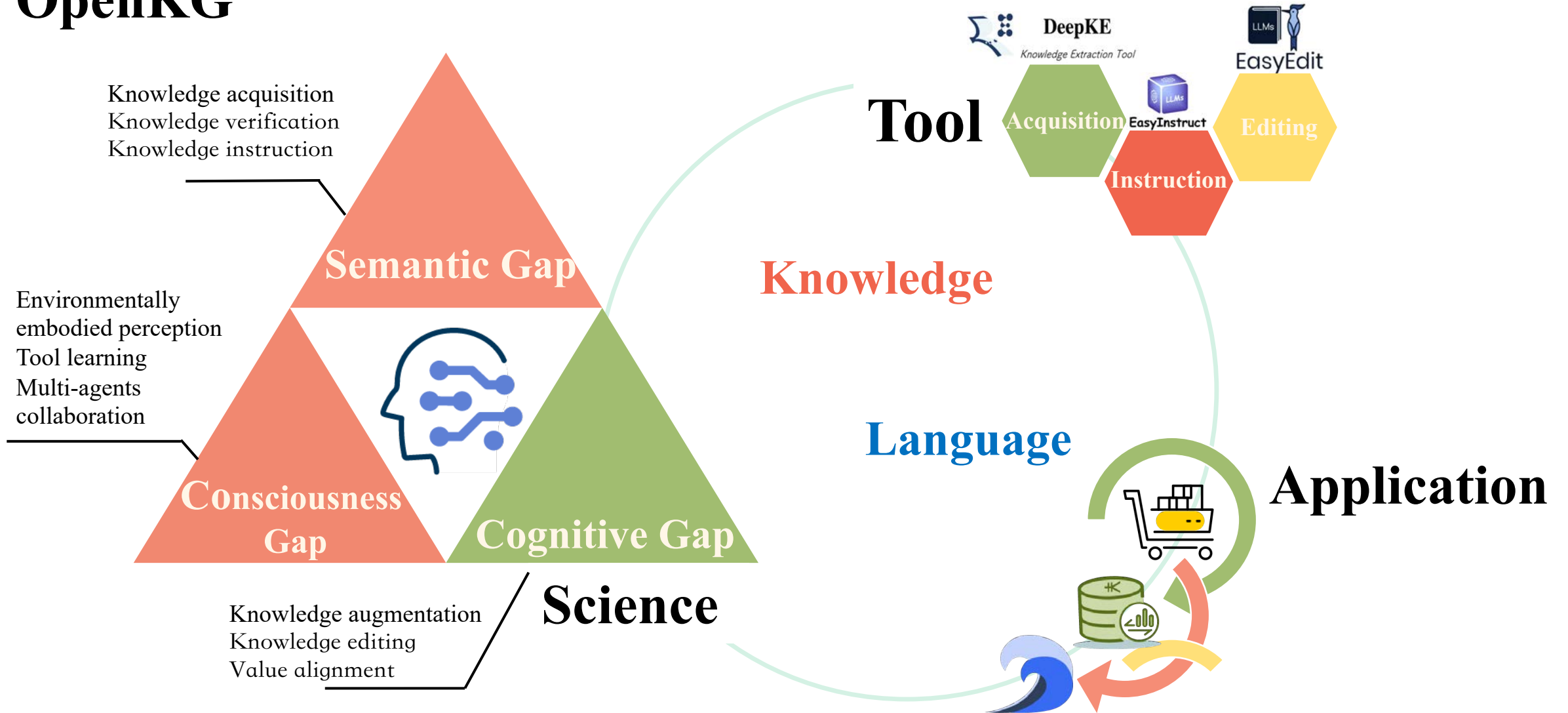
SPG-based Knowledge Graph Engine



LLM and SPG dual-drive applications

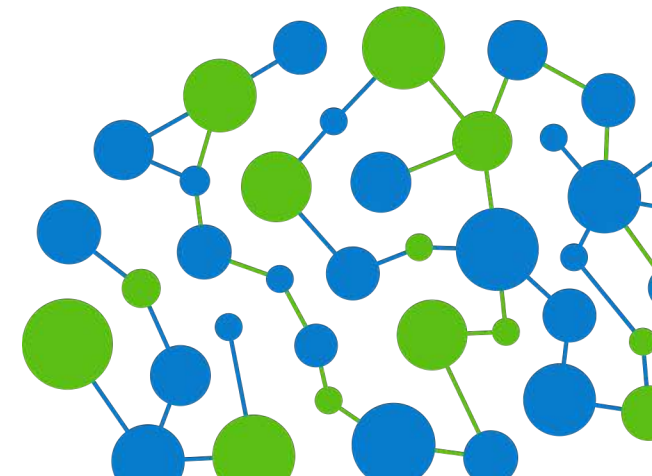


OpenKG



Language as "form", knowledge as "heart", graph as "skeleton"

- The Rise of LLM
- The Development of KG
- The Emerging Paradigm
- OpenKG
- **Conclusion and Outlook**



Knowledge In LLM Era – Knowledge and General Intelligence

Open Knowledge Corpus

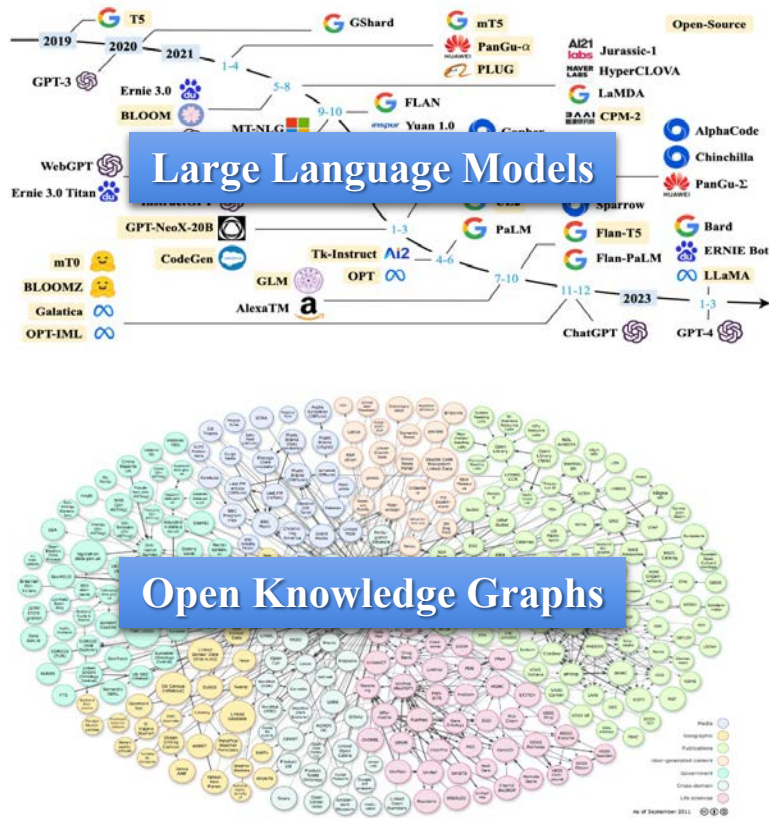
Web Crawl

Open Books

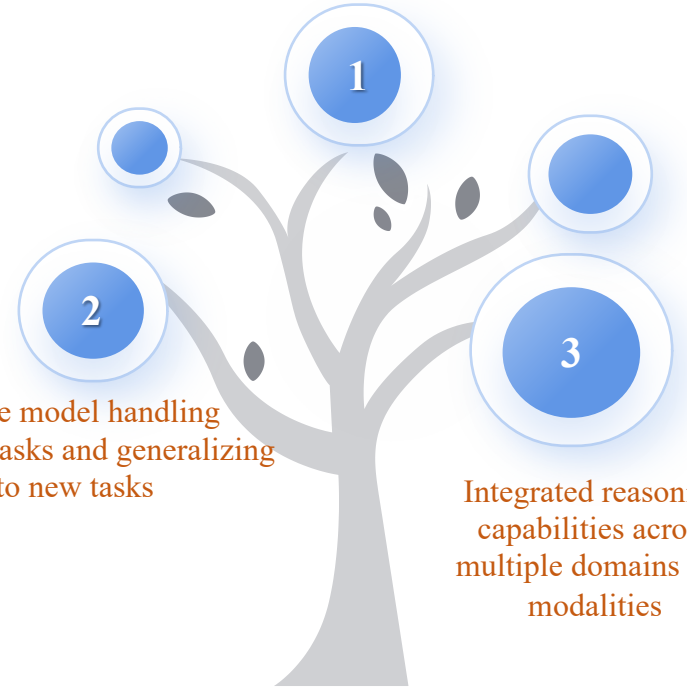
Wikipedia

Opensource Code

.....



Commonsense knowledge with sufficient coverage



Single model handling multiple tasks and generalizing to new tasks

Integrated reasoning capabilities across multiple domains and modalities

General Intelligence

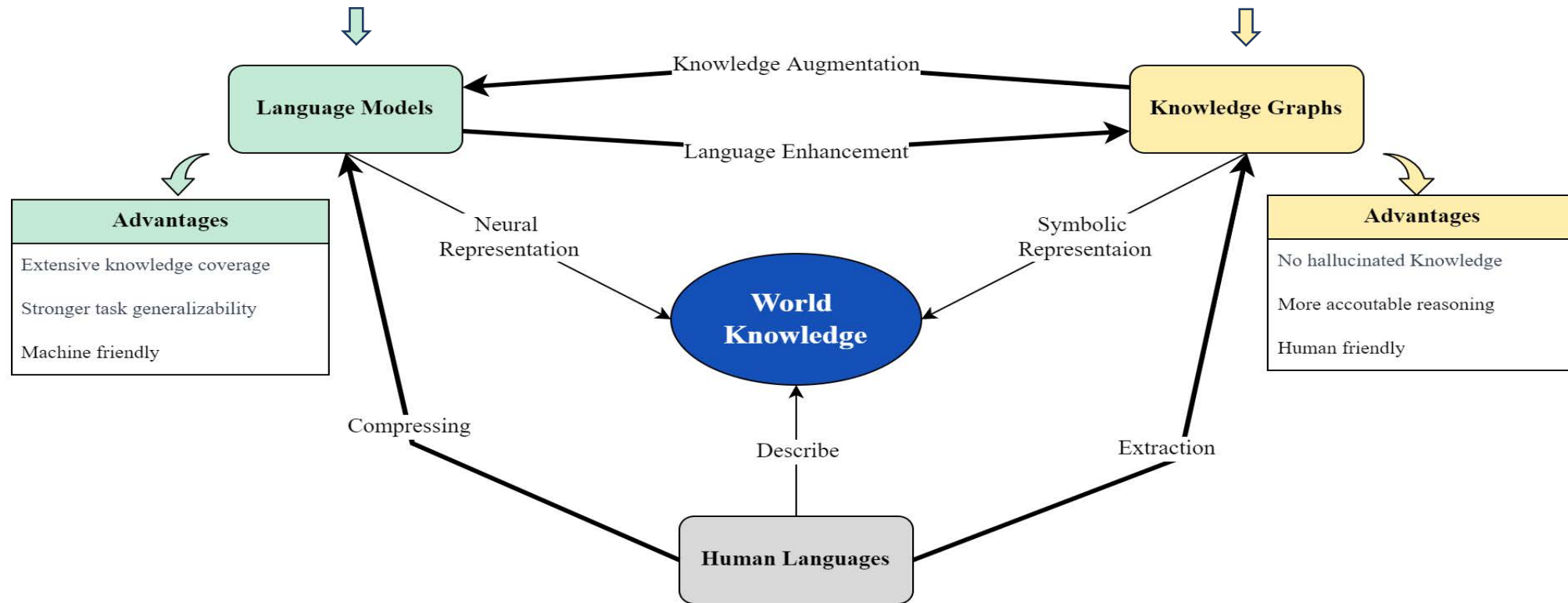
Implication

Both existing large language models and traditional knowledge graphs attempt to establish a **shared knowledge base for general intelligence** by leveraging the vast amount of open knowledge accumulated on the internet over time.

Knowledge In LLM Era – Knowledge and General Intelligence

Focus on scale & has high coverage

Focus on presentation & has high accuracy

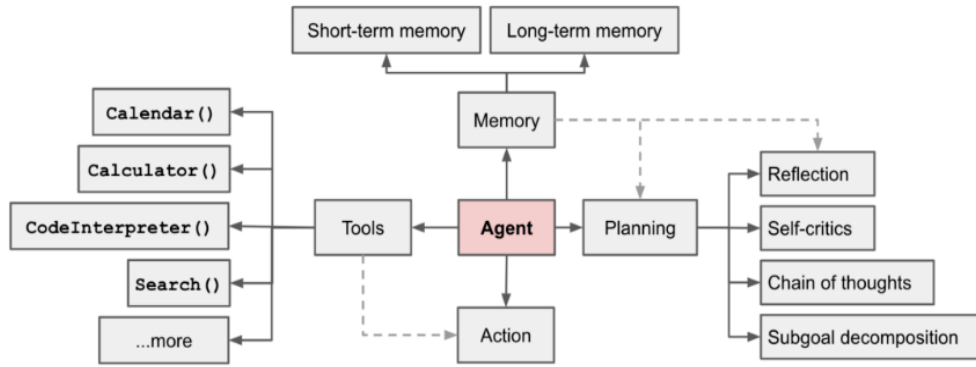


Large Knowledge Models: Perspective and Challenges. 2024

Implication

The **complementarity and mutual enhancement** between symbolic knowledge and language models have significant research importance and practical value.

The Rise of World Model



Theory of Mind: Reasoning about **hidden mental variables** that drive **observable actions**

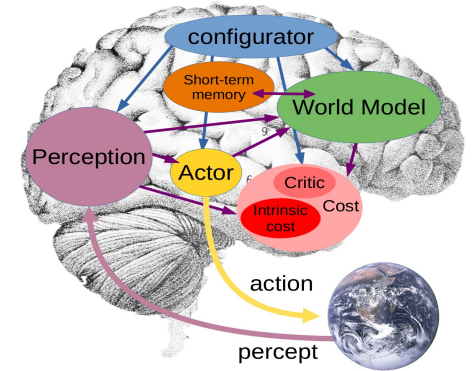
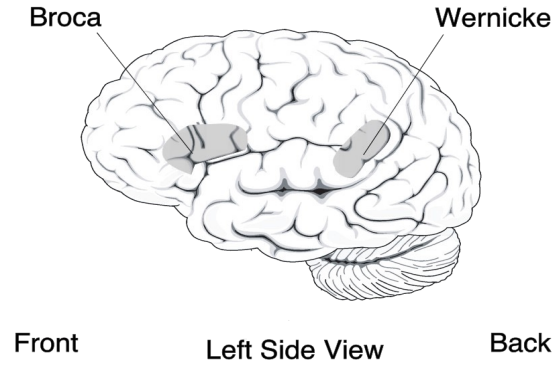


Goal: Sit down

Belief: The chair was not moved

False belief

caused by the person on the right



LeCun (2022)



- Autoregressive large language models (at best) only approximately approach the functions of the Wernicke and Broca areas of the brain.

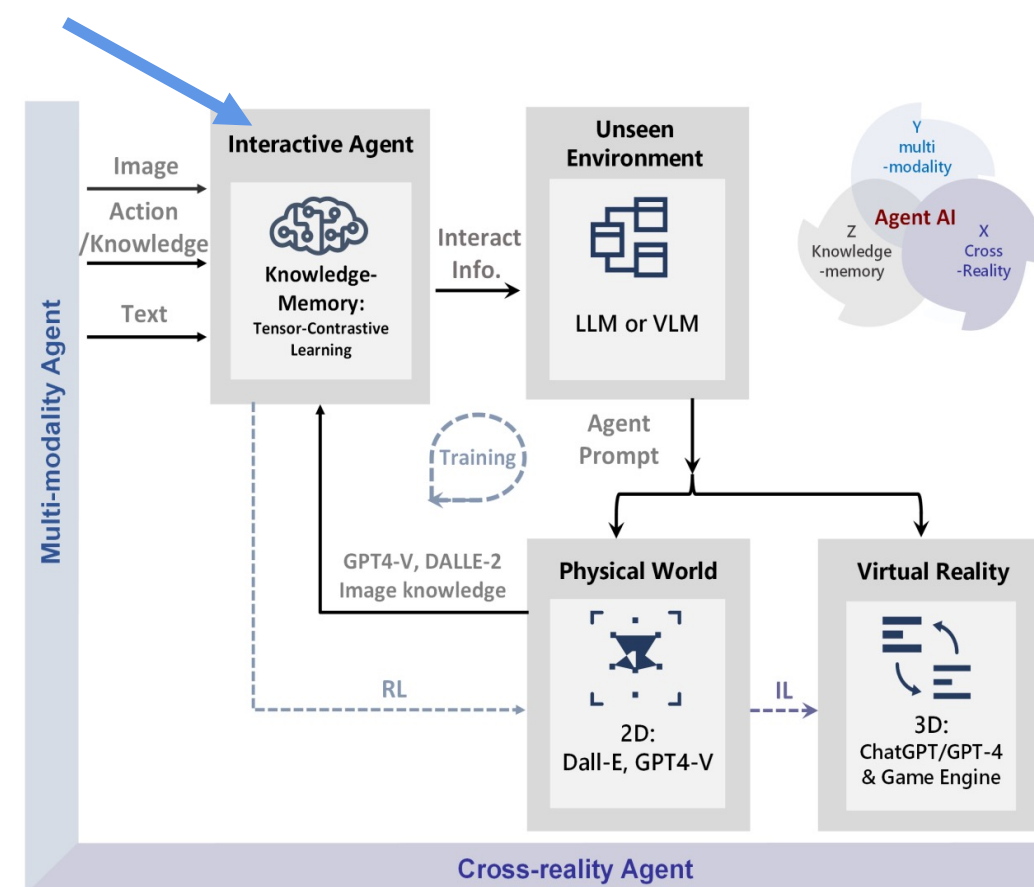
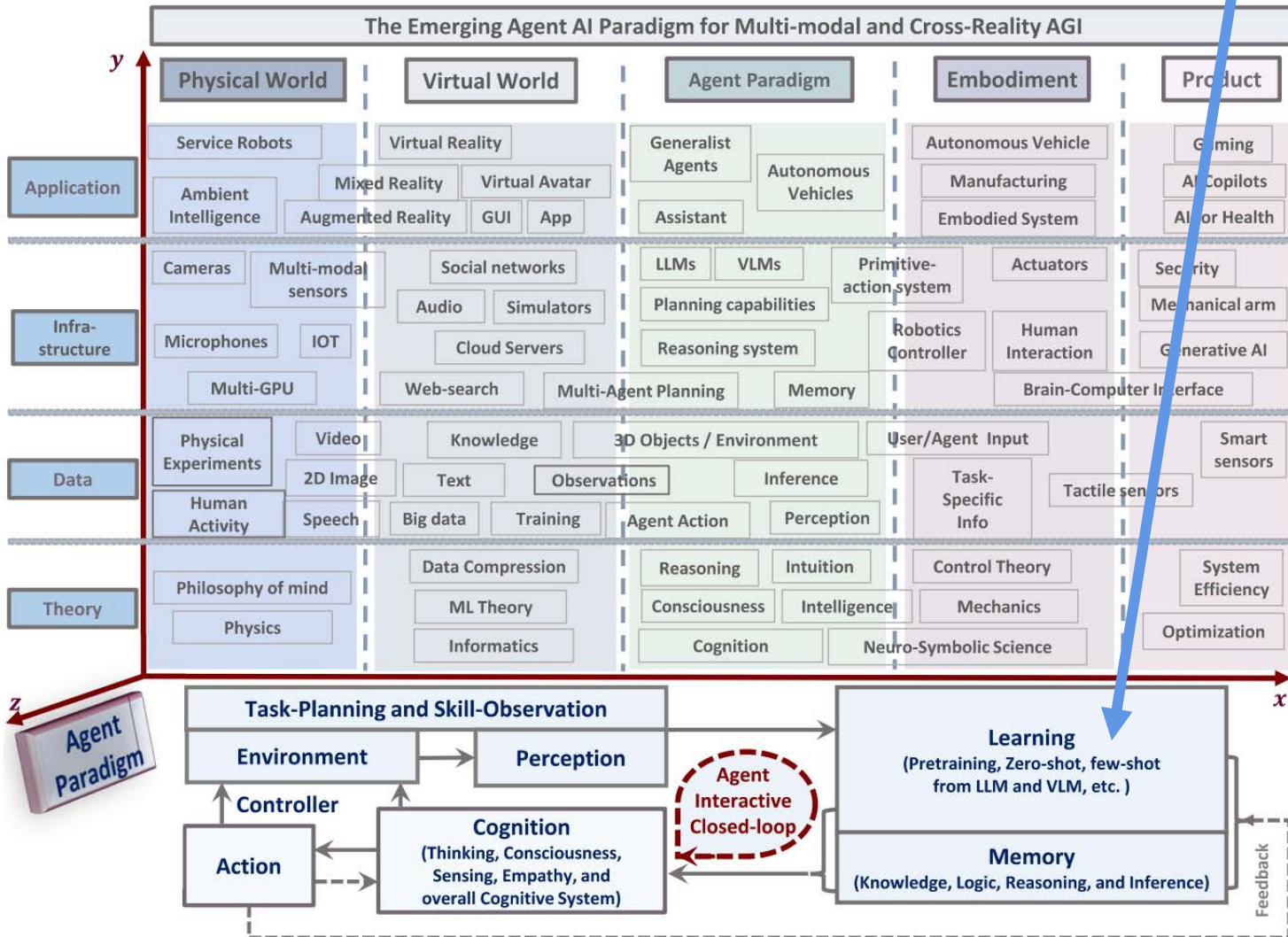
- What about the prefrontal cortex?

- Current AI technology is (still) far from human-level intelligence.

- Autonomous intelligence: configurator, perception, world model, cost, and participants

The Role of Knowledge and Memory

Knowledge and Memory

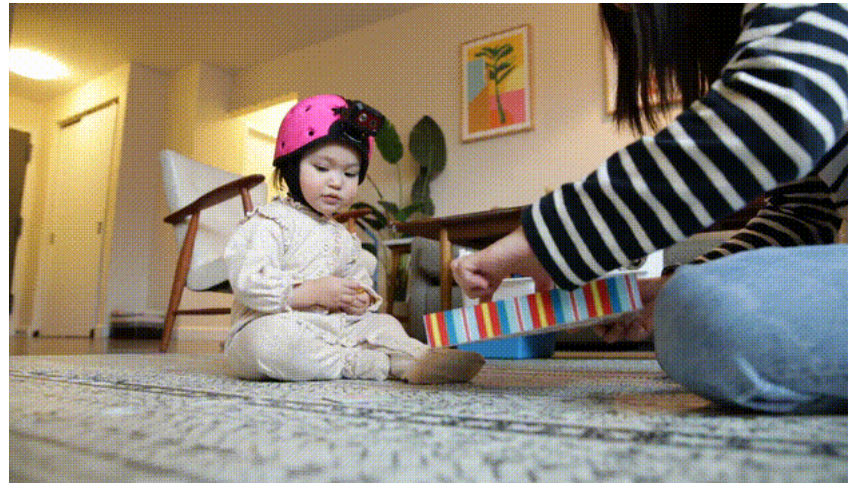


AGENT AI:
SURVEYING THE HORIZONS OF MULTIMODAL INTERACTION

Zane Durante^{1*}, Qiuyuan Huang^{2†*}, Naoki Wake^{2*},
Ran Gong^{3†}, Jae Sung Park^{4†}, Bidipta Sarkar^{1†}, Rohan Taori^{1†}, Yusuke Noda⁵,
Demetri Terzopoulos³, Yejin Choi⁴, Katsushi Ikeuchi², Hoi Vo⁵, Li Fei-Fei¹, Jianfeng Gao²

¹Stanford University; ²Microsoft Research, Redmond;
³University of California, Los Angeles; ⁴University of Washington; ⁵Microsoft Gaming

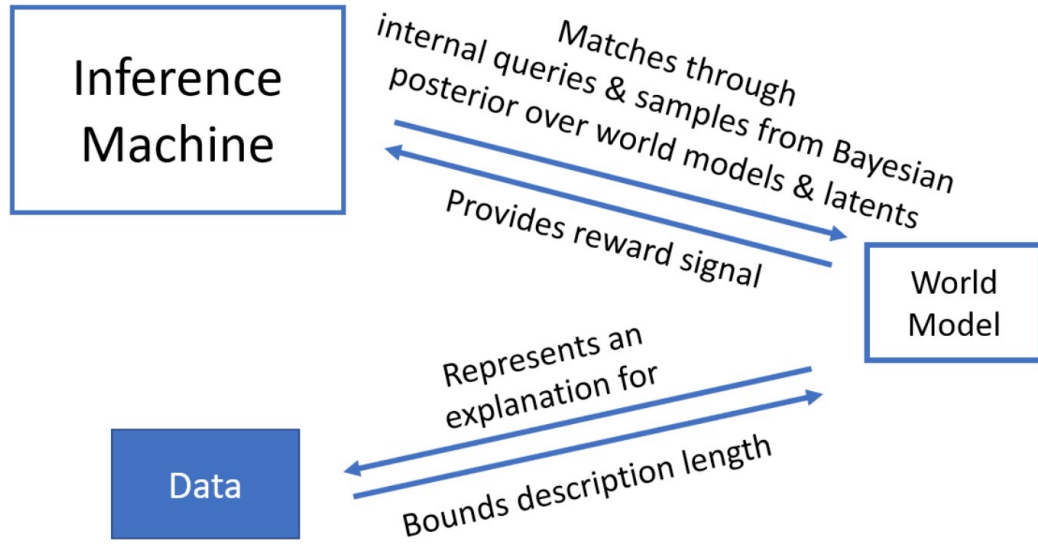
World Model – Baby Learning



From Baby Talk to Baby A.I.
Could a better understanding of how infants acquire language help us build smarter A.I. models?

Grounded language acquisition through the eyes and ears of a single child, **Science 2024**

Knowledge Offloading



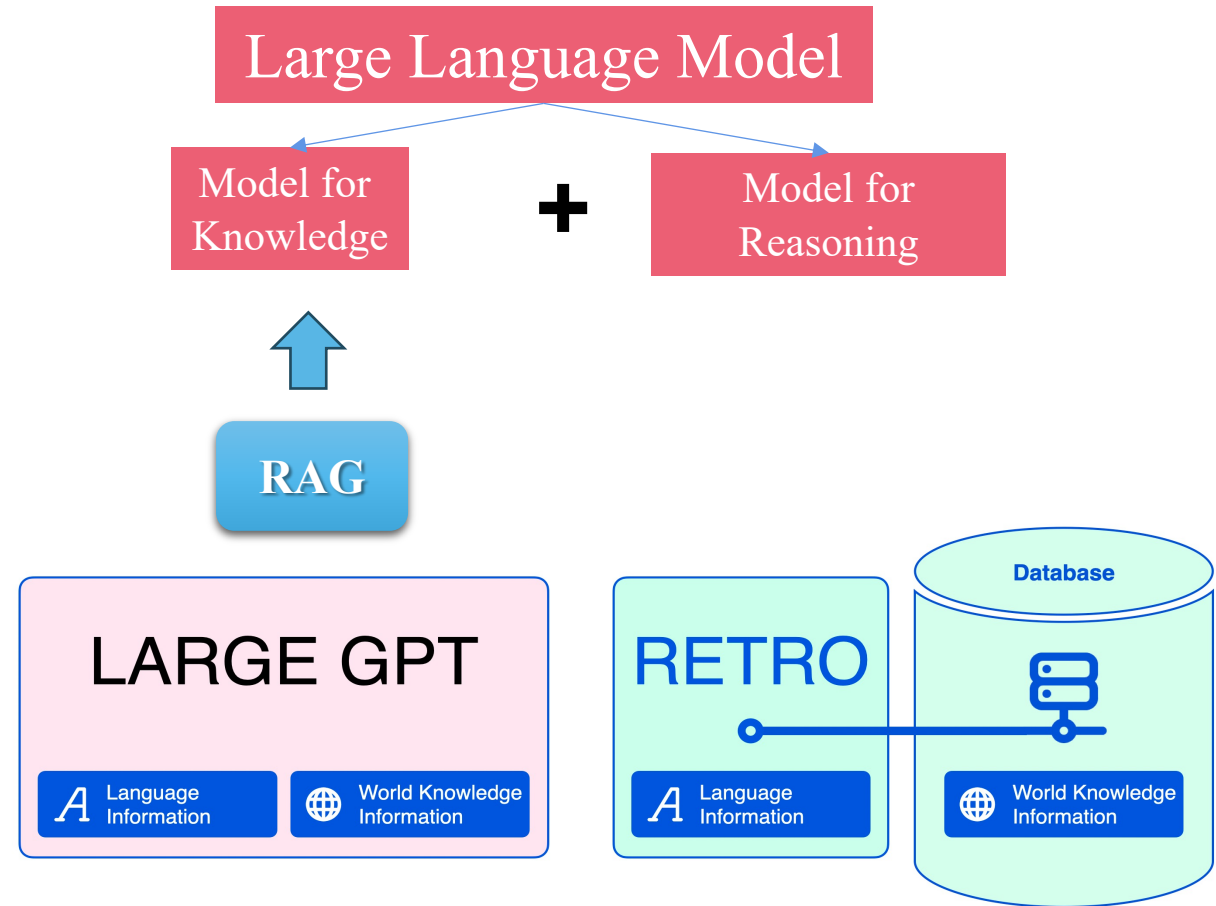
Scaling in the service of reasoning & model-based ML

Published 21 March 2023 by yoshuabengio



use some data to learn the world model, and some data to learn the inference machine.

Intelligence = Knowledge + Inference



DeepMind's RETRO (Retrieval-Enhanced TRansfOrmer)

Building the Next Generation Knowledge Engineering

■ Goals of Knowledge Engineering

- Knowledge accumulation and reuse, knowledge reasoning and decision-making

■ Impact of Large Models on Knowledge Engineering

- Knowledge is not limited to symbolic representation, symbolic reasoning capabilities can be achieved through parameterization

■ Future Research in Knowledge Engineering: Embracing Large Models

- **KG for LLM** : Knowledge augmentation for large language models
- **LLM for KG** : Leveraging large language models to achieve better knowledge accumulation
- **LLM + KG** : Exploring the synergy between large language models and knowledge graphs to establish a "new symbolic system"

CiteScore 2023

6.6 = $\frac{1,158 \text{ Citations } 2020 - 2023}{175 \text{ Documents } 2020 - 2023}$

Calculated on 05 May, 2024

Category	Rank	Percentile
Computer Science		
Computer Science Applications	#214/817	73rd
Computer Science		
Information Systems	#107/394	72nd
Computer Science		
Artificial Intelligence	#119/350	66th

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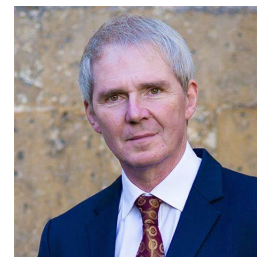
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Thank you



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