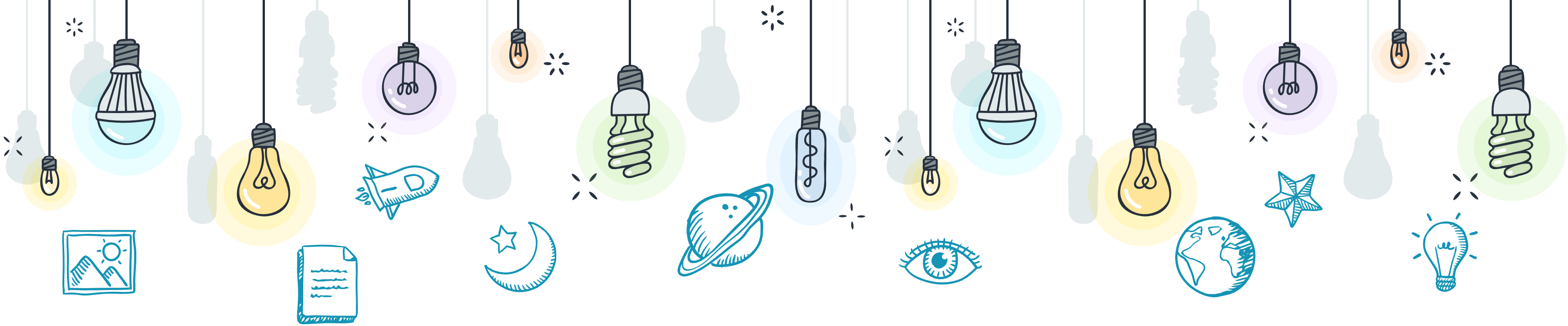

From Multimodal LLM to Human-level AI

Modality, *Instruction*, *Reasoning*, *Efficiency* **and Beyond**

https://mllm2024.github.io/CVPR2024/

CVPR
JUNE 17-21, 2024
SEATTLE, WA

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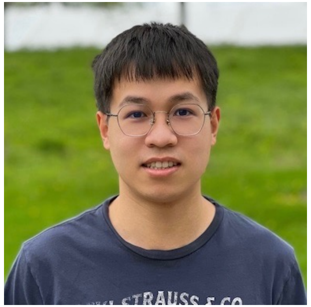

Haotian Liu

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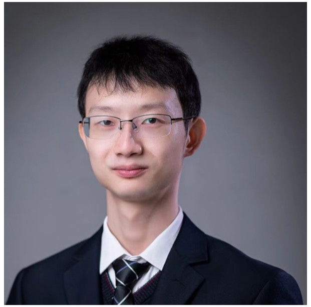

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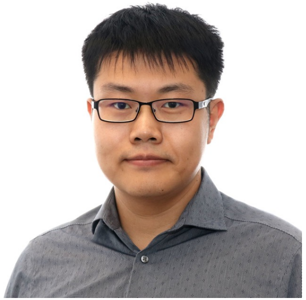

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Kunlun 2050 Research, Skywork AI

Part-VI

Multimodal Reasoning

Zhuosheng Zhang
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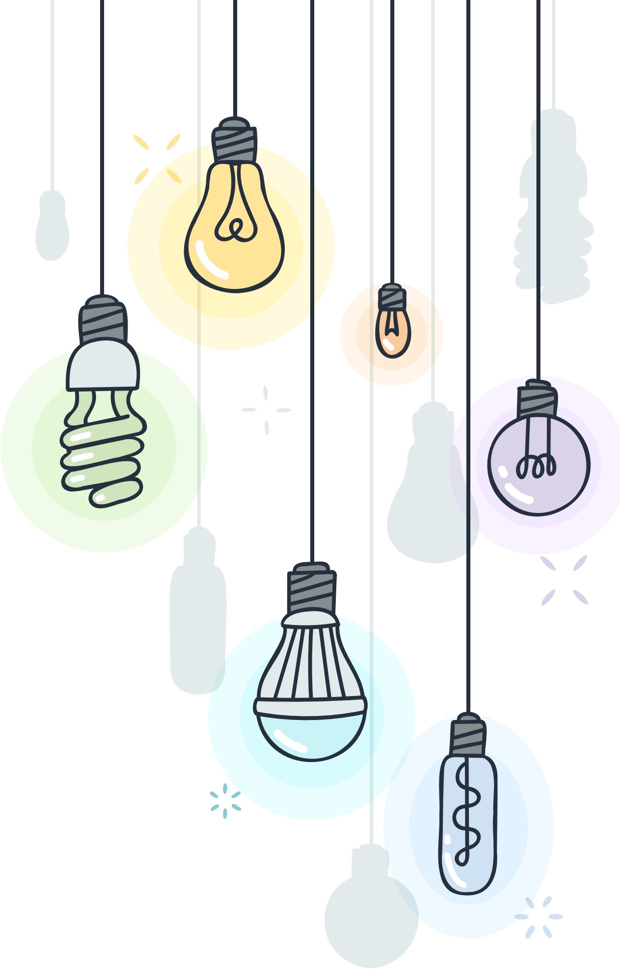


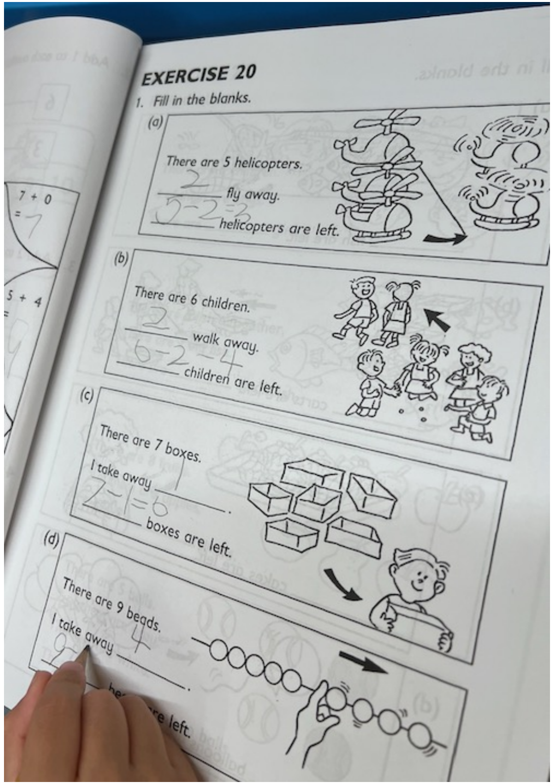
Table of Content

- Basics of Multimodal Reasoning
  - Background, Definition, and Development
- Multimodal Chain-of-Thought Reasoning
  - Paradigm Shift, the Role of Multimodal CoT
- Towards Multimodal LLM Agents
  - Taxonomy, Architecture, Applications
- Challenges
  - Evolutionary Reasoning, Interactive Reasoning, Reasoning Alignment

1

Basics of Multimodal Reasoning

Multimodal Reasoning



7 + 0
= 7

5 + 4
=

EXERCISE 20

1. *Fill in the blanks.*

(a)
There are 5 helicopters.
2 fly away.
5-2=3 helicopters are left.

(b)
There are 6 children.
2 walk away.
6-2=4 children are left.

(c)
There are 7 boxes.
I take away 1.
7-1=6 boxes are left.

(d)
There are 9 beads.
I take away 4.
9
be re left.

Prompt

Please create a blog post about a trip to New York, where a dog and his owner had lots of fun. Include a few pictures of the dog posing happily at different landmarks.

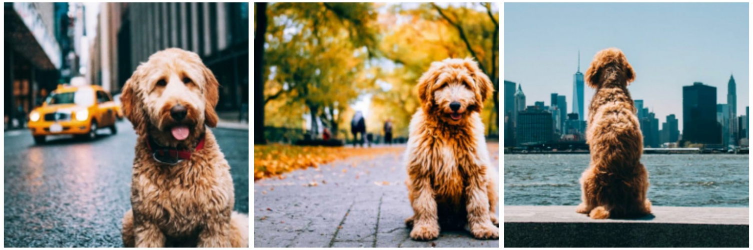
Model Response

Hi, I'm Cooper. I'm a 2 year old Goldendoodle who loves to travel. Last month, my family and I went to New York City. It was my first time in the Big Apple, and I had a blast!

We stayed in a hotel near Times Square. It was so much fun to see all the bright lights and people. We went to see a Broadway show, and I even got to meet some of the actors.

One of my favorite parts of New York City was Central Park. It was so big and beautiful. I loved running around and playing fetch. We also went to the Statue of Liberty and the Empire State Building. I was so excited to see all the famous landmarks.

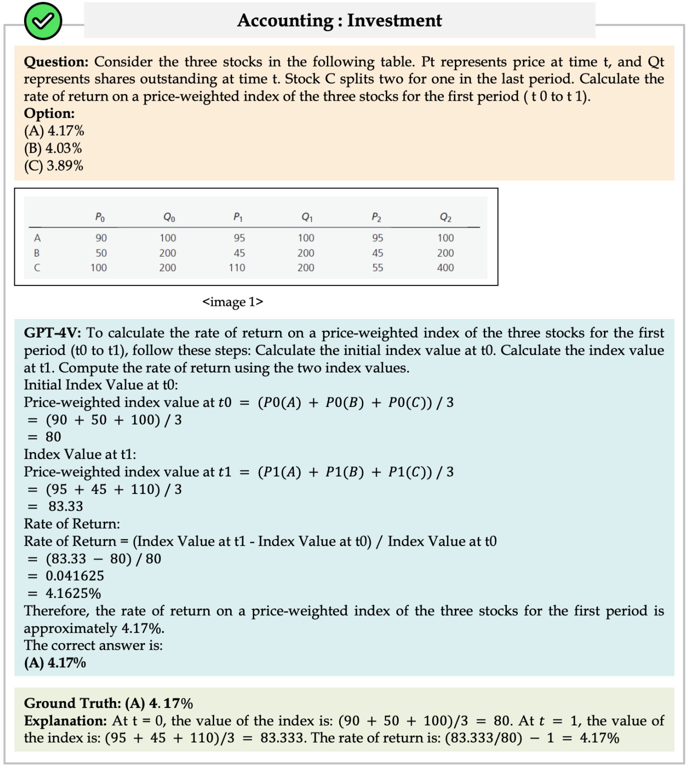
I had so much fun in New York City. It's definitely one of my favorite places to travel. I can't wait to go back someday!



https://www.astonzhang.com/img/mm-cot-idea.png
Gemini Team Google. Gemini: A Family of Highly Capable Multimodal Models. arXiv:2312.11805.

Multimodal Reasoning

- **Concept: a process of deriving high-level conclusions from multiple modalities, possibly via multiple logical steps based on atomic evidences**



Accounting : Investment

Question: Consider the three stocks in the following table. Pt represents price at time t, and Qt represents shares outstanding at time t. Stock C splits two for one in the last period. Calculate the rate of return on a price-weighted index of the three stocks for the first period (t 0 to t 1).

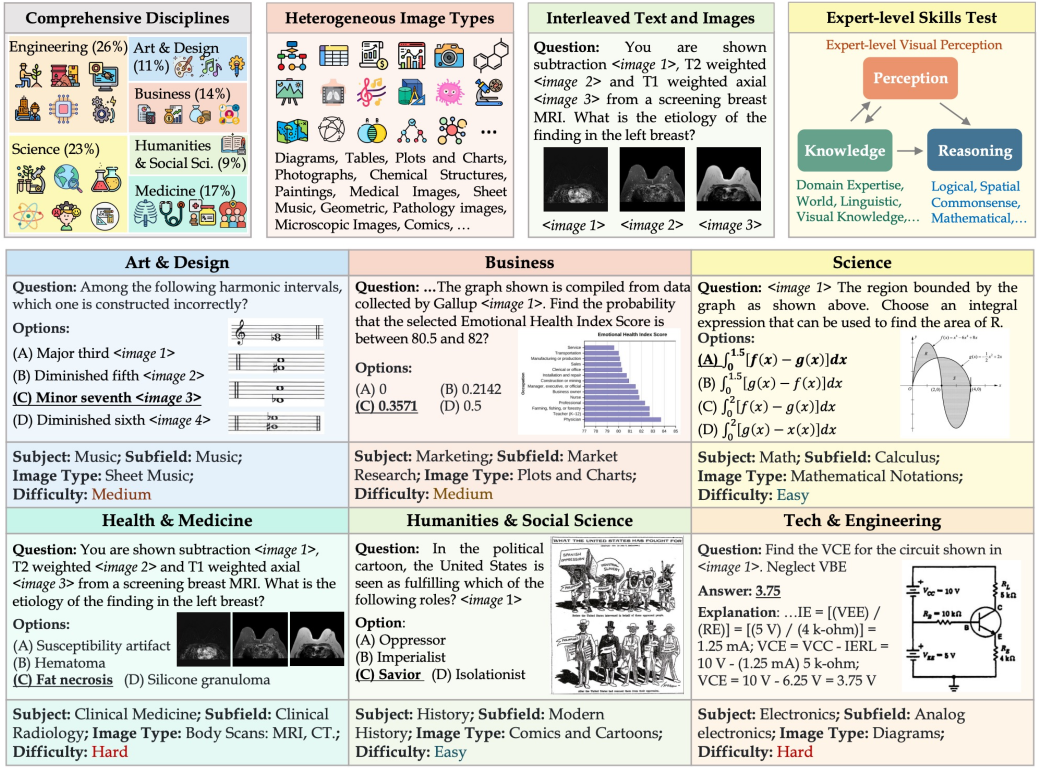
Option:
(A) 4.17%
(B) 4.03%
(C) 3.89%

	P_0	Q_0	P_1	Q_1	P_2	Q_2
A	90	100	95	100	95	100
B	50	200	45	200	45	200
C	100	200	110	200	55	400

<image 1>

GPT-4V: To calculate the rate of return on a price-weighted index of the three stocks for the first period (t0 to t1), follow these steps: Calculate the initial index value at t0. Calculate the index value at t1. Compute the rate of return using the two index values.
Initial Index Value at t0:
Price-weighted index value at $t0 = (P0(A) + P0(B) + P0(C))/3$
$= (90 + 50 + 100)/3$
$= 80$
Index Value at t1:
Price-weighted index value at $t1 = (P1(A) + P1(B) + P1(C))/3$
$= (95 + 45 + 110)/3$
$= 83.33$
Rate of Return:
Rate of Return = (Index Value at t1 - Index Value at t0) / Index Value at t0
$= (83.33 - 80)/80$
$= 0.041625$
$= 4.1625\%$
Therefore, the rate of return on a price-weighted index of the three stocks for the first period is approximately 4.17%.
The correct answer is:
(A) 4.17%

Ground Truth: (A) 4.17%
Explanation: At t = 0, the value of the index is: $(90 + 50 + 100)/3 = 80$. At $t = 1$, the value of the index is: $(95 + 45 + 110)/3 = 83.333$. The rate of return is: $(83.333/80) - 1 = 4.17\%$



Comprehensive Disciplines

Heterogeneous Image Types

Diagrams, Tables, Plots and Charts, Photographs, Chemical Structures, Paintings, Medical Images, Sheet Music, Geometric, Pathology images, Microscopic Images, Comics, …

Interleaved Text and Images

Question: You are shown subtraction *<image 1>*, T2 weighted *<image 2>* and T1 weighted axial *<image 3>* from a screening breast MRI. What is the etiology of the finding in the left breast?

<image 1> *<image 2>* *<image 3>*

Expert-level Skills Test
Expert-level Visual Perception
Perception
Knowledge
Reasoning
Domain Expertise, World, Linguistic, Visual Knowledge,…
Logical, Spatial Commonsense, Mathematical,…

Art & Design

Question: Among the following harmonic intervals, which one is constructed incorrectly?
Options:
(A) Major third *<image 1>*
(B) Diminished fifth *<image 2>*
(C) Minor seventh *<image 3>*
(D) Diminished sixth *<image 4>*

Subject: Music; **Subfield:** Music;
Image Type: Sheet Music;
Difficulty: Medium

Business

Question: …The graph shown is compiled from data collected by Gallup *<image 1>*. Find the probability that the selected Emotional Health Index Score is between 80.5 and 82?
Options:
(A) 0 (B) 0.2142
(C) 0.3571 (D) 0.5

Subject: Marketing; **Subfield:** Market Research; **Image Type:** Plots and Charts;
Difficulty: Medium

Science

Question: *<image 1>* The region bounded by the graph as shown above. Choose an integral expression that can be used to find the area of R.
Options:
(A) $\int_0^{1.5}[f(x) - g(x)]dx$
(B) $\int_0^{1.5}[g(x) - f(x)]dx$
(C) $\int_0^{2}[f(x) - g(x)]dx$
(D) $\int_0^{2}[g(x) - x(x)]dx$

Subject: Math; **Subfield:** Calculus;
Image Type: Mathematical Notations;
Difficulty: Easy

Health & Medicine

Question: You are shown subtraction *<image 1>*, T2 weighted *<image 2>* and T1 weighted axial *<image 3>* from a screening breast MRI. What is the etiology of the finding in the left breast?
Options:
(A) Susceptibility artifact
(B) Hematoma
(C) Fat necrosis (D) Silicone granuloma

Subject: Clinical Medicine; **Subfield:** Clinical Radiology; **Image Type:** Body Scans: MRI, CT.;
Difficulty: Hard

Humanities & Social Science

Question: In the political cartoon, the United States is seen as fulfilling which of the following roles? *<image 1>*
Option:
(A) Oppressor
(B) Imperialist
(C) Savior (D) Isolationist

Subject: History; **Subfield:** Modern History; **Image Type:** Comics and Cartoons;
Difficulty: Easy

Tech & Engineering

Question: Find the VCE for the circuit shown in *<image 1>*. Neglect VBE
Answer: 3.75
Explanation: …IE = [(VEE) / (RE)] = [(5 V) / (4 k-ohm)] = 1.25 mA; VCE = VCC - IERL = 10 V - (1.25 mA) 5 k-ohm; VCE = 10 V - 6.25 V = 3.75 V

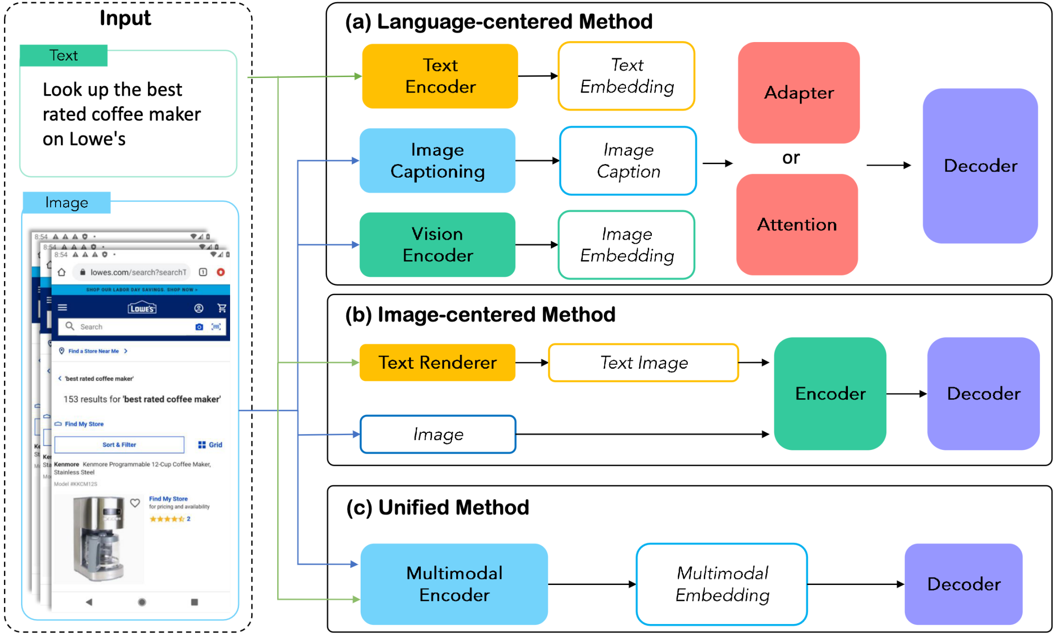
Subject: Electronics; **Subfield:** Analog electronics; **Image Type:** Diagrams;
Difficulty: Hard

Yue, X., Ni, Y., Zhang, K., Zheng, T., Liu, R., Zhang, G., Stevens, S., Jiang, D., Ren, W., Sun, Y. and Wei, C. Mmmu: A massive multi-discipline multimodal understanding and reasoning benchmark for expert agi. CVPR 2024.

Model Architecture

- **Three architectures:**

  (a) language-centered method; (b) image-centered method; (c) unified method



Input

Text

Look up the best rated coffee maker on Lowe's

Image

lowes.com/search?searchT
SHOP OUR LABOR DAY SAVINGS. SHOP NOW
LOWE'S
Search
Find a Store Near Me
'best rated coffee maker'
153 results for 'best rated coffee maker'
Find My Store
Sort & Filter
Grid
Kenmore Kenmore Programmable 12-Cup Coffee Maker, Stainless Steel
Find My Store
for pricing and availability

(a) Language-centered Method

Text Encoder → *Text Embedding*

Image Captioning → *Image Caption*

Vision Encoder → *Image Embedding*

→ Adapter or Attention → Decoder

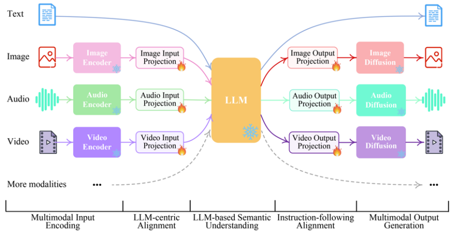
(b) Image-centered Method

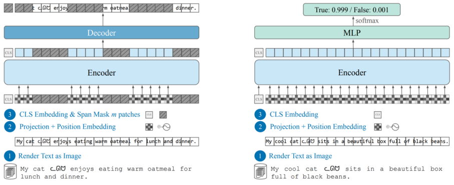
Text Renderer → *Text Image* → Encoder → Decoder

Image → Encoder

(c) Unified Method

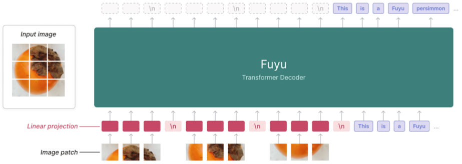
Multimodal Encoder → *Multimodal Embedding* → Decoder





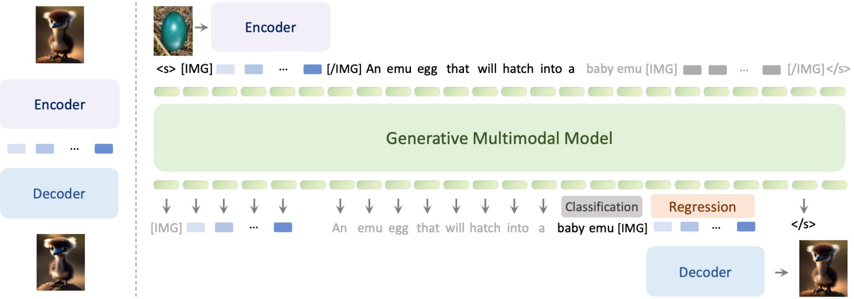
Decoder
Encoder
MLP
True: 0.999 / False: 0.001
softmax
CLS Embedding & Span Mask m patches
Projection + Position Embedding
Render Text as Image
My cat enjoys eating warm oatmeal for lunch and dinner.
CLS Embedding
My cool cat sits in a beautiful box full of black beans.

(a) PIXEL pretraining (b) PIXEL finetuning

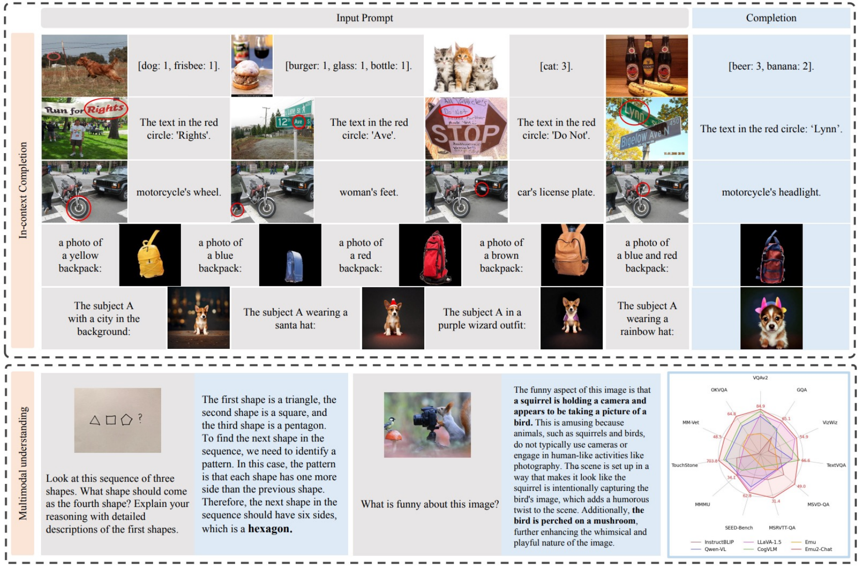


Wu, S., Fei, H., Qu, L., Ji, W. and Chua, T.S., 2023. Next-gpt: Any-to-any multimodal llm. ICMLR 2024.
Rust, P., Lotz, J.F., Bugliarello, E., Salesky, E., de Lhoneux, M. and Elliott, D., 2023, September. Language Modelling with Pixels. ICLR 2023.
Rohan Bavishi, Erich Elsen, Curtis Hawthorne, Maxwell Nye, Augustus Odena, Arushi Somani, and Sagnak Ta¸sırlar. Introducing our multimodal models: fuyu-8b, 2023. https://www.adept.ai/blog/fuyu-8b.

In-Context Learning


Encoder
Decoder
Encoder
<s> [IMG] ··· [/IMG] An emu egg that will hatch into a baby emu [IMG] ··· [/IMG]</s>
Generative Multimodal Model
Classification
Regression
[IMG] ··· An emu egg that will hatch into a baby emu [IMG] ··· </s>
Decoder

- ☐ **Each image in the multimodal sequence is tokenized into embeddings via a visual encoder, and then interleaved with text tokens for autoregressive modeling.**
- ☐ **Leveraging few-shot Prompting for diverse reasoning tasks**

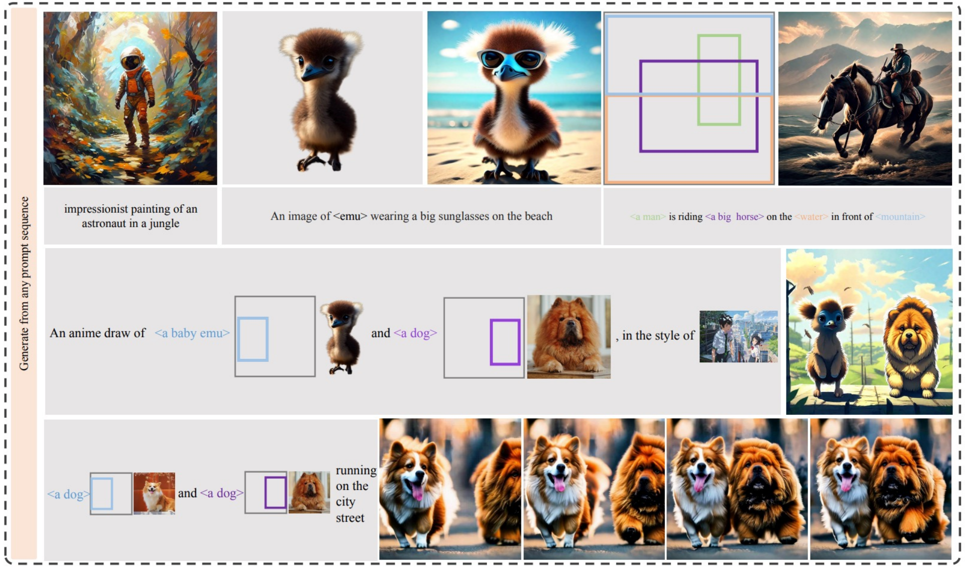

Input Prompt
Completion
In-context Completion
[dog: 1, frisbee: 1].
[burger: 1, glass: 1, bottle: 1].
[cat: 3].
[beer: 3, banana: 2].
The text in the red circle: 'Rights'.
The text in the red circle: 'Ave'.
The text in the red circle: 'Do Not'.
The text in the red circle: 'Lynn'.
motorcycle's wheel.
woman's feet.
car's license plate.
motorcycle's headlight.
a photo of a yellow backpack:
a photo of a blue backpack:
a photo of a red backpack:
a photo of a brown backpack:
a photo of a blue and red backpack:
The subject A with a city in the background:
The subject A wearing a santa hat:
The subject A in a purple wizard outfit:
The subject A wearing a rainbow hat:
Multimodal understanding
VQAv2
GQA
VizWiz
TextVQA
MSVD-QA
MSRVTT-QA
SEED-Bench
MMMU
TouchStone
MM-Vet
OKVQA
InstructBLIP
Qwen-VL
LLaVA-1.5
CogVLM
Emu
Emu2-Chat

Look at this sequence of three shapes. What shape should come as the fourth shape? Explain your reasoning with detailed descriptions of the first shapes.

The first shape is a triangle, the second shape is a square, and the third shape is a pentagon. To find the next shape in the sequence, we need to identify a pattern. In this case, the pattern is that each shape has one more side than the previous shape. Therefore, the next shape in the sequence should have six sides, which is a **hexagon.**

What is funny about this image?

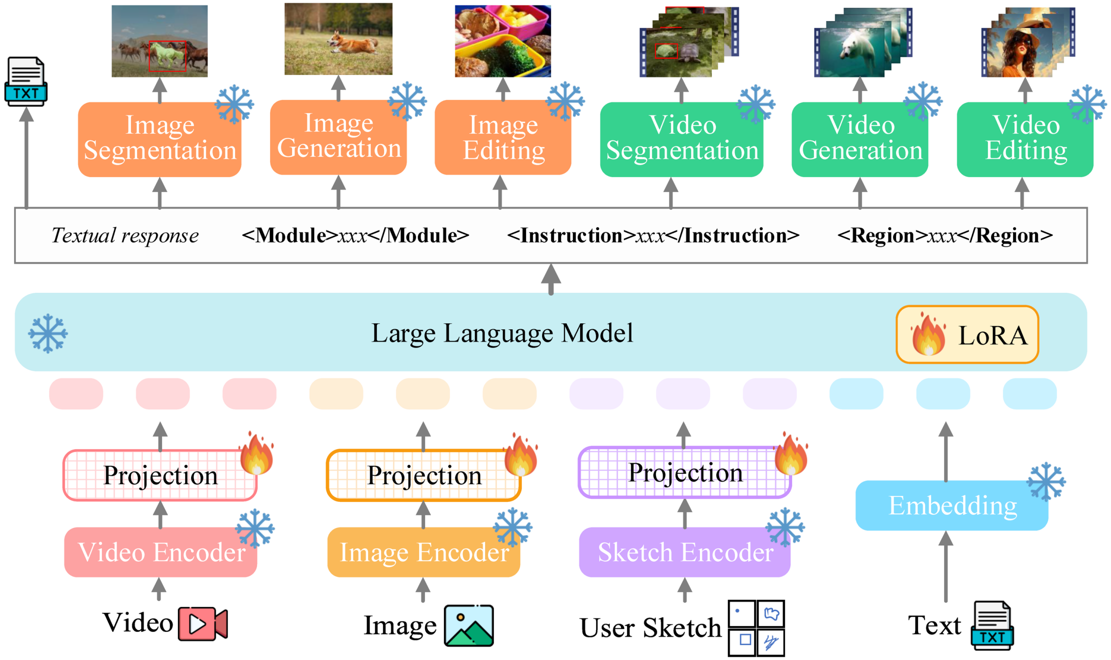
The funny aspect of this image is that **a squirrel is holding a camera and appears to be taking a picture of a bird.** This is amusing because animals, such as squirrels and birds, do not typically use cameras or engage in human-like activities like photography. The scene is set up in a way that makes it look like the squirrel is intentionally capturing the bird's image, which adds a humorous twist to the scene. Additionally, **the bird is perched on a mushroom,** further enhancing the whimsical and playful nature of the image.

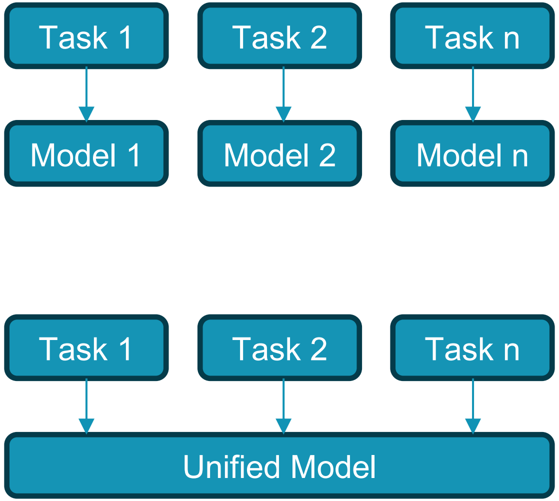

Generate from any prompt sequence
impressionist painting of an astronaut in a jungle
An image of <emu> wearing a big sunglasses on the beach
<a man> is riding <a big horse> on the <water> in front of <mountain>
An anime draw of <a baby emu> and <a dog> , in the style of
<a dog> and <a dog> running on the city street

Sun, Q., Cui, Y., Zhang, X., Zhang, F., Yu, Q., Luo, Z., Wang, Y., Rao, Y., Liu, J., Huang, T. and Wang, X. Generative multimodal models are in-context learners. CVPR 2024.

Evolution of Multimodal Reasoning

❑ From task-specific to centralized paradigms

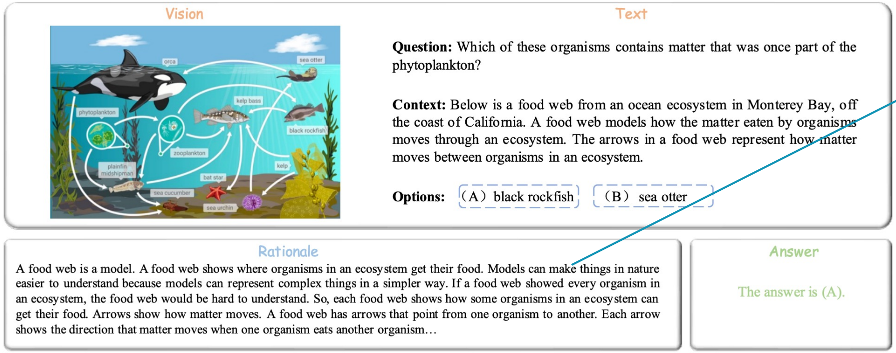




VITRON: A Unified Pixel-level Vision LLM for Understanding, Generating, Segmenting, Editing. https://vitron-llm.github.io/

Evolution of Multimodal Reasoning

❑ From (implicit) single-step prediction to (explicit) multi-step reasoning



Question: Which of these organisms contains matter that was once part of the phytoplankton?

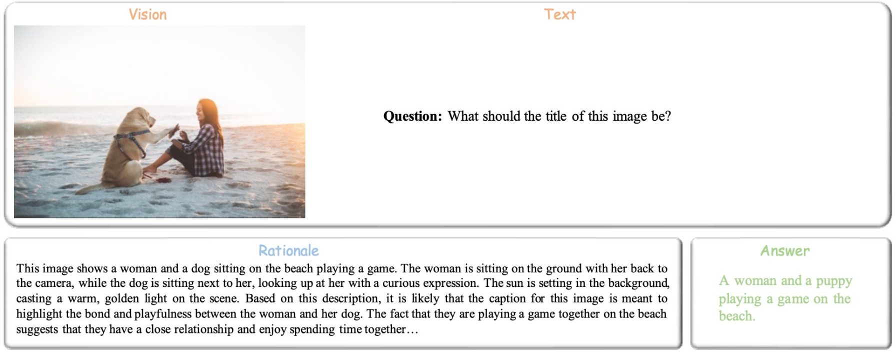
Context: Below is a food web from an ocean ecosystem in Monterey Bay, off the coast of California. A food web models how the matter eaten by organisms moves through an ecosystem. The arrows in a food web represent how matter moves between organisms in an ecosystem.

Options: (A) black rockfish (B) sea otter

A food web is a model. A food web shows where organisms in an ecosystem get their food. Models can make things in nature easier to understand because models can represent complex things in a simpler way. If a food web showed every organism in an ecosystem, the food web would be hard to understand. So, each food web shows how some organisms in an ecosystem can get their food. Arrows show how matter moves. A food web has arrows that point from one organism to another. Each arrow shows the direction that matter moves when one organism eats another organism…

The answer is (A).

(a) An example of ScienceQA.



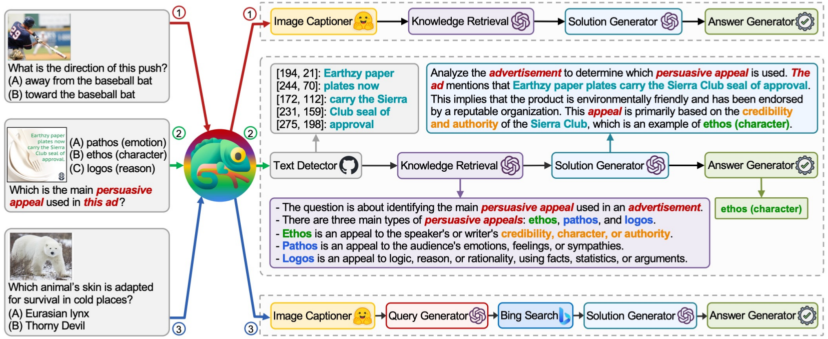
Question: What should the title of this image be?

This image shows a woman and a dog sitting on the beach playing a game. The woman is sitting on the ground with her back to the camera, while the dog is sitting next to her, looking up at her with a curious expression. The sun is setting in the background, casting a warm, golden light on the scene. Based on this description, it is likely that the caption for this image is meant to highlight the bond and playfulness between the woman and her dog. The fact that they are playing a game together on the beach suggests that they have a close relationship and enjoy spending time together…

A woman and a puppy playing a game on the beach.

(b) An example of CoCo-MMRD.

- ❑ **Improved Interpretability**: offer an interpretable glimpse into the decision-making process
- ❑ **Improved Controllability**: interfere the reasoning process, e.g., adding complementary information, verifying and correcting mistakes
- ❑ **Improved Flexibility:** allow interactive communications between different models



What is the direction of this push?
(A) away from the baseball bat
(B) toward the baseball bat

(A) pathos (emotion)
(B) ethos (character)
(C) logos (reason)
Which is the main ***persuasive appeal*** used in ***this ad***?

Which animal's skin is adapted for survival in cold places?
(A) Eurasian lynx
(B) Thorny Devil

[194, 21]: **Earthzy paper**
[244, 70]: **plates now**
[172, 112]: **carry the Sierra**
[231, 159]: **Club seal of**
[275, 198]: **approval**

Analyze the ***advertisement*** to determine which ***persuasive appeal*** is used. ***The ad*** mentions that **Earthzy paper plates carry the Sierra Club seal of approval**. This implies that the product is environmentally friendly and has been endorsed by a reputable organization. This ***appeal*** is primarily based on the **credibility and authority** of the **Sierra Club**, which is an example of **ethos (character)**.

- The question is about identifying the main ***persuasive appeal*** used in an ***advertisement***.
- There are three main types of ***persuasive appeals***: **ethos**, **pathos**, and **logos**.
- **Ethos** is an appeal to the speaker's or writer's **credibility, character, or authority**.
- **Pathos** is an appeal to the audience's emotions, feelings, or sympathies.
- **Logos** is an appeal to logic, reason, or rationality, using facts, statistics, or arguments.

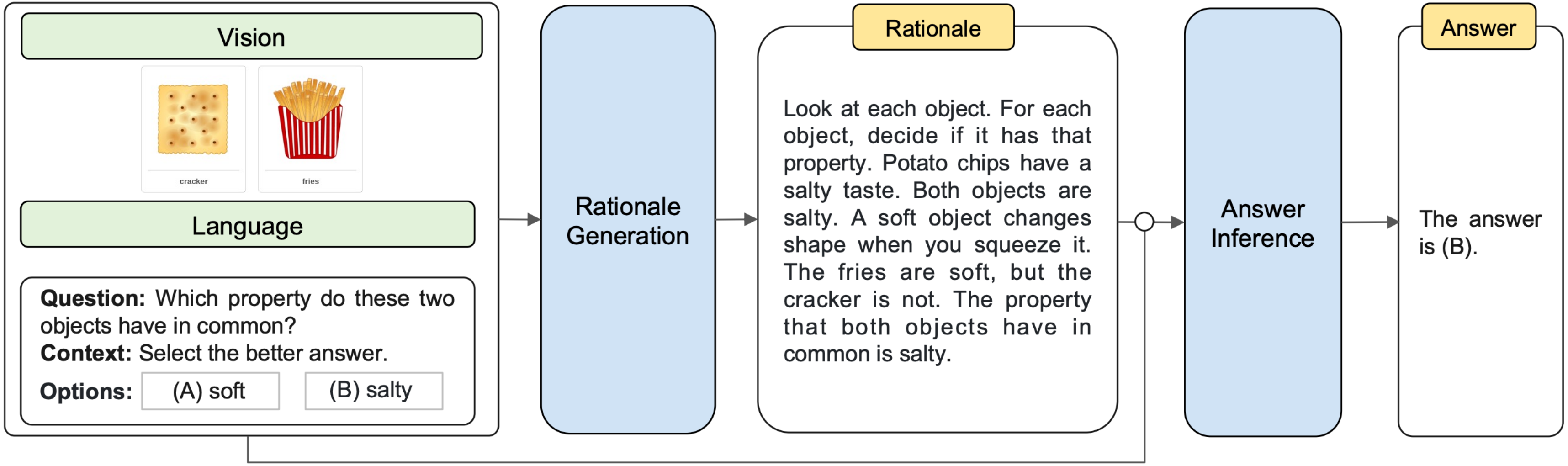
Wei, J., Tan, C., Gao, Z., Sun, L., Li, S., Yu, B., Guo, R. and Li, S.Z., 2023. Enhancing Human-like Multi-Modal Reasoning: A New Challenging Dataset and Comprehensive Framework. arXiv preprint arXiv:2307.12626.

2

Multimodal Chain-of-Thought Reasoning

Multimodal Chain-of-Thought Reasoning

- Think **step by step**, formulate intermediate steps before deriving an answer
- Paradigm shift of task format
  - Standard Format: <input → output>
  - CoT Format: <input → rationale → output>



Question: Which property do these two objects have in common?
Context: Select the better answer.
Options: (A) soft (B) salty

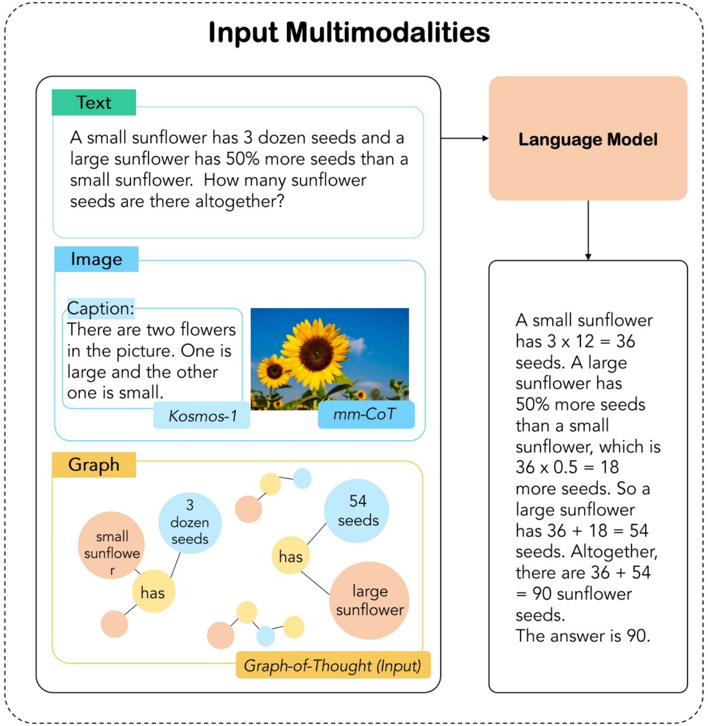
Look at each object. For each object, decide if it has that property. Potato chips have a salty taste. Both objects are salty. A soft object changes shape when you squeeze it. The fries are soft, but the cracker is not. The property that both objects have in common is salty.

The answer is (B).

Zhang, Z., Zhang, A., Li, M., Zhao, H., Karypis, G. and Smola, A. Multimodal chain-of-thought reasoning in language models. TMLR 2024.

Multimodal Chain-of-Thought Reasoning

- ☐ **Input: Various modalities such as text, image, and graph are incorporated into the model's input**
- ☐ **Output: Multimodalities, including text and image, are generated in the model's output**



Input Multimodalities

Text

A small sunflower has 3 dozen seeds and a large sunflower has 50% more seeds than a small sunflower. How many sunflower seeds are there altogether?

Image

Caption: There are two flowers in the picture. One is large and the other one is small.

Kosmos-1

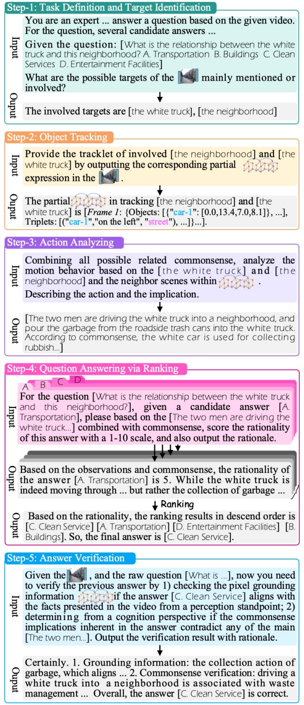
mm-CoT

Graph

Graph-of-Thought (Input)

Language Model

A small sunflower has 3 x 12 = 36 seeds. A large sunflower has 50% more seeds than a small sunflower, which is 36 x 0.5 = 18 more seeds. So a large sunflower has 36 + 18 = 54 seeds. Altogether, there are 36 + 54 = 90 sunflower seeds.
The answer is 90.



Step-1: Task Definition and Target Identification

Input: You are an expert ... answer a question based on the given video. For the question, several candidate answers ...

Given the question: [What is the relationship between the white truck and this neighborhood? A. Transportation B. Buildings C. Clean Services D. Entertainment Facilities]

What are the possible targets of the mainly mentioned or involved?

Ouput: The involved targets are [the white truck], [the neighborhood]

Step-2: Object Tracking

Input: Provide the tracklet of involved [the neighborhood] and [the white truck] by outputting the corresponding partial expression in the .

Ouput: The partial in tracking [the neighborhood] and [the white truck] is [*Frame 1*: {Objects: [{"car-1": [0.0,13.4,7.0,8.1]}, ...], Triplets: [("car-1","on the left", "street"), ...]}...].

Step-3: Action Analyzing

Input: Combining all possible related commonsense, analyze the motion behavior based on the [the white truck] and [the neighborhood] and the neighbor scenes within .

Describing the action and the implication.

Ouput: [The two men are driving the white truck into a neighborhood, and pour the garbage from the roadside trash cans into the white truck. According to commonsense, the white car is used for collecting rubbish...]

Step-4: Question Answering via Ranking

Input: For the question [What is the relationship between the white truck and this neighborhood?], given a candidate answer [A. Transportation], please based on the [The two men are driving the white truck...] combined with commonsense, score the rationality of this answer with a 1-10 scale, and also output the rationale.

Ouput: Based on the observations and commonsense, the rationality of the answer [A. Transportation] is 5. While the white truck is indeed moving through ... but rather the collection of garbage ...

Ranking

Ouput: Based on the rationality, the ranking results in descend order is [C. Clean Service] [A. Transportation] [D. Entertainment Facilities] [B. Buildings]. So, the final answer is [C. Clean Service].

Step-5: Answer Verification

Input: Given the , and the raw question [What is ...], now you need to verify the previous answer by 1) checking the pixel grounding information if the answer [C. Clean Service] aligns with the facts presented in the video from a perception standpoint; 2) determining from a cognition perspective if the commonsense implications inherent in the answer contradict any of the main [The two men...]. Output the verification result with rationale.

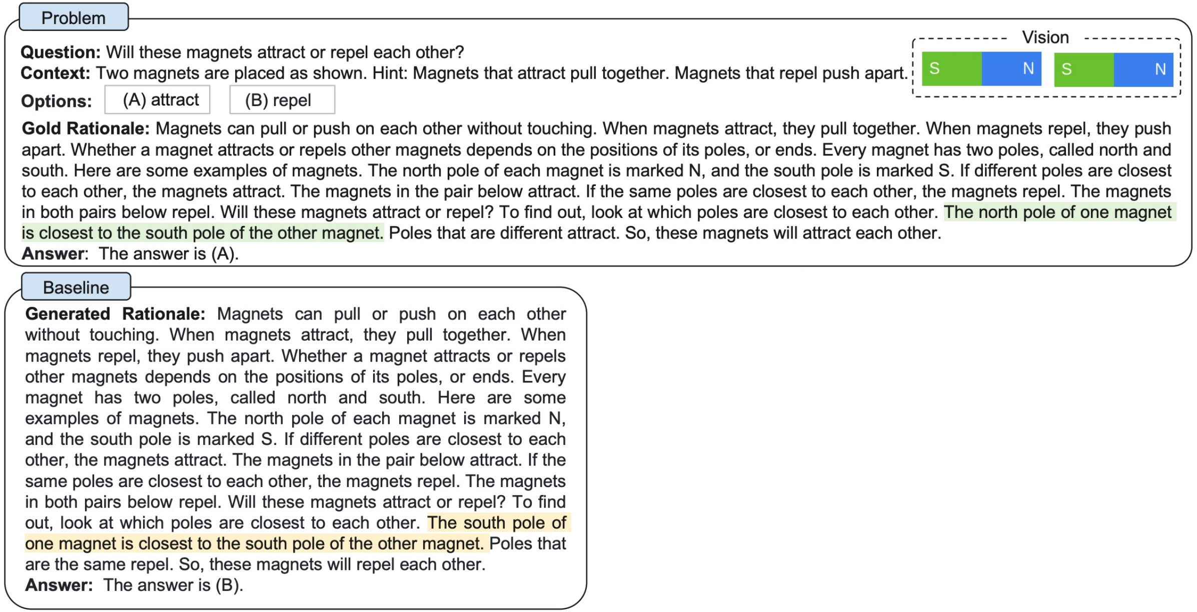
Ouput: Certainly. 1. Grounding information: the collection action of garbage, which aligns ... 2. Commonsense verification: driving a white truck into a neighborhood is associated with waste management ... Overall, the answer [C. Clean Service] is correct.

Video-of-Thought (VoT)

Zhang, Z., Yao, Y., Zhang, A., Tang, X., Ma, X., He, Z., Wang, Y., Gerstein, M., Wang, R., Liu, G. and Zhao, H., 2023. Igniting Language Intelligence: The Hitchhiker's Guide From Chain-of-Thought Reasoning to Language Agents. arXiv preprint arXiv:2311.11797.
Fei, H., Wu, S., Ji, W., Zhang, H., Zhang, H., Lee, M., Hsu, W., 2024. Video-of-Thought: Step-by-Step Video Reasoning from Perception to Cognition. ICML 2024.

The Role of (Multimodal) Chain-of-Thought

- ☐ **Role 1: Introducing more reliable input results in more convincing reasoning process**
- ☐ **Case studies: 50 error cases**
  - **Imperfect training data: when the vision input is missing**
  - **Generate hallucinated rationales that mislead the answer inference (64%)**



Problem

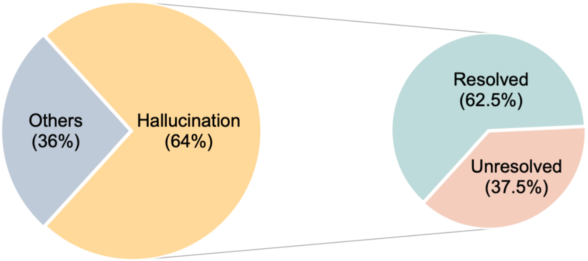
Question: Will these magnets attract or repel each other?
Context: Two magnets are placed as shown. Hint: Magnets that attract pull together. Magnets that repel push apart.
Options: (A) attract (B) repel

Vision
S
N
S
N

Gold Rationale: Magnets can pull or push on each other without touching. When magnets attract, they pull together. When magnets repel, they push apart. Whether a magnet attracts or repels other magnets depends on the positions of its poles, or ends. Every magnet has two poles, called north and south. Here are some examples of magnets. The north pole of each magnet is marked N, and the south pole is marked S. If different poles are closest to each other, the magnets attract. The magnets in the pair below attract. If the same poles are closest to each other, the magnets repel. The magnets in both pairs below repel. Will these magnets attract or repel? To find out, look at which poles are closest to each other. The north pole of one magnet is closest to the south pole of the other magnet. Poles that are different attract. So, these magnets will attract each other.
Answer: The answer is (A).

Baseline

Generated Rationale: Magnets can pull or push on each other without touching. When magnets attract, they pull together. When magnets repel, they push apart. Whether a magnet attracts or repels other magnets depends on the positions of its poles, or ends. Every magnet has two poles, called north and south. Here are some examples of magnets. The north pole of each magnet is marked N, and the south pole is marked S. If different poles are closest to each other, the magnets attract. The magnets in the pair below attract. If the same poles are closest to each other, the magnets repel. The magnets in both pairs below repel. Will these magnets attract or repel? To find out, look at which poles are closest to each other. The south pole of one magnet is closest to the south pole of the other magnet. Poles that are the same repel. So, these magnets will repel each other.
Answer: The answer is (B).



(a) ratio of hallucination mistakes (b) correction rate w/ vision features

Table 3. Two-stage setting of (i) rationale generation (RougeL) and (ii) answer inference (Accuracy).

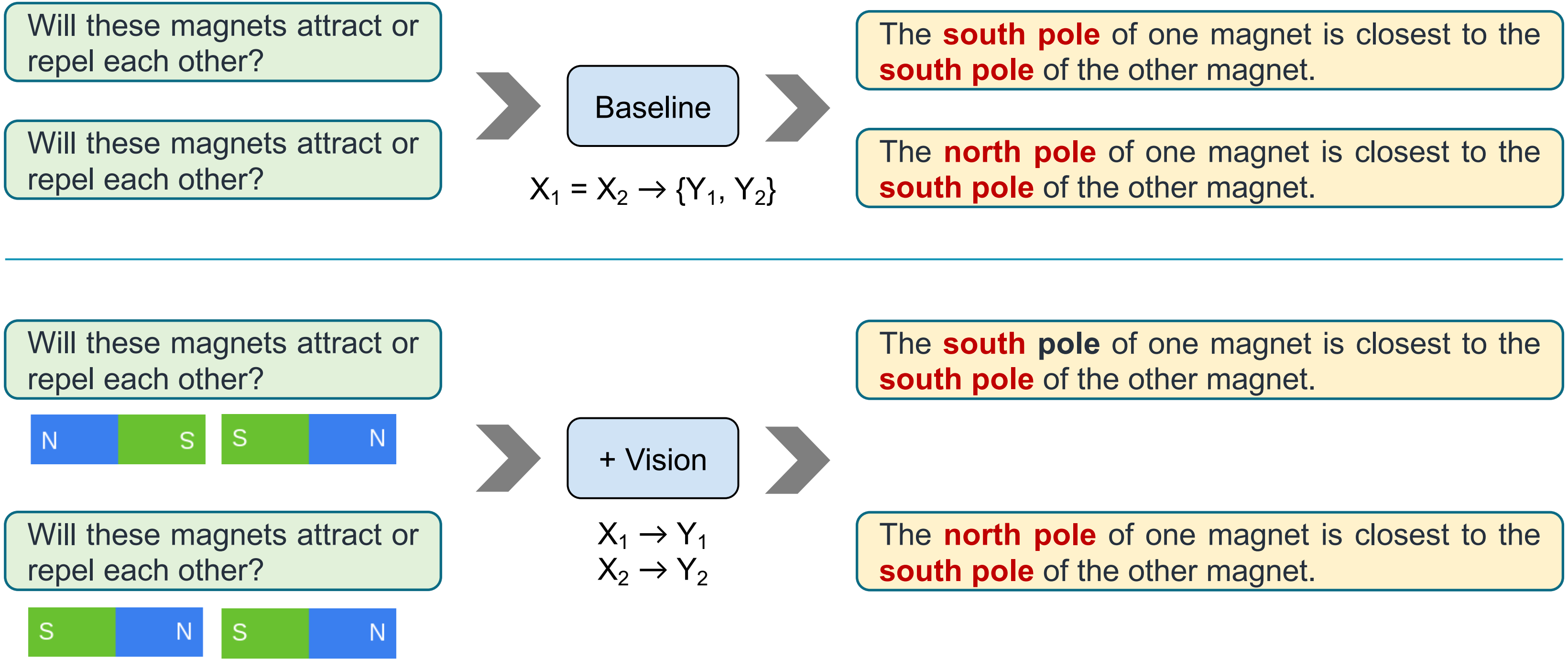
Method	(i) QCM→ R	(ii) QCMR→ A
Two-Stage Framework	91.76	70.53
w/ Captions	91.85	71.12
w/ Vision Features	96.97	84.91

Zhang, Z., Zhang, A., Li, M., Zhao, H., Karypis, G. and Smola, A. Multimodal chain-of-thought reasoning in language models. TMLR 2024.

The Role of (Multimodal) Chain-of-Thought

☐ **Role 1: Introducing more reliable input results in more convincing reasoning process**

- **More accurate perception, less hallucinations during the reasoning process**



Will these magnets attract or repel each other?

Will these magnets attract or repel each other?

Baseline

$X_1 = X_2 \rightarrow \{Y_1, Y_2\}$

The **south pole** of one magnet is closest to the **south pole** of the other magnet.

The **north pole** of one magnet is closest to the **south pole** of the other magnet.

Will these magnets attract or repel each other?

Will these magnets attract or repel each other?

+ Vision

$X_1 \rightarrow Y_1$
$X_2 \rightarrow Y_2$

The **south pole** of one magnet is closest to the **south pole** of the other magnet.

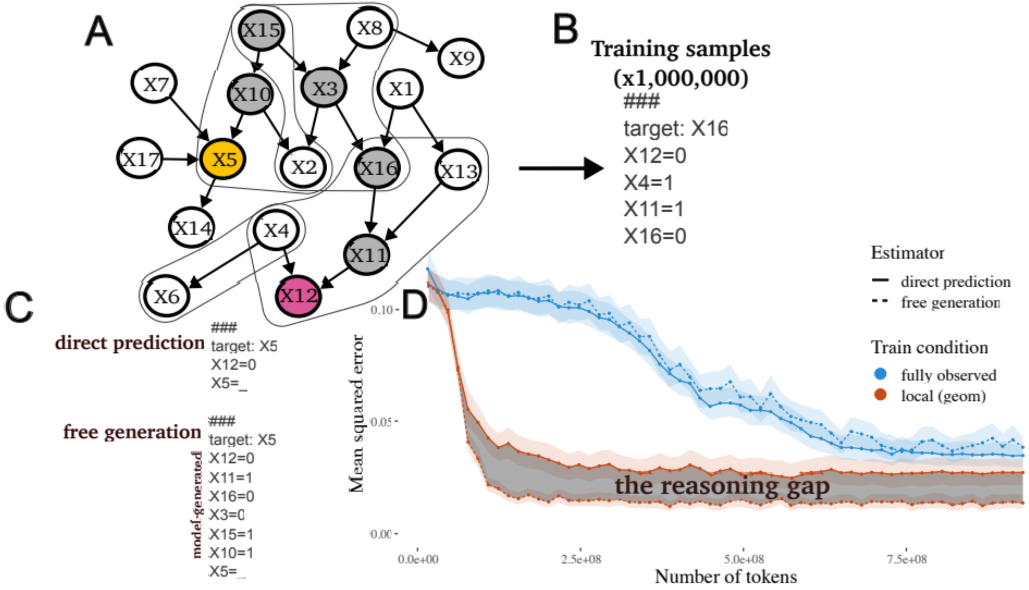
The **north pole** of one magnet is closest to the **south pole** of the other magnet.

Zhang, Z., Zhang, A., Li, M., Zhao, H., Karypis, G. and Smola, A. Multimodal chain-of-thought reasoning in language models. TMLR 2024.

The Role of (Multimodal) Chain-of-Thought

Role 2: Breaking complex problems into smaller, manageable sub-problems

- **identifies atomic knowledge components essential for reasoning processes**
- **integrates their relationships, thereby constructing coherent reasoning steps**



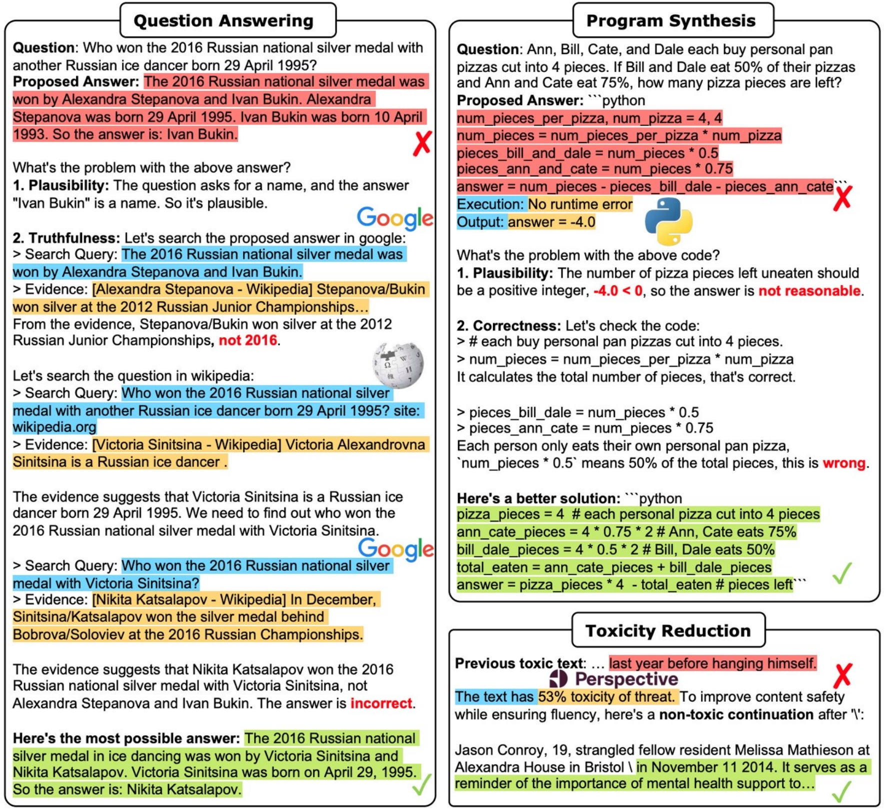
CoT reasoning is useful because

1) direct prediction is inaccurate for some inferences because the relevant variables are rarely seen together in training
2) chain-of-thought reasoning improves estimation by incrementally chaining local statistical dependencies that are observed frequently in training

Prystawski, B., Li, M., & Goodman, N. Why think step by step? Reasoning emerges from the locality of experience. NeurIPS 2024.

The Role of (Multimodal) Chain-of-Thought

❑ Role 3: Available for stepwise knowledge update and self-correction (w/ external feedback)



Question Answering

Question: Who won the 2016 Russian national silver medal with another Russian ice dancer born 29 April 1995?
Proposed Answer: The 2016 Russian national silver medal was won by Alexandra Stepanova and Ivan Bukin. Alexandra Stepanova was born 29 April 1995. Ivan Bukin was born 10 April 1993. So the answer is: Ivan Bukin. ✗

What's the problem with the above answer?
1. Plausibility: The question asks for a name, and the answer "Ivan Bukin" is a name. So it's plausible.

2. Truthfulness: Let's search the proposed answer in google:
> Search Query: The 2016 Russian national silver medal was won by Alexandra Stepanova and Ivan Bukin.
> Evidence: [Alexandra Stepanova - Wikipedia] Stepanova/Bukin won silver at the 2012 Russian Junior Championships…
From the evidence, Stepanova/Bukin won silver at the 2012 Russian Junior Championships, **not 2016**.

Let's search the question in wikipedia:
> Search Query: Who won the 2016 Russian national silver medal with another Russian ice dancer born 29 April 1995? site: wikipedia.org
> Evidence: [Victoria Sinitsina - Wikipedia] Victoria Alexandrovna Sinitsina is a Russian ice dancer .

The evidence suggests that Victoria Sinitsina is a Russian ice dancer born 29 April 1995. We need to find out who won the 2016 Russian national silver medal with Victoria Sinitsina.
> Search Query: Who won the 2016 Russian national silver medal with Victoria Sinitsina?
> Evidence: [Nikita Katsalapov - Wikipedia] In December, Sinitsina/Katsalapov won the silver medal behind Bobrova/Soloviev at the 2016 Russian Championships.

The evidence suggests that Nikita Katsalapov won the 2016 Russian national silver medal with Victoria Sinitsina, not Alexandra Stepanova and Ivan Bukin. The answer is **incorrect**.

Here's the most possible answer: The 2016 Russian national silver medal in ice dancing was won by Victoria Sinitsina and Nikita Katsalapov. Victoria Sinitsina was born on April 29, 1995. So the answer is: Nikita Katsalapov. ✓

Program Synthesis

Question: Ann, Bill, Cate, and Dale each buy personal pan pizzas cut into 4 pieces. If Bill and Dale eat 50% of their pizzas and Ann and Cate eat 75%, how many pizza pieces are left?
Proposed Answer: ```python

```
num_pieces_per_pizza, num_pizza = 4, 4
num_pieces = num_pieces_per_pizza * num_pizza
pieces_bill_and_dale = num_pieces * 0.5
pieces_ann_and_cate = num_pieces * 0.75
answer = num_pieces - pieces_bill_dale - pieces_ann_cate```
```

✗

Execution: No runtime error
Output: answer = -4.0

What's the problem with the above code?
1. Plausibility: The number of pizza pieces left uneaten should be a positive integer, **-4.0 < 0**, so the answer is **not reasonable**.

2. Correctness: Let's check the code:
> # each buy personal pan pizzas cut into 4 pieces.
> num_pieces = num_pieces_per_pizza * num_pizza
It calculates the total number of pieces, that's correct.

> pieces_bill_dale = num_pieces * 0.5
> pieces_ann_cate = num_pieces * 0.75
Each person only eats their own personal pan pizza, `num_pieces * 0.5` means 50% of the total pieces, this is **wrong**.

Here's a better solution: ```python

```
pizza_pieces = 4  # each personal pizza cut into 4 pieces
ann_cate_pieces = 4 * 0.75 * 2 # Ann, Cate eats 75%
bill_dale_pieces = 4 * 0.5 * 2 # Bill, Dale eats 50%
total_eaten = ann_cate_pieces + bill_dale_pieces
answer = pizza_pieces * 4  - total_eaten # pieces left```
```

✓

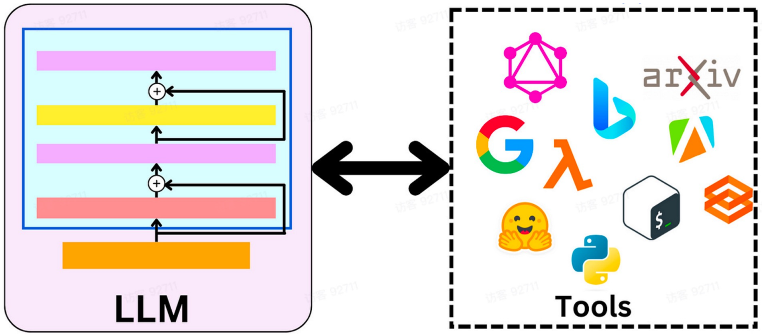
Toxicity Reduction

Previous toxic text: … last year before hanging himself. ✗
Perspective
The text has 53% toxicity of threat. To improve content safety while ensuring fluency, here's a **non-toxic continuation** after '\':

Jason Conroy, 19, strangled fellow resident Melissa Mathieson at Alexandra House in Bristol \ in November 11 2014. It serves as a reminder of the importance of mental health support to… ✓

❑ Chain-of-Thought w/ Tools

- Plan-Solve, augment and correct intermediate steps with tools
- Overcome the Intrinsic ability deficiency of LLMs such as calculation, searching



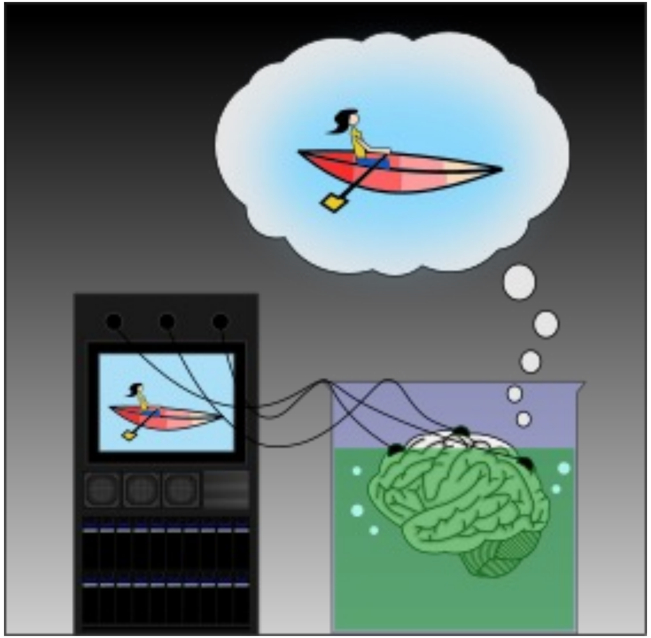
Gou, Zhibin, et al. "Critic: Large language models can self-correct with tool-interactive critiquing. ICLR 2024.

3

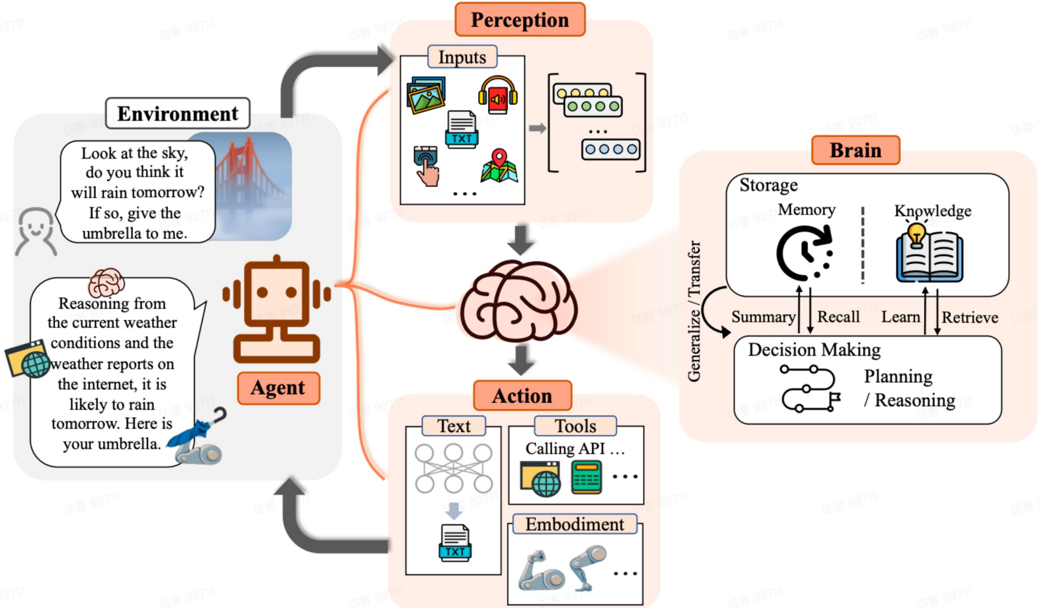
Towards Multimodal LLM Agents

Towards Multimodal LLM Agents

- ❑ **From content-based reasoning to behavior control (w/ multimodalities)**
- ❑ ***"Those who know but do not act simply do not yet know"***



Brain in a Vat



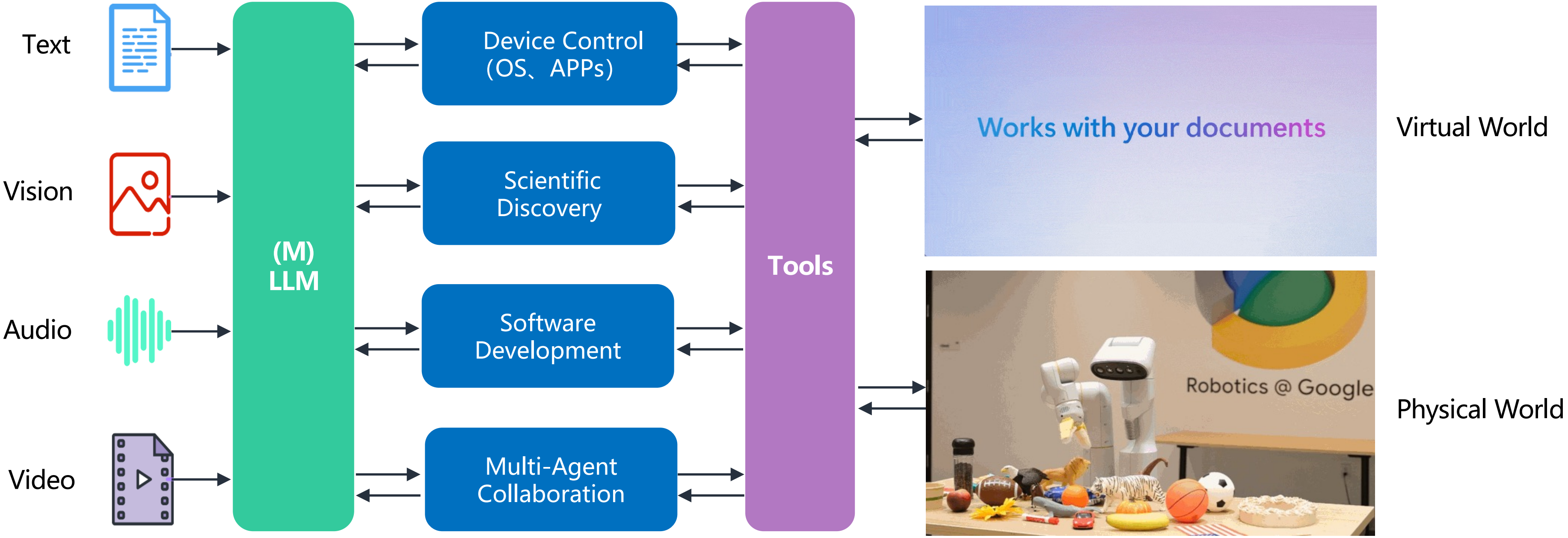
Look at the sky, do you think it will rain tomorrow? If so, give the umbrella to me.

Reasoning from the current weather conditions and the weather reports on the internet, it is likely to rain tomorrow. Here is your umbrella.

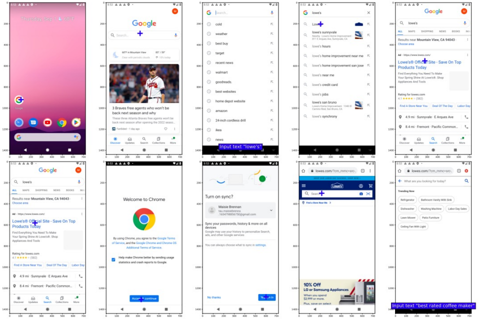
Ma, Y., Zhang, C. and Zhu, S.C., 2023. Brain in a vat: On missing pieces towards artificial general intelligence in large language models. arXiv preprint arXiv:2307.03762.
Xi, Z., Chen, W., Guo, X., He, W., Ding, Y., Hong, B., Zhang, M., Wang, J., Jin, S., Zhou, E. and Zheng, R., 2023. The rise and potential of large language model based agents: A survey. arXiv preprint arXiv:2309.07864.

Towards Multimodal LLM Agents

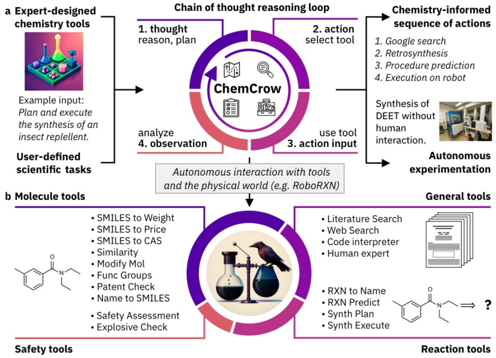
- **(M)LLM Agents:** follow language instructions and execute actions in environments, possibly use tools
- **Features:** General, Autonomous, Adaptive, Evolutionary, Socialized



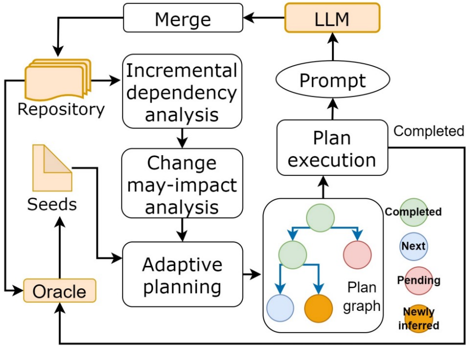
Towards Multimodal LLM Agents


Goal: Look up the best rated coffee maker on Lowe's.

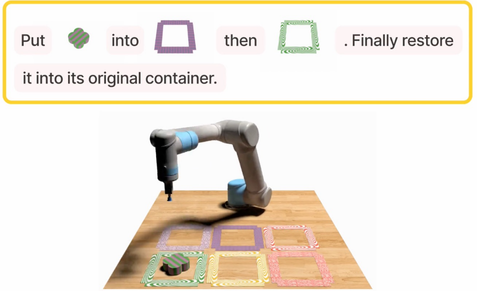
Control: OS and Applications



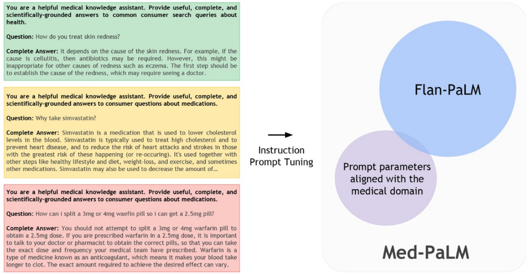
Research: Organic Synthesis



Programming: Code Generation



Control: Embodied Systems


You are a helpful medical knowledge assistant. Provide useful, complete, and scientifically-grounded answers to common consumer search queries about health.

Question: How do you treat skin redness?

Complete Answer: It depends on the cause of the skin redness. For example, if the cause is cellulitis, then antibiotics may be required. However, this might be inappropriate for other causes of redness such as eczema. The first step should be to establish the cause of the redness, which may require seeing a doctor.

You are a helpful medical knowledge assistant. Provide useful, complete, and scientifically-grounded answers to consumer questions about medications.

Question: Why take simvastatin?

Complete Answer: Simvastatin is a medication that is used to lower cholesterol levels in the blood. Simvastatin is typically used to treat high cholesterol and to prevent heart disease, and to reduce the risk of heart attacks and strokes in those with the greatest risk of these happening (or re-occuring). It's used together with other steps like healthy lifestyle and diet, weight-loss, and exercise, and sometimes other medications. Simvastatin may also be used to decrease the amount of...

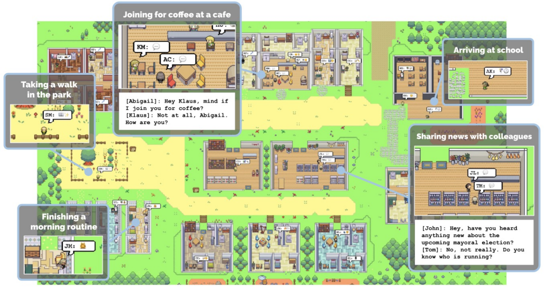
You are a helpful medical knowledge assistant. Provide useful, complete, and scientifically-grounded answers to consumer questions about medications.

Question: How can i split a 3mg or 4mg waefin pill so i can get a 2.5mg pill?

Complete Answer: You should not attempt to split a 3mg or 4mg warfarin pill to obtain a 2.5mg dose. If you are prescribed warfarin in a 2.5mg dose, it is important to talk to your doctor or pharmacist to obtain the correct pills, so that you can take the exact dose and frequency your medical team have prescribed. Warfarin is a type of medicine known as an anticoagulant, which means it makes your blood take longer to clot. The exact amount required to achieve the desired effect can vary.

Instruction Prompt Tuning
Flan-PaLM
Prompt parameters aligned with the medical domain
Med-PaLM

Research: Medical Assistance


[Abigail]: Hey Klaus, mind if I join you for coffee?
[Klaus]: Not at all, Abigail. How are you?

[John]: Hey, have you heard anything new about the upcoming mayoral election?
[Tom]: No, not really. Do you know who is running?

Joining for coffee at a cafe
KM:
AC:
Taking a walk in the park
SM:
Arriving at school
AK:
Sharing news with colleagues
JL:
TM:
Finishing a morning routine
JM:

Interaction: Multi-Agent Collaboration

Ma, Y., Zhang, C. and Zhu, S.C., 2023. Brain in a vat: On missing pieces towards artificial general intelligence in large language models. arXiv preprint arXiv:2307.03762.
Xi, Z., Chen, W., Guo, X., He, W., Ding, Y., Hong, B., Zhang, M., Wang, J., Jin, S., Zhou, E. and Zheng, R., 2023. The rise and potential of large language model based agents: A survey. arXiv preprint arXiv:2309.07864.

Taxonomy of (M)LLM Agents

Autonomous Agents

Action Transformer
https://www.adept.ai/blog/act-1

AITW
https://github.com/google-research/google-research/tree/master/android_in_the_wild

WebArena
https://webarena.dev

Auto-UI
https://github.com/cooelf/Auto-UI

Communicative Agents

CAMEL
https://github.com/camel-ai/camel

Generative Agents
https://github.com/joonspk-research/generative_agents

VOYAGER
https://voyager.minedojo.org/

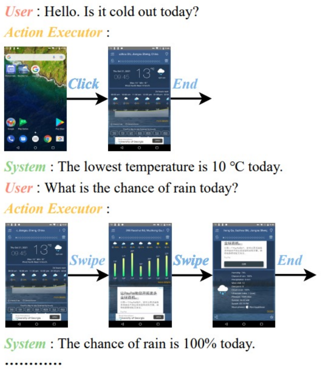
ChatDev
https://github.com/OpenBMB/ChatDev

More: AutoGPT, BabyAGI, Meta-GPT, AgentGPT

Taxonomy of (M)LLM Agents

Autonomous Agents: mainly task automation

Mobile Device Automation



User : Hello. Is it cold out today?

Action Executor :

System : The lowest temperature is 10 ℃ today.

User : What is the chance of rain today?

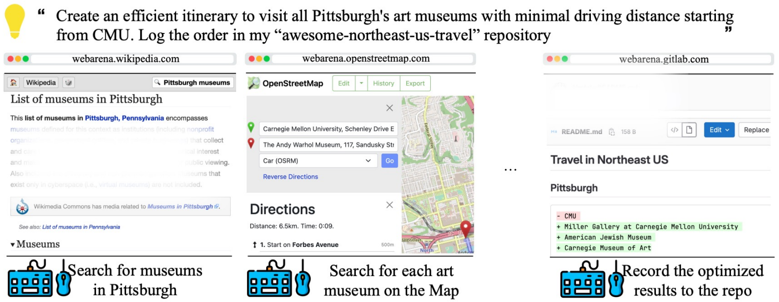
Action Executor :

System : The chance of rain is 100% today.

…………

Meta-GUI

Webpage Automation


webarena.wikipedia.com
Wikipedia
Pittsburgh museums
List of museums in Pittsburgh
This list of museums in Pittsburgh, Pennsylvania encompasses
Wikimedia Commons has media related to Museums in Pittsburgh.
See also: List of museums in Pennsylvania
▾Museums
webarena.openstreetmap.com
OpenStreetMap
Edit
History
Export
Carnegie Mellon University, Schenley Drive E
The Andy Warhol Museum, 117, Sandusky Str
Car (OSRM)
Go
Reverse Directions
Directions
Distance: 6.5km. Time: 0:09.
1. Start on Forbes Avenue
500m
…
webarena.gitlab.com
README.md
158 B
Edit
Replace
Travel in Northeast US
Pittsburgh

“ Create an efficient itinerary to visit all Pittsburgh's art museums with minimal driving distance starting from CMU. Log the order in my “awesome-northeast-us-travel” repository ”

```
- CMU
+ Miller Gallery at Carnegie Mellon University
+ American Jewish Museum
+ Carnegie Museum of Art
```

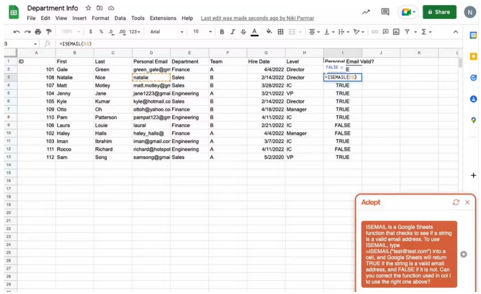
Search for museums in Pittsburgh

Search for each art museum on the Map

Record the optimized results to the repo

WebArena

Application Automation



=ISEMAIL(D3)

	A	B	C	D	E	F	G	H	I
1	ID	First	Last	Personal Email	Department	Team	Hire Date	Level	Personal Email Valid?
2	101	Gale	Green	green_gale@gm	Finance	A	4/4/2022	Director	FALSE
3	108	Natalie	Nice	natalie	Sales	B	2/14/2022	Director	=ISEMAIL(D3)
4	107	Matt	Motley	matt.motley@gm	Sales	B	3/28/2022	IC	TRUE
5	104	Jenny	Jane	jane1223@gmai	Engineering	A	3/21/2022	VP	TRUE
6	105	Kyle	Kumar	kyle@hotmail.co	Sales	B	2/14/2022	Director	TRUE
7	109	Otto	Oh	ottoh@yahoo.co	Finance	B	4/18/2022	Manager	TRUE
8	110	Pam	Patterson	pampat123@gm	Engineering	B	4/11/2022	IC	TRUE
9	106	Laura	Louie	laural	Finance	B	2/21/2022	IC	FALSE
10	102	Haley	Halls	haley_halls@	Finance	A	4/4/2022	Manager	FALSE
11	103	Iman	Ibrahim	iman@gmail.cor	Engineering	A	3/7/2022	IC	TRUE
12	111	Rocco	Richard	richard@hotspot	Engineering	A	4/11/2022	IC	FALSE
13	112	Sam	Song	samsong@gmai	Sales	A	5/2/2020	VP	TRUE

ISEMAIL is a Google Sheets function that checks to see if a string is a valid email address. To use ISEMAIL, type =ISEMAIL("test@test.com") into a cell, and Google Sheets will return TRUE if the string is a valid email address, and FALSE if it is not. Can you correct the function used in col I to use the right one above?

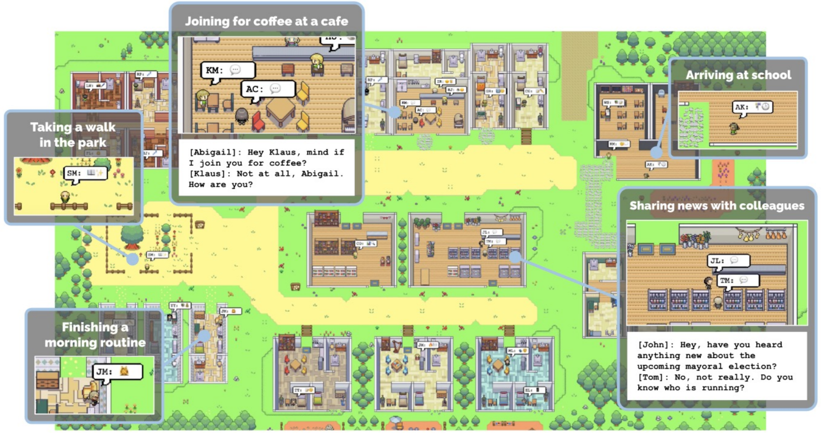
ACT-1

Sun, Liangtai, et al. "META-GUI: Towards Multi-modal Conversational Agents on Mobile GUI." *EMNLP 2022.*
Zhou, Shuyan, et al. "Webarena: A realistic web environment for building autonomous agents." *arXiv preprint arXiv:2307.13854* (2023).
https://www.adept.ai/blog/act-1

Taxonomy of (M)LLM Agents

Communicative Agents: personalized, socialized, interactive

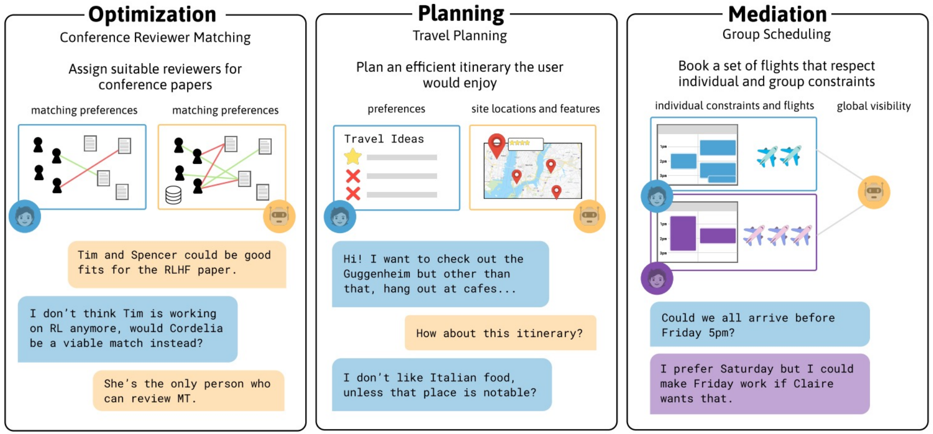
Agents-Agents


Joining for coffee at a cafe
KM:
AC:
Taking a walk in the park
SM:
Arriving at school
AK:
Sharing news with colleagues
JL:
TM:
Finishing a morning routine
JM:

[Abigail]: Hey Klaus, mind if I join you for coffee?
[Klaus]: Not at all, Abigail. How are you?

[John]: Hey, have you heard anything new about the upcoming mayoral election?
[Tom]: No, not really. Do you know who is running?

Agents-Human



Assign suitable reviewers for conference papers

Tim and Spencer could be good fits for the RLHF paper.

I don't think Tim is working on RL anymore, would Cordelia be a viable match instead?

She's the only person who can review MT.

Plan an efficient itinerary the user would enjoy

Hi! I want to check out the Guggenheim but other than that, hang out at cafes...

How about this itinerary?

I don't like Italian food, unless that place is notable?

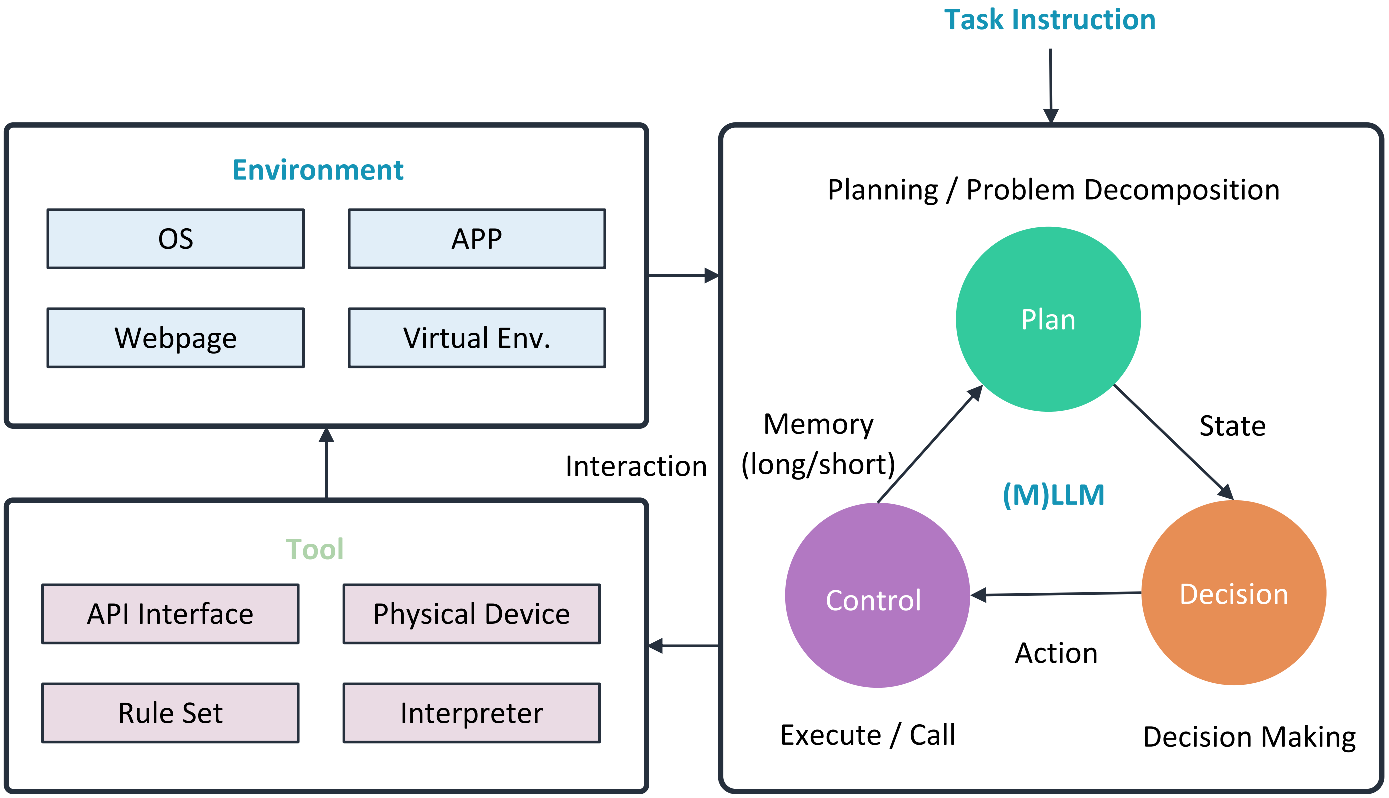
Book a set of flights that respect individual and group constraints

Could we all arrive before Friday 5pm?

I prefer Saturday but I could make Friday work if Claire wants that.

Park, Joon Sung, et al. "Generative agents: Interactive simulacra of human behavior." *arXiv preprint arXiv:2304.03442* (2023).
Lin, Jessy, et al. "Decision-Oriented Dialogue for Human-AI Collaboration." *arXiv preprint arXiv:2305.20076* (2023).

Technological Paradigm



Task Instruction

Environment

OS

APP

Webpage

Virtual Env.

Interaction

Tool

API Interface

Physical Device

Rule Set

Interpreter

Planning / Problem Decomposition

Plan

Memory (long/short)

State

(M)LLM

Control

Decision

Action

Execute / Call

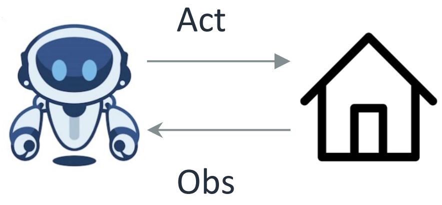
Decision Making

Foundation

- Multimodalities
- Long-context Modeling

Workflow

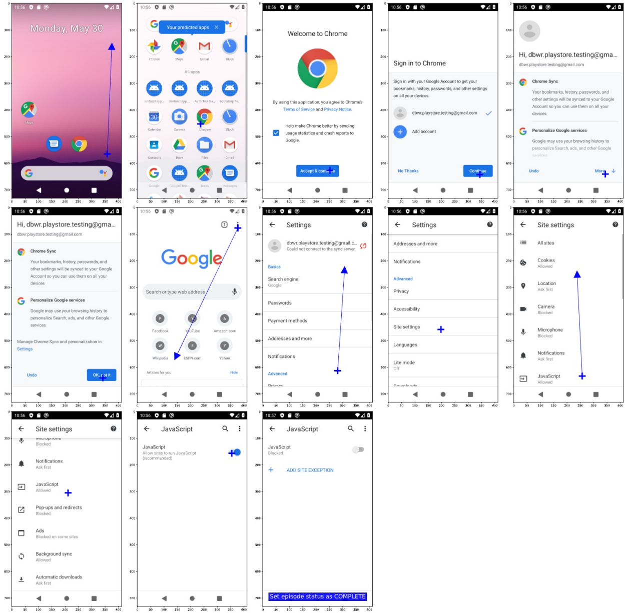
- Perception
- Planning & Decision Making
- Action (w/ Tool Use)
- Interaction
- Memory
- Multi-Agent Collaboration

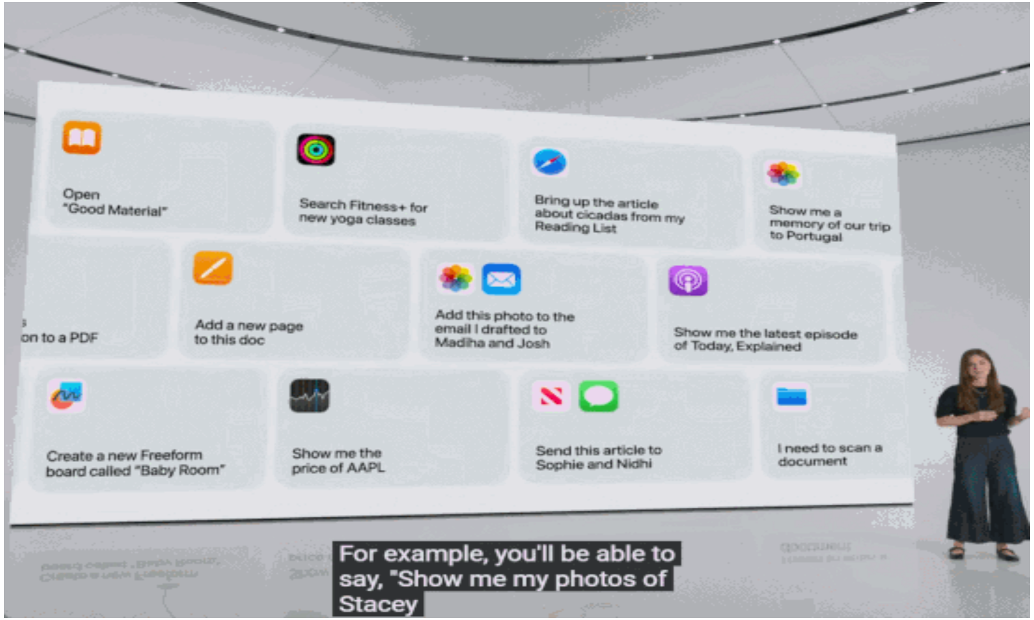


GUI Agents

- **Auto-GUI： Multimodal Autonomous Agents for GUI control**
  - assist users in completing tasks in distinct environments such as operation systems, specific applications, and web browsers
  - Imitate human clicking, scrolling, and typing actions, and operate directly with the GUI

Goal: turn off javascript in the chrome app



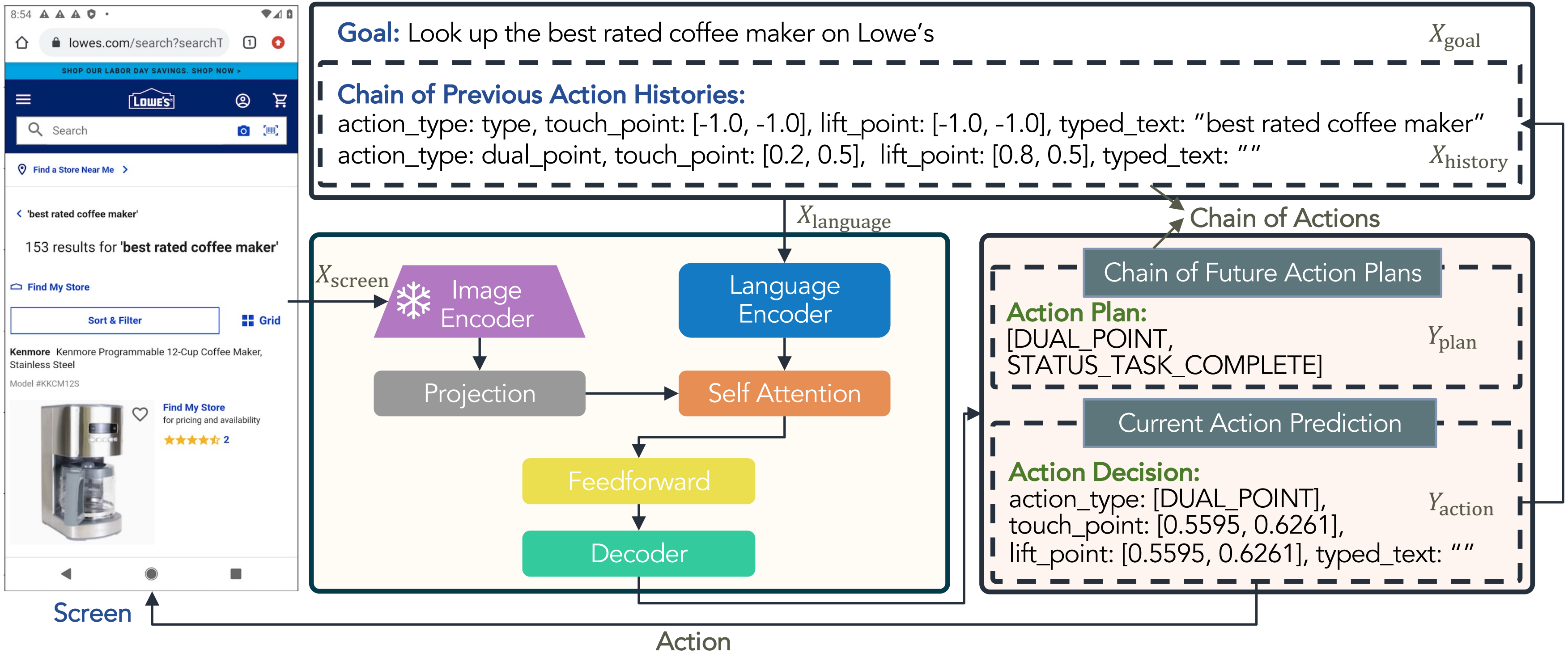

Open "Good Material"
Search Fitness+ for new yoga classes
Bring up the article about cicadas from my Reading List
Show me a memory of our trip to Portugal
on to a PDF
Add a new page to this doc
Add this photo to the email I drafted to Madiha and Josh
Show me the latest episode of Today, Explained
Create a new Freeform board called "Baby Room"
Show me the price of AAPL
Send this article to Sophie and Nidhi
I need to scan a document

For example, you'll be able to say, "Show me my photos of Stacey

Zhuosheng Zhang, Aston Zhang. You Only Look at Screens: Multimodal Chain-of-Action Agents. Findings of ACL 2024.
Xinbei Ma, Zhuosheng Zhang, Hai Zhao. Comprehensive Cognitive LLM Agent for Smartphone GUI Automation. Findings of ACL 2024.
https://machinelearning.apple.com/research/ferret..

Auto-UI

- ☐ **Multimodal Agent: BLIP2 + FLAN-Alpaca**
- ☐ **Chain-of-Action: a series of intermediate previous action histories and future action plans**



Goal: Look up the best rated coffee maker on Lowe's X_{goal}

Chain of Previous Action Histories:
action_type: type, touch_point: [-1.0, -1.0], lift_point: [-1.0, -1.0], typed_text: "best rated coffee maker"
action_type: dual_point, touch_point: [0.2, 0.5], lift_point: [0.8, 0.5], typed_text: "" X_{history}

Action Plan:
[DUAL_POINT,
STATUS_TASK_COMPLETE] Y_{plan}

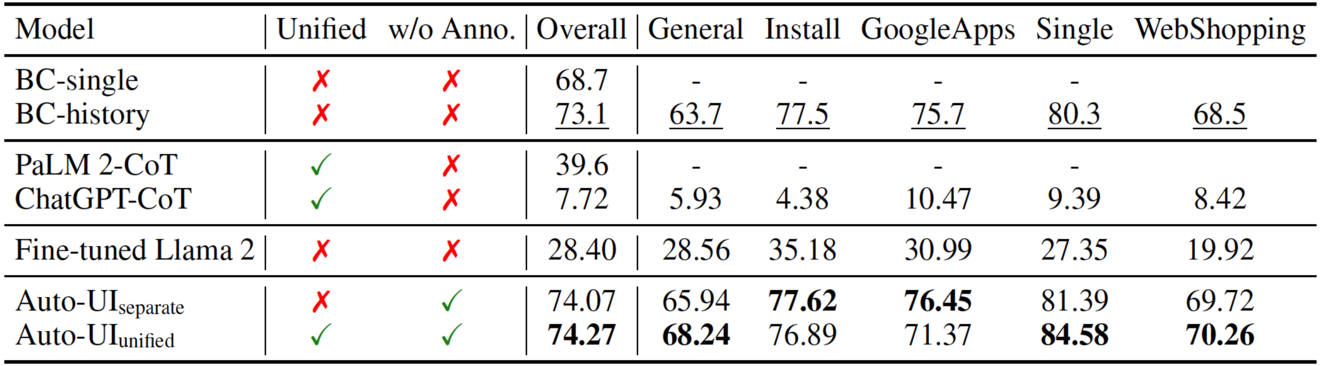
Action Decision:
action_type: [DUAL_POINT],
touch_point: [0.5595, 0.6261],
lift_point: [0.5595, 0.6261], typed_text: "" Y_{action}

8:54
lowes.com/search?searchT
SHOP OUR LABOR DAY SAVINGS. SHOP NOW >
LOWE'S
Search
Find a Store Near Me
'best rated coffee maker'
153 results for 'best rated coffee maker'
Find My Store
Sort & Filter
Grid
Kenmore Kenmore Programmable 12-Cup Coffee Maker, Stainless Steel
Model #KKCM12S
Find My Store
for pricing and availability
2
Screen
X_language
X_screen
Image Encoder
Language Encoder
Projection
Self Attention
Feedforward
Decoder
Chain of Actions
Chain of Future Action Plans
Current Action Prediction
Action

Zhuosheng Zhang, Aston Zhang. You Only Look at Screens: Multimodal Chain-of-Action Agents. Findings of ACL 2024.

Results

- A **unified multimodal model** out of ***first principles thinking*** can serve as a strong autonomous agent
  - can be adapted to **different scenarios** without the need to train specific models for each task
  - does not need additional annotations (screen parsing) and is **easy to use**
- Coverage: 30K unique instructions, 350+ Apps and websites
- **Action Type Accuracy: 90%+, Action Success Rate: 74%+**



Model	Unified	w/o Anno.	Overall	General	Install	GoogleApps	Single	WebShopping
BC-single	✗	✗	68.7	-	-	-	-	
BC-history	✗	✗	73.1	63.7	77.5	75.7	80.3	68.5
PaLM 2-CoT	✓	✗	39.6	-	-	-	-	
ChatGPT-CoT	✓	✗	7.72	5.93	4.38	10.47	9.39	8.42
Fine-tuned Llama 2	✗	✗	28.40	28.56	35.18	30.99	27.35	19.92
Auto-UI$_{\text{separate}}$	✗	✓	74.07	65.94	**77.62**	**76.45**	81.39	69.72
Auto-UI$_{\text{unified}}$	✓	✓	**74.27**	**68.24**	76.89	71.37	**84.58**	**70.26**

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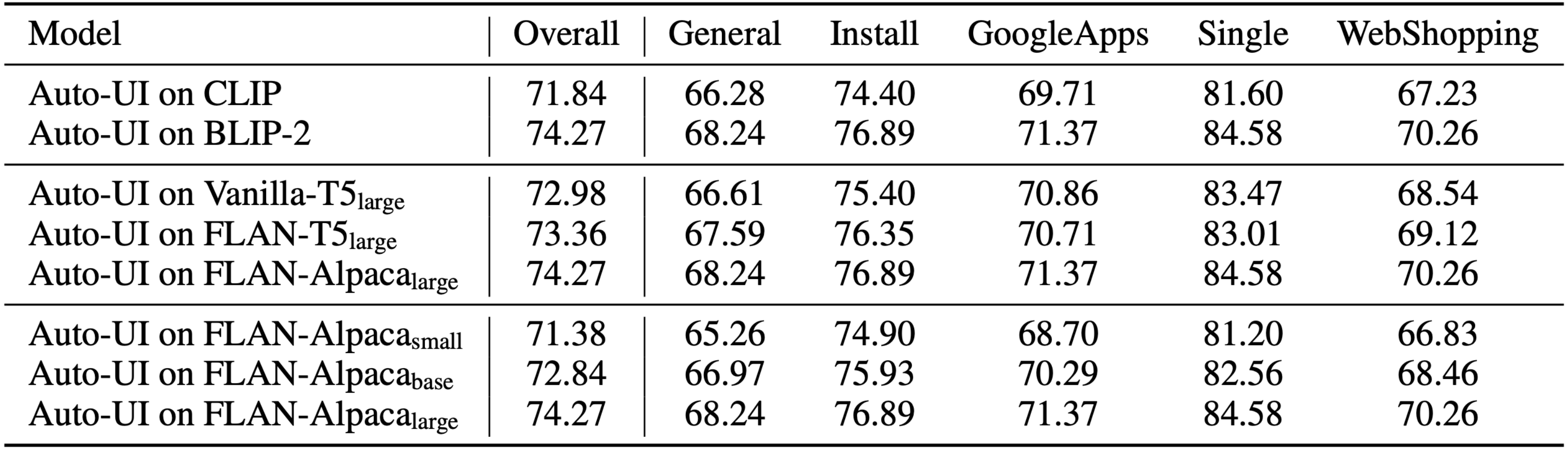
Insights

- The bottleneck seems to be the **multimodal perception**, misleading the reasoning process
  - GUI involves comprehensive elements (interleaved, icons, texts, boxes)
  - Changing vision encoders influences the performance dramatically
- Scaling does not always improve performance



Model	Overall	General	Install	GoogleApps	Single	WebShopping
Auto-UI on CLIP	71.84	66.28	74.40	69.71	81.60	67.23
Auto-UI on BLIP-2	74.27	68.24	76.89	71.37	84.58	70.26
Auto-UI on Vanilla-T5$_{\text{large}}$	72.98	66.61	75.40	70.86	83.47	68.54
Auto-UI on FLAN-T5$_{\text{large}}$	73.36	67.59	76.35	70.71	83.01	69.12
Auto-UI on FLAN-Alpaca$_{\text{large}}$	74.27	68.24	76.89	71.37	84.58	70.26
Auto-UI on FLAN-Alpaca$_{\text{small}}$	71.38	65.26	74.90	68.70	81.20	66.83
Auto-UI on FLAN-Alpaca$_{\text{base}}$	72.84	66.97	75.93	70.29	82.56	68.46
Auto-UI on FLAN-Alpaca$_{\text{large}}$	74.27	68.24	76.89	71.37	84.58	70.26

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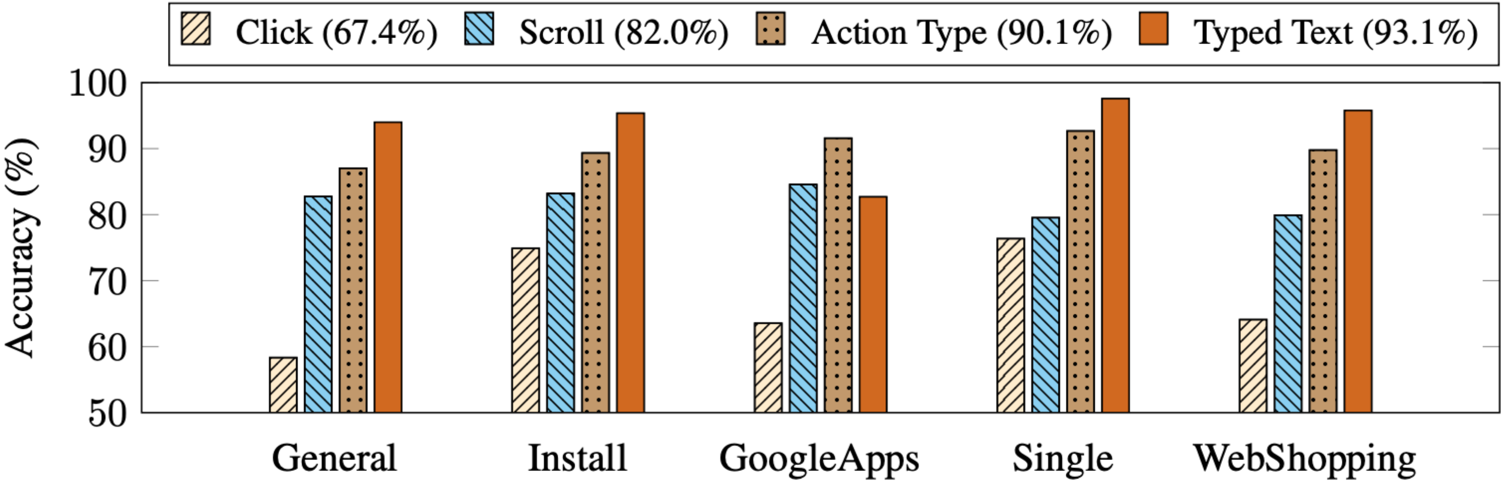
Insights

- ☐ **Category Accuracy:** the major challenges lie within the click region and scroll direction predictions
  - ● The model tends to click a wrong place or scroll in a wrong direction
- ☐ Challenge in “really” understanding the GUI layouts, e.g., relationship between GUI elements



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4

Challenges

Challenges

- Multimodal reasoning drives smart MLLMs
  - More broader scenarios (physical and virtual worlds)
  - More comprehensive scenarios (evolutionary, interactive)

Evolutionary Reasoning

- Active explore and evolve from environments
- Learn from (un)successful attempts

Interactive Reasoning

- Human-in-the-loop interference
- Error identification and correction abilities

Reasoning Alignment

- Align both content safety, and behavior safety
- Decide the action trajectory with foresights

Summary

- Basics of Multimodal Reasoning
  - Concept: derive high-level conclusions from multiple modalities, possibly via multiple logical steps based on atomic evidences
  - Developments: (a) From task-specific to centralized paradigms; (b) From single-step prediction to multi-step reasoning
  - Popular Approaches: (a) In-Context Learning: (b) Multimodal Chain-of-Thought
- Multimodal Chain-of-Thought Reasoning
  - Paradigm Shift: From “<input → output>” to <input → rationale → output>
  - Role 1: Introducing more reliable input results in more convincing reasoning process
  - Role 2: Breaking complex problems into smaller, manageable sub-problems
  - Role 3: Available for stepwise knowledge update and self-correction (w/ external feedback)
- Towards Multimodal LLM Agents
  - Taxonomy: Autonomous Agents and Communicative Agents
  - Technical Components: Foundation (multimodality & long-context modeling); (b) Workflow (plan, act, memory, feedback)
- Challenges
  - Evolutionary Reasoning, Interactive Reasoning, Reasoning Alignment

Thanks!

Any questions?

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- zhangzs@sjtu.edu.cn