DSC291: Machine Learning with Few Labels

Enhancing Large Language Models: Overview

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Lecture 10, April 22, 2024

UC San Diego
HALICIOĞLU DATA SCIENCE INSTITUTE

Outline: Enhancing the Backend Beyond LMs

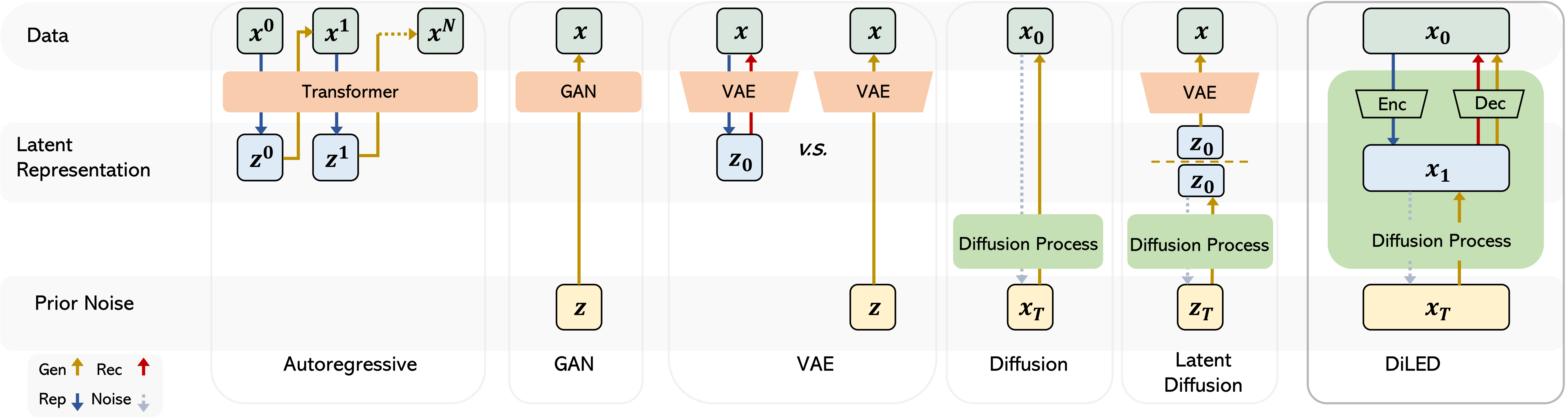
- Richer learning mechanisms
  - Learning with Embodied Experiences
  - Social Learning
- Multi-modal capabilities
- **Latent-space reasoning**
- Agent models with external augmentations (e.g., tools)

Latent-space Reasoning

- What's the best space for carrying out reasoning?
  - Natural language space?
  - Raw sensory space (e.g., video)?
  - **Learned** latent space?
    - Single-level / multi-level latent space?
- Consider a long-term planning problem, e.g., economic planning for U.S. in 2024
  - Extremely complex, long-horizon reasoning
  - Inefficient/infeasible with LLM token-by-token reasoning or Video Model frame-by-frame reasoning
- Multi-level latent spaces are needed for multi-granularity reasoning

Latent-space Reasoning

- But how to learn a good latent space in the first place?



[Liu et al., 2024] Generating, Reconstructing, and Representing Discrete and Continuous Data: Generalized Diffusion with Learnable Encoding-Decoding

Outline: Enhancing the Backend Beyond LMs

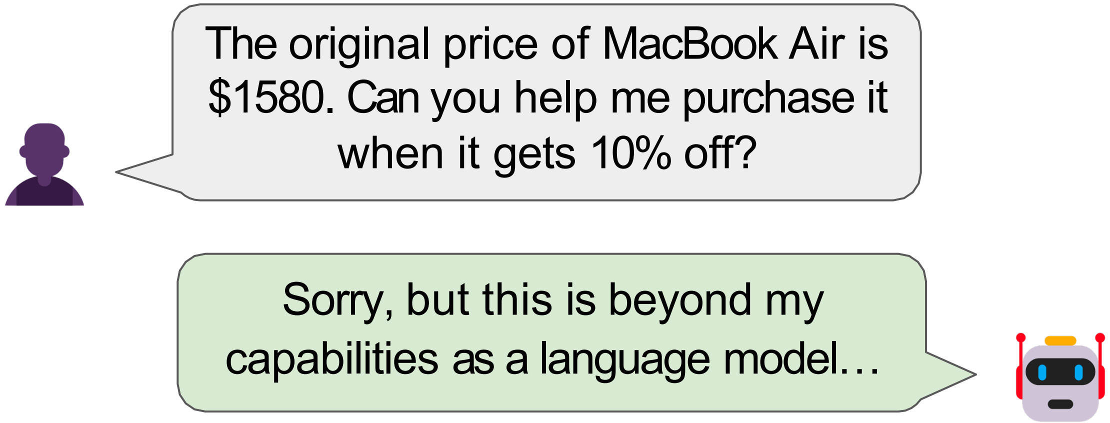
- Richer learning mechanisms
  - Learning with Embodied Experiences
  - Social Learning
- Multi-modal capabilities
- Latent-space reasoning
- **Agent models with external augmentations (e.g., tools)**

Agent models with external augmentations

- External augmentations for added capabilities:
  - Tools: telescope, vehicles, …
  - Data about a skill: demonstration videos of climbing a snowy mountain
  - Knowledge bases: domain knowledge

[Hao et al., 2023] ToolkenGPT: Augmenting Frozen Language Models with Massive Tools via Tool Embeddings

LLMs need external tools for real-world tasks

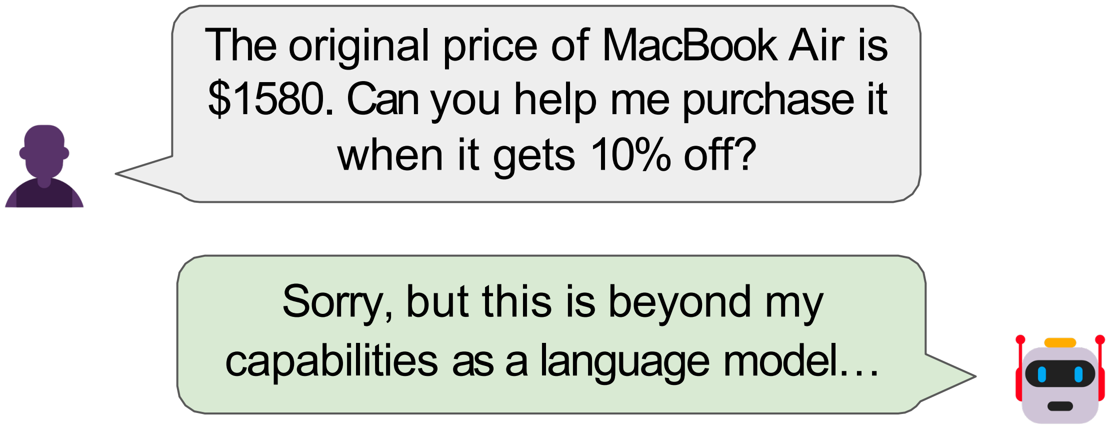


The original price of MacBook Air is $1580. Can you help me purchase it when it gets 10% off?

Sorry, but this is beyond my capabilities as a language model…

LLMs need external tools for real-world tasks

Lacking the abilities for



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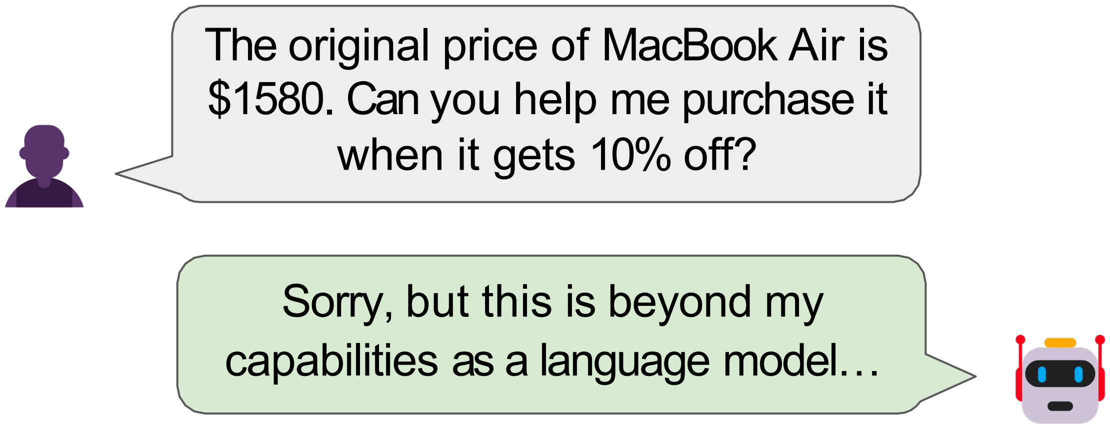

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Lacking the abilities for

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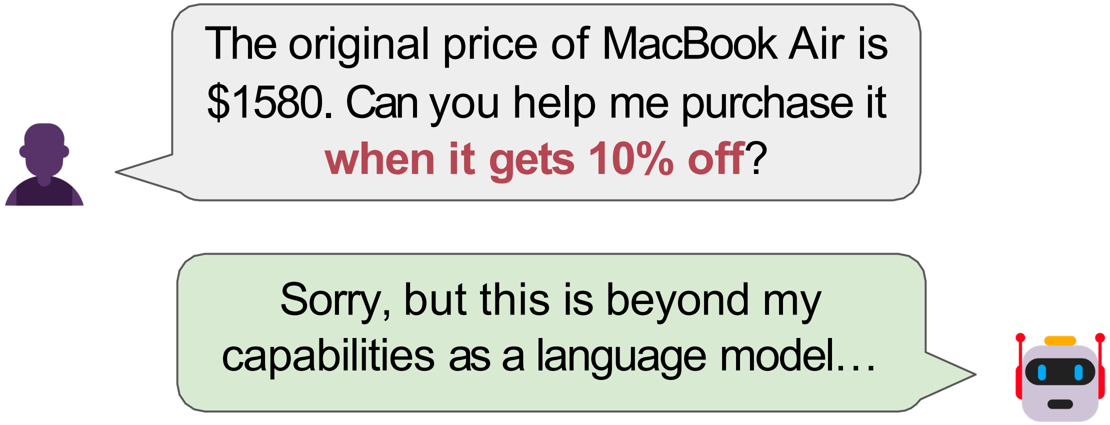
Up-to-date knowledge



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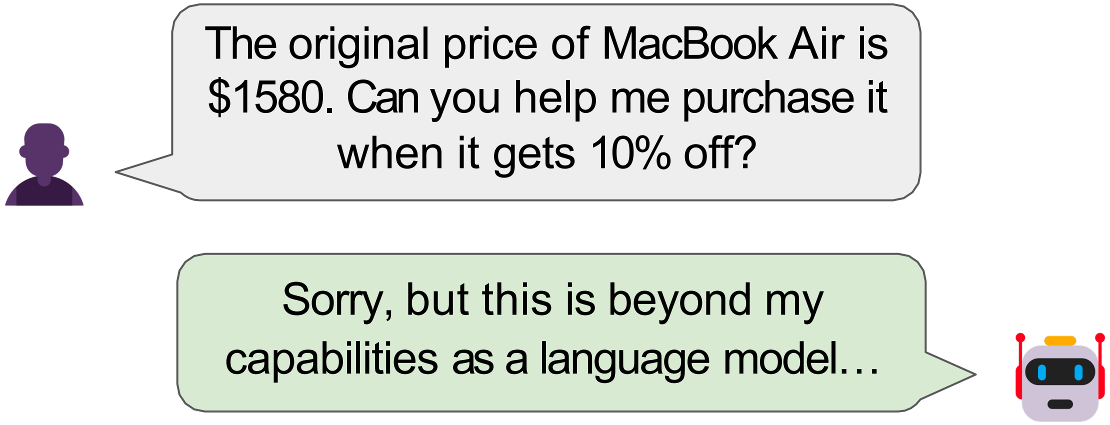

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Lacking the abilities for

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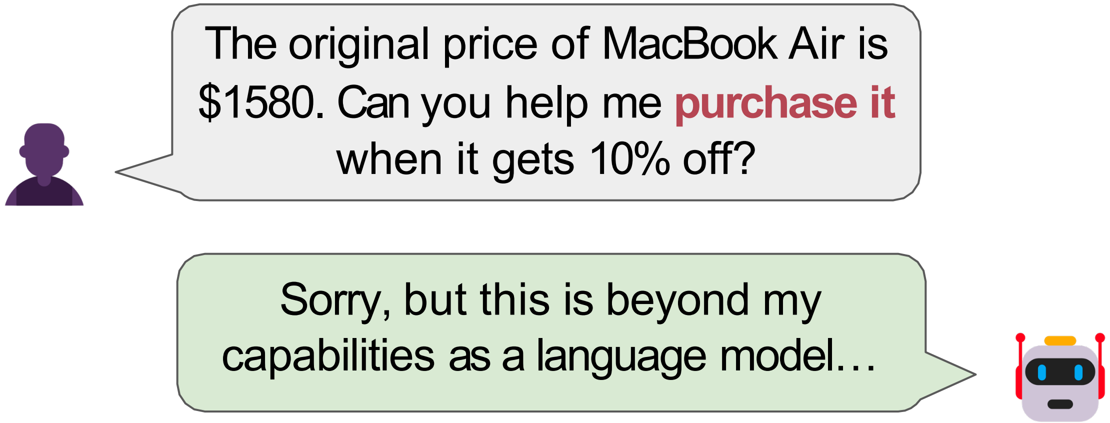
Real-world actions



The original price of MacBook Air is $1580. Can you help me **purchase it** when it gets 10% off?

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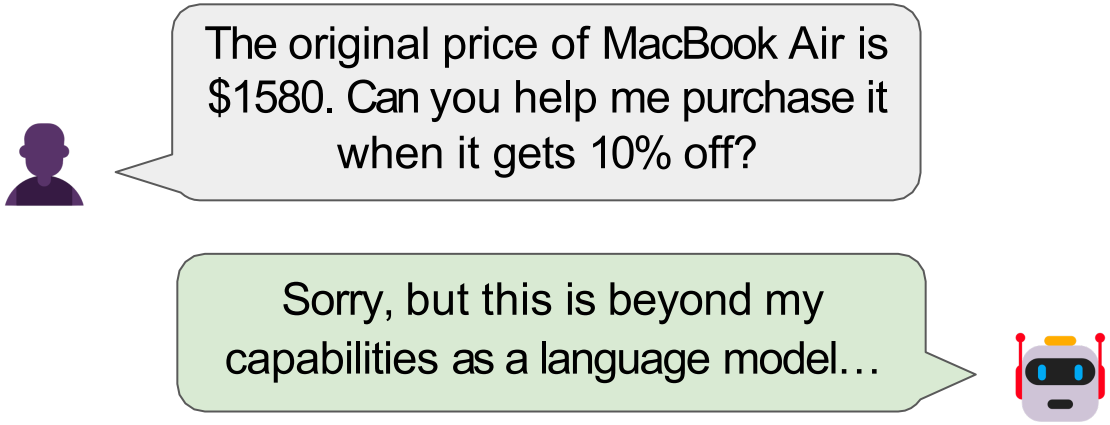
LLMs need external tools for real-world tasks

Lacking the abilities for

- Accurate math calculation
- Accessing up-to-date knowledge
- Taking real-world actions



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LLMs need external tools for real-world tasks

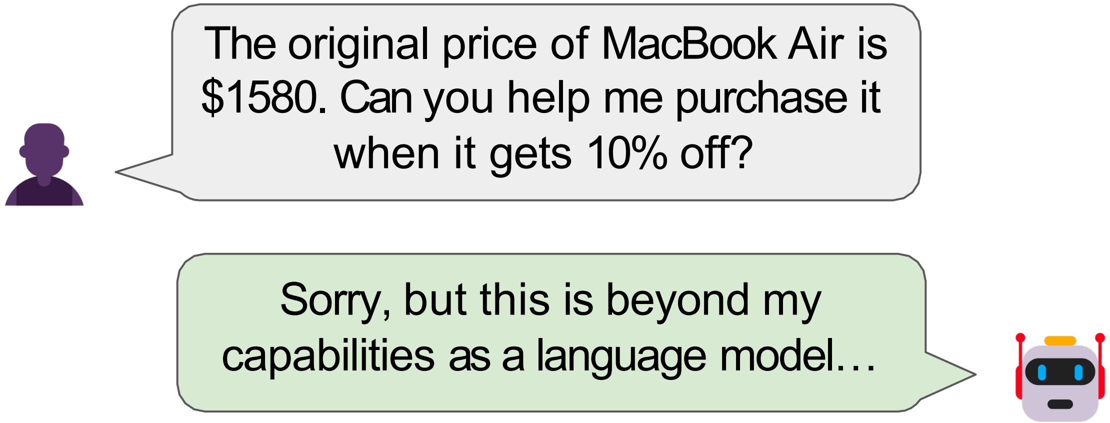
Augmenting language models with tools will help unlock those abilities!

- Accurate math calculation
- Accessing up-to-date knowledge
- Taking real-world actions
- …

Calculator

Database

API/Robot



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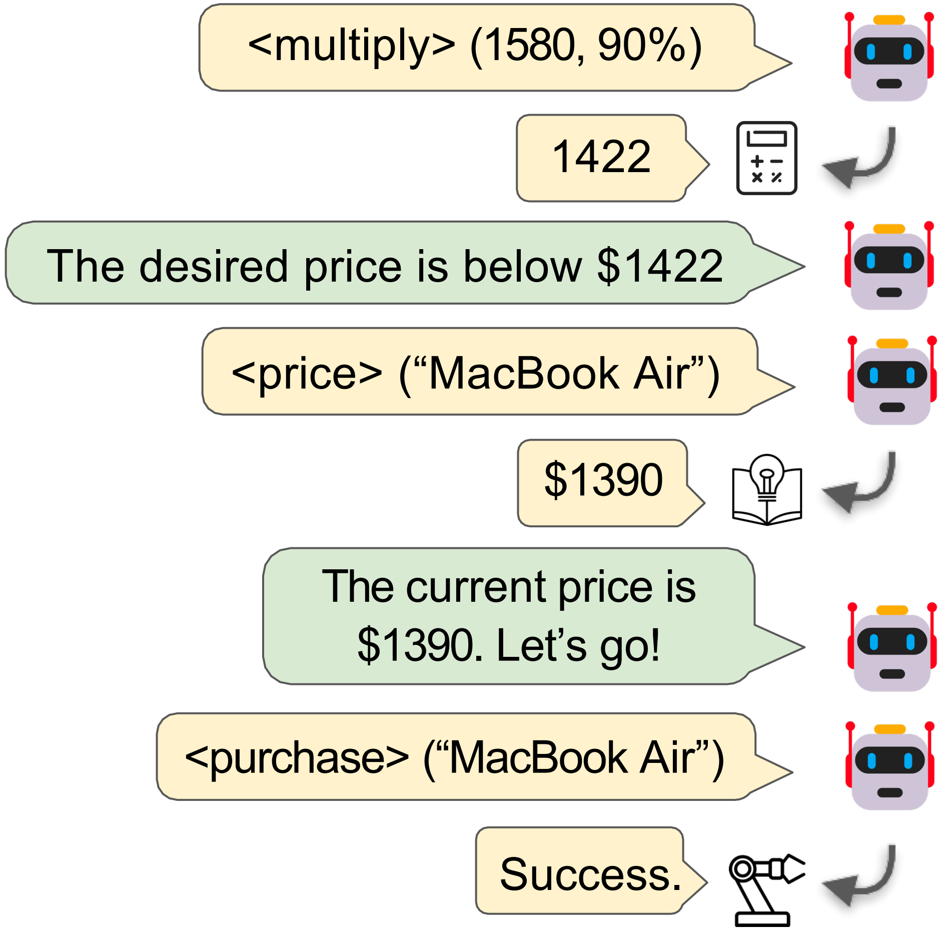
LLMs need external tools for real-world tasks

Augmenting language models with tools will help unlock those abilities!

• Accurate math calculation	Calculator
• Accessing up-to-date knowledge	Database
• Taking real-world actions	API/Robot
• …	



<multiply> (1580, 90%)

1422

The desired price is below $1422

<price> (“MacBook Air”)

$1390

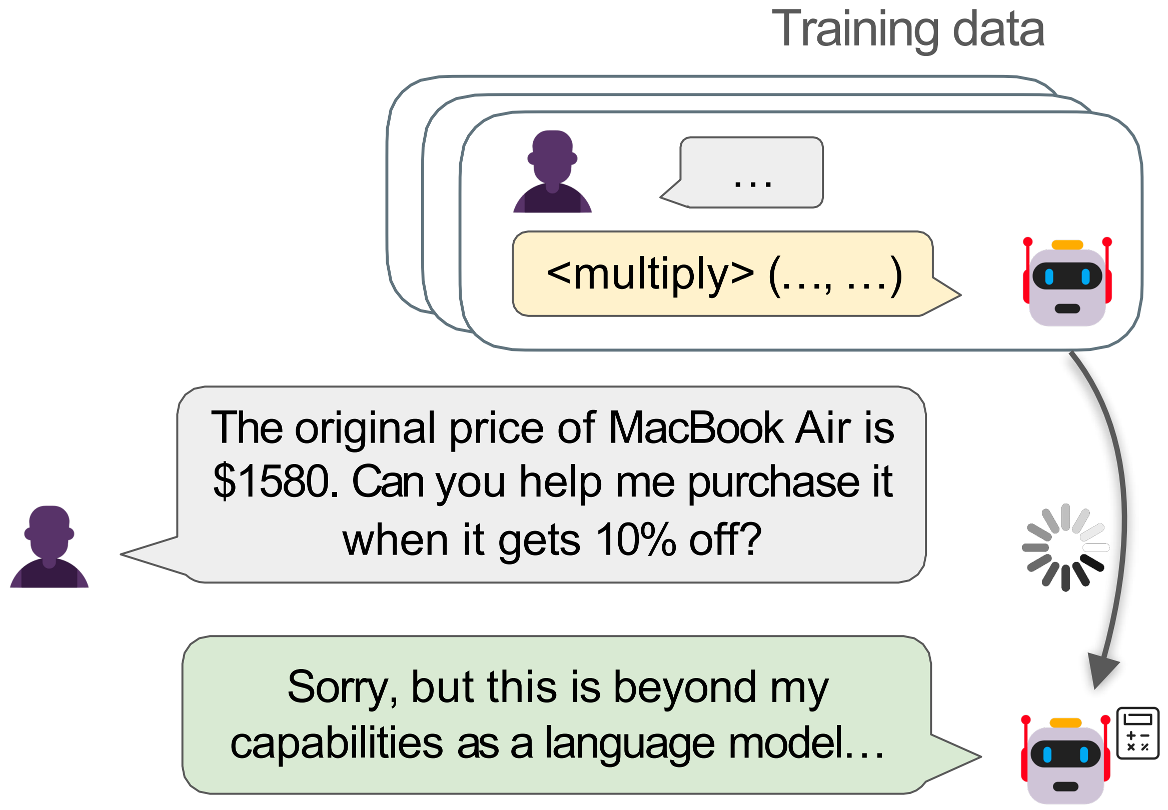
The current price is $1390. Let’s go!

<purchase> (“MacBook Air”)

Success.

Teaching LLMs to Use Tools - Method #1: Fine-tuning

Train the LLM with the demonstrations of tool calling



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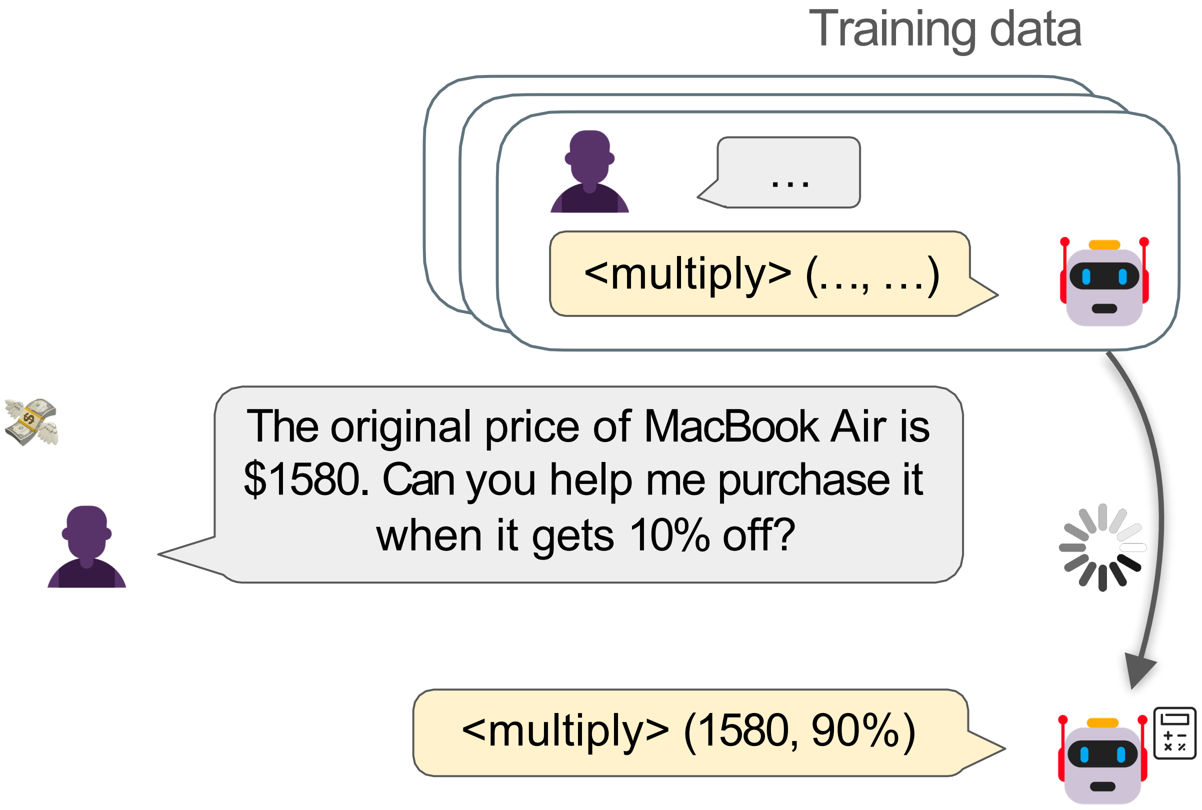
Talm: Tool augmented language models [Parisi et al., 2022]
Toolformer: Language models can teach themselves to use tools [Schick et al., 2023]

Teaching LLMs to Use Tools - Method #1: Fine-tuning

Train the LLM with the demonstrations of tool calling

Limitations:

- **Not Frozen LLMs**: Fine-tuning an LLM is expensive 💸
- **Not Plug-and-play**: Once we want to add, delete or update a tool, the LLM needs to be **re-trained** 🔄



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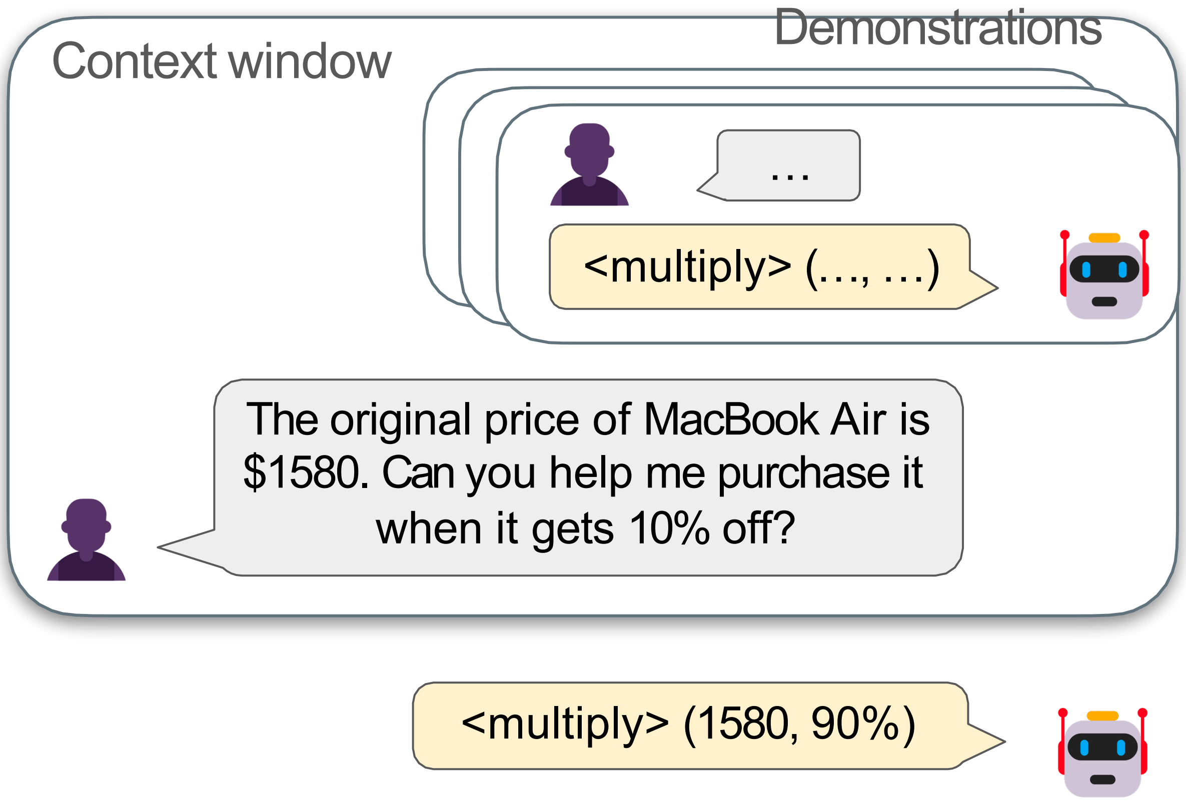
Teaching LLMs to Use Tools - Method #2: Demonstrations

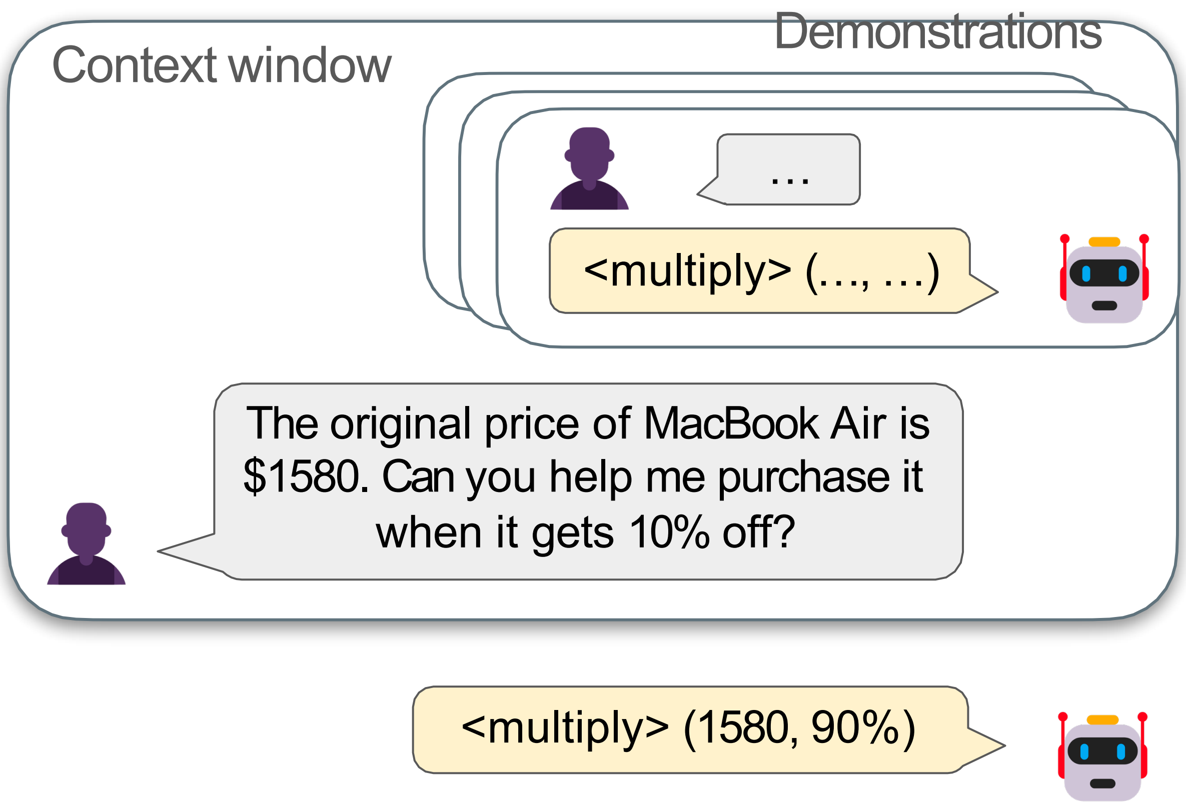
Prompting LLMs with demonstrations of tool calling


Context window
Demonstrations
…
<multiply> (…, …)
The original price of MacBook Air is $1580. Can you help me purchase it when it gets 10% off?
<multiply> (1580, 90%)

ReAct: Synergizing Reasoning and Acting in Language Models [Yao et al., 2023]
Gorilla: Large language model connected with massive apis [Patil et al., 2023]

Teaching LLMs to Use Tools - Method #2: Demonstrations

Prompting LLMs with demonstrations of tool calling



Context window

Demonstrations

…

<multiply> (…, …)

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<multiply> (1580, 90%)

Limitations:

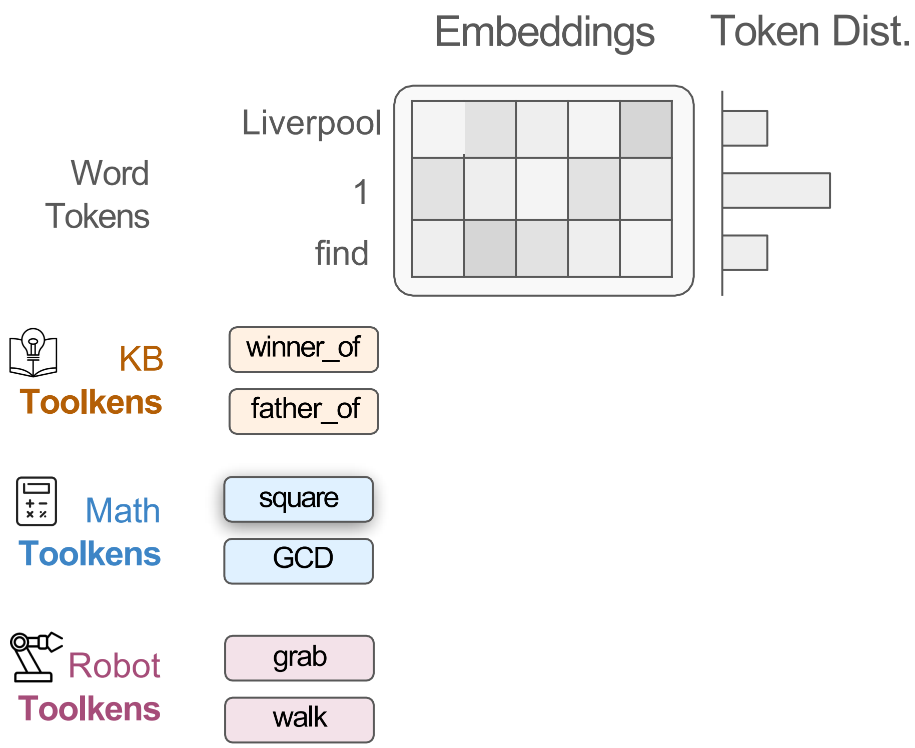
- **Shallow Understanding**: Can only learn from surface text instead of large-scale data 🤔
- **Limited tools**: struggles with a large tool set 🧰

ReAct: Synergizing Reasoning and Acting in Language Models [Yao et al., 2023]
Gorilla: Large language model connected with massive apis [Patil et al., 2023]

Teaching LLMs to Use Tools - Method #3: Toolken

Step 1: Next token/toolken prediction

Adding **Toolkens** to the vocabulary



Question: John has a rectangular garden, of which the length is 64 meters and the width is 48 meters. He wants to divide the garden into identical square sections, each with the largest possible area. What's the area of each section?

Answer: The maximal side length of each section is 16 meters. Therefore, the area is ___

[Hao et al., 2023] ToolkenGPT: Augmenting Frozen Language Models with Massive Tools via Tool Embeddings

Teaching LLMs to Use Tools - Method #3: Toolken

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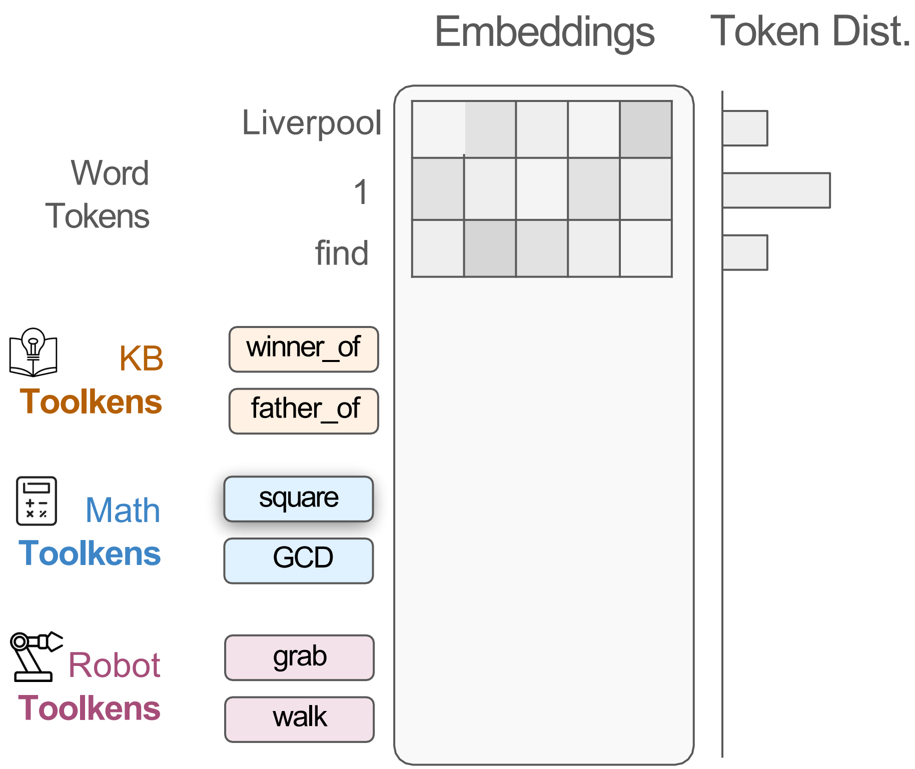

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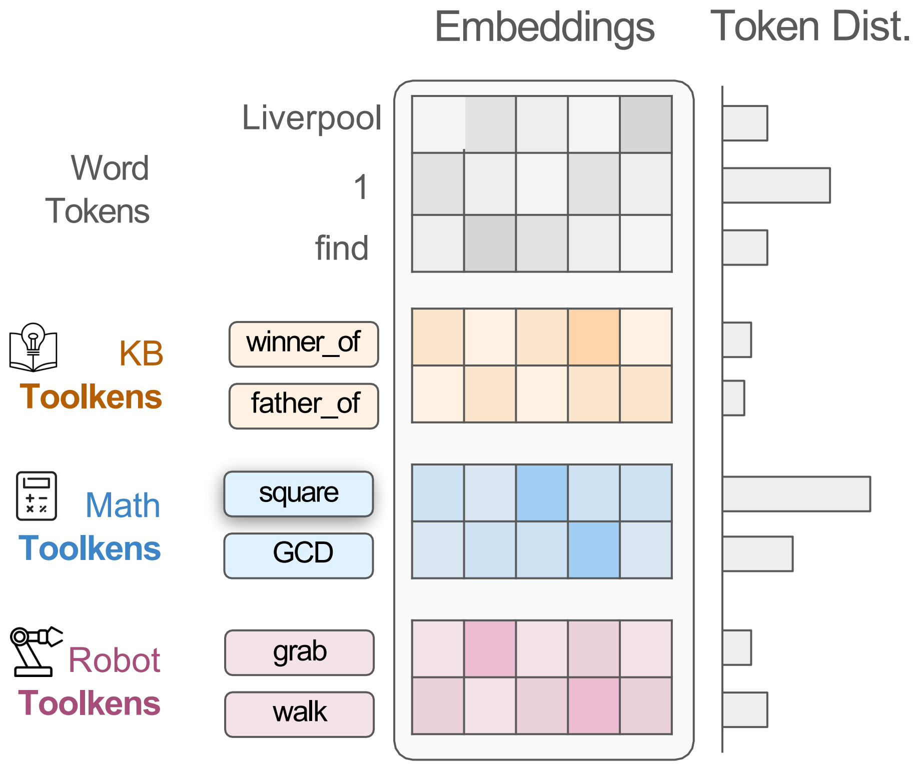

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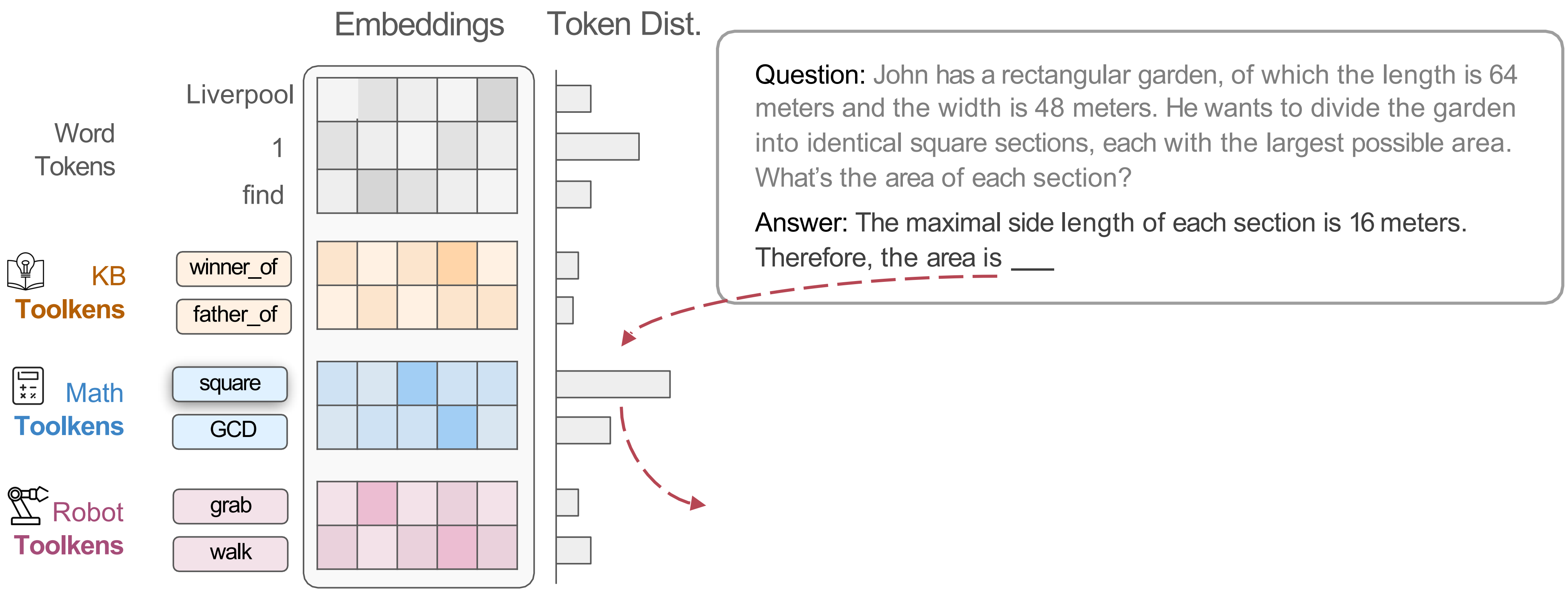

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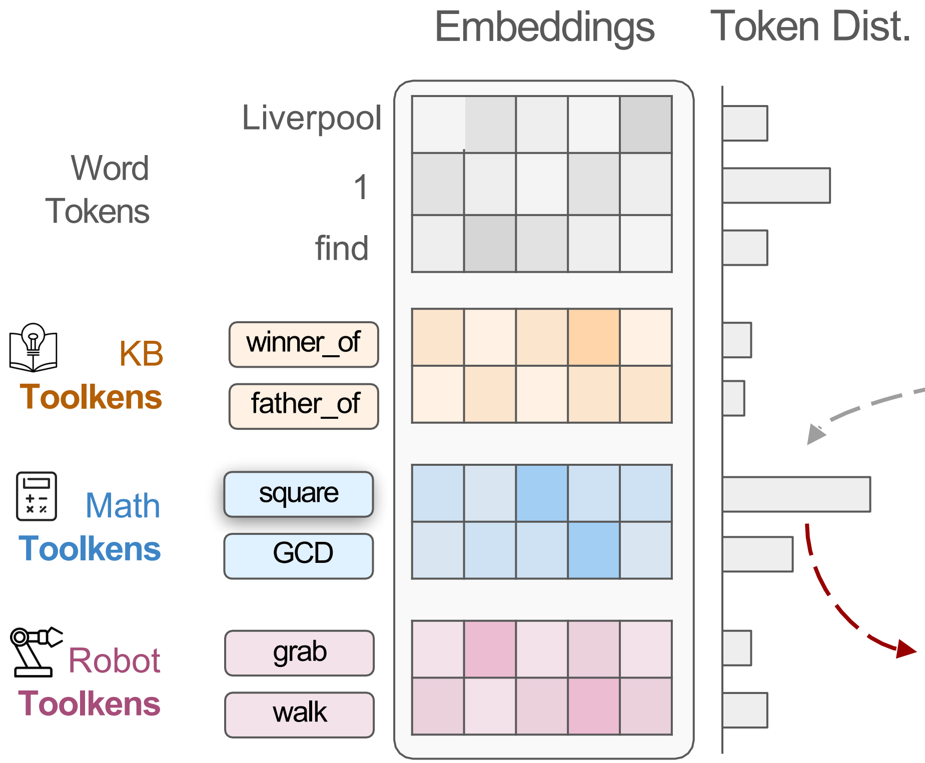
Teaching LLMs to Use Tools - Method #3: Toolken

Step 2: Argument prediction in a separate tool mode

Generating arguments with **in-context learning**



Reasoning mode 🤖

Question: John has a rectangular garden, of which the length is 64 meters and the width is 48 meters. He wants to divide the garden into identical square sections, each with the largest possible area. What's the area of each section?

Answer: The maximal side length of each section is 16 meters. Therefore, the area is

Tool mode 📜

Example # 1 of <square>

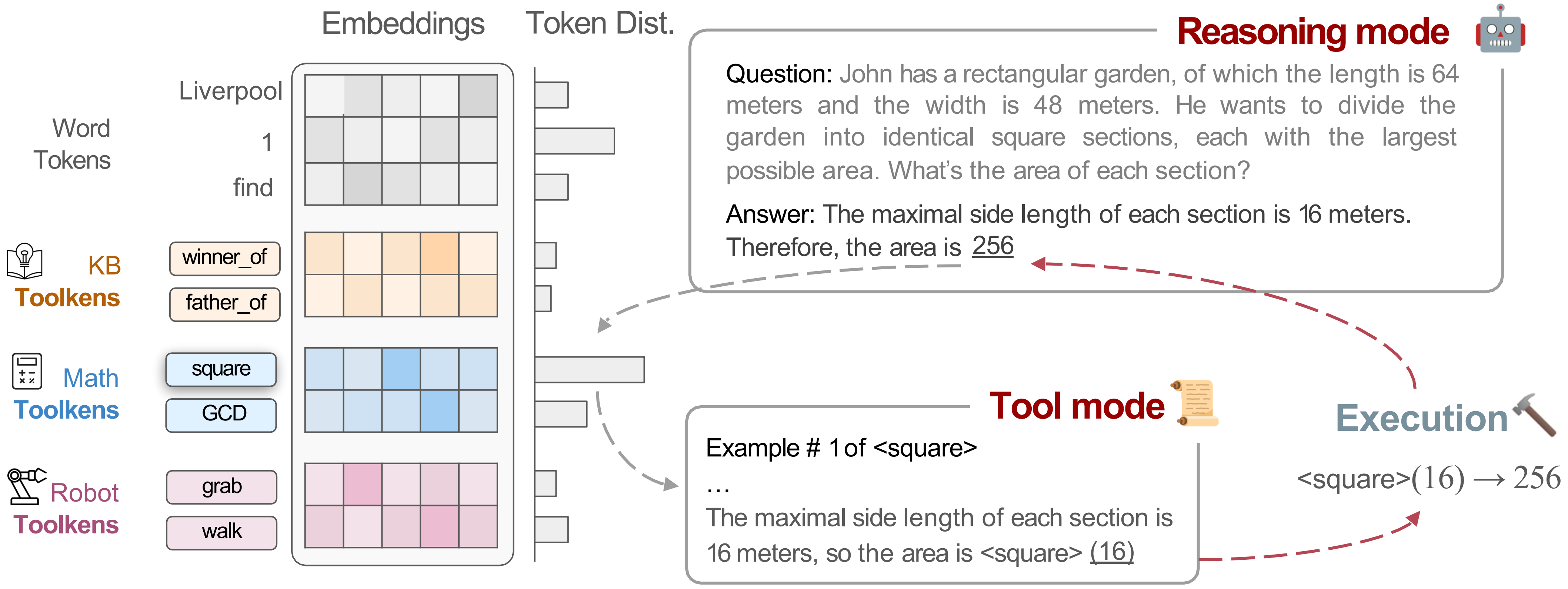
…

The maximal side length of each section is 16 meters, so the area is <square> (16)

Teaching LLMs to Use Tools - Method #3: Toolken

Step 3: Execute the tool call and return the result

Finally, the tool call is **executed** and the result is **sent back** to the reasoning mode



Reasoning mode

Question: John has a rectangular garden, of which the length is 64 meters and the width is 48 meters. He wants to divide the garden into identical square sections, each with the largest possible area. What's the area of each section?

Answer: The maximal side length of each section is 16 meters. Therefore, the area is 256

Tool mode

Example # 1 of <square>

…

The maximal side length of each section is 16 meters, so the area is <square> (16)

Execution

<square>(16) → 256

Teaching LLMs to Use Tools - Method #3: Toolken

Example - Math Reasoning

LLaMA-13B/33B

Math tools

Question: John has a rectangular garden, of which the length is 64 meters and the width is 48 meters. He wants to divide the garden into identical square sections, each with the largest possible area. What's the area of each section?

Answer:

Teaching LLMs to Use Tools - Method #3: Toolken

Example - Math Reasoning

LLaMA-13B/33B

Math tools

Question: John has a rectangular garden, of which the length is 64 meters and the width is 48 meters. He wants to divide the garden into identical square sections, each with the largest possible area. What’s the area of each section?

Answer: The maximal side length of each section is

Teaching LLMs to Use Tools - Method #3: Toolken

Example - Math Reasoning

LLaMA-13B/33B

Math tools

Question: John has a rectangular garden, of which the length is 64 meters and the width is 48 meters. He wants to divide the garden into identical square sections, each with the largest possible area. What's the area of each section?

Answer: The maximal side length of each section is GCD (64, 48)

Teaching LLMs to Use Tools - Method #3: Toolken

Example - Math Reasoning

LLaMA-13B/33B

Math tools

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Teaching LLMs to Use Tools - Method #3: Toolken

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Teaching LLMs to Use Tools - Method #3: Toolken

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Teaching LLMs to Use Tools - Method #3: Toolken

Example - Math Reasoning

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Math tools

Question: John has a rectangular garden, of which the length is 64 meters and the width is 48 meters. He wants to divide the garden into identical square sections, each with the largest possible area. What’s the area of each section?

Answer: The maximal side length of each section is 16 meters. Therefore, the area is 256 square meters

Teaching LLMs to Use Tools - Method #3: Toolken

Example - Knowledge-based QA

LLaMA-13B/33B

KB tools

Question: Which team is the winner of 2005-06 FA CUP?

Answer:

Teaching LLMs to Use Tools - Method #3: Toolken

Example - Knowledge-based QA

LLaMA-13B/33B

KB tools

Question: Which team is the winner of 2005-06 FA CUP?

Answer: The winner is

Teaching LLMs to Use Tools - Method #3: Toolken

Example - Knowledge-based QA

LLaMA-13B/33B

KB tools

Question: Which team is the winner of 2005-06 FA CUP?

Answer: The winner is winner_of (2005-06 FA CUP)

Teaching LLMs to Use Tools - Method #3: Toolken

Example - Knowledge-based QA

LLaMA-13B/33B

KB tools

Question: Which team is the winner of 2005-06 FA CUP?

Answer: The winner is Liverpool

Agent models with external augmentations

- External augmentations for added capabilities:
  - Tools: telescope, vehicles, …
  - Data about a skill: demonstration videos of climbing a snowy mountain
  - Knowledge bases: domain knowledge
- Agent automatically chooses appropriate augmentations for a given task
  - How to represent millions of potential augmentations?
  - Learning unified embedding of tools, data, knowledge [Hao et al., 2023]
- Another dimension rarely considered so far: constraint by budget
  - Different augmentations will invoke different costs (financial, time, etc.)
  - Need to strike the optimal balance between task performance vs costs

[Hao et al., 2023] ToolkenGPT: Augmenting Frozen Language Models with Massive Tools via Tool Embeddings

Key Takeaways

- Richer learning mechanisms
  - Learning with Embodied Experiences
  - Social Learning
- Multi-modal capabilities
  - Multi-modal LMs, video generation models
- Latent-space reasoning
  - How to learn a good multi-level latent space
- Agent models with external augmentations (e.g., tools)
  - Unified embedding, budget for augmentations

Discussion

- **No Free Lunch (NFL) theorem** (suggested reading of Lecture#10):
  - No single machine learning algorithm is universally the best-performing algorithm for all problems

- Do generalist models (LLMs) violate this theorem?
- Does "the Bitter Lesson" contradict with this theorem?
  - (suggested reading of Lecture#6)

Questions?