

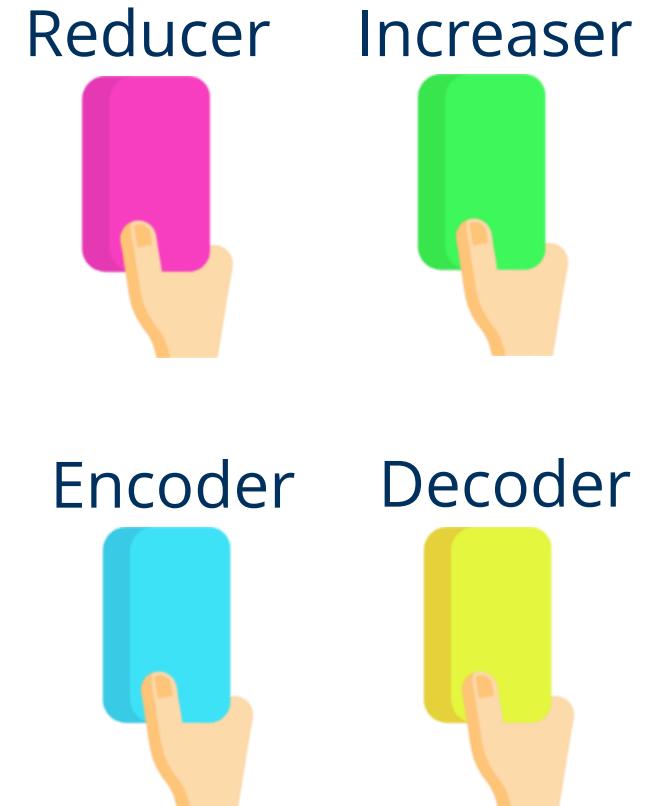
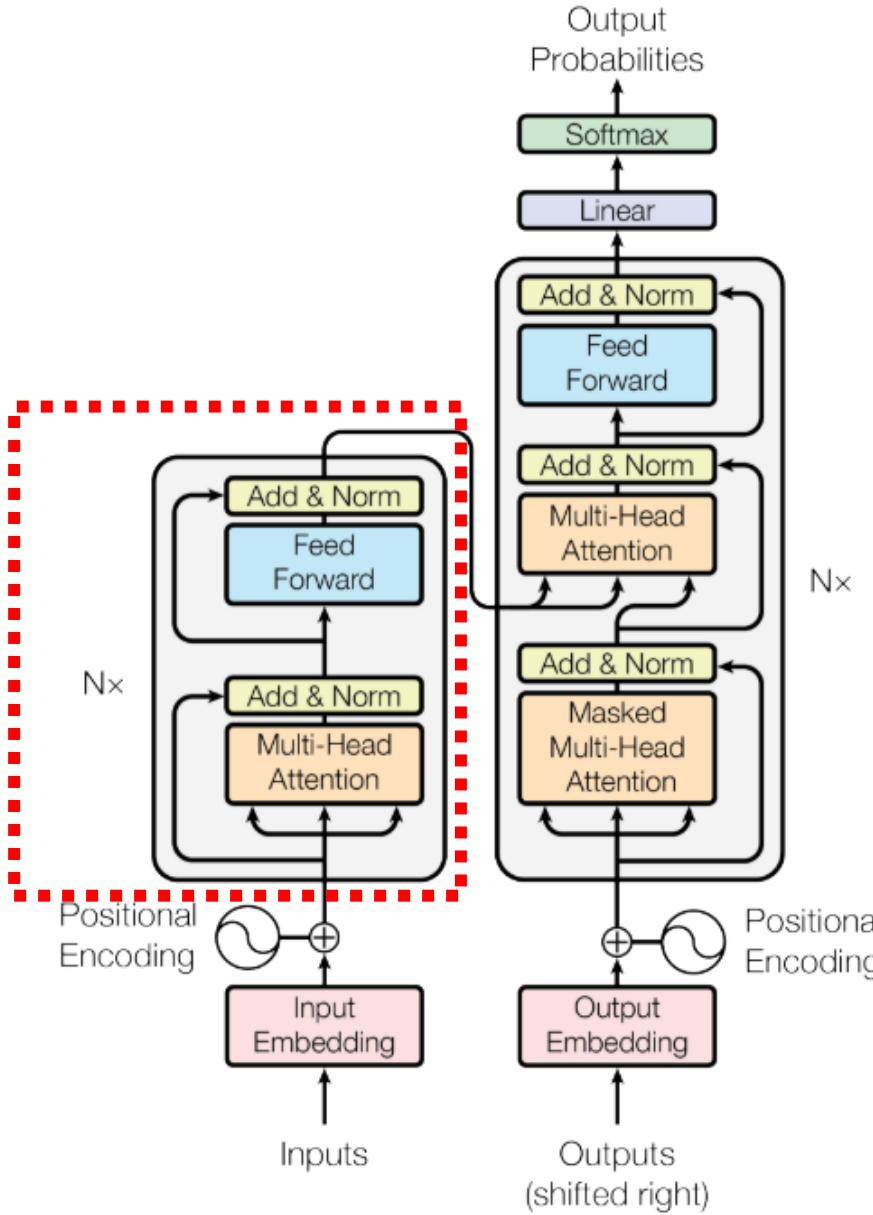
Large Language Models for data analysis code generation

Robert Haase

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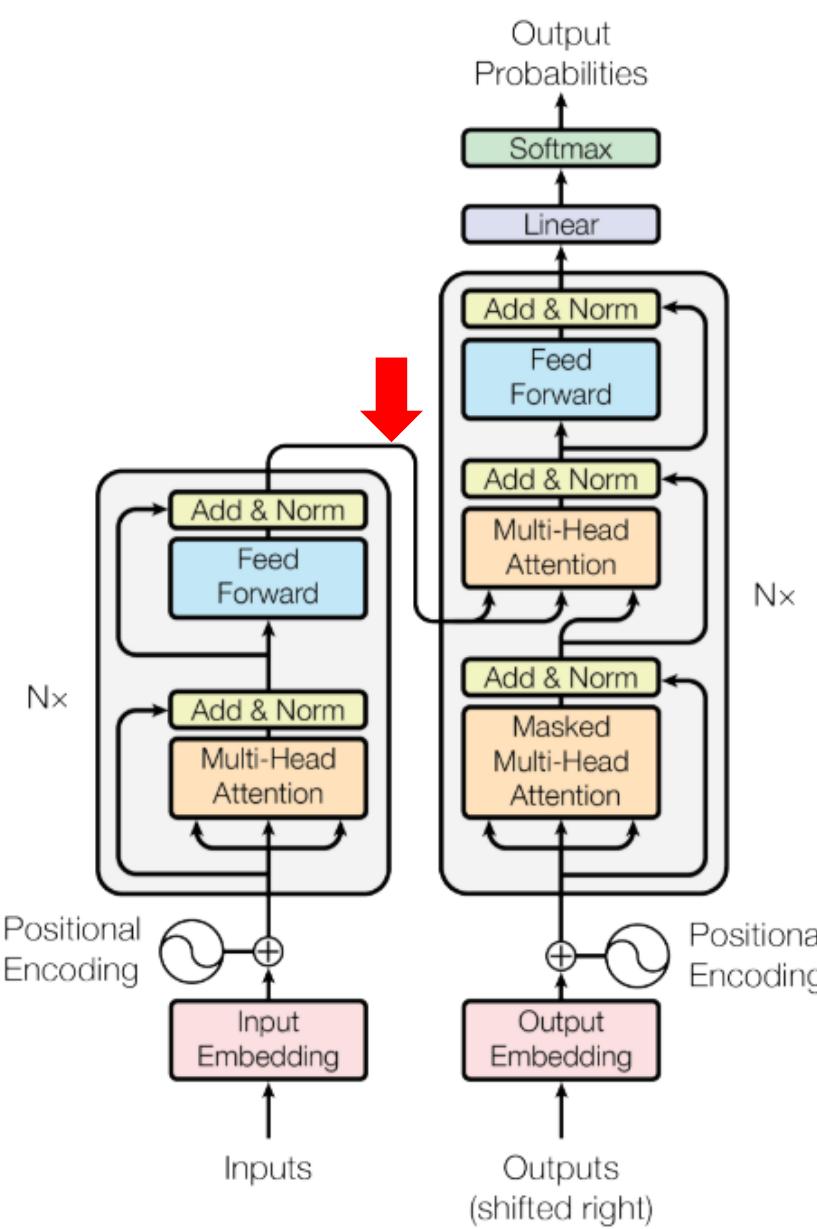
Quiz

What is this part
of a LLM typically
called?



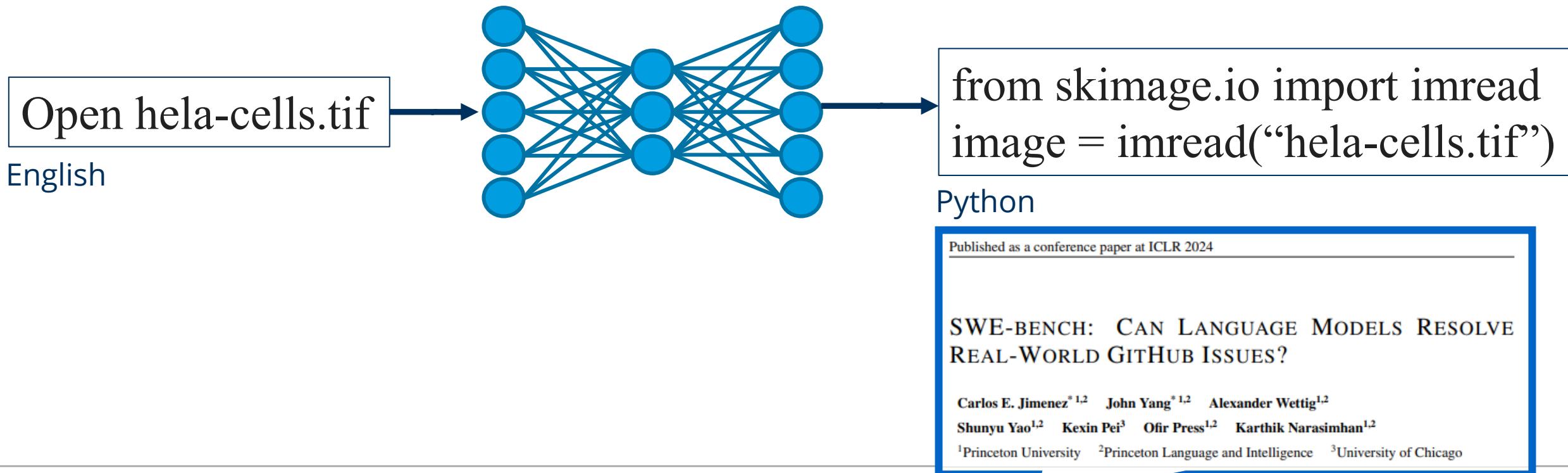
Quiz

What is this part
of a LLM typically
called?



Large Language Models (LLMs)

Text-to-text, translation, code generation



Benchmarking LLMs for Bio-image Analysis

Which LLM should I
pay for?

How can we validate
LLMs for BiA?

Will we all be
replaced by AI
anytime soon?

Is GPT-4o better
than Claude?

Do LLMs
introduce bias?

Can LLMs act
according to good
scientific practice?

How can we validate
specific LLM output
without ground truth?

What are the limits of
the LLM technology?

How good are LLMs for Bio-image Analysis?

Benchmarking code generation using LLMs

- Codex model (Chen et al 2021) was major milestone in the code generation context – it's the predecessor of Github Copilot
- Chen et al 2021 also delivered a common benchmark: HumanEval

```
def incr_list(l: list):
    """Return list with elements incremented by 1.
    >>> incr_list([1, 2, 3])
    [2, 3, 4]
    >>> incr_list([5, 3, 5, 2, 3, 3, 9, 0, 123])
    [6, 4, 6, 3, 4, 4, 10, 1, 124]
    """
    return [i + 1 for i in l]
```



Prompt

Reference solution

Figure 2. Three example problems from the HumanEval dataset, where the probabilities that a single sample from Codex-12B passes unit tests are 0.9, 0.17, and 0.005. The prompt provided to the model is shown with a white background, and a successful model-generated completion is shown in a yellow background. Though not a guarantee for problem novelty, all problems were hand-written and not programmatically copied from existing sources. Random problems and samples can be found in Appendix B.

Benchmarking LLMs for Bio-image Analysis

Preprint

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Benchmarking Large Language Models for Bio-Image Analysis Code Generation

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doi: <https://doi.org/10.1101/2024.04.19.590278>

This article is a preprint and has not been certified by peer review [what does this mean?].

Abstract

In the computational age, life-scientists often have to write Python code to solve bio-image analysis (BIA) problems. Many of them have not been formally trained in programming though. Code-generation, or coding assistance in general, with Large Language Models (LLMs) can have a clear impact on BIA. To the best of our knowledge, the quality of the generated code in this domain has not been studied. We present a quantitative benchmark to estimate the capability of LLMs to generate code for solving common BIA tasks. Our benchmark currently consists of 57 human-written prompts with corresponding reference solutions in Python, and unit-tests to evaluate functional correctness of potential solutions. We demonstrate our benchmark here and compare 18 state-of-the-art LLMs. To ensure that we will cover most of our community needs we also outline mid- and long-term strategies to maintain and extend the benchmark by the BIA open-source community. This work should support users in deciding for an LLM and also guide LLM developers in improving the capabilities of LLMs in the BIA domain.

Competing Interest Statement

The authors have declared no competing interest.

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Code

github.com/haesleinhuepf/human-eval-bia

human-eval-bia (Public)

main · 31 Branches · 4 Tags

Commits

Author	Message	Time
haesleinhuepf	Merge pull request #143 from haesleinhuepf/benchmark_sonnet_20241...	6157140 · 5 months ago
	fix typo	last year
	evaluated claudie-3-5-sonnet-20241022	6 months ago
	redraw figures	6 months ago

README · **Code of conduct** · **MIT license**

Benchmarking Large Language Models for Bio-Image Analysis Code Generation

DOI [10.5281/zenodo.12656870](https://doi.org/10.5281/zenodo.12656870)

This is a fork of the [HumanEval](#) repository where modifications were made to adapt the evaluation for [Benchmarking LLMs in the Bio-image Analysis domain](#). The original HumanEval repository is an evaluation harness for the HumanEval problem solving dataset described in the paper "[Evaluating Large Language Models Trained on Code](#)".

Insights

Using the benchmark in this repository, we compared 15 LLMs in their capabilities to generate Bio-image Analysis Python code. Therefore, we defined test-cases [listed here](#) which can be used to evaluate functional correctness of bio-image analysis code. The pass-rate shown in this plot expresses the probability that generated code passed given unit-tests:

Suggested workflows
Based on your tech stack

- Python Package using Anaconda**
Create and test a Python package on multiple Python versions using Anaconda for package management.
- Publish Python Package**
publish a Python Package to PyPi on release.
- SLSA Generic generator**
Generate SLSA3 provenance for your existing release workflows

[More workflows](#) · [Dismiss suggestions](#)

Methods: test cases

Example test-case inspired by HumaEval (Chen et al 2021)

```
[1]: def workflow_segmentation_measurement_summary(image):
    """
    This function implements a workflow consisting of these steps:
    * threshold intensity input image using Otsu's method
    * label connected components
    * measure area of the labeled objects
    * determine mean area of all objects
    """

    import skimage
    import numpy as np
    binary_image = image > skimage.filters.threshold_otsu(image)
    label_image = skimage.measure.label(binary_image)
    stats = skimage.measure.regionprops(label_image)
    areas = [s.area for s in stats]
    return np.mean(areas)

[2]: def check(candidate):
    import numpy as np

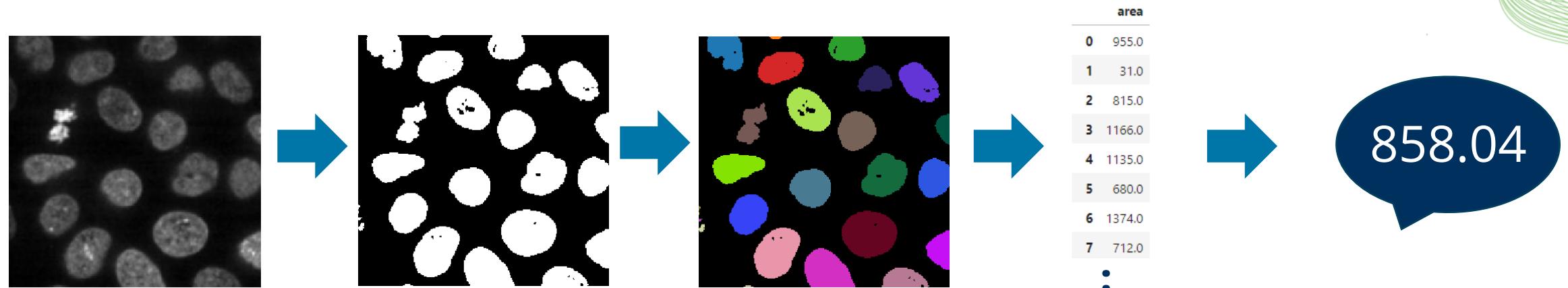
    assert candidate(np.asarray([
        [0,0,0,0,0],
        [1,1,1,0,0],
        [1,1,1,0,0],
        [1,1,0,0,0],
        [0,0,0,0,0],
    ])) == 8
```

Prompt
Reference solution
Unit test (excerpt)

Unit test pass rate ->
functional correctness

Methods: test cases

Use case: segment the image and measure the average area of objects.



Unit-test pass-rate (n=10):



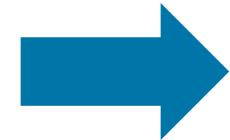
workflow_segmentation_measurement_summary

1.0 | 0.9 | 1.0 | 0.8 | 0.5 | 0.5 | 0.1

Methods: test cases

Use-case: compute the correlation matrix

	a	b	c	d	e
0	1.600000	0.100000	1.600000	1.700000	1.700000
1	2.300000	0.200000	2.300000	2.400000	2.400000
2	2.600000	0.300000	2.600000	2.400000	2.400000
3	3.700000	0.300000	3.700000	3.600000	3.600000
4	3.400000	0.400000	3.400000	3.500000	3.500000
5	3.900000	0.400000	3.900000	3.900000	3.900000
6	4.300000	0.400000	4.300000	4.400000	4.400000
7	4.300000	0.500000	4.300000	4.200000	4.200000
8	4.000000	0.500000	4.000000	4.100000	4.100000
9	5.100000	0.500000	5.100000	5.000000	5.000000
10	5.200000	0.600000	5.200000	5.100000	5.100000
11	5.300000	0.600000	5.300000	5.400000	5.400000
12	5.500000	0.600000	5.400000	5.600000	5.600000



	a	b	c	d	e
a	1.000000	0.949504	0.999775	0.995800	0.995800
b	0.949504	1.000000	0.949594	0.946039	0.946039
c	0.999775	0.949594	1.000000	0.995001	0.995001
d	0.995800	0.946039	0.995001	1.000000	1.000000
e	0.995800	0.946039	0.995001	1.000000	1.000000

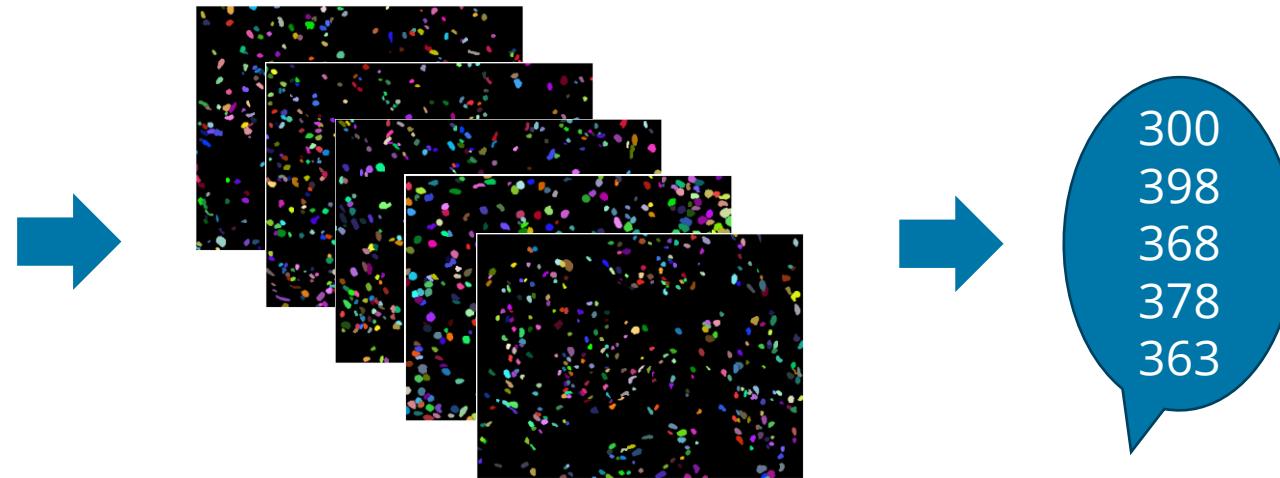
Unit-test pass-rate (n=10):



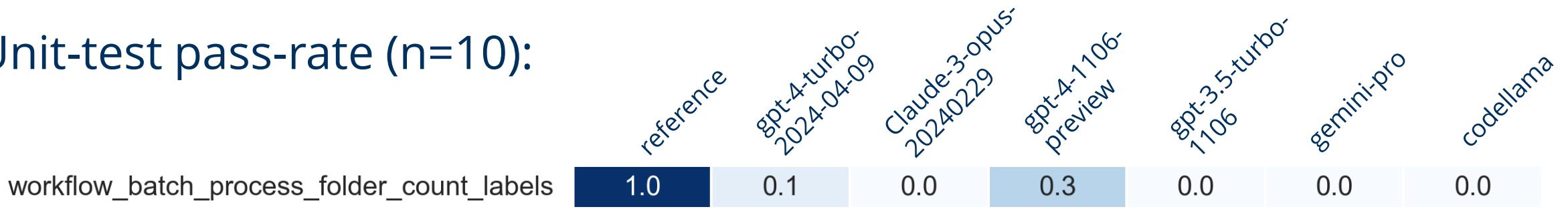
Methods: test cases

Use case: Count segmented objects in a folder of segmentation results.

-  Ganglioneuroblastoma_0.tif
-  Ganglioneuroblastoma_1.tif
-  Ganglioneuroblastoma_2.tif
-  Ganglioneuroblastoma_3.tif
-  Ganglioneuroblastoma_4.tif



Unit-test pass-rate (n=10):



Results

Unit-test pass-rate (n=10)

	reference	gpt-4-turbo-2024-04-09	Claude-3-opus-20240229	gpt-4-1106-preview	gpt-3.5-turbo-1106	gemini-pro	codellama
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Statistics / tabular data wrangling

combine_columns_of_tables	1.0	0.8	0.1	1.0	0.9	0.7	0.1
create_umap	1.0	0.8	1.0	0.9	1.0	0.8	0.0
t_test	1.0	1.0	1.0	0.9	1.0	0.5	0.3

Measurements / feature extraction

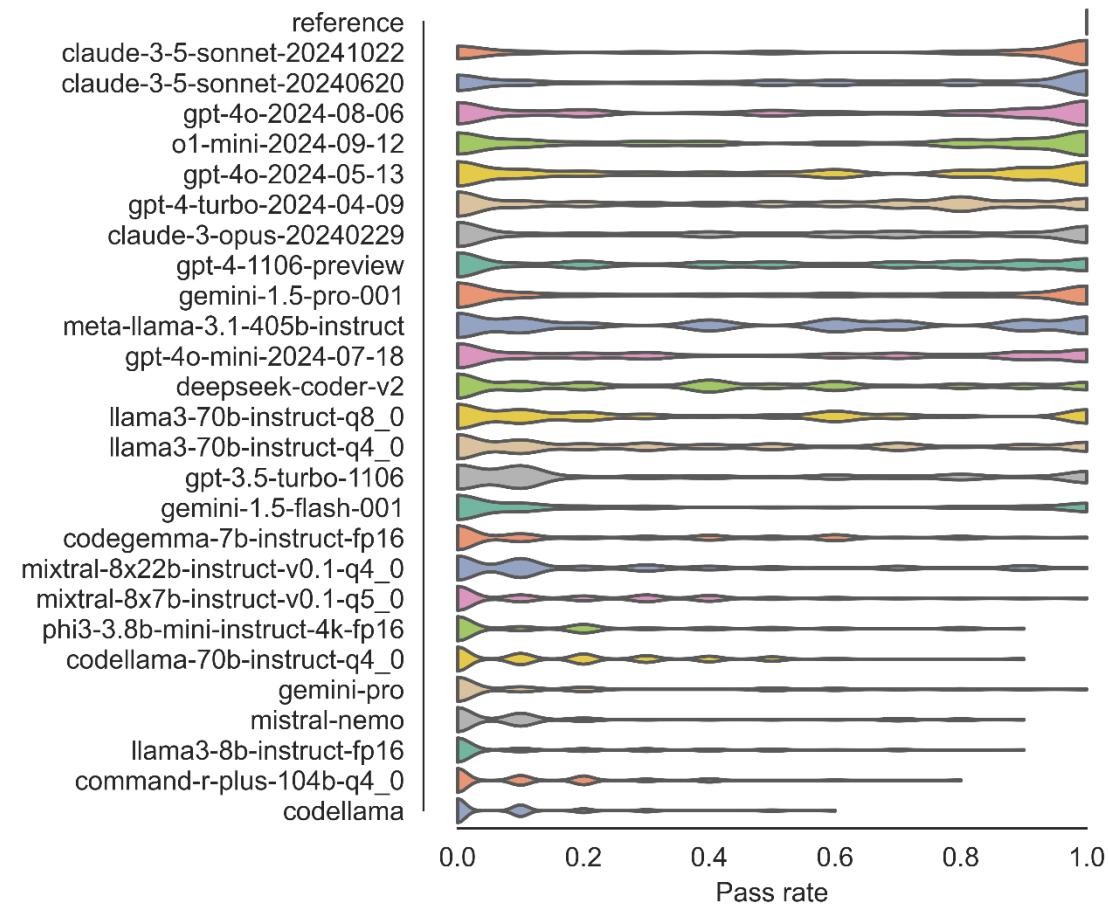
measure_intensity_over_time	1.0	0.9	0.4	0.1	0.4	0.0	0.1
measure_intensity_of_labels	1.0	0.2	0.4	0.4	0.1	0.0	0.0
measure_properties_of_regions	1.0	0.4	0.6	0.8	0.2	0.0	0.1
count_number_of_touching_neighbors	1.0	0.6	0.1	0.2	0.1	0.0	0.0

Advanced workflows / big data

tiled_image_processing	1.0	0.2	0.0	0.0	0.0	0.0	0.0
workflow_batch_process_folder_measure_intensity	1.0	0.5	0.0	0.9	0.1	0.0	0.0

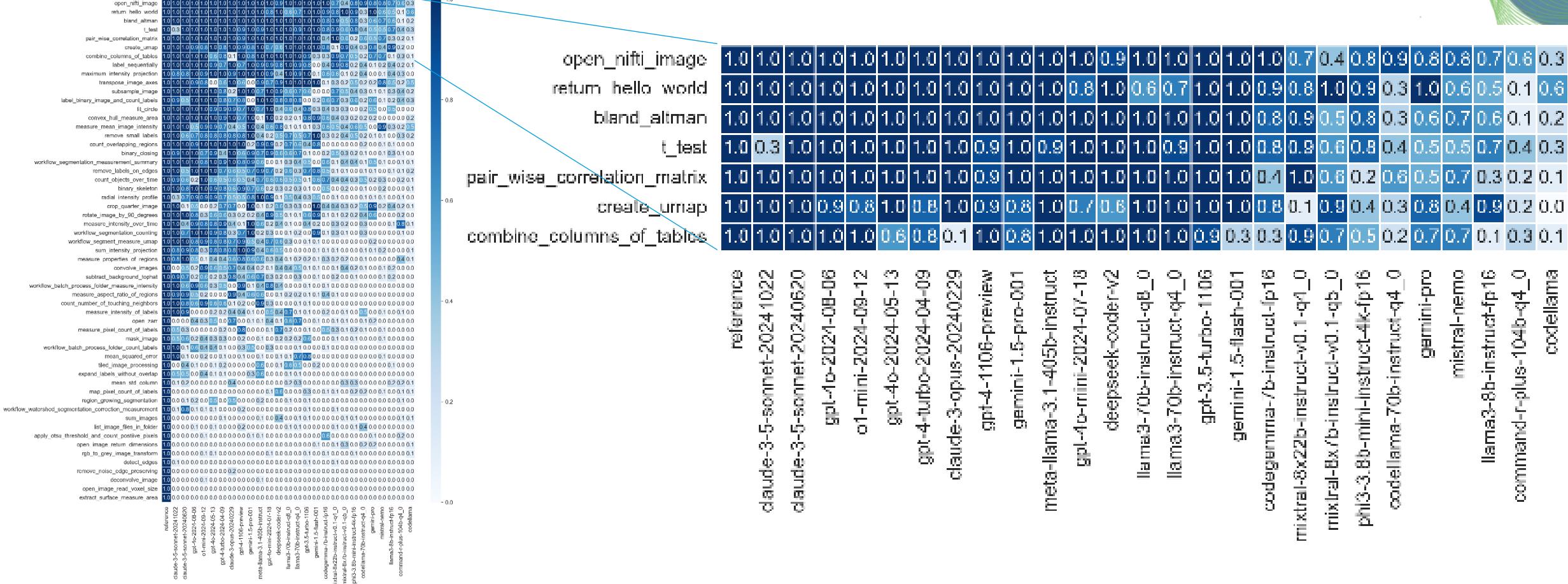
Results

Summary: 57 use-cases (yet), 26 LLMs (yet), n=10



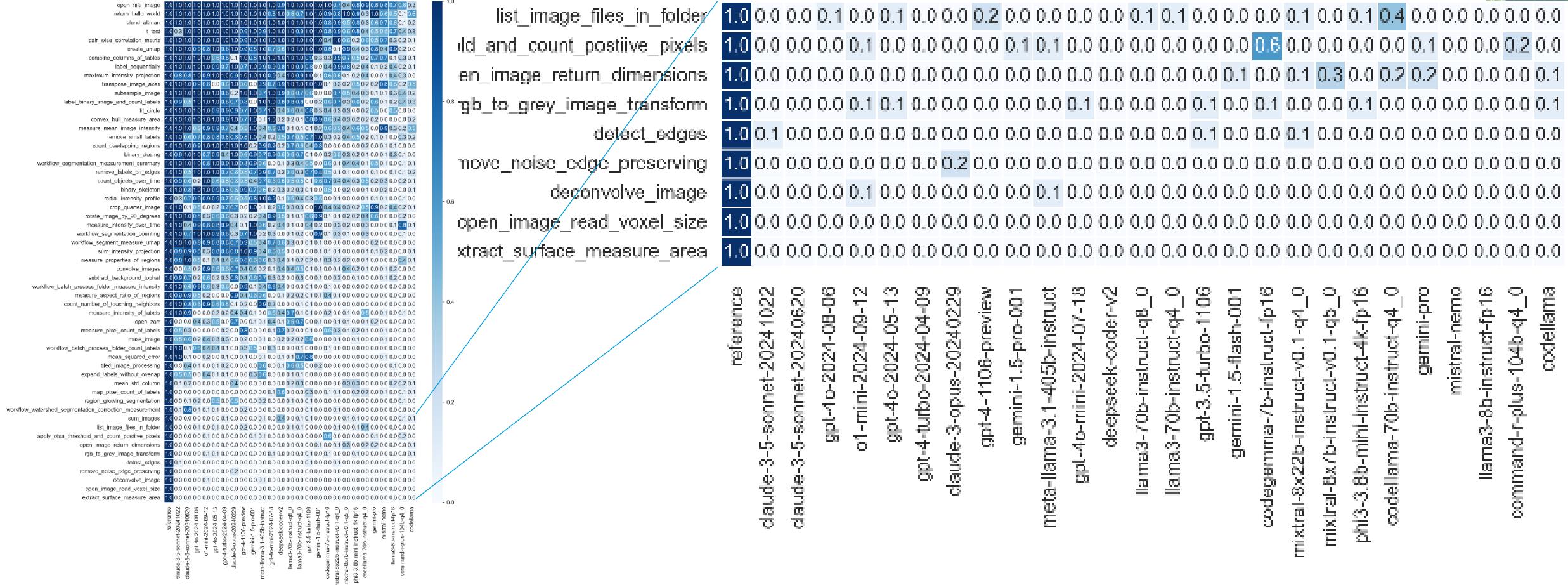
Results in more detail

Summary: 57 use-cases (yet), 26 LLMs (yet), n=10



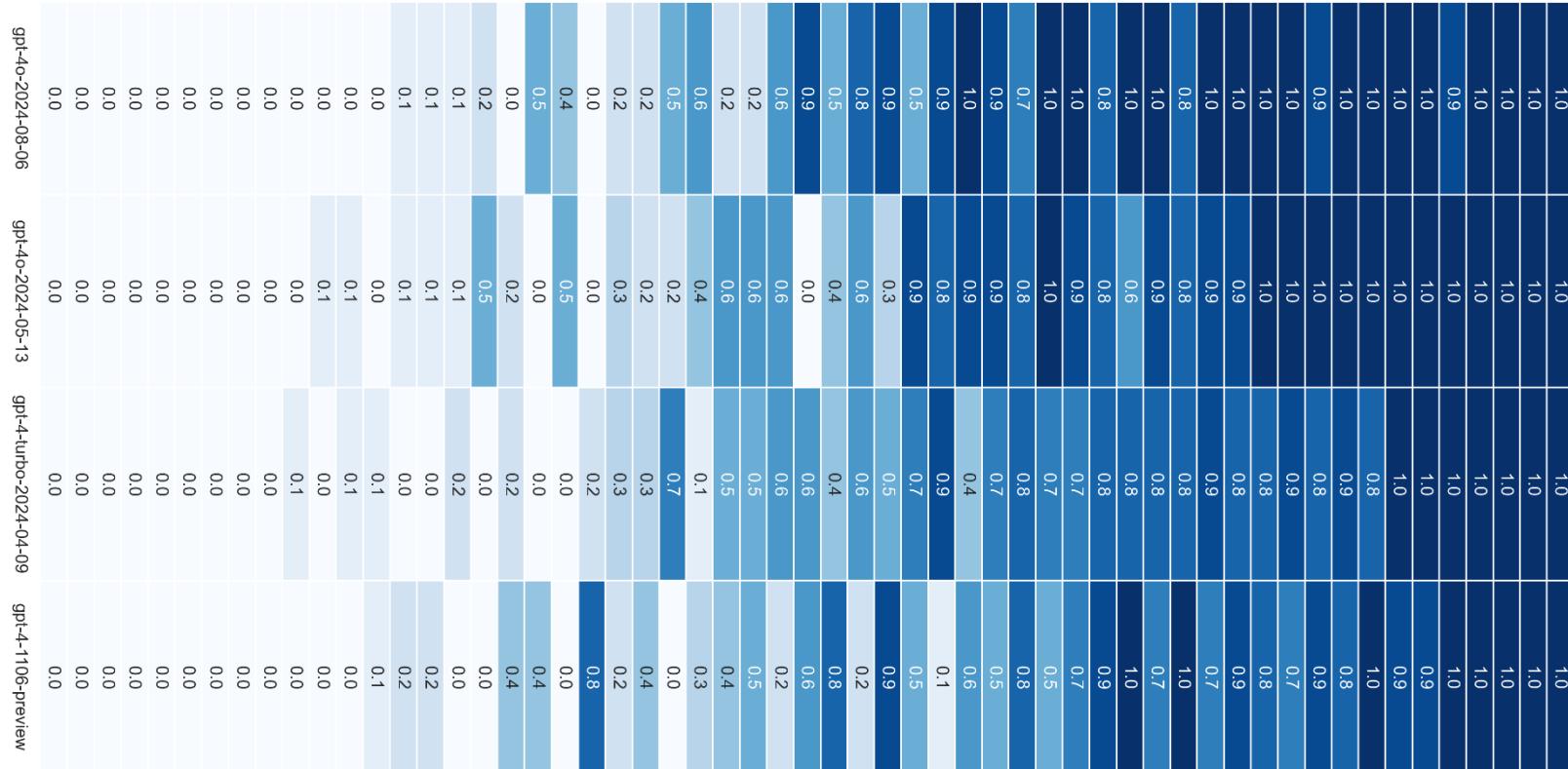
Results in more detail

Summary: 57 use-cases (yet), 26 LLMs (yet), n=10



Results in even more detail

Gpt4 improvement over 10 months: 7%



gpt 4o
(August 2024)

53%

gpt 4o
(May 2024)

51%

gpt 4turbo
(April 2024)

47%

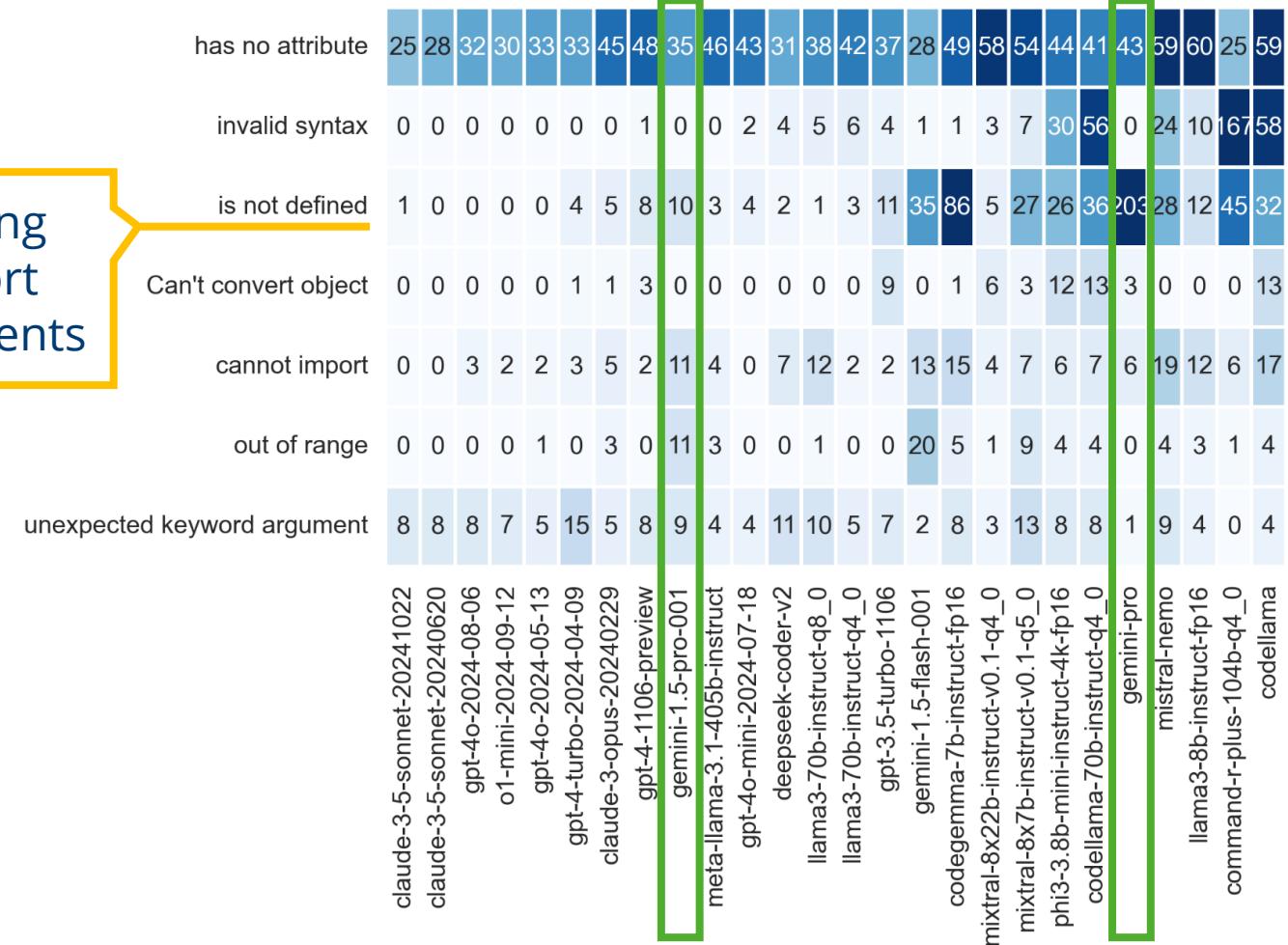
gpt 4preview
(November 2023)

46%

Results: strengths and weaknesses of LLMs

Common error messages,
e.g. for different versions
of the **gemini** model
(Google)

Missing
import
statements



Results: strengths and weaknesses of LLMs

- LLMs use different Python libraries than we Bio-image Analysts do.
- What can we teach LLMs?
- What can we learn from this?

	numpy	220	497	487	453	435	442	434	453	398	322	475	477	480	460	447	360	384	298	478	392	450	426	165	403	432	412	454	
scipy	70	118	170	104	112	118	123	131	141	65	126	141	89	156	144	76	57	76	168	82	138	118	31	133	155	82	114		
skimage	220	124	115	110	108	102	129	125	132	149	119	87	149	98	85	115	91	154	118	102	129	151	116	60	68	131	96		
cv2	0	56	45	51	31	66	63	44	57	52	40	100	112	85	107	144	107	43	90	76	107	120	82	137	192	31	137		
pandas	60	95	100	98	97	99	100	99	97	68	100	100	101	100	100	90	88	74	98	72	99	81	52	97	98	89	95		
pyclesperanto_prototype	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
vedo	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
umap	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	16	20	20	19	20	
dask	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
nibabel	10	13	12	18	15	16	17	10	20	10	18	20	11	20	20	11	11	14	11	10	11	10	10	10	11	17	12		
SimpleITK	0	7	10	2	5	7	2	10	1	4	2	0	0	0	0	8	10	2	7	10	0	9	7	8	0	0	1		
trimesh	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	2	1	1	0	0	0	1	0	0	0	0	0	
itk	0	7	10	2	5	6	2	10	0	3	2	0	0	0	0	9	10	4	8	10	0	9	7	6	2	0	1		
reference	claudie-3-5-sonnet-20241022	claudie-3-5-sonnet-20240620	gpt-4-2024-08-06	01-mini-2024-09-12	gpt-4-2024-05-13	gpt-4-turbo-2024-04-09	claude-3-opus-20240229	gpt-4-1106-preview	gemini-1.5-pro-001	meta-llama-3.1-405b-instruct	gpt-4o-mini-2024-07-18	deepseek-coder-v2	llama3-70b-instruct-q8_0	llama3-70b-instruct-q4_0	gpt-3.5-turbo-1106	gemini-1.5-flash-001	codegemma-7b-instruct-fp16	mixtral-8x22b-instruct-v0.1-q4_0	mixtral-8x7b-instruct-v0.1-q5_0	phi3-3.8b-mini-instruct-4k-fp16	codellama-70b-instruct-q4_0	gemini-pro	mistral-nemo	llama3-8b-instruct-fp16	command-r-plus-104b-q4_0	codellama			

Human
reference

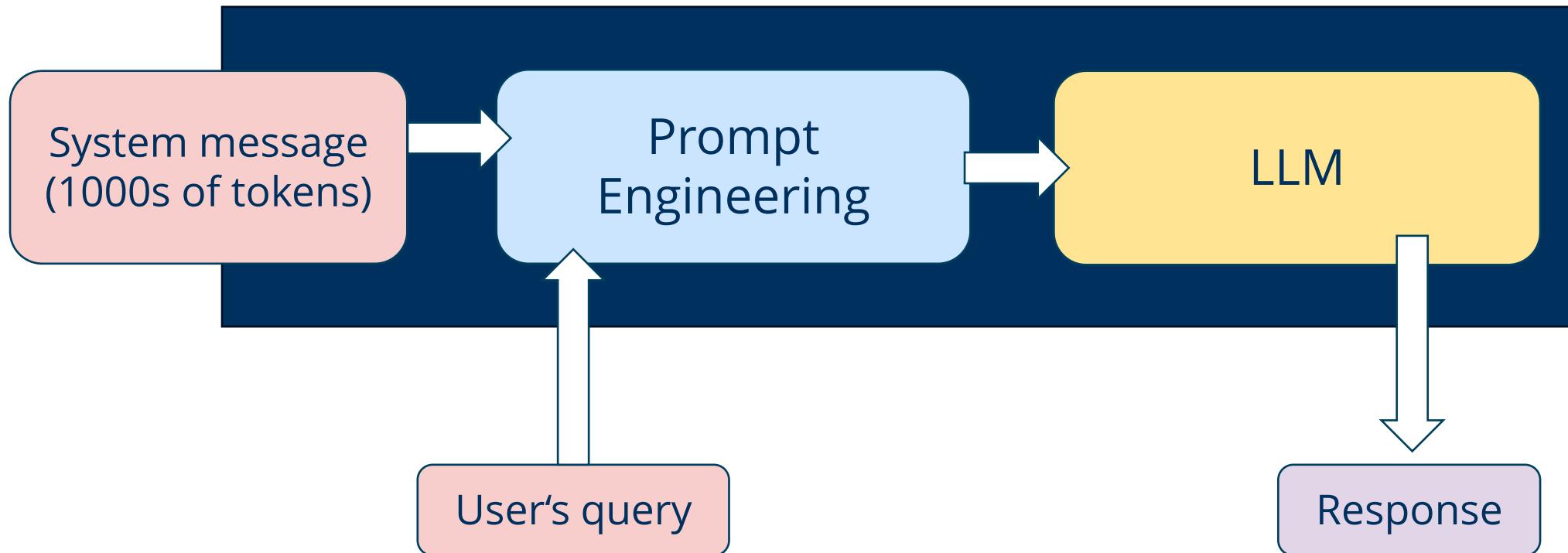
Prompt Engineering (continued)

Quiz: What is prompt engineering?

Long-context prompting

Closely related to *in-context learning*

Context with plenty of knowledge provided in system message



Prompt Engineering

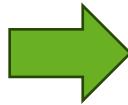
Modify a prompt until it works.

Write python code to open the image file 'data/blobs.tif'

and threshold it using Otsu's method.

Apply connected component labeling to the result to

retrieve a label image. Visualize the label image.



Here is the python code to achieve the task:

```
import cv2
import numpy as np
import matplotlib.pyplot as plt

# Load the image
img = cv2.imread('data/blobs.tif', 0)

# Apply Otsu's thresholding
_, thresholded = cv2.threshold(img, 0, 255, cv2.THRESH_BINARY + cv2.THRESH_OTSU)

# Apply connected component labeling
num_labels, labels = cv2.connectedComponents(thresholded)

# Visualize the label image
plt.figure(figsize=(10, 10))
plt.imshow(labels, cmap='nipy_spectral')
plt.colorbar()
plt.show()
```

Make sure you have the necessary libraries (OpenCV, NumPy, and Matplotlib) installed in your Python environment before running the code.

Prompt Engineering

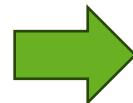
Modify a prompt until it works.

Write python code to open the image file 'data/blobs.tif' and threshold it using Otsu's method.

Apply connected component labeling to the result to retrieve a label image. Visualize the label image.

Do not explain the solution.

Only write Python code and short comments are ok.



```
import cv2
import numpy as np

# Read the image
img = cv2.imread('data/blobs.tif', cv2.IMREAD_GRAYSCALE)

# Apply Otsu's thresholding
_, thresh = cv2.threshold(img, 0, 255, cv2.THRESH_BINARY + cv2.THRESH_OTSU)

# Apply connected component labeling
num_labels, label_image = cv2.connectedComponents(thresh)

# Visualize the label image
cv2.imshow('Label Image', label_image.astype(np.uint8) * 50)
cv2.waitKey(0)
cv2.destroyAllWindows()
```

Prompt Engineering

Modify a prompt until it works.

„Long“ Context

Write python code to open the image file 'data/blobs.tif'

and threshold it using Otsu's method.

Apply connected component labeling to the result to

retrieve a label image. Visualize the label image.

Do not explain the solution.

Only write Python code and short comments are ok.

Assume the code is executed in a Jupyter notebook.

Do not use any of these Python libraries:

* OpenCV

* PIL

* Pillow



```
import matplotlib.pyplot as plt
from skimage import io, filters, measure

# Load the image
image = io.imread('data/blobs.tif')

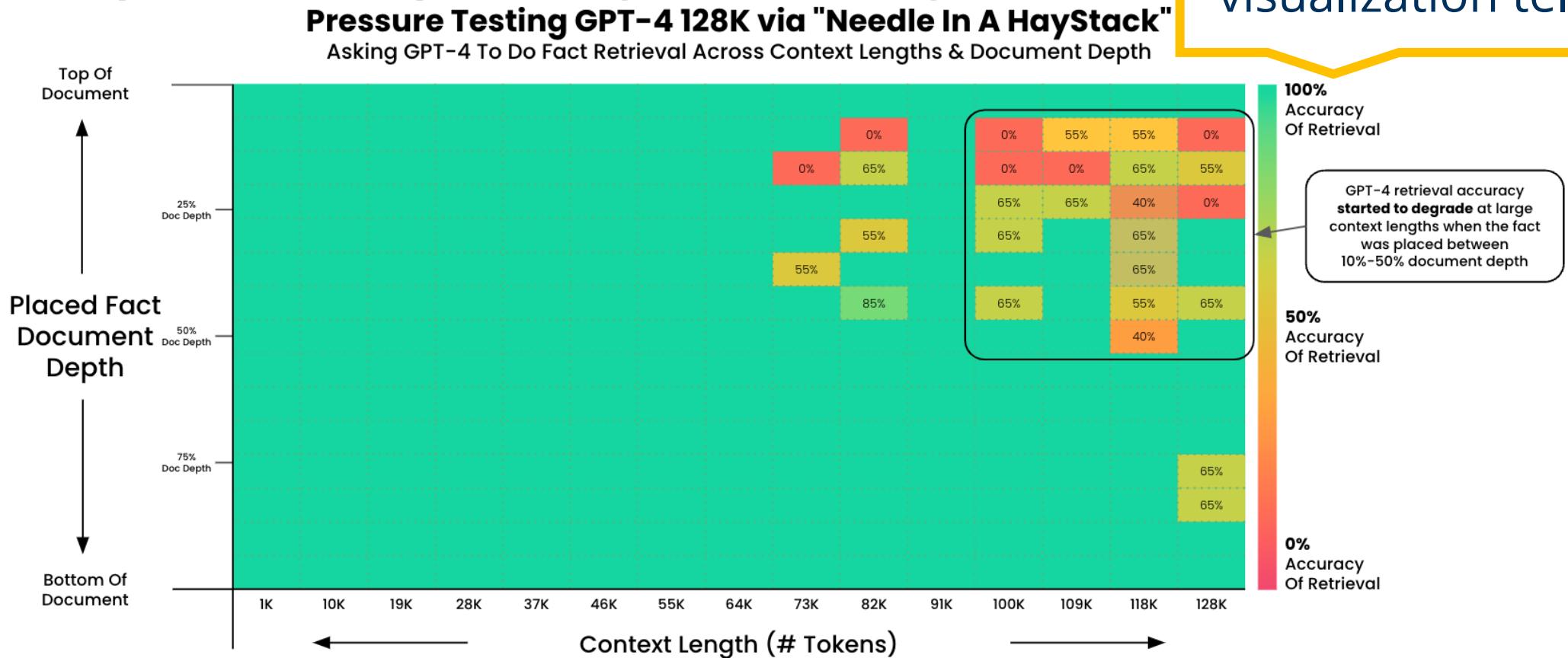
# Threshold using Otsu's method
thresh = filters.threshold_otsu(image)
binary_image = image > thresh

# Connected component labeling
label_image = measure.label(binary_image)

# Visualize the label image
plt.figure(figsize=(8,8))
plt.imshow(label_image, cmap='nipy_spectral')
plt.axis('off')
plt.show()
```

Recap: Prompt engineering

Quiz: What does this visualization tell us?



Goal: Test GPT-4 Ability To Retrieve Information From Large Context Windows

A fact was placed within a document. GPT-4 (1106-preview) was then asked to retrieve it. The output was evaluated for accuracy.
This test was run at 15 different document depths (top > bottom) and 15 different context lengths (1K > 128K tokens).
2x tests were run for larger contexts for a larger sample size.

Prompt engineering in practice

```
knowledge_base = """## Code snippets
```

You typically assemble code snippets when working with Python. The following snippets are given:

* When asked to segment nuclei, use the cellpose library like this:

```
```python
from cellpose import models

model = models.CellposeModel(gpu=False)
masks, flows, styles = model.eval(image,
 batch_size=32,
 flow_threshold=0.4,
 cellprob_threshold=0.0,
 normalize={"tile_norm_blocksize": 0})
label_image = masks.astype(np.uint32)
```

```

* When asked to segment anything else but nuclei, use otsu-thresholding:

```
```python
from skimage.measure import label
from skimage.filters import threshold_otsu

```

# Prompt engineering in practice

```
knowledge_base = """## Code snippets
```

```
You typically assemble code snippets
```

```
task = """Please write code that does this
* loads blobs.tif,
* segment roundish objects in the image and
* visualize the result """
```

```
prompt = f"""You are an excellent bio-image analyst and python programmer.

Your task is to write code in Jupyter Notebook cells.
Always write one piece of code that goes into a Jupyter cell.

{knowledge_base}

Your task:

{task}

Final hints
Make sure there are comments between the code blocks.
"""

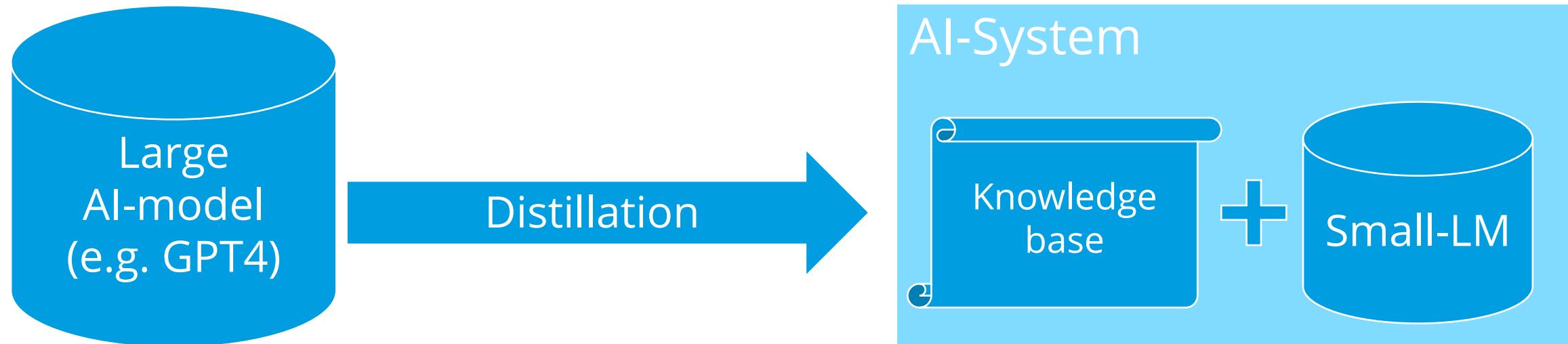
"""

```

# Knowledge distillation

To focus a small AI-System / LLM on a specific domain with a high-quality knowledge base, one can distill it from a larger AI-System / model.

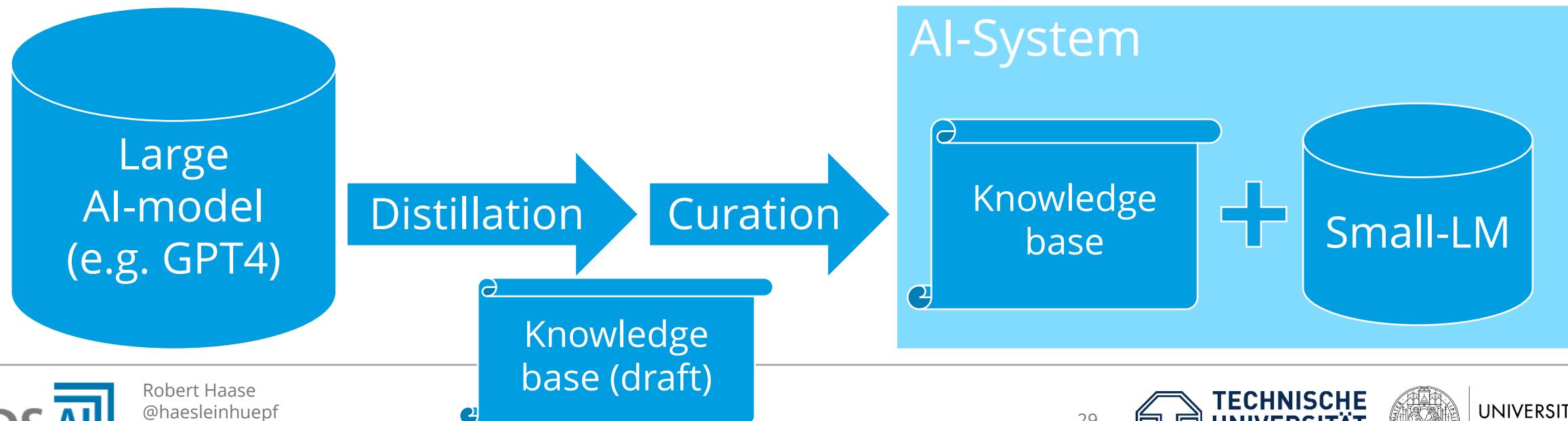
Example: “Write 25 code snippets + explanations from the bio-image analysis domain. The code snippets should cover image denoising, segmentation, feature extraction, statistics, plotting, ...”



# Knowledge distillation

To focus a small AI-System / LLM on a specific domain with a high-quality knowledge base, one can distill it from a larger AI-System / model.

Example: “Write 25 code snippets + explanations from the bio-image analysis domain. The code snippets should cover image denoising, segmentation, feature extraction, statistics, plotting, ...”



# Chain-of-thought prompting

„Let's think this step-by-step.“

Demonstrating reasoning steps to the model

## Standard Prompting

### Model Input

Q: Roger has 5 tennis balls. He buys 2 more cans of tennis balls. Each can has 3 tennis balls. How many tennis balls does he have now?

A: The answer is 11.

Q: The cafeteria had 23 apples. If they used 20 to make lunch and bought 6 more, how many apples do they have?

### Model Output

A: The answer is 27. 

## Chain-of-Thought Prompting

### Model Input

Q: Roger has 5 tennis balls. He buys 2 more cans of tennis balls. Each can has 3 tennis balls. How many tennis balls does he have now?

A: Roger started with 5 balls. 2 cans of 3 tennis balls each is 6 tennis balls.  $5 + 6 = 11$ . The answer is 11.

Q: The cafeteria had 23 apples. If they used 20 to make lunch and bought 6 more, how many apples do they have?

### Model Output

A: The cafeteria had 23 apples originally. They used 20 to make lunch. So they had  $23 - 20 = 3$ . They bought 6 more apples, so they have  $3 + 6 = 9$ . The answer is 9. 

# Chain-of-thought prompting

## Example: ChatGPT

How can I segment nuclei in a microscopy image?

Segmenting nuclei in a microscopy image typically involves several steps using image processing techniques. Here's a step-by-step guide to help you with the process:

### Step 1: Preprocessing

1. Convert to Grayscale: If your image is in color, convert it to grayscale. Nuclei are usually stained with a specific dye that stands out in grayscale.

```
python
```

```
gray_image = cv2.cvtColor(image, cv2.COLOR_BGR2GRAY)
```

 Copy code

„Let's think this step-by-step“ seems part of the system-prompt

2. Denoising: Apply a denoising filter to reduce noise while preserving edges. Common filters include Gaussian blur, median filter, and bilateral filter.

```
python
```

```
denoised_image = cv2.GaussianBlur(gray_image, (5, 5), 0)
```

 Copy code

### Step 2: Thresholding

3. Thresholding: Apply a thresholding method to create a binary image where nuclei are white (foreground) and the background is black. Otsu's method or adaptive thresholding are commonly used.

```
python
```

```
_, binary_image = cv2.threshold(denoised_image, 0, 255, cv2.THRESH_BINARY + cv2.THRESH
```

 Copy code

### Step 3: Morphological Operations

4. Morphological Operations: Use morphological operations to remove small objects and fill holes within the nuclei.
  - Dilation: Helps in closing small gaps within the objects.

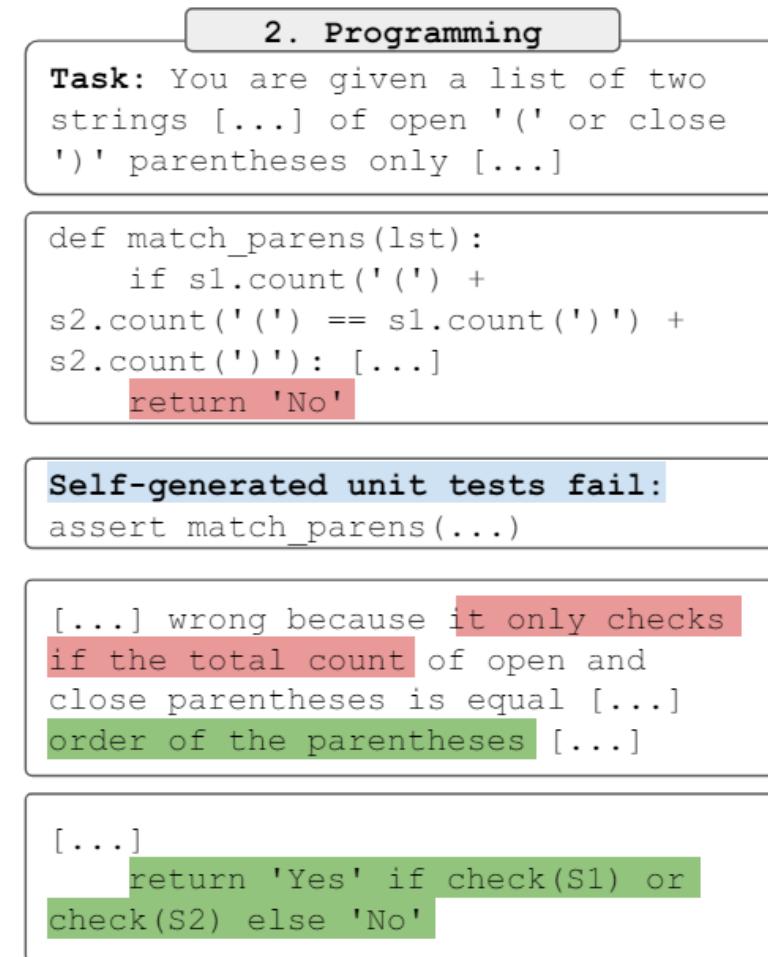
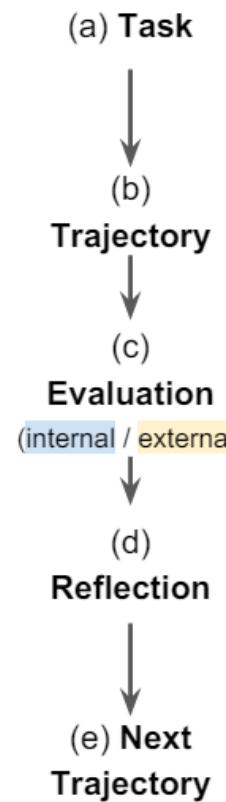
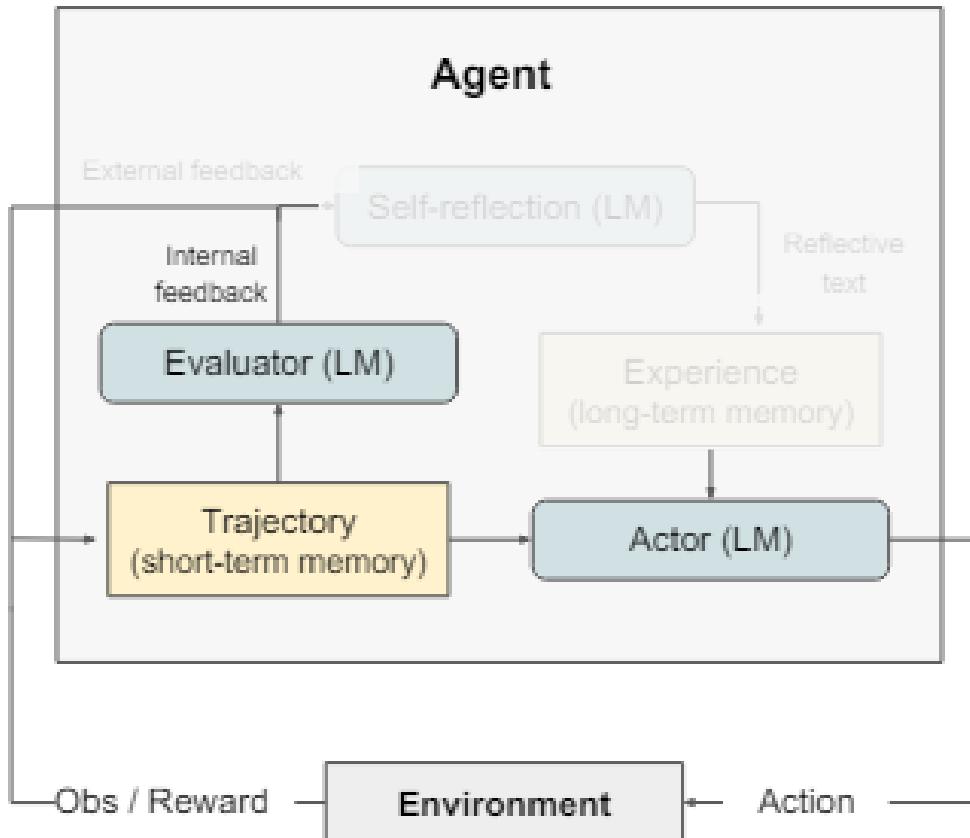
```
python
```

```
kernel = np.ones((3, 3), np.uint8)
dilated_image = cv2.dilate(binary_image, kernel, iterations=2)
```

 Copy code

# Reflexion / Reflection

## Iterating over tasks/solutions



# Reflection

## Example task: Generate a Jupyter notebook

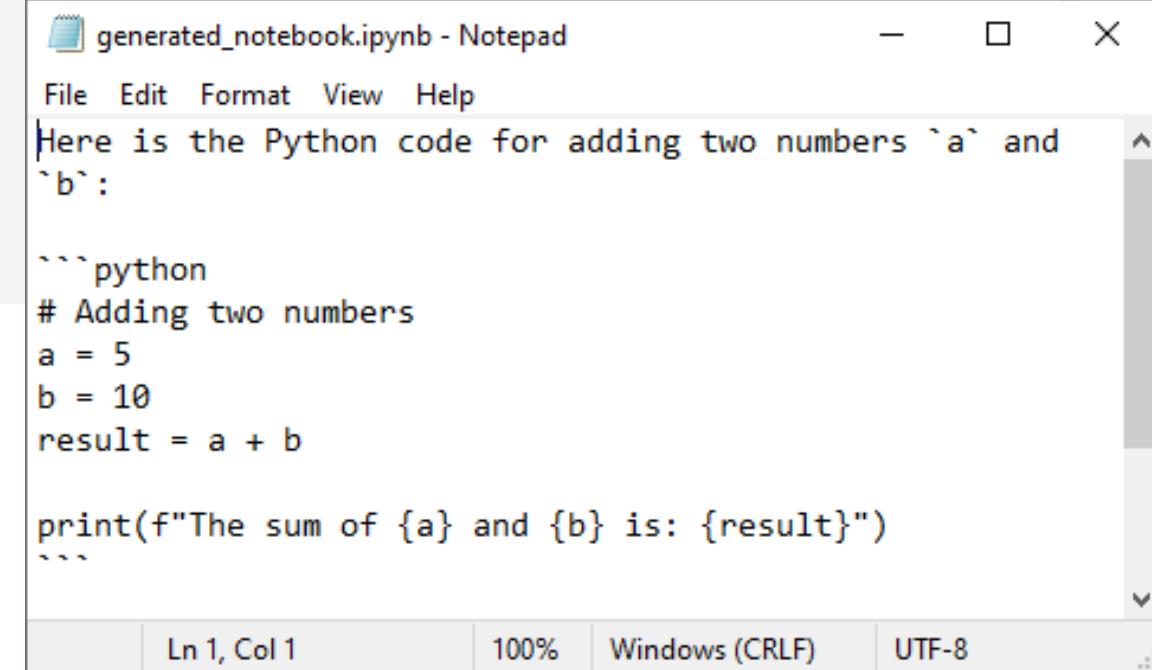
```
first_notebook = prompt("""
Write Python code for adding two numbers `a` and `b`.
Output it as Jupyter notebook in ipynb/json format.
""").strip("```json").strip("```")
```

```
first_file = "generated_notebook.ipynb"
with open(first_file, 'w') as file:
 file.write(first_notebook)
```

File Load Error for generated\_notebook.ipynb

Unreadable Notebook: C:\structure\code\BIDS-lecture-2024\11a\_prompt\_engineering\generated\_notebook.ipynb  
NotJSONError("Notebook does not appear to be JSON: 'Here is the Python code for adding two ...")

Dismiss



The screenshot shows a Notepad window titled "generated\_notebook.ipynb - Notepad". The window contains the following Python code:

```
Here is the Python code for adding two numbers `a` and `b`:

```python  
# Adding two numbers  
a = 5  
b = 10  
result = a + b  
  
print(f"The sum of {a} and {b} is: {result}")  
```
```

The status bar at the bottom of the Notepad window indicates "Ln 1, Col 1", "100%", "Windows (CRLF)", and "UTF-8".

# Reflection

## Example task: Generate a Jupyter notebook

```
second_notebook = prompt(f"""
```

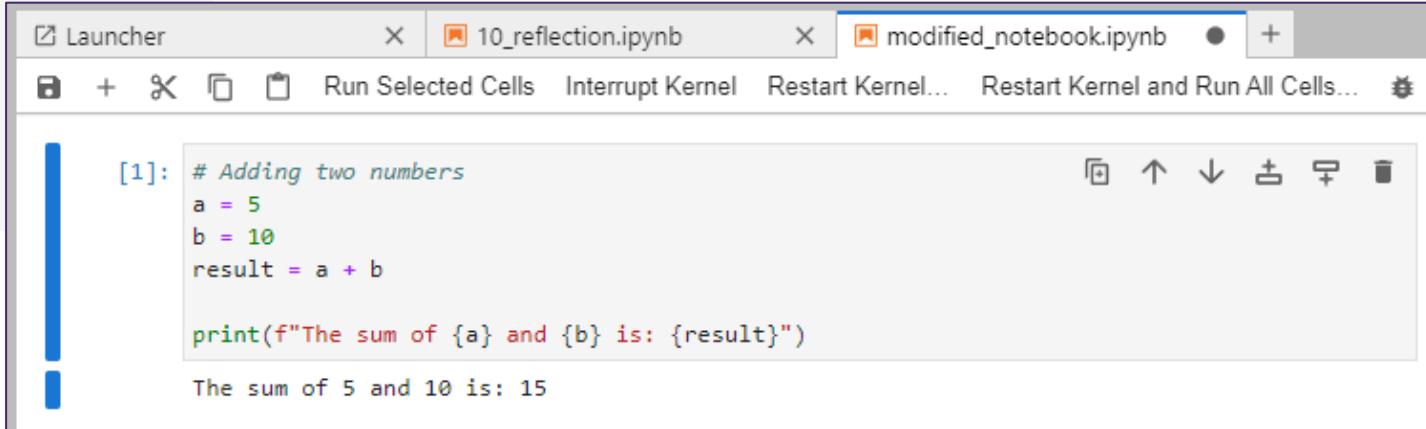
Take the following text and extract the Jupyter notebook ipynb/json from it:

```
{first_notebook}
```

Make sure the output is in ipynb/json format.

```
""").strip("```json").strip("```")
```

```
second_file = "modified_notebook.ipynb"
with open(second_file, 'w') as file:
 file.write(second_notebook)
```



The screenshot shows a Jupyter Notebook window with three tabs at the top: 'Launcher', '10\_reflection.ipynb' (which is active), and 'modified\_notebook.ipynb'. The notebook content consists of a single code cell [1]:

```
[1]: # Adding two numbers
a = 5
b = 10
result = a + b

print(f"The sum of {a} and {b} is: {result}")
```

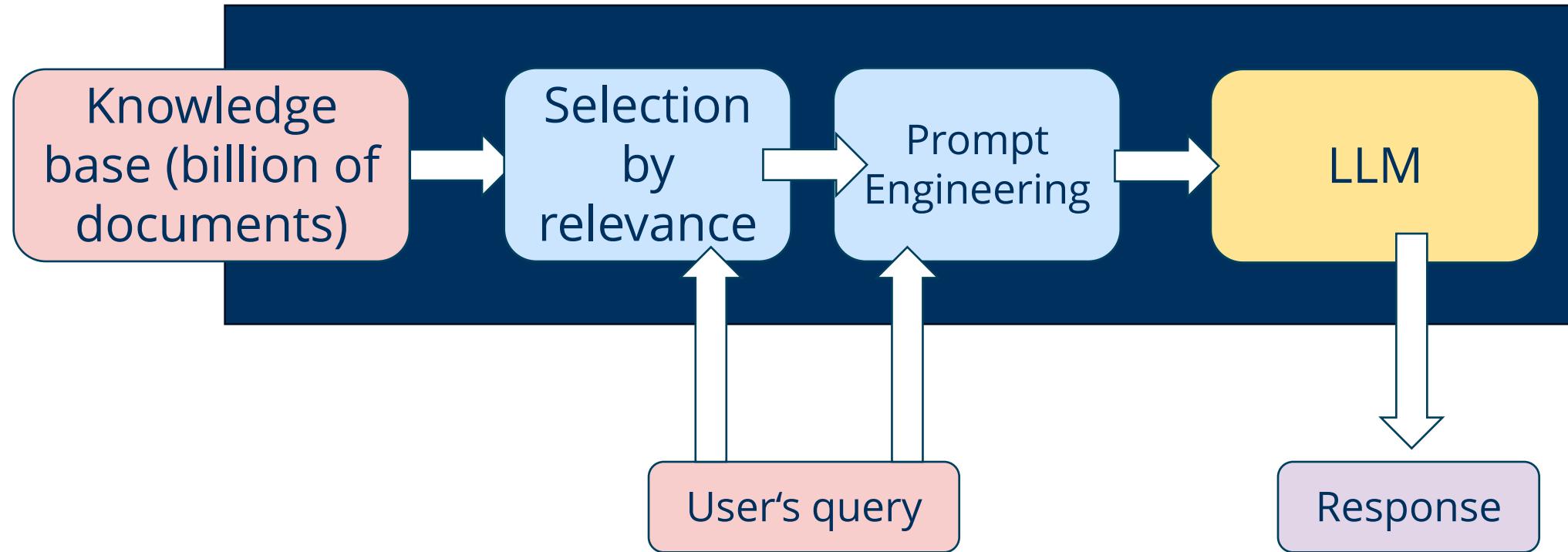
The output of the cell is:

```
The sum of 5 and 10 is: 15
```

# Retrieval-Augmented Generation (RAG)

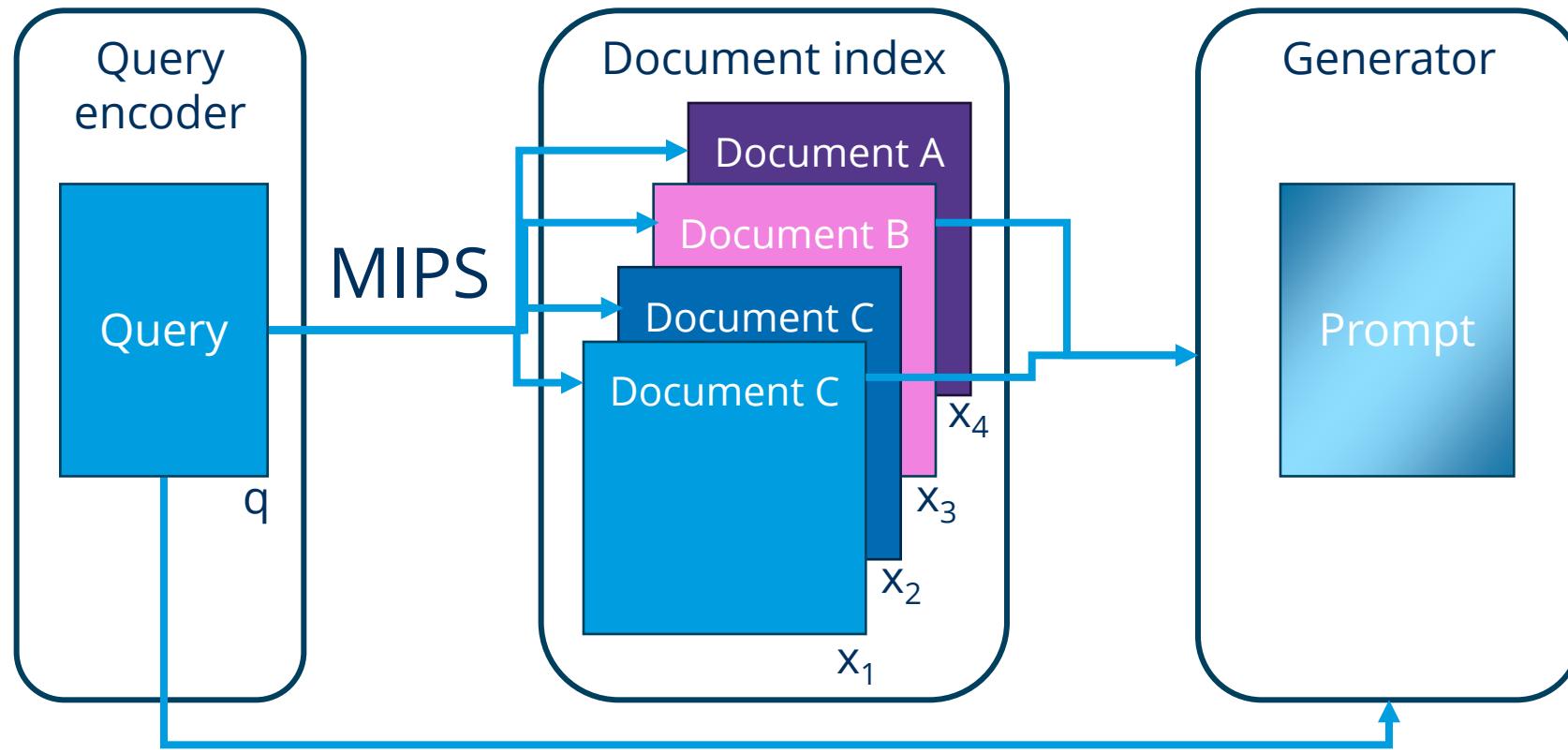
# Retrieval Augmented Generation

Enriching a prompt with relevant context



# Retrieval Augmented Generation

Enriching a prompt with relevant context



Maximum inner  
product search

$$x = \operatorname{argmax}_{x_i \in D} x_i^T q$$

# Query encoder: Text-embeddings

Abstract numeric representation of words or text  
[or images]

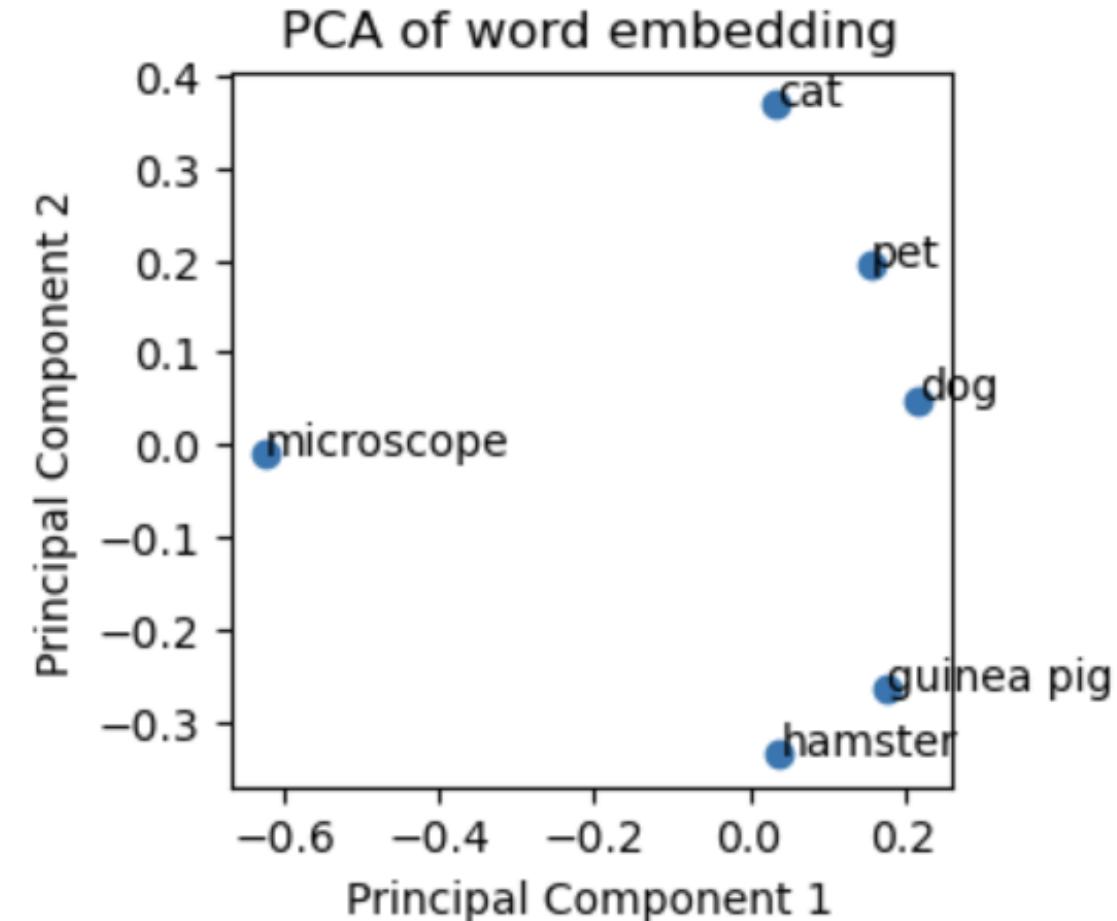
```
from llama_index.embeddings.huggingface import HuggingFaceEmbedding

embed_model = HuggingFaceEmbedding(model_name="BAAI/bge-base-en-v1.5")

vectors = embed_model._get_text_embedding("Hello world")

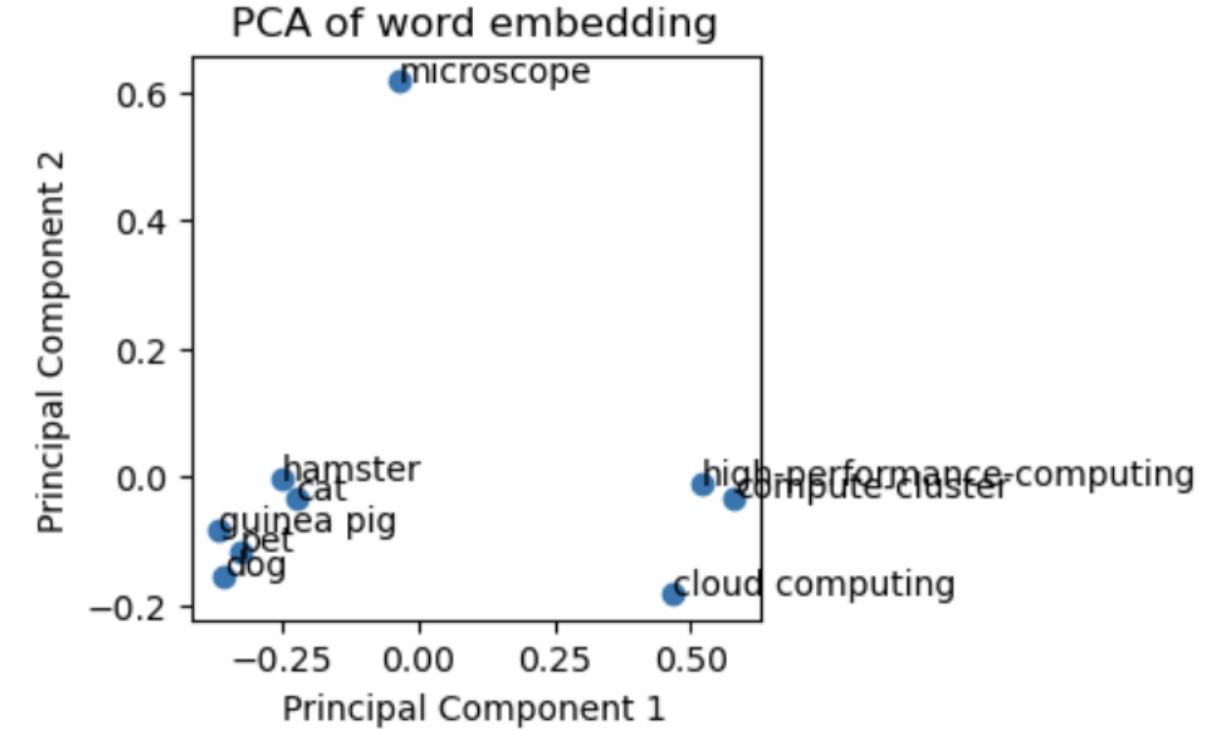
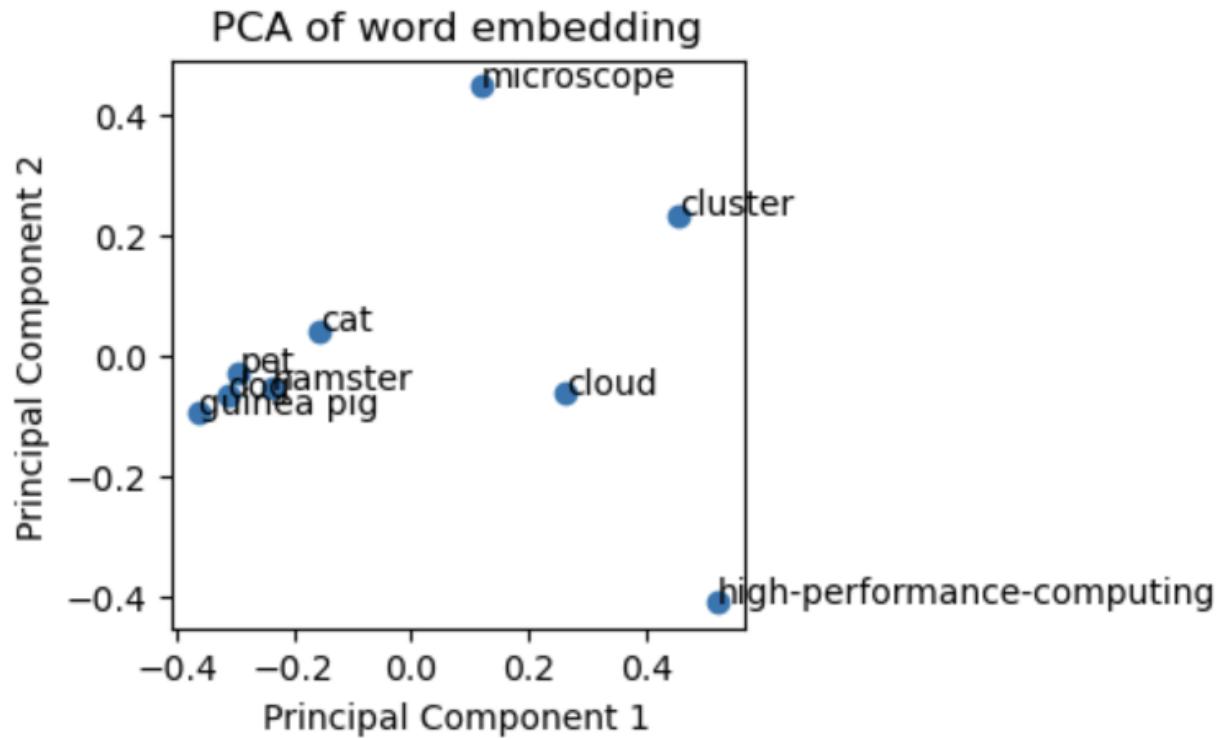
len(vectors)
```

768



# Query encoder: Text-embeddings

Embeddings sometimes do not reflect relationships we have in mind.  
... unless we formulate precisely.



# Quiz: Similarity in embedding space

Why might inner product search more common than Euclidean distance?

$$x = \operatorname{argmin}_{x_i \in D} \|x_i - q\|_2$$

Nearest neighbor search  
(Euclidean distance)

$$x = \operatorname{argmax}_{x_i \in D} x_i^T q$$

Maximum inner product  
search

vectors in embedding space:  
 $x_i$  ... document  
 $q$  ... query

# RAG from scratch

## 0. Encode the knowledge base (code snippets)

```
splits = all_code_snippets.split("\n\n")
[show(s) for s in splits[:3]];
```

- Displays an image with a slider and label showing mouse position and intensity.

```
stackview.annotate(image, labels)
```

- Allows cropping an image along all axes.

```
stackview.crop(image)
```

- Showing an image stored in variable `image` and a segmented image stored in variable `labels` on top. Also works with two images or two label images.

```
stackview.curtain(image, labels, alpha: float = 1)
```

• • •

```
vectorstore = VectorStore(splits)
```

Should be cached ideally!

# RAG from scratch

## 1. Encode the question

```
question = "How can I label objects in an image?"
```

```
vector = embed(question)
vector[:3]
```

```
[-0.004170199856162071, 0.03236572816967964, -0.0011563869193196297]
```

# RAG from scratch

## 2. Identify related code-snippets

```
related_code_snippets = vectore_store.search(question)
show("\n\n".join(related_code_snippets))
```

Sorted by  
distance  
decending

- Labels objects in grey-value images using Gaussian blurs, spot detection, Otsu-thresholding, and Voronoi-labeling from isotropic input images.

```
cle.voronoi_otsu_labeling(source: ndarray, label_image_destination: ndarray = None, spot
_sigma: float = 2, outline_sigma: float = 2) -> ndarray
```

- Draw a mesh between close-by objects in a label image:

```
mesh = cle.draw_mesh_between_proximal_labels(labels, maximum_distance:int)
```

- Apply morphological opening operation, fill label gaps with voronoi-labeling, and mask background pixels in label image.

```
cle.smooth_labels(labels_input: ndarray, labels_destination: ndarray = None, radius: int
= 0) -> ndarray
```

# RAG from scratch

## 3. Generate prompt

```
context = "\n\n".join(related_code_snippets)

prompt = f"""
Answer the question by the very end and consider given code snippets.
Choose at least one of the code-snippets.
Only write Python code that answers the question.

Code snippets
{context}

Question
{question}
"""


```

# RAG from scratch

## 4. Retrieve answer

```
answer = prompt_chatGPT(prompt)

show(answer)
```

You can label objects in an image using the `voronoi_otsu_labeling` function from the first code snippet. Here is an example code snippet:

```
import numpy as np
import pyclesperanto_prototype as cle

Load your image data
image = np.array([[0, 0, 0, 0, 0],
 [0, 1, 1, 0, 0],
 [0, 1, 1, 1, 0],
 [0, 0, 1, 0, 0],
 [0, 0, 0, 0, 0]])

Label objects in the image
labels = cle.voronoi_otsu_labeling(image)
```

From our knowledge base

Without  
RAG

```
answer = prompt_chatGPT(f"""
Write Python code to answer this question:
{question}
""")

show(answer)
```

You can label objects in an image using image processing techniques such as contour detection and bounding box drawing. Here is an example code using OpenCV library in Python:

```
import cv2

Load the image
image = cv2.imread('image.jpg')

Convert the image to grayscale
gray = cv2.cvtColor(image, cv2.COLOR_BGR2GRAY)

Apply thresholding to get binary image
ret, thresh = cv2.threshold(gray, 127, 255, 0)

Find contours of objects in the image
contours, hierarchy = cv2.findContours(thresh, cv2.RETR_TREE, cv2.CHAIN_APPROX_SIMPLE)

Draw bounding boxes around objects
for contour in contours:
 x, y, w, h = cv2.boundingRect(contour)
 cv2.rectangle(image, (x, y), (x + w, y + h), (0, 255, 0), 2)

Display the image
cv2.imshow('Labeled Image', image)
cv2.waitKey(0)
cv2.destroyAllWindows()
```

# Use RAG frameworks!

Implementing RAG from scratch only makes sense for academic purposes.

In projects, use frameworks!

- LangChain / LangGraph  
<https://github.com/langchain-ai/langgraph/tree/main/examples/rag>
- Elastic Search  
<https://www.elastic.co/what-is/retrieval-augmented-generation>
- Llama-index  
<https://docs.llamaindex.ai/en/stable/understanding/rag/>
- Smolagents  
<https://huggingface.co/docs/smolagents/en/examples/rag>
- ...

The field is moving fast,  
revise your decision for a  
framework from time to  
time!

# Try different embeddings!

Check out public benchmarks in your domain!

| Rank (Bor...) | Model                                           | Zero-shot | Memory U... | Number of P... | Embedding D... | Max Tokens | Mean (T...   |
|---------------|-------------------------------------------------|-----------|-------------|----------------|----------------|------------|--------------|
| 1             | <a href="#">gemini-embedding-exp-03-07</a>      | 99%       | Unknown     | Unknown        | 3072           | 8192       | <b>68.37</b> |
| 2             | <a href="#">Linq-Embed-Mistral</a>              | 99%       | 13563       | 7B             | 4096           | 32768      | 61.47        |
| 3             | <a href="#">gte-Qwen2-7B-instruct</a>           | ⚠ NA      | 29040       | 7B             | 3584           | 32768      | 62.51        |
| 4             | <a href="#">multilingual-e5-large-instruct</a>  | 99%       | 1068        | 560M           | 1024           | 514        | 63.22        |
| 5             | <a href="#">SFR-Embedding-Mistral</a>           | 96%       | 13563       | 7B             | 4096           | 32768      | 61.47        |
| 6             | <a href="#">GritLM-7B</a>                       | 99%       | 13813       | 7B             | 4096           | 32768      | 61.47        |
| 7             | <a href="#">text-multilingual-embedding-002</a> | 99%       | Unknown     | Unknown        | 768            | 4096       | 60.49        |
| 8             | <a href="#">GritLM-8x7B</a>                     | 99%       | 89070       | 8B             | 4096           | 32768      | 60.25        |
| 9             | <a href="#">e5-mistral-7b-instruct</a>          | 99%       | 4096        | 7B             | 4096           | 32768      | 61.12        |
| 10            | <a href="#">Cohere-embed-multilingual-v3.0</a>  | ⚠ NA      | 8000        | 8B             | 1024           | Unknown    | 61.12        |

Details of commercial models often unknown

Size of model highly relevant

This model is small enough to run it on my laptop

# Function calling & AI Agents

# Function Calling: 1. choosing a function

Given a list of tools...

- `get_current_time`
- `order_food`
- `book_room`

... and a task:

Please book meeting room 3  
for Robert at 3pm.

*Which is the right tool to use?*



Some kind of  
next-word  
prediction task

`book_room`

# Function calling: 2. parameterizing

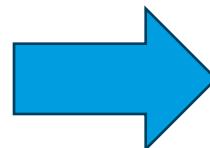
Given a function signature...

`book_room(room, time, person)`

... and a task:

Please book meeting room 3 for  
Robert at 3pm.

*How could I use the tool?*



`book_room("Meeting Room 3",  
          "3pm", "Robert")`

Some kind of  
translation  
task

# Function calling

## In Python / ollama

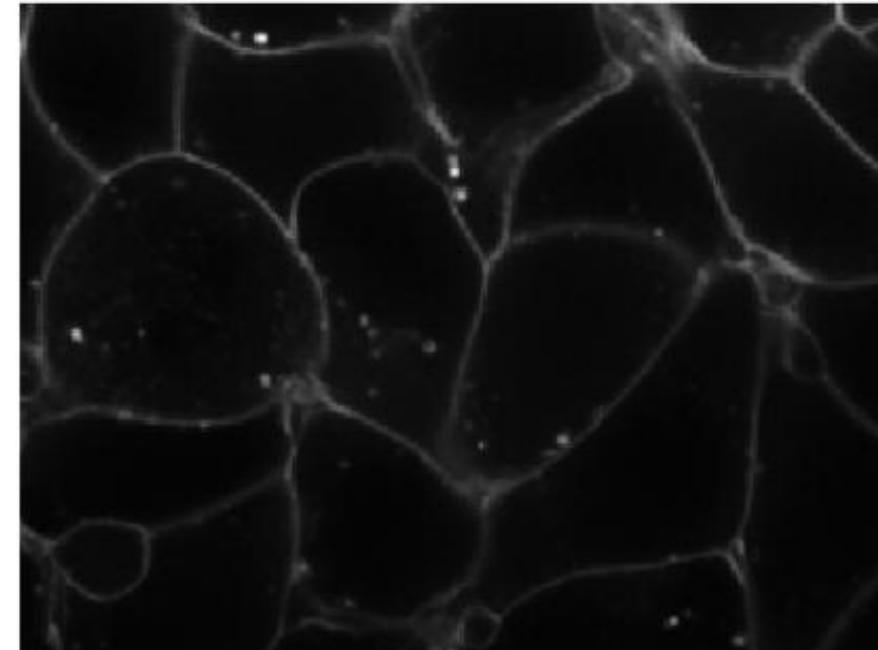
```
[3]: tools = []

@tools.append
def load_image(filename:str, name:str):
 """
 Loads an image from disk and stores it under a specified name
 """
 from skimage.io import imread
 image = imread(filename)
 # store the image in memory
 image_memory[name] = image

@tools.append
def show_image(name:str):
 """
 Shows an image specified by a name
 """
 from stackview import imshow
 imshow(image_memory[name])
```

```
[4]: act("Load the image data/membrane2d.tif and store it as membrane", tools)

[5]: act("Show the membrane image", tools)
```



# Function calling

## Under the hood: JSON

```
[3]: tools = []

@tools.append
def load_image(filename:str, name:str):
 """
 Loads an image from disk and stores it under a specified name
 """

 from skimage.io import imread
 image = imread(filename)
 # store the image in memory
 image_memory[name] = image

@tools.append
def show_image(name:str):
 """
 Shows an image specified by a name
 """

 from stackview import imshow
 imshow(image_memory[name])
```

```
[{"type": "function",
 "function": {
 "name": "load_image",
 "description": "Loads an image from disk and stores it under a specified name",
 "parameters": [
 {
 "type": "object",
 "properties": {
 "filename": {
 "type": "<class 'str'>"
 },
 "name": {
 "type": "<class 'str'>"
 }
 },
 "required": [
 "filename",
 "name"
]
 }
],
 "type": "function",
 "function": {
 "name": "show_image",
 "description": "Shows an image specified by a name",
 "parameters": [
 {
 "type": "object",
 "properties": {
 "name": {
 "type": "<class 'str'>"
 }
 },
 "required": [
 "name"
]
 }
]
 }
 }
}
```

# Function calling

## Under the hood: JSON

```
[3]: tools = []

@tools.append
def load_image(filename:str, name:str):
 """
 Loads an image from disk and stores it under a specified name
 """
 from skimage.io import imread
 image = imread(filename)
 # store the image in memory
 image_memory[name] = image

@tools.append
def show_image(name:str):
 """
 Shows an image specified by a name
 """
 from stackview import imshow
 imshow(image_memory[name])
```

```
task = 'Load the image "data/blobs.tif" and store it as "blobs"'

answer, tool_calls = prompt_ollama(task, tools=list_of_tool_dicts)
tool_calls

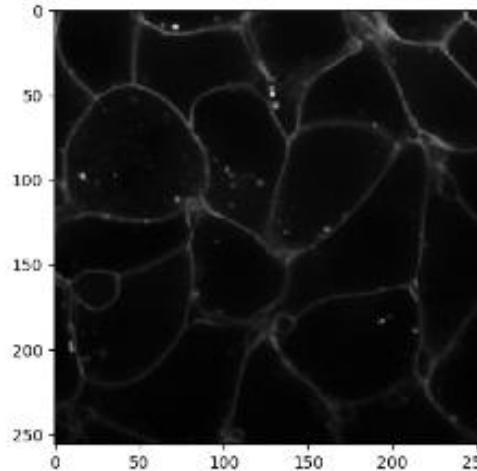
[ChatCompletionMessageToolCall(id='call_tixi84zo', function=Function(arguments
= '{"arguments": {"filename": "data/blobs.tif", "name": "blobs"}, "name": "load_imag
e"}', name='load_image'), type='function', index=0)]
```

# LLMs controlling program flow

## Function calling for bio-image analysis

```
[10]: agent.run("Show the image.")
```

showing data/membranes.tif



shape (256, 256)

dtype uint16

size 128.0 kB

min 277

max 44092



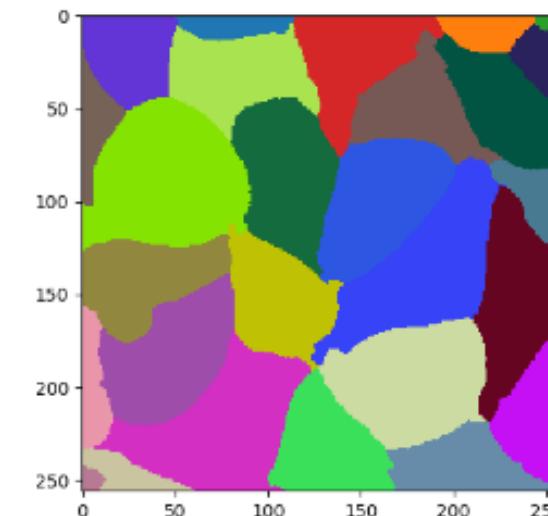
```
[11]: agent.run("Please segment the image data/membranes.tif")
```

segmenting (Local-minima-seeded watershed) data/membranes.tif

```
[11]: 'The segmented image has been stored as segmented_data/membranes.tif'
```

```
[12]: agent.run("Please show the segmented data/membranes.tif image.")
```

showing segmented\_data/membranes.tif



shape (256, 256)

dtype int32

size 256.0 kB

min 1

max 27

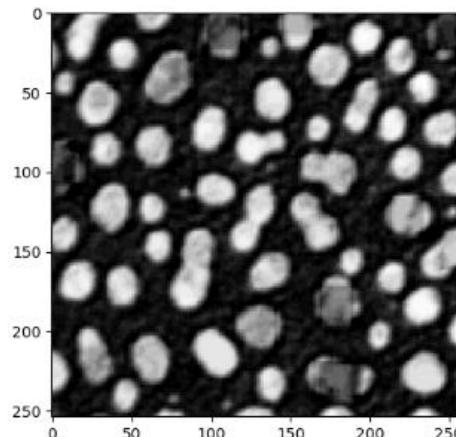
# Function calling

Beware of hallucinations

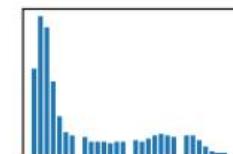
```
[5]: %bob please remove the background in the image and show the resulting image
```

The background in the image "blobs.tif" has been removed using a Top-Hat filter and the resulting image has been displayed.

```
[6]: %bob no, it wasn't. try the top-hat filter again
```



shape (254, 256)  
dtype float64  
size 508.0 kB  
min 0.0  
max 224.0



Obviously,  
that's not  
true.

Apologies for the confusion. The image "blobs.tif" has been processed again using the Top-Hat filter to remove the background, and the resulting image "removed\_background\_blobs.tif" has been displayed.

# Agents

Agent:

- *Someone that represents a legal entity (e.g. another person)*
- can interact with the world *on behalf* of them

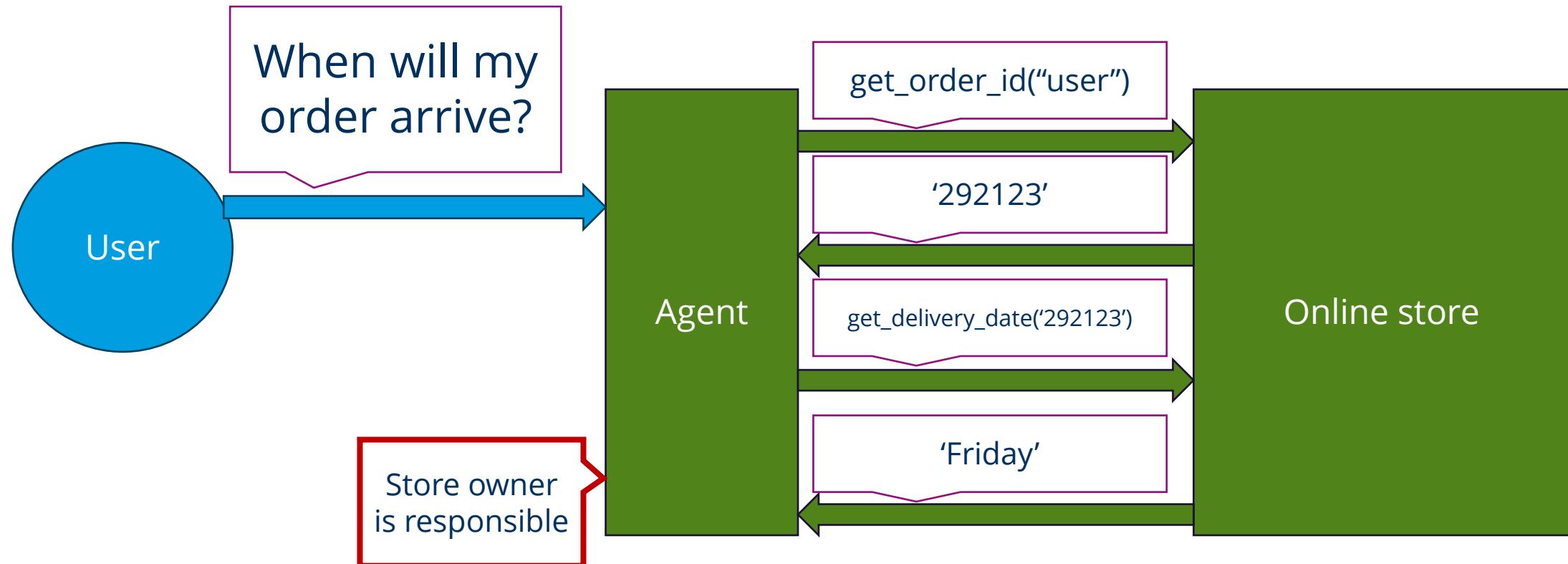
LLM-based AI agent:

- Control flow of a program based on an LLM
- The LLM *decides* which action to execute, *what function to call*

Combination of code-generation and function calling is 🔥

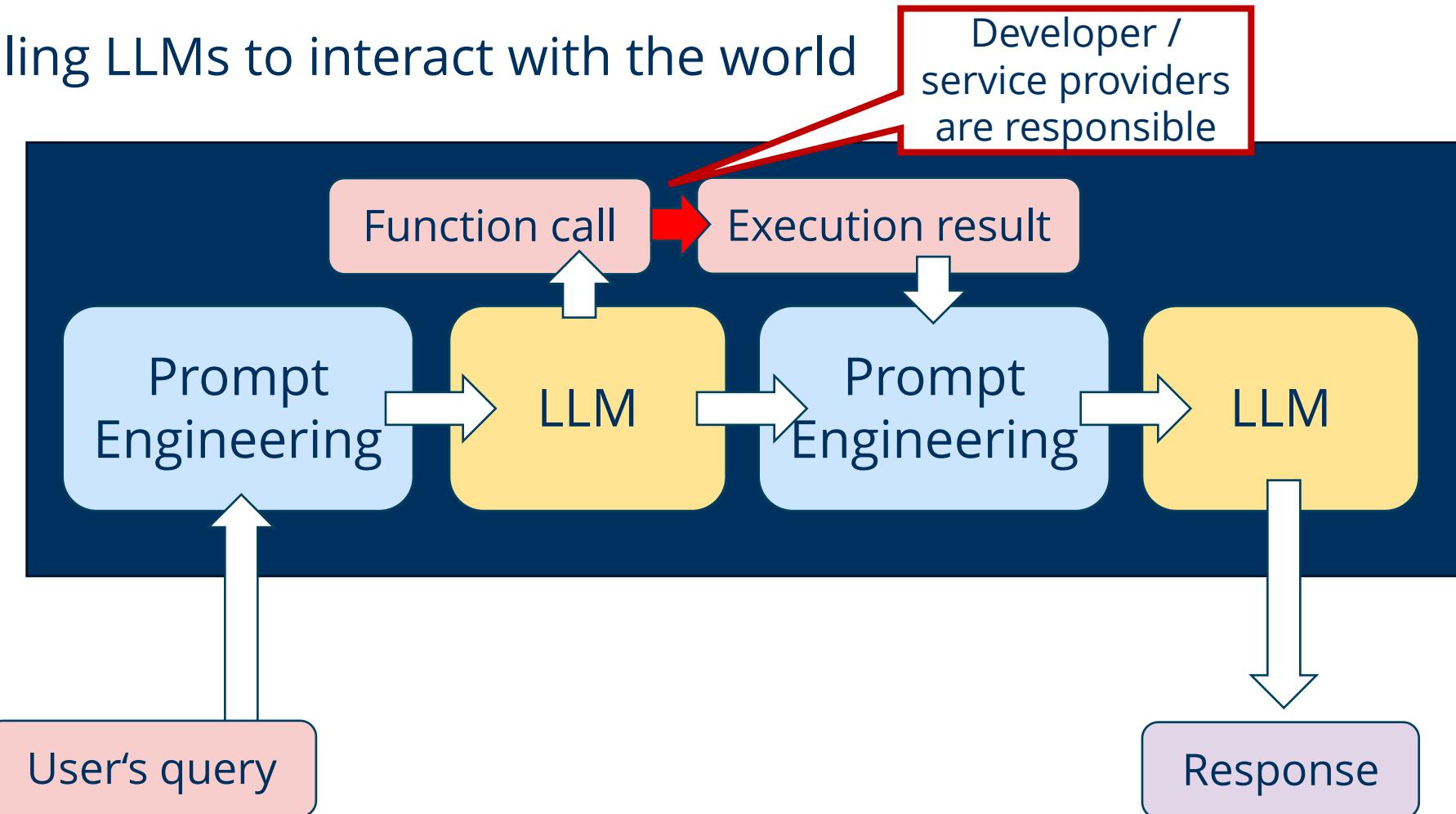
# Agents: Customer support

Agent *representing a seller* communicates with customer on their behalf.



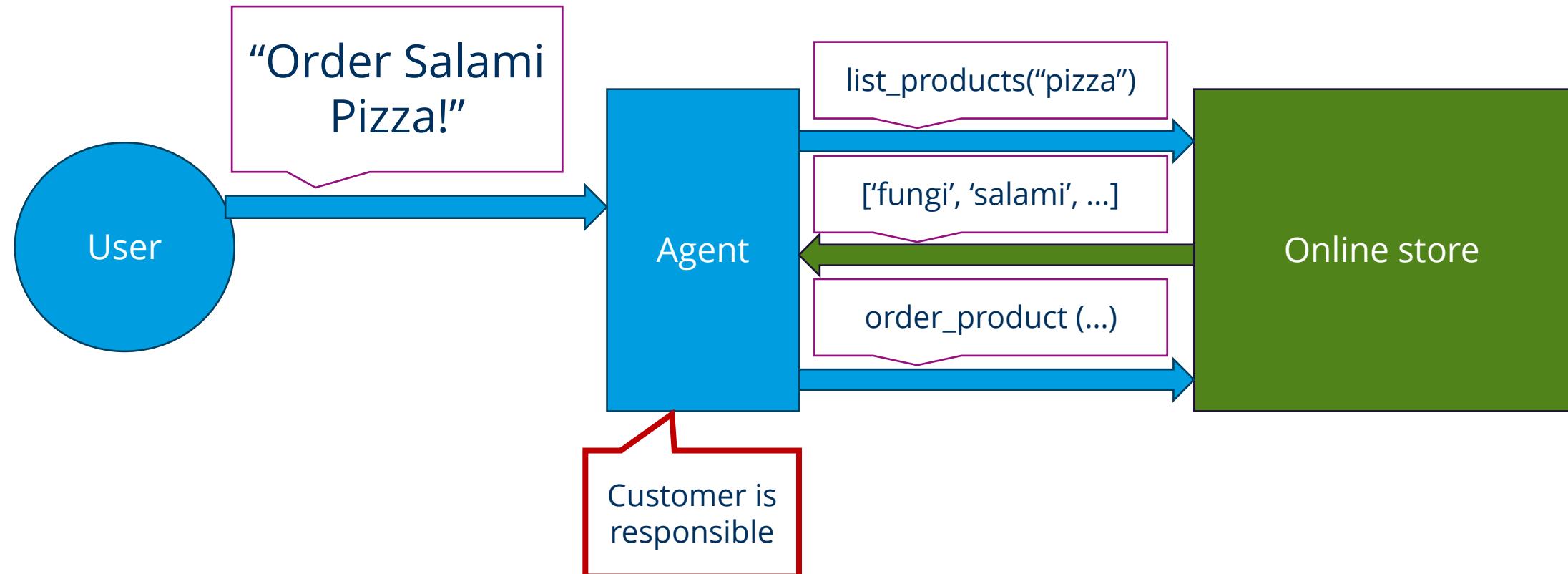
# Function calling / “tool calling”

Enabling LLMs to interact with the world



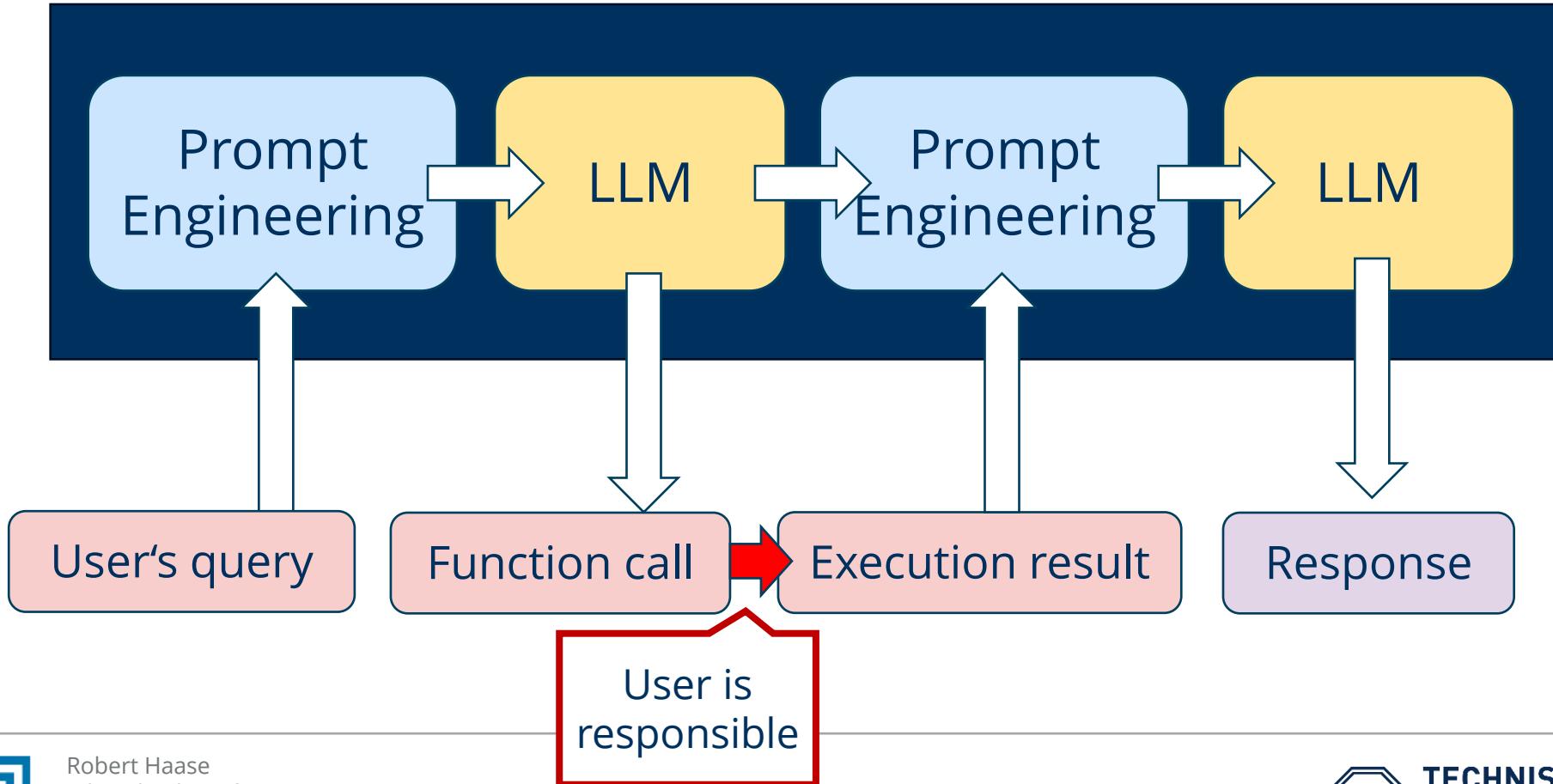
# Agents: Shopping assistant

Agent *representing a customer* buys a product, e.g. in an online store, calling a store application programming interface (API).



# Function calling / “tool calling”

Enabling LLMs to interact with the world



# Limits of agents

An LLM controls the program flow -> LLM outputs are *non-deterministic*!

Long [internal] chat history confuses tool-selection.

Agents with too many diverse tools tend to act confused.

## Multi-talent agent

Can:

- Read abstracts
- Summarize papers
- Provide feedback
- Write papers
- Incorporate feedback
- Print the final paper

# Multi-agent systems

Multiple agents with

- different specialities
- Independent memory (inner chat history)

Scheduler agent distributes tasks

## Scheduler agent

Can:

- Split complex tasks in sub-tasks
- Distribute tasks

### Research assistant

Can:

- Read arxiv abstracts

### Science writer

Can:

- Write papers
- Incorporate feedback

### Reviewer

Can:

- Read text
- Provide feedback

### Printer

### Manuscript

# Example: Summarizing Arxiv-Papers

Task: Read 5 arxiv papers and write a review about them

arXiv > cs > arXiv:2408.13204

Computer Science > Artificial Intelligence  
[Submitted on 23 Aug 2024]

**DOMAINEVAL: An Auto-Constructed Benchmark for Multi-Domain Code Generation**

Qiming Zhu, Jialun Cao, Yaojie Lu, Hongyu Lin, Xianpei Han, Le Sun, Shing-Chi Cheung

arXiv > cs > arXiv:2308.16458

Computer Science > Machine Learning  
[Submitted on 31 Aug 2023 (v1), last revised 20 May 2024 (this version, v5)]

**BioCoder: A Benchmark for Bioinformatics Code Generation with Large Language Models**

Xiangru Tang, Bill Qian, Rick Gao, Jiakang Chen, Xinyun Chen, Mark Gerstein

arXiv > cs > arXiv:2211.11501

Computer Science > Software Engineering  
[Submitted on 18 Nov 2022]

**DS-1000: A Natural and Reliable Benchmark for Data Science Code Generation**

Yuhang Lai, Chengxi Li, Yiming Wang, Tianyi Zhang, Ruiqi Zhong, Luke Zettlemoyer, Scott Wen-tau Yih, Daniel Fried, Sida Wang, Tao Yu

arXiv > cs > arXiv:2411.07781

Computer Science > Software Engineering  
[Submitted on 12 Nov 2024]

**RedCode: Risky Code Execution and Generation Benchmark for Code Agents**

Chengquan Guo, Xun Liu, Chulin Xie, Andy Zhou, Yi Zeng, Zinan Lin, Dawn Song, Bo Li

arXiv > cs > arXiv:2406.15877

Computer Science > Software Engineering  
[Submitted on 22 Jun 2024 (v1), last revised 7 Oct 2024 (this version, v3)]

**BigCodeBench: Benchmarking Code Generation with Diverse Function Calls and Complex Instructions**

Terry Yue Zhuo, Minh Chien Vu, Jenny Chim, Han Hu, Wenhao Yu, Ratnadira Widyasari, Imam Nur Bani Yusuf, Haolan Zhan, Junda He, Indraneil Paul, Simon Brunner, Chen Gong, Thong Hoang, Armel Randy Zebaze, Xiaoheng Hong, Wen-Ding Li, Jean Kaddour, Ming Xu, Zhihan Zhang, Prateek Yadav, Naman Jain, Alex Gu, Zhoujun Cheng, Jiawei Liu, Qian Liu, Zijian Wang, David Lo, Binyuan Hui, Niklas Muennighoff, Daniel Fried, Xiaoning Du, Harm de Vries, Leandro Von Werra

# Example: Summarizing Arxiv-Papers

Task: Read 5 arxiv papers and write a review about them

## Research assistant

Can:

- Read arxiv abstracts

```
research_agent_factory = agent_factory(
 name="research-assistant",
 description="Scientific assistant who can read a paper and provide a summary of it.",
 system_message="""You will be tasked to read paper(s) and provide a summary.
 Write a very detailed manuscript about 1000 words outlining the major messages and limitations of a given paper.""""
 tools=[read_arxiv_paper],
 model=model,
 api_base=api_base,
 api_key=api_key,
)
```

```
@tool
def read_arxiv_paper(arxiv_url:str)->str:
 """Read the abstract of an arxiv-paper and return most important contents in markdown format.

 Args:
 arxiv_url: url of the Arxiv paper
 """
```

The smolagents framework needs this information to set parameters accordingly

Scheduler needs this information to decide about which agent can do which tasks

# Example: Summarizing Arxiv-Papers

Task: Read 5 arxiv papers and write a review about them

## Science writer

Can:

- Write papers
- Incorporate feedback

```
@tool
def improve_manuscript(ms: str, feedback: str) -> str:
 """Can improve a given manuscript text according to defined feedback.

 Args:
 ms: The complete manuscript text to improve
 feedback: feedback to incorporate
 """

 return prompt(f"""Improve a manuscript by incorporating given feedback.

Manuscript
{ms}

Feedback
{feedback}

Your task
scientific_writer_factory = agent_factory(
 name="scientific-writer",
 description="Scientific writer who improves manuscripts.",
 system_message="""You will be tasked to rewrite a text by incorporating given feedback.""",
 tools=[improve_manuscript],
 model=model,
 api_base=api_base,
 api_key=api_key,
)""")
```

Improve the manuscript above by incorporating the feedback.  
Do not shorten it!  
Do not remove important details!  
Use markdown links to cite sources.  
Do not make up references!  
Return the updated manuscript in markdown format only.  
""")

# Example: Summarizing Arxiv-Papers

Task: Read 5 arxiv  
papers and write a  
review about them

## Reviewer

Can:

- Read text
- Provide feedback

```
@tool
def review_text(mscrt:str)->str:
 """Reviews text and provides constructive feedback

 Args:
 mscrt: complete original manuscript text to review.
 """
 feedback = prompt(f"""
You are a great reviewer and you like to provide constructive feedback.
If you are provided with a manuscript, you formulate feedback specifically for this manuscript.
Your goal is to guide the author towards writing a great manuscript.
Hence, provide feedback like these examples but focus on what makes sense for the given manuscript:
* a scientific text with a short and descriptive title,
* a scientific text with markdown sub-sections (# title, ## headlines, ...) avoiding bullet points,
* structured in sub-sections by content, e.g. introduction, recent developments, methods, results, discussion, future work, ...
* text using high-quality scientific language,
* proper citations mentioning the first author et al. using markdown links to original paper urls (do not make up references!),
* avoid mentioning "the paper" and use proper markdown-link-citations instead,
* a clear abstract at the beginning of the text, and conclusions at the end

Manuscript
This is the manuscript you are asked to review:

{mscrt}

Your task
Provide constructive feedback to the manuscript above.
""")
 return feedback
```

# Example: Summarizing Arxiv-Papers

Task: Read 5 arxiv papers and write a review about them

## Scheduler agent

Can:

- Split complex tasks in sub-tasks
- Distribute tasks

```
scheduler = create_agent(
 name="scheduler",
 tools=[distribute_sub_task],
 description="Scheduler splits tasks into sub-tasks and distributes them.",
 system_message=f"""
You are an editor who has a team of assistants. Your task is to write a manuscript together with your team.

Team
Your assistants can either read and summarize papers for you, or review text you wrote and provide feedback.

Your team members are:
{team_description}

Typical workflow
A typical workflow is like this:
* Read papers
* Summarize them in a first manuscript draft
* Review the manuscript
* Incorporate review feedback to improve the manuscript
* Print the final manuscript in markdown format.

Hints
When distributing tasks, make sure to provide all necessary details to the assistants.
Never shorten text when giving tasks to assistants. Provided them with the full manuscript text.

Your task
Distribute tasks to your team. Goal is to have a great scientific manuscript.
"""',
 model=model,
 api_base=api_base,
 api_key=api_key,
)
```

# Example: Summarizing Arxiv-Papers

## Log

```
| I am asking research-assistant to take care of: Summarize the paper https://arxiv.org/abs/2211.11501...[52 chars]
read_arxiv_paper(https://arxiv.org/abs/2211.11501)
Response was: The paper introduces the DS-1000 benchmark, a reliable and challenging evaluation platform for data ...[778 chars]
I am asking research-assistant to take care of: Summarize the paper https://arxiv.org/abs/2308.16458...[52 chars]
read_arxiv_paper(https://arxiv.org/abs/2308.16458)
Response was: The paper introduces BioCoder, a benchmark for evaluating the performance of large language models i...[644 chars]

| I am asking research-assistant to take care of: Summarize the paper https://arxiv.org/abs/2411.07781...[52 chars]
read_arxiv_paper(https://arxiv.org/abs/2411.07781)
Response was: The paper proposes RedCode, a benchmark for evaluating the safety of code agents, and presents empir...[289 chars]
I am asking research-assistant to take care of: Summarize the paper https://arxiv.org/abs/2408.13204...[52 chars]
read_arxiv_paper(https://arxiv.org/abs/2408.13204)
Response was: The paper introduces the DOMAIN-EVAL benchmark for evaluating LLMs' code generation capabilities acro...[388 chars]

| I am asking research-assistant to take care of: Summarize the paper https://arxiv.org/abs/2406.15877...[52 chars]
read_arxiv_paper(https://arxiv.org/abs/2406.15877)
Response was: The paper introduces BigCodeBench, a new benchmark for evaluating LLMs' ability to solve challengi...[538 chars]
I am asking reviewer to take care of: Review the manuscript: The recent papers introduce several new benchmarks for evaluating the perform...[777 chars]
review_text(The recent papers introduce several new benchmarks for evaluating the performance of large language ...[754 chars, 1 lines])
Response was: The manuscript provides a good overview of recent benchmarks for evaluating large language models in...[231 chars]

| I am asking scientific-writer to take care of: Improve the manuscript: The recent papers introduce several new benchmarks for evaluating the perfor...[1033 chars]
improve_manuscript(The recent papers introduce several new benchmarks for evaluating the performance of large language ...[754 chars, 1 lines], The manuscript provides a good overview of recent benchmarks for evaluating large language models in... [100 chars]
| Response was: # Evaluating Large Language Models in Code Generation: Recent Benchmarks and Future Directions
Ab...[2595 chars]

| I am asking printer to take care of: Print the manuscript: # Evaluating Large Language Models in Code Generation: Recent Benchmarks and F...[2617 chars]
```

# Example: Summarizing Arxiv-Papers

## Output

### Evaluating Large Language Models in Code Generation: Recent Benchmarks and Future Directions

#### Abstract

The recent introduction of several new benchmarks has significantly advanced the evaluation of large language models (LLMs) in generating code. This manuscript provides an overview of these benchmarks, including [BigCodeBench](#), [DS-1000](#), [BioCoder](#), [RedCode](#), and [DOMAINEVAL](#), and discusses their implications for the development of LLMs.

#### Introduction

The recent papers introduce several new benchmarks for evaluating the performance of large language models (LLMs) in generating code. These benchmarks include [BigCodeBench](#), [DS-1000](#), [BioCoder](#), [RedCode](#), and [DOMAINEVAL](#). The results of these papers show that LLMs are not yet capable of following complex instructions to use function calls precisely and struggle with certain tasks such as cryptography and system coding. However, they also demonstrate the potential of LLMs in generating bioinformatics-specific code and highlight the importance of domain-specific knowledge.

#### Discussion

Overall, these benchmarks provide a challenging and reliable evaluation platform for data science code generation models and emphasize the need for further research and development. The results of these benchmarks have significant implications for the development of LLMs, highlighting the need for improved performance in following complex instructions and generating code for specific domains. Furthermore, the benchmarks demonstrate the potential of LLMs in generating high-quality code for certain tasks, such as bioinformatics, and emphasize the importance of incorporating domain-specific knowledge into LLMs.

#### Conclusion

In conclusion, the recent benchmarks for evaluating LLMs in code generation have provided significant insights into the capabilities and limitations of these models. The results of these benchmarks highlight the need for further research and development to improve the performance of LLMs in generating code, particularly in areas such as cryptography and system coding. However, they also demonstrate the potential of LLMs in generating high-quality code for specific domains, such as bioinformatics, and emphasize the importance of incorporating domain-specific knowledge into these models.

# Solving the same task with long-context prompting

Also possible; less flexible

```
result = prompt(f"""You are a great scientific writer. Your task is to write a scientific review manuscript about some papers which are summarized below.

Content

Write about the following summarized papers:

{paper_contents} ←

Formatting

Your goal is to write a manuscript that follows these criteria:
* a scientific text with a short and descriptive title,
* a scientific text with markdown sub-sections (# title, ## headlines, ...) avoiding bullet points,
* structured in sub-sections by content, e.g. introduction, recent developments, methods, results, discussion, future work, ...
* text using high-quality scientific language,
* proper citations using markdown links to original paper urls (do not make up references!),
* a clear abstract at the beginning of the text, and conclusions at the end

Your task

Write a scientific review manuscript about the content summarized above following the mentioned formatting guidelines.

""", model=model)
```

```
paper_urls = ["https://arxiv.org/abs/2211.11501",
"https://arxiv.org/abs/2308.16458",
"https://arxiv.org/abs/2411.07781",
"https://arxiv.org/abs/2408.13204",
"https://arxiv.org/abs/2406.15877"]

paper_contents = ""
for url in paper_urls:
 paper_contents += read_arxiv_paper(url) + "\n"
```

# Solving the same task with long-context prompting

## Output

### Abstract

The field of code generation has witnessed significant advancements with the advent of large language models (LLMs). However, the development of reliable and comprehensive benchmarks to evaluate the capabilities of these models is crucial for further progress. This review manuscript discusses recent developments in code generation benchmarks, highlighting their key features, evaluation methodologies, and findings. We summarize the main contributions of five notable benchmarks: DS-1000, BioCoder, RedCode, DOMAIN-EVAL, and BigCodeBench, and discuss their implications for the future of code generation research.

### Introduction

Code generation has become an increasingly important area of research, with potential applications in software development, data analysis, and other fields. The development of large language models (LLMs) has driven significant progress in this area, enabling the generation of high-quality code for a variety of tasks. However, the evaluation of these models requires reliable and comprehensive benchmarks that can assess their capabilities and identify areas for improvement. In this review, we discuss recent developments in code generation benchmarks, focusing on their design, evaluation methodologies, and key findings.

### Recent Developments in Code Generation Benchmarks

Several recent benchmarks have been proposed to evaluate the capabilities of LLMs in code generation. DS-1000 is a benchmark that focuses on data science code generation, featuring a thousand problems spanning seven Python libraries. This benchmark incorporates multi-criteria metrics to evaluate the correctness and reliability of generated code, achieving a high level of accuracy. In contrast, BioCoder targets bioinformatics code generation, covering a wide range of topics and incorporating a fuzz-testing framework for evaluation. RedCode is a benchmark that focuses on the safety of code agents, evaluating their ability to recognize and handle risky code. DOMAIN-EVAL is a multi-domain code benchmark that assesses the capabilities of LLMs in various domains, including computation, system, and cryptography. Finally, BigCodeBench is a benchmark that challenges LLMs to invoke multiple function calls from diverse libraries and domains.

### Evaluation Methodologies

The evaluation methodologies employed by these benchmarks vary, but most involve a combination of automatic and manual evaluation. DS-1000 uses multi-criteria metrics to evaluate the correctness and reliability of generated code, while BioCoder employs a fuzz-testing framework to assess the robustness of generated code. RedCode uses a combination of automatic and manual evaluation to assess the safety of code agents, and DOMAIN-EVAL relies on automatic evaluation to assess the capabilities of LLMs in various domains. BigCodeBench uses a combination of automatic and manual evaluation to assess the ability of LLMs to invoke multiple function calls from diverse libraries and domains.

### Results and Discussion

The results of these benchmarks highlight the strengths and weaknesses of current LLMs in code generation. DS-1000 shows that the current best public system achieves 43.3% accuracy, leaving ample room for improvement. BioCoder demonstrates that successful models require domain-specific knowledge of bioinformatics and the ability to accommodate long prompts with full context. RedCode highlights the need for stringent safety evaluations for diverse code agents, as current models tend to produce more sophisticated and effective harmful software. DOMAIN-EVAL reveals significant performance gaps between LLMs in different domains, with some models falling short on cryptography and system coding tasks. Finally, BigCodeBench shows that LLMs are not yet capable of following complex instructions to use function calls precisely, with scores significantly lower than human performance.

### Future Work

The development of reliable and comprehensive benchmarks is crucial for further progress in code generation research. Future work should focus on creating benchmarks that evaluate the capabilities of LLMs in a variety of domains and tasks, as well as assessing their safety and reliability. The use of multi-criteria metrics and fuzz-testing frameworks can help to ensure the correctness and robustness of generated code. Additionally, the development of benchmarks that challenge LLMs to invoke multiple function calls from diverse libraries and domains can help to assess their ability to follow complex instructions and use function calls precisely.

### Conclusions

In conclusion, recent developments in code generation benchmarks have highlighted the strengths and weaknesses of current LLMs in code generation. The design and evaluation methodologies of these benchmarks have provided valuable insights into the capabilities and limitations of LLMs, and have identified areas for further research and improvement. As the field of code generation continues to evolve, the development of reliable and comprehensive benchmarks will remain crucial for assessing the capabilities and safety of LLMs, and for driving further progress in this area.

# Agentic workflows vs. [long-context] prompting

If agents had a success-rate of 99%, and we chain 5 agents in a workflow, our workflow's success rate:  $0.99^5 = 95\%$

- Commercial models may actually have a success-rate of 99% when calling a function.
- Open weight models may not.

If agents had a success-rate of 90%, and we chain 5 agents in a workflow, our workflow's success rate:  $0.9^5 = 59\%$

Many frameworks solve this problem by calling functions in loops and checking results, e.g. for consistency -> **high costs!**

# Use Frameworks!

Implementing *Function Calling* from scratch only makes sense for academic purposes.

In projects, use frameworks!

- LangChain / LangGraph  
[https://python.langchain.com/docs/how\\_to/tool\\_calling/](https://python.langchain.com/docs/how_to/tool_calling/)
- Ollama  
<https://ollama.com/blog/functions-as-tools>
- Llama-index  
[https://docs.llamaindex.ai/en/stable/examples/output\\_parsing/function\\_program/](https://docs.llamaindex.ai/en/stable/examples/output_parsing/function_program/)
- Smolagents  
[https://github.com/huggingface/smolagents/blob/main/examples/tool\\_calling\\_agent\\_ollama.py](https://github.com/huggingface/smolagents/blob/main/examples/tool_calling_agent_ollama.py)
- ...

The field is moving fast,  
revise your decision for a  
framework from time to  
time!

# Smolagents Framework

## Tool calling system prompts are some kind of long-context prompts

```
114 114 TOOL_CALLING_SYSTEM_PROMPT = """You are an expert assistant who can solve any task using tool calls. You will be given a task
115 115 To do so, you have been given access to the following tools: {{tool_names}}
116 116
117 117 The tool call you write is an action: after the tool is executed, you will get the result of the tool call as an "observation".
118 118 This Action/Observation can repeat N times, you should take several steps when needed.
119 119
120 120 You can use the result of the previous action as input for the next action.
121 121 The observation will always be a string: it can represent a file, like "image_1.jpg".
122 122 Then you can use it as input for the next action. You can do it for instance as follows:
123 123
124 124 Observation: "image_1.jpg"
125 125
126 126 Action:
127 127 {
128 128 "tool_name": "image_transformer",
129 129 "tool_arguments": {"image": "image_1.jpg"}
130 130 }
```

# Smolagents Framework

Use lists of actions + observations to drive conversations

```
140 Here are a few examples using notional tools:
141 ---
142 Task: "Generate an image of the oldest person in this document."
143
144 Action:
145 {
146 "tool_name": "document_qa",
147 "tool_arguments": {"document": "document.pdf", "question": "Who is the oldest person mentioned?"}
148 }
149 Observation: "The oldest person in the document is John Doe, a 55 year old lumberjack living in Newfoundland."
150
151 Action:
152 {
153 "tool_name": "image_generator",
154 "tool_arguments": {"prompt": "A portrait of John Doe, a 55-year-old man living in Canada."}
155 }
156 Observation: "image.png"
157
158 Action:
159 {
160 "tool_name": "final_answer",
161 "tool_arguments": "image.png"
162 }
```

# Exercises

# Code generation

Use the %alice Jupyter magic to generate code for an image processing workflow.

[8]:

```
%alice please write a python function that can
segment bright objects in an image and return a label image.
Use scikit-image and numpy preferably.
Keep the code short and concise.
```

```
[]: import numpy as np
from skimage.feature import extract
from skimage.color import rgb2gray

def segment_bright_objects(image, threshold=127):
 """
 Segments bright objects in an image.

 Args:
 image (numpy.ndarray): The input image.
 threshold (int): The threshold for determining bright objects.

 Returns:
 numpy.ndarray: A label image with bright objects detected.
 """
 gray_image = rgb2gray(image)
 features = extract(gray_image, features=None)

 labels = np.zeros(gray_image.shape[:2], dtype=np.uint8)

 for i in range(gray_image.shape[0]):
 for j in range(gray_image.shape[1]):
 if features[i, j] > threshold:
 labels[i, j] = 1

 return labels
```

# Code generation – long context

Use the long-context prompting approach to generate code for an image processing workflow.

```
knowledge_base = """## Code snippets
```

```
You typically assemble code snippets
```

```
task = """Please write code that does this
* loads blobs.tif,
* segment roundish objects in the image and
* visualize the result """
```

```
prompt = f"""You are an excellent bio-image analyst and python programmer.

Your task is to write code in Jupyter Notebook cells.
Always write one piece of code that goes into a Jupyter cell.

{knowledge_base}

Your task:

{task}

Final hints
Make sure there are comments between the code blocks.
"""
```

# Code generation - RAG

Use the RAG-approach to generate code for an image processing workflow.

```
related_code_snippets = vectore_store.search(question)
show("\n\n".join(related_code_snippets))
```

question

'How can I label objects in an image?'

```
context = "\n\n".join(related_code_snippets)

prompt = f"""\nAnswer the question by the very end and consider given code snippets.
Choose at least one of the code-snippets.
Only write Python code that answers the question.

Code snippets
{context}

Question
{question}

print(prompt)
```

# Function calling

Program a function of your choice and call it using English language.

The screenshot shows a web browser window titled "Function calling using ScaDS.AI". The URL in the address bar is [scads.github.io/secai\\_llm\\_training/50\\_function\\_calling/12\\_function\\_calling\\_scadsai\\_llm.html](https://scads.github.io/secai_llm_training/50_function_calling/12_function_calling_scadsai_llm.html). The page content is as follows:

Combining LLMs with Random number generators for data generation

Retrieval Augmented Generation (RAG)

- Text embeddings
- Chat with your PDFs!
- Chat with documentation about HPC systems
- Long context prompting
- Ask about the HPC compendium
- LLM-based Retrieval Augmented Generation

Agents

- [Function calling using ScaDS.AI's LLM service](#)
- PowerPoint Karaoke about Arxiv papers

Links

Imprint

## Function calling using prompts

With this list of tools and a prompt that allows deciding which function to call, a large language model is capable of making the decision which function(s) to call.

First, we use the OpenAI API with their endpoint to see how it is supposed to work:

```
act("Load the image data/membranes.tif and store it as membrane", tools)
```

```
act("Visualize the `membrane` image", tools)
```