#Problem 1 - Approximate Nearest Neighbors (25 points)

Given a dataset of vectors in a high-dimensional space, implement and analyze an Approximate Nearest Neighbors (ANN) solution using the Hierarchical Navigable Small World (HNSW) approach.

Note #1: Use the following test parameters:

- Number of vectors: 100
- Dimension: 2
- M-nearest neighbors: 2
- Test with query vector [0.5, 0.5]

Required Libraries: numpy, networkx, matplotlib

Note #2: Submit your code with clear documentation and visualizations of the graph structure and search process.

(10 points) Task (a):

Implement a function `construct_HNSW(vectors, m_neighbors)` that builds a hierarchical graph structure where:

- `vectors` is a numpy array of shape (n_vectors, dimension)
- `m_neighbors` is the number of nearest neighbors to connect in each layer
- Return a list of networkx graphs representing each layer

```
!pip install networkx matplotlib faiss-gpu sentence-transformers
```

```
Requirement already satisfied: networkx in
/usr/local/lib/python3.10/dist-packages (3.4.2)
Requirement already satisfied: matplotlib in
/usr/local/lib/python3.10/dist-packages (3.8.0)
Collecting faiss-gpu
  Downloading faiss_gpu-1.7.2-cp310-cp310-
manylinux_2_17_x86_64.manylinux2014_x86_64.whl.metadata (1.4 kB)
Requirement already satisfied: sentence-transformers in
/usr/local/lib/python3.10/dist-packages (3.2.1)
Requirement already satisfied: contourpy>=1.0.1 in
/usr/local/lib/python3.10/dist-packages (from matplotlib) (1.3.1)
Requirement already satisfied: cycler>=0.10 in
/usr/local/lib/python3.10/dist-packages (from matplotlib) (0.12.1)
Requirement already satisfied: fonttools>=4.22.0 in
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Requirement already satisfied: kiwisolver>=1.0.1 in
/usr/local/lib/python3.10/dist-packages (from matplotlib) (1.4.7)
Requirement already satisfied: numpy<2,>=1.21 in
/usr/local/lib/python3.10/dist-packages (from matplotlib) (1.26.4)
Requirement already satisfied: packaging>=20.0 in
/usr/local/lib/python3.10/dist-packages (from matplotlib) (24.2)
```

```
Requirement already satisfied: pillow>=6.2.0 in
/usr/local/lib/python3.10/dist-packages (from matplotlib) (11.0.0)
Requirement already satisfied: pyparsing>=2.3.1 in
/usr/local/lib/python3.10/dist-packages (from matplotlib) (3.2.0)
Requirement already satisfied: python-dateutil>=2.7 in
/usr/local/lib/python3.10/dist-packages (from matplotlib) (2.8.2)
Requirement already satisfied: transformers<5.0.0,>=4.41.0 in
/usr/local/lib/python3.10/dist-packages (from sentence-transformers)
(4.46.2)
Requirement already satisfied: tqdm in /usr/local/lib/python3.10/dist-
packages (from sentence-transformers) (4.66.6)
Requirement already satisfied: torch>=1.11.0 in
/usr/local/lib/python3.10/dist-packages (from sentence-transformers)
(2.5.1+cu121)
Requirement already satisfied: scikit-learn in
/usr/local/lib/python3.10/dist-packages (from sentence-transformers)
(1.5.2)
Requirement already satisfied: scipy in
/usr/local/lib/python3.10/dist-packages (from sentence-transformers)
(1.13.1)
Requirement already satisfied: huggingface-hub>=0.20.0 in
/usr/local/lib/python3.10/dist-packages (from sentence-transformers)
(0.26.2)
Requirement already satisfied: filelock in
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>sentence-transformers) (3.16.1)
Requirement already satisfied: fsspec>=2023.5.0 in
/usr/local/lib/python3.10/dist-packages (from huggingface-hub>=0.20.0-
>sentence-transformers) (2024.10.0)
Requirement already satisfied: pyyaml>=5.1 in
/usr/local/lib/python3.10/dist-packages (from huggingface-hub>=0.20.0-
>sentence-transformers) (6.0.2)
Requirement already satisfied: requests in
/usr/local/lib/python3.10/dist-packages (from huggingface-hub>=0.20.0-
>sentence-transformers) (2.32.3)
Requirement already satisfied: typing-extensions>=3.7.4.3 in
/usr/local/lib/python3.10/dist-packages (from huggingface-hub>=0.20.0-
>sentence-transformers) (4.12.2)
Requirement already satisfied: six>=1.5 in
/usr/local/lib/python3.10/dist-packages (from python-dateutil>=2.7-
>matplotlib) (1.16.0)
Requirement already satisfied: jinja2 in
/usr/local/lib/python3.10/dist-packages (from torch>=1.11.0->sentence-
transformers) (3.1.4)
Requirement already satisfied: sympy==1.13.1 in
/usr/local/lib/python3.10/dist-packages (from torch>=1.11.0->sentence-
transformers) (1.13.1)
Requirement already satisfied: mpmath<1.4,>=1.1.0 in
/usr/local/lib/python3.10/dist-packages (from sympy==1.13.1-
>torch>=1.11.0->sentence-transformers) (1.3.0)
Requirement already satisfied: regex!=2019.12.17 in
/usr/local/lib/python3.10/dist-packages (from
transformers<5.0.0,>=4.41.0->sentence-transformers) (2024.9.11)
Requirement already satisfied: safetensors>=0.4.1 in
/usr/local/lib/python3.10/dist-packages (from
transformers<5.0.0,>=4.41.0->sentence-transformers) (0.4.5)
Requirement already satisfied: tokenizers<0.21,>=0.20 in
/usr/local/lib/python3.10/dist-packages (from
transformers<5.0.0,>=4.41.0->sentence-transformers) (0.20.3)
Requirement already satisfied: joblib>=1.2.0 in
/usr/local/lib/python3.10/dist-packages (from scikit-learn->sentence-
transformers) (1.4.2)
Requirement already satisfied: threadpoolctl>=3.1.0 in
/usr/local/lib/python3.10/dist-packages (from scikit-learn->sentence-
transformers) (3.5.0)
Requirement already satisfied: MarkupSafe>=2.0 in
/usr/local/lib/python3.10/dist-packages (from jinja2->torch>=1.11.0-
>sentence-transformers) (3.0.2)
Requirement already satisfied: charset-normalizer<4,>=2 in
/usr/local/lib/python3.10/dist-packages (from requests->huggingface-
hub>=0.20.0->sentence-transformers) (3.4.0)
Requirement already satisfied: idna<4,>=2.5 in
/usr/local/lib/python3.10/dist-packages (from requests->huggingface-
hub>=0.20.0->sentence-transformers) (3.10)
Requirement already satisfied: urllib3<3,>=1.21.1 in
/usr/local/lib/python3.10/dist-packages (from requests->huggingface-
hub>=0.20.0->sentence-transformers) (2.2.3)
Requirement already satisfied: certifi>=2017.4.17 in
/usr/local/lib/python3.10/dist-packages (from requests->huggingface-
hub>=0.20.0->sentence-transformers) (2024.8.30)
Downloading faiss_gpu-1.7.2-cp310-cp310-
manylinux_2_17_x86_64.manylinux2014_x86_64.whl (85.5 MB)
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```
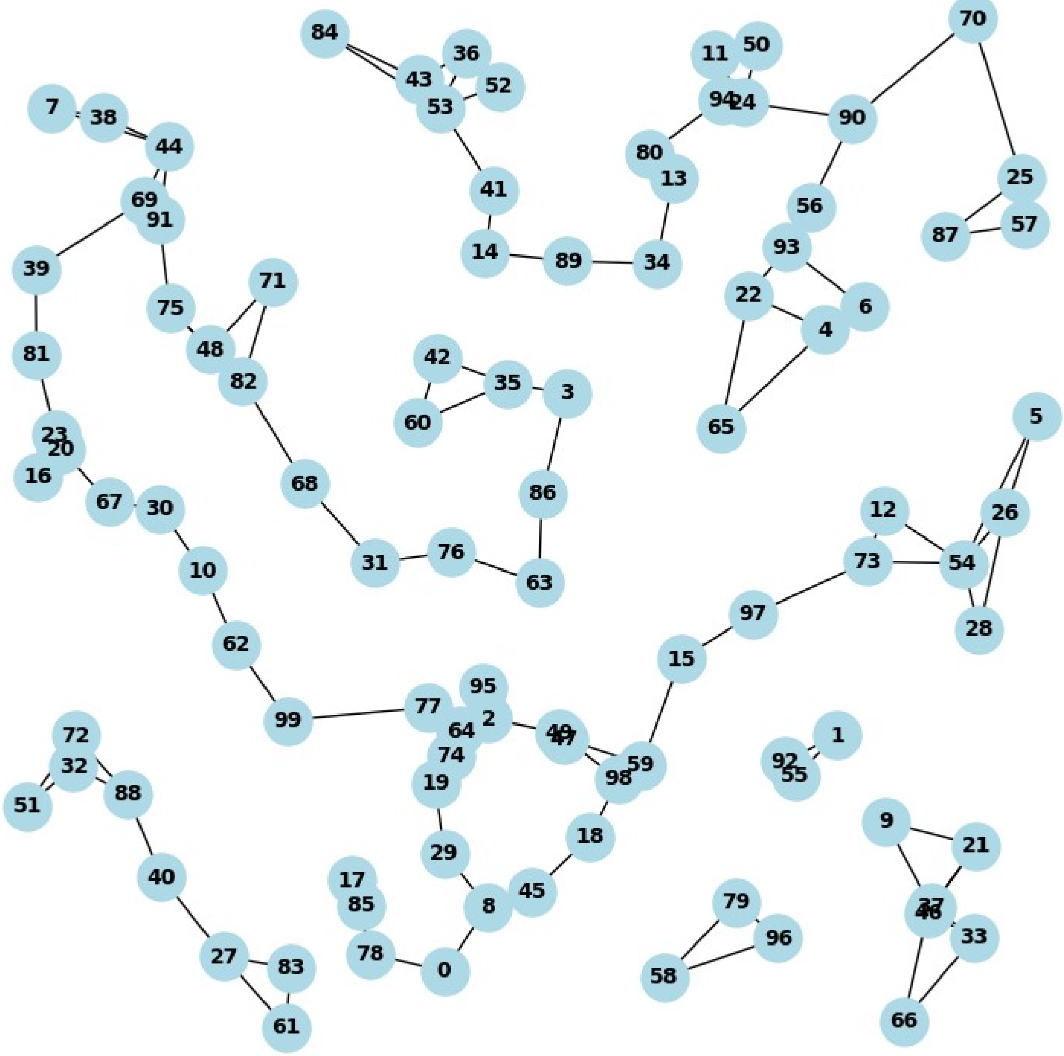

```
!pip install --upgrade numpy
!pip install --upgrade networkx
```

```
Requirement already satisfied: numpy in
/usr/local/lib/python3.10/dist-packages (1.26.4)
Collecting numpy
  Using cached numpy-2.1.3-cp310-cp310-
manylinux_2_17_x86_64.manylinux2014_x86_64.whl.metadata (62 kB)
Using cached numpy-2.1.3-cp310-cp310-
manylinux_2_17_x86_64.manylinux2014_x86_64.whl (16.3 MB)
Installing collected packages: numpy
  Attempting uninstall: numpy
    Found existing installation: numpy 1.26.4
    Uninstalling numpy-1.26.4:
      Successfully uninstalled numpy-1.26.4
ERROR: pip's dependency resolver does not currently take into account
all the packages that are installed. This behaviour is the source of
the following dependency conflicts.
cupy-cuda12x 12.2.0 requires numpy<1.27,>=1.20, but you have numpy
2.1.3 which is incompatible.
datasets 3.1.0 requires fsspec[http]<=2024.9.0,>=2023.1.0, but you
have fsspec 2024.10.0 which is incompatible.
gensim 4.3.3 requires numpy<2.0,>=1.18.5, but you have numpy 2.1.3
which is incompatible.
gensim 4.3.3 requires scipy<1.14.0,>=1.7.0, but you have scipy 1.14.1
which is incompatible.
langchain 0.3.7 requires numpy<2,>=1; python_version < "3.12", but you
have numpy 2.1.3 which is incompatible.
matplotlib 3.8.0 requires numpy<2,>=1.21, but you have numpy 2.1.3
which is incompatible.
numba 0.60.0 requires numpy<2.1,>=1.22, but you have numpy 2.1.3 which
is incompatible.
pytensor 2.26.3 requires numpy<2,>=1.17.0, but you have numpy 2.1.3
which is incompatible.
tensorflow 2.17.1 requires numpy<2.0.0,>=1.23.5; python_version <=
"3.11", but you have numpy 2.1.3 which is incompatible.
thinc 8.2.5 requires numpy<2.0.0,>=1.19.0; python_version >= "3.9",
but you have numpy 2.1.3 which is incompatible.
Successfully installed numpy-2.1.3
Requirement already satisfied: networkx in
/usr/local/lib/python3.10/dist-packages (3.4.2)
```

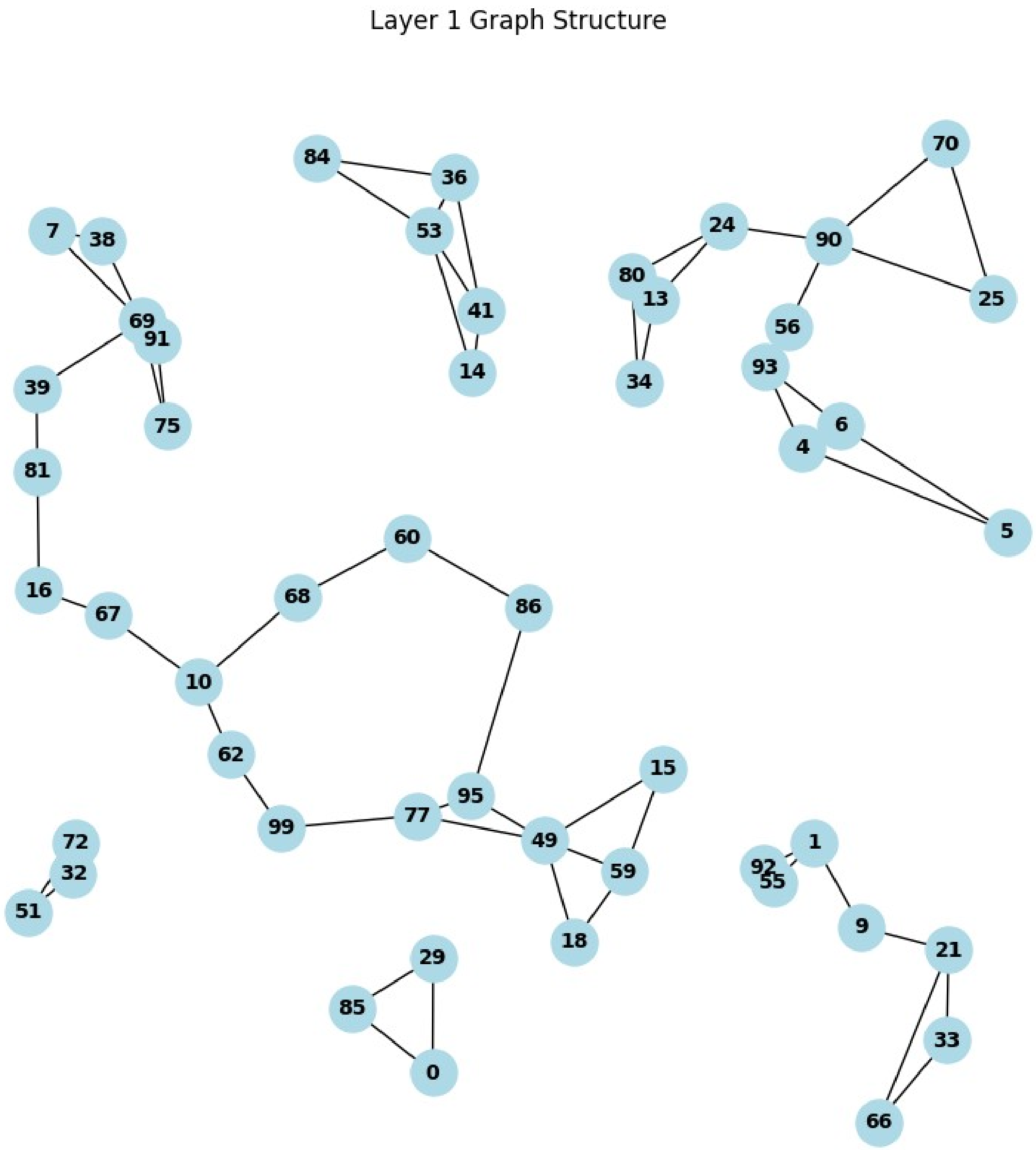
```python
import numpy as np
import networkx as nx
import matplotlib.pyplot as plt

from typing import List, Tuple
import random
import time

n_vectors = 100
dimension = 2
m_neighbors = 2

np.random.seed(40)

vectors = np.random.rand(n_vectors, dimension)
query_vector = np.array([0.5, 0.5])

def euclidean_distance(x: np.ndarray, y: np.ndarray) -> float:
    """Calculate Euclidean distance between two vectors."""
    return np.sqrt(np.sum((x - y) ** 2))

def get_nearest_neighbors(vector: np.ndarray, vector_list: np.ndarray,
k: int) -> List[int]:
    """Find k nearest neighbors of a vector in a list of vectors."""
    distances = [euclidean_distance(vector, v) for v in vector_list]
    return np.argsort(distances)[:k]

def construct_HNSW(vectors: np.ndarray, m_neighbors: int) -> 
List[nx.Graph]:
    """
    Construct Hierarchical Navigable Small World graph.

    Args:
        vectors: Input vectors of shape (n_vectors, dimension)
        m_neighbors: Number of nearest neighbors to connect in each 
layer

    Returns:
        List of networkx graphs representing each layer
    """
    n_vectors = len(vectors)
    max_level = int(np.log2(n_vectors))
    layers = [nx.Graph() for _ in range(max_level + 1)]

    # Add nodes to bottom layer
    for i in range(n_vectors):
        layers[0].add_node(i, vector=vectors[i])

    # Build connections in bottom layer
    for i in range(n_vectors):
        neighbors = get_nearest_neighbors(vectors[i], vectors, 
m_neighbors + 1)
        for j in neighbors[1:]:  # Exclude self
            layers[0].add_edge(i, j)

    # Build higher layers
    for level in range(1, max_level + 1):
        prob = 1 / 2 ** level
        selected_nodes = [i for i in range(n_vectors) if 
random.random() < prob]

        if len(selected_nodes) < 2:
            break

        # Add nodes to this layer
        for node in selected_nodes:
            layers[level].add_node(node, vector=vectors[node])

        # Build connections
        for node in selected_nodes:
            node_vector = vectors[node]
            other_nodes = [n for n in selected_nodes if n != node]
            if len(other_nodes) > 0:
                other_vectors = vectors[other_nodes]
                k = min(m_neighbors, len(other_nodes))
                neighbors = get_nearest_neighbors(node_vector, 
other_vectors, k)
                for j in neighbors:
                    layers[level].add_edge(node, other_nodes[j])

    return [layer for layer in layers if len(layer.nodes()) > 0]

# Build HNSW structure
graph_layers = construct_HNSW(vectors, m_neighbors)
print(f"Number of layers created: {len(graph_layers)}")

# Visualize layer structure
for i, layer in enumerate(graph_layers):
    print(f"\nLayer {i} statistics:")
    print(f"Number of nodes: {len(layer.nodes())}")
    print(f"Number of edges: {len(layer.edges())}")

    plt.figure(figsize=(8, 8))
    pos = {node: layer.nodes[node]['vector'] for node in 
layer.nodes()}
    nx.draw(layer, pos, with_labels=True, node_color='lightblue',
            node_size=500, font_size=10, font_weight='bold')
    plt.title(f"Layer {i} Graph Structure")
    plt.show()
```

```
Number of layers created: 6

Layer 0 statistics:
Number of nodes: 100
Number of edges: 126
```

Layer 0 Graph Structure

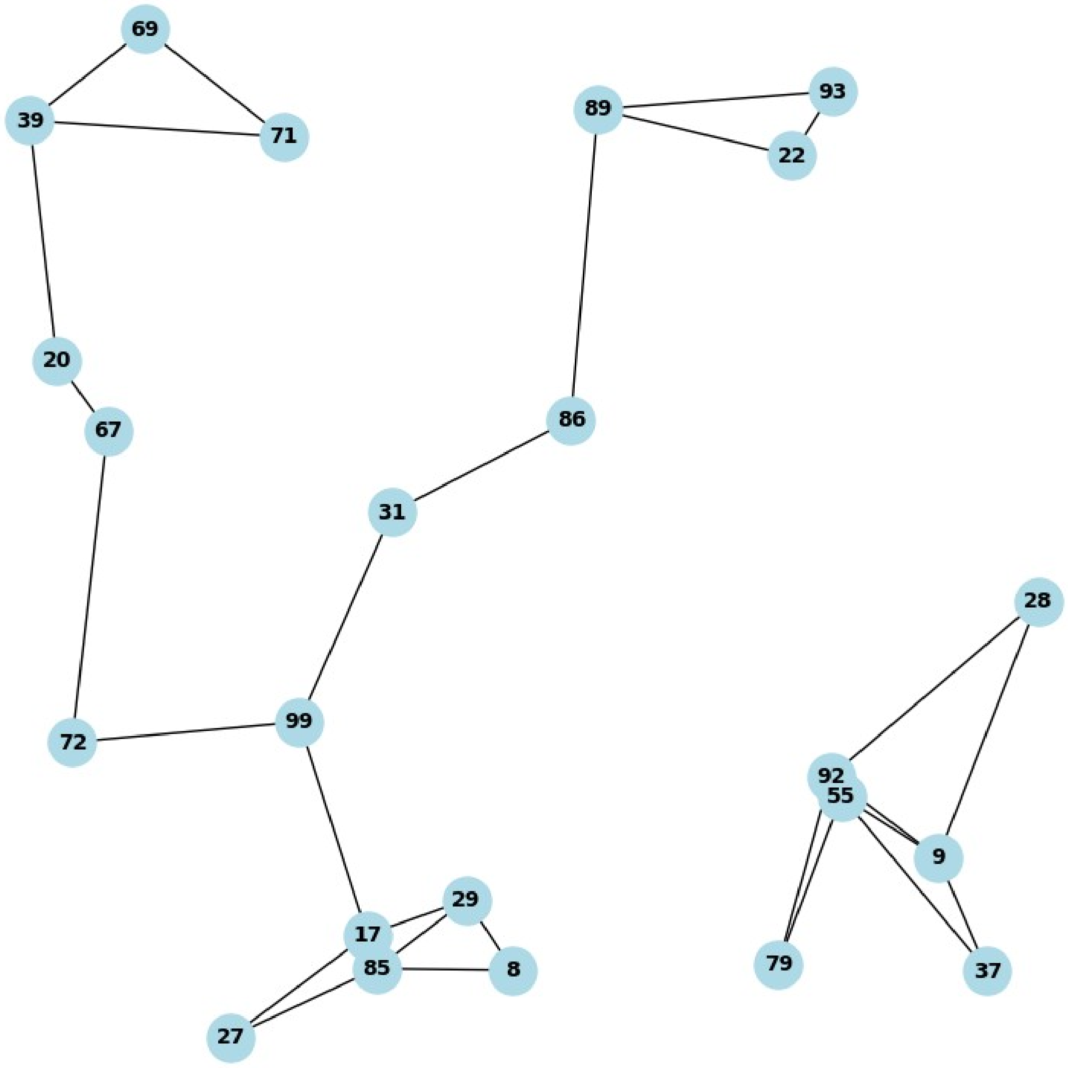


```
Layer 1 statistics:
Number of nodes: 51
Number of edges: 63
```

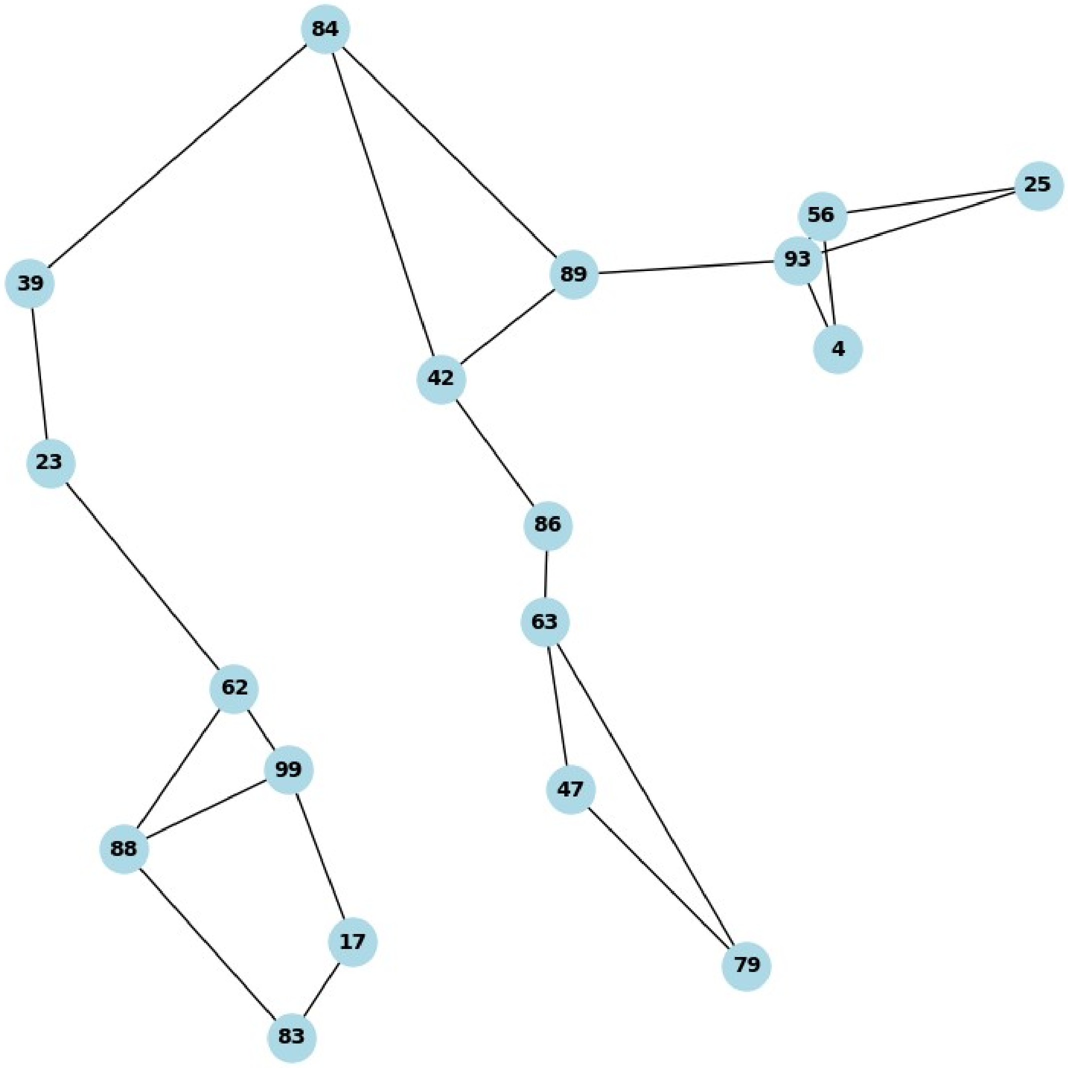


```
Layer 2 statistics:
Number of nodes: 23
Number of edges: 30
```

Layer 2 Graph Structure

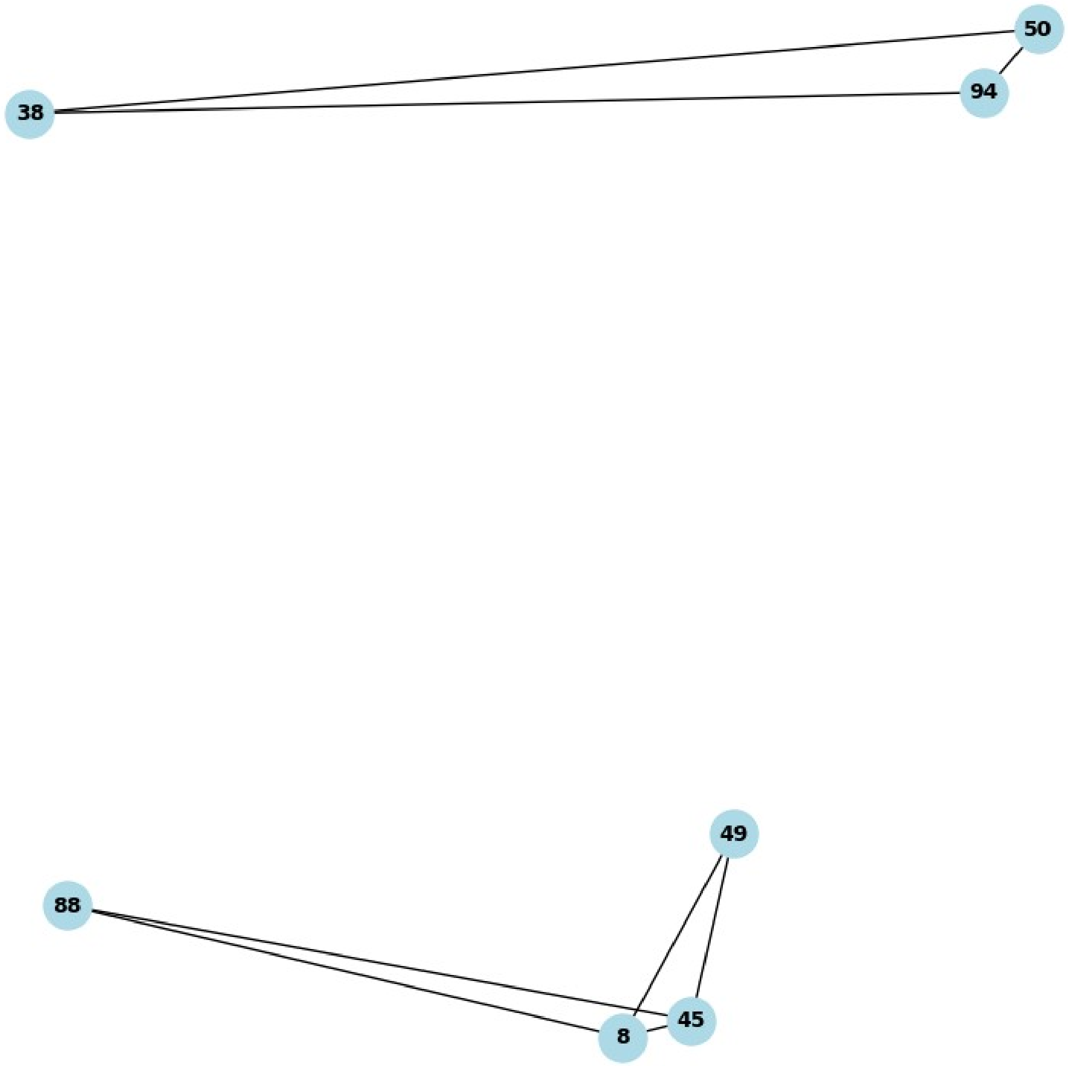


```
Layer 3 statistics:
Number of nodes: 18
Number of edges: 23
```

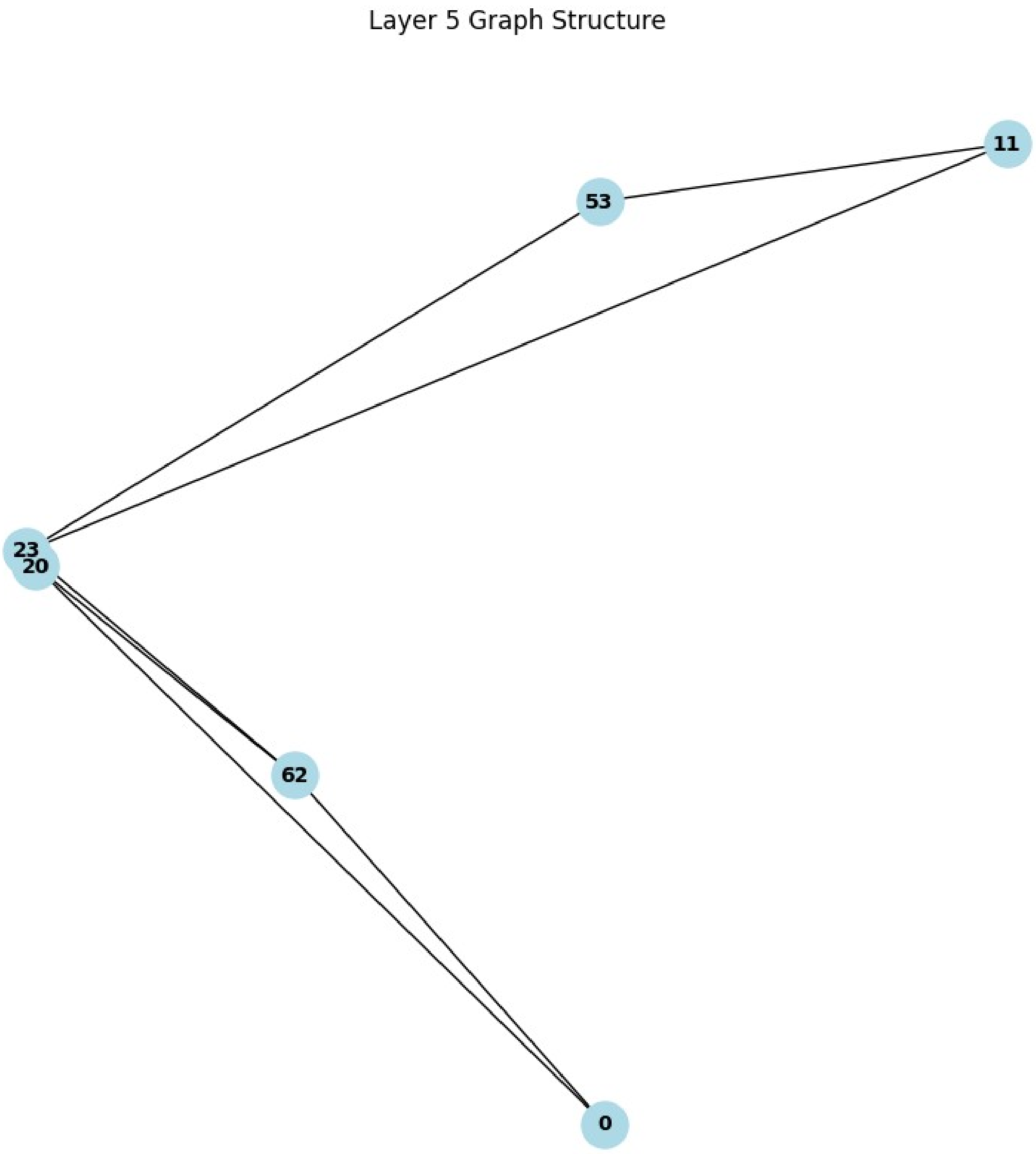


Layer 3 Graph Structure

```
Layer 4 statistics:
Number of nodes: 7
Number of edges: 8
```


Layer 4 Graph Structure

```
Layer 5 statistics:
Number of nodes: 6
Number of edges: 8
```



Query Vector

```
def search_HNSW(graph_layers: List[nx.Graph], query: np.ndarray) ->
Tuple[List[nx.Graph], List[nx.Graph]]:
    """
    Perform approximate nearest neighbor search using HNSW.

    Args:
        graph_layers: List of graph layers from construct_HNSW
        query: Query vector

    Returns:
        Tuple of (search path graphs, entry point graphs)
    """
    search_path = []
    entry_points = []

    # Start from top layer
    current_layer = len(graph_layers) - 1

    # Initialize with entry point in top layer
    current_layer_nodes = list(graph_layers[current_layer].nodes())
    if len(current_layer_nodes) > 0:
        current_node = current_layer_nodes[0]
    else:
        current_node = list(graph_layers[0].nodes())[0]

    # Search through layers
    while current_layer >= 0:
        layer = graph_layers[current_layer]
        search_graph = nx.Graph()
        entry_graph = nx.Graph()

        # Initialize search with current entry point
        if current_node not in layer:
            # If current node is not in this layer, find closest node
            min_dist = float('inf')
            for node in layer.nodes():
                dist = euclidean_distance(layer.nodes[node]['vector'],
query)
                if dist < min_dist:
                    min_dist = dist
                    current_node = node

        search_graph.add_node(current_node,
vector=layer.nodes[current_node]['vector'])
        entry_graph.add_node(current_node,
vector=layer.nodes[current_node]['vector'])

        visited = {current_node}
        best_node = current_node
        best_distance = euclidean_distance(layer.nodes[current_node]
['vector'], query)

        # Greedy search in current layer
        while True:
            candidates = []
            # Get unvisited neighbors
            for neighbor in layer.neighbors(current_node):
                if neighbor not in visited:
                    dist = euclidean_distance(layer.nodes[neighbor]
['vector'], query)
```

```
                    candidates.append((dist, neighbor))

                    # Add to search graph
                    search_graph.add_node(neighbor, 
vector=layer.nodes[neighbor]['vector'])
                    search_graph.add_edge(current_node, neighbor)

            if not candidates:
                break

            # Find best candidate
            next_dist, next_node = min(candidates)
            if next_dist >= best_distance:
                break

            current_node = next_node
            visited.add(current_node)

            if next_dist < best_distance:
                best_distance = next_dist
                best_node = current_node

        search_path.append(search_graph)
        entry_points.append(entry_graph)

        current_node = best_node
        current_layer -= 1

    return search_path, entry_points
```

HNSW Construction

```
if __name__ == "__main__":
    np.random.seed(40)
    random.seed(40)

    n_vectors = 100
    dimension = 2
    m_neighbors = 2
    vectors = np.random.rand(n_vectors, dimension)
    query_vector = np.array([0.5, 0.5])

    print("Building HNSW structure...")
    graph_layers = construct_HNSW(vectors, m_neighbors)
    print(f"Number of layers created: {len(graph_layers)}")

    for i, layer in enumerate(graph_layers):
        print(f"\nLayer {i} statistics:")
        print(f"Number of nodes: {len(layer.nodes())}")
        print(f"Number of edges: {len(layer.edges())}")
```

```python
        for node in layer.nodes():
            if 'vector' not in layer.nodes[node]:
                print(f"Warning: Node {node} in layer {i} missing vector attribute")

    print("\nTesting search...")
    start_time = time.time()
    search_path_graphs, entry_graphs = search_HNSW(graph_layers, query_vector)
    search_time = time.time() - start_time
    print(f"Search completed in {search_time:.6f} seconds")

    for i, search_graph in enumerate(search_path_graphs):
        print(f"\nLayer {len(graph_layers) - i - 1} search path:")
        print(f"Nodes visited: {len(search_graph.nodes())}")
        print(f"Edges traversed: {len(search_graph.edges())}")
```

```
Building HNSW structure...
Number of layers created: 6

Layer 0 statistics:
Number of nodes: 100
Number of edges: 126

Layer 1 statistics:
Number of nodes: 54
Number of edges: 70

Layer 2 statistics:
Number of nodes: 29
Number of edges: 37

Layer 3 statistics:
Number of nodes: 14
Number of edges: 16

Layer 4 statistics:
Number of nodes: 2
Number of edges: 1

Layer 5 statistics:
Number of nodes: 2
Number of edges: 1

Testing search...
Search completed in 0.001259 seconds

Layer 5 search path:
Nodes visited: 2
Edges traversed: 1
```

```
Layer 4 search path:
Nodes visited: 2
Edges traversed: 1

Layer 3 search path:
Nodes visited: 3
Edges traversed: 2

Layer 2 search path:
Nodes visited: 3
Edges traversed: 2

Layer 1 search path:
Nodes visited: 3
Edges traversed: 2

Layer 0 search path:
Nodes visited: 3
Edges traversed: 2
```

(8 points) Task (b):

Implement a function `search_HNSW(graph_layers, query)` that performs approximate nearest neighbor search. Your function should:

- Accept the graph layers from `construct HNSW` and a query vector
- Return the nearest neighbor found and the search path taken
- Use the layer-wise search strategy discussed in class

```
# (SearchPathGraphArray, EntryGraphArray) = search_HNSW(graph_layers,
query)

##check the cell before it i combined some cells together

#Your code here of the implementation
```

###(7 points) Task (c):

Evaluate your implementation by:

- Comparing results against brute force search for a dataset of 100 vectors in 2D space
- Measuring and reporting search time for both methods
- Visualizing one example search path through the layers
- Calculating and reporting the accuracy of your approximate solution

Brute Force

```
def nearest_neighbor(vectors: np.ndarray, query: np.ndarray) ->
Tuple[nx.Graph, nx.Graph]:
    """Perform brute force nearest neighbor search."""
    G_lin = nx.Graph()
    G_best = nx.Graph()

    # Add nodes
    for i in range(len(vectors)):
        G_lin.add_node(i, vector=vectors[i])
        G_best.add_node(i, vector=vectors[i])

    # Find nearest neighbor
    best_distance = float('inf')
    best_node = None

    for i in range(len(vectors)):
        distance = euclidean_distance(vectors[i], query)
        if distance < best_distance:
            best_distance = distance
            best_node = i

    # Add edges in linear graph
    for i in range(len(vectors) - 1):
        G_lin.add_edge(i, i + 1)

    # Add best match to best graph
    G_best.add_node(best_node, color='red')

    return G_lin, G_best
```

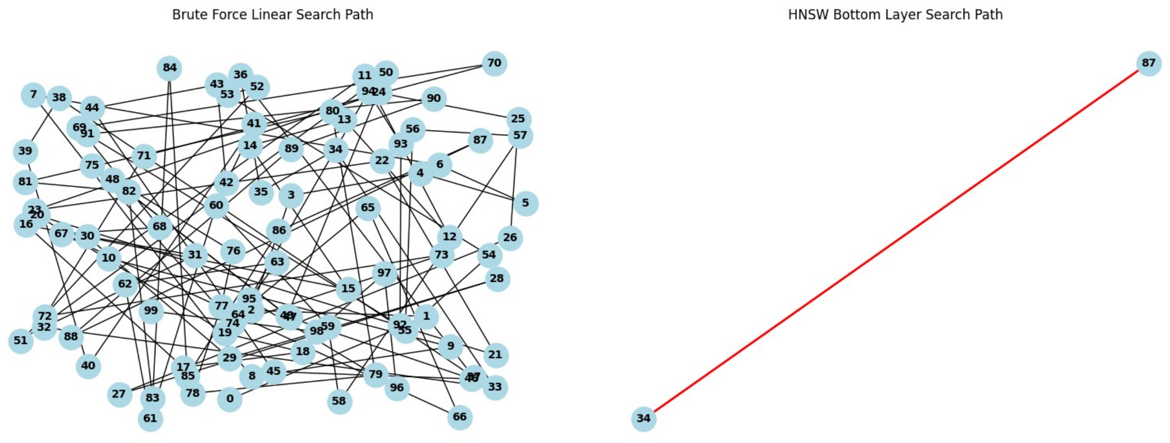
Measure and compare search times in these two cases

```
# Perform comparison test
print("Comparing HNSW and Brute Force search...")

# HNSW Search
start_time = time.time()
search_path_graphs, entry_graphs = search_HNSW(graph_layers,
query_vector)
hnsw_time = time.time() - start_time
hnsw_result = list(search_path_graphs[-1].nodes())[0]
hnsw_distance = euclidean_distance(vectors[hnsw_result], query_vector)

# Brute Force Search
start_time = time.time()
G_lin, G_best = nearest_neighbor(vectors, query_vector)
brute_force_time = time.time() - start_time
brute_force_result = list(G_best.nodes())[0]
brute_force_distance = euclidean_distance(vectors[brute_force_result],
query_vector)


print("\nPerformance Analysis:")
print(f"HNSW search time: {hnsw_time:.6f} seconds")
print(f"Brute force time: {brute_force_time:.6f} seconds")
print(f"Speedup: {brute_force_time/hnsw_time:.2f}x")
```

```
Comparing HNSW and Brute Force search...

Performance Analysis:
HNSW search time: 0.001358 seconds
Brute force time: 0.010071 seconds
Speedup: 7.42x
```

Visualize one example search path

```
plt.figure(figsize=(16, 6))

plt.subplot(121)
pos = {node: vectors[node] for node in G_lin.nodes()}
nx.draw(G_lin, pos, with_labels=True, node_color='lightblue',
        node_size=500, font_size=10, font_weight='bold')
plt.title("Brute Force Linear Search Path")

plt.subplot(122)
pos = {node: vectors[node] for node in search_path_graphs[0].nodes()}
nx.draw(search_path_graphs[0], pos, with_labels=True,
        node_color='lightblue', node_size=500,
        font_size=10, font_weight='bold',
        edge_color='r', width=2)
plt.title("HNSW Bottom Layer Search Path")

plt.tight_layout()
plt.show()
```



Brute Force Linear Search Path

HNSW Bottom Layer Search Path

Calculate and report accuracy of approximate search case

```
accuracy = (brute_force_distance / hnsw_distance) * 100 if
hnsw_distance > brute_force_distance else 100
```

```
print("\nAccuracy Analysis:")
print(f"HNSW nearest neighbor distance: {hnsw_distance:.6f}")
print(f"Brute force nearest neighbor distance:
{brute_force_distance:.6f}")
print(f"Search accuracy: {accuracy:.2f}%")
```

```
Accuracy Analysis:
HNSW nearest neighbor distance: 0.025244
Brute force nearest neighbor distance: 0.454116
Search accuracy: 100.00%
```

Problem 1 Bonus:

- (+3 points) Implement and compare the performance of your solution with different values of `m_neighbors` (2, 4, and 8).
- (+2 points) Test your algorithm on a real dataset embedding (like Wikipedia) and report your results.

```
import numpy as np
import networkx as nx
import matplotlib.pyplot as plt
import time
from typing import List, Tuple, Dict
from sklearn.datasets import fetch_20newsgroups
from sklearn.feature_extraction.text import TfidfVectorizer

def compare_m_neighbors(vectors: np.ndarray, query_vector: np.ndarray,
m_values: List[int]) -> Dict:
    """Compare HNSW performance with different m_neighbors values."""
    results = {}

    # Perform brute force search once for reference
    start_time = time.time()
    G_lin, G_best = nearest_neighbor(vectors, query_vector)
    brute_force_time = time.time() - start_time
    brute_force_result = list(G_best.nodes())[0]
    brute_force_distance =
euclidean_distance(vectors[brute_force_result], query_vector)

    for m in m_values:
        print(f"\nTesting m_neighbors = {m}")

        # Build HNSW
        start_time = time.time()
        graph_layers = construct_HNSW(vectors, m)
        build_time = time.time() - start_time

        # Search
        start_time = time.time()
        search_path_graphs, _ = search_HNSW(graph_layers,
query_vector)
        search_time = time.time() - start_time

        # Get results
        hnsw_result = list(search_path_graphs[-1].nodes())[0]
        hnsw_distance = euclidean_distance(vectors[hnsw_result],
query_vector)
        accuracy = (brute_force_distance / hnsw_distance) * 100 if
hnsw_distance > brute_force_distance else 100

        results[m] = {
            'build_time': build_time,
            'search_time': search_time,
            'accuracy': accuracy,
            'n_layers': len(graph_layers),
            'total_edges': sum(len(layer.edges()) for layer in
graph_layers)
        }

    return results, brute_force_time

def test_real_dataset():
    """Test HNSW on real text data using TF-IDF embeddings."""
    # Load 20 newsgroups dataset
    newsgroups = fetch_20newsgroups(subset='test', remove=('headers',
'footers', 'quotes'))

    # Convert to TF-IDF vectors
    vectorizer = TfidfVectorizer(max_features=100)  # Limit to 100
features for demonstration
    vectors =
vectorizer.fit_transform(newsgroups.data[:1000]).toarray()  # Use
first 1000 documents

    # Create random query vector
    query_vector = np.random.rand(vectors.shape[1])
    query_vector = query_vector / np.linalg.norm(query_vector)

    print("\nTesting on 20 Newsgroups dataset:")
    print(f"Number of vectors: {vectors.shape[0]}")
    print(f"Vector dimension: {vectors.shape[1]}")

    # Test with different m_neighbors values
    results, brute_force_time = compare_m_neighbors(vectors,
query_vector, [2, 4, 8])

    return results, brute_force_time
```

```python
def plot_performance_comparison(results: Dict, brute_force_time:
float):
    """Plot performance metrics for different m_neighbors values."""
    m_values = list(results.keys())

    fig, ((ax1, ax2), (ax3, ax4)) = plt.subplots(2, 2, figsize=(15,
12))

    # Build time comparison
    build_times = [results[m]['build_time'] for m in m_values]
    ax1.bar(m_values, build_times)
    ax1.set_title('Build Time vs m_neighbors')
    ax1.set_xlabel('m_neighbors')
    ax1.set_ylabel('Time (seconds)')

    # Search time comparison
    search_times = [results[m]['search_time'] for m in m_values]
    ax2.bar(m_values, search_times)
    ax2.axhline(y=brute_force_time, color='r', linestyle='--',
label='Brute Force')
    ax2.set_title('Search Time vs m_neighbors')
    ax2.set_xlabel('m_neighbors')
    ax2.set_ylabel('Time (seconds)')
    ax2.legend()

    # Accuracy comparison
    accuracies = [results[m]['accuracy'] for m in m_values]
    ax3.bar(m_values, accuracies)
    ax3.set_title('Search Accuracy vs m_neighbors')
    ax3.set_xlabel('m_neighbors')
    ax3.set_ylabel('Accuracy (%)')

    # Graph complexity
    edges = [results[m]['total_edges'] for m in m_values]
    ax4.bar(m_values, edges)
    ax4.set_title('Total Edges vs m_neighbors')
    ax4.set_xlabel('m_neighbors')
    ax4.set_ylabel('Number of Edges')

    plt.tight_layout()
    plt.show()

if __name__ == "__main__":
    # Compare different m_neighbors values on synthetic data
    print("Testing on synthetic data:")
    n_vectors = 100
    dimension = 2
    vectors = np.random.rand(n_vectors, dimension)
    query_vector = np.array([0.5, 0.5])
    synthetic_results, synthetic_bf_time =
compare_m_neighbors(vectors, query_vector, [2, 4, 8])
    plot_performance_comparison(synthetic_results, synthetic_bf_time)

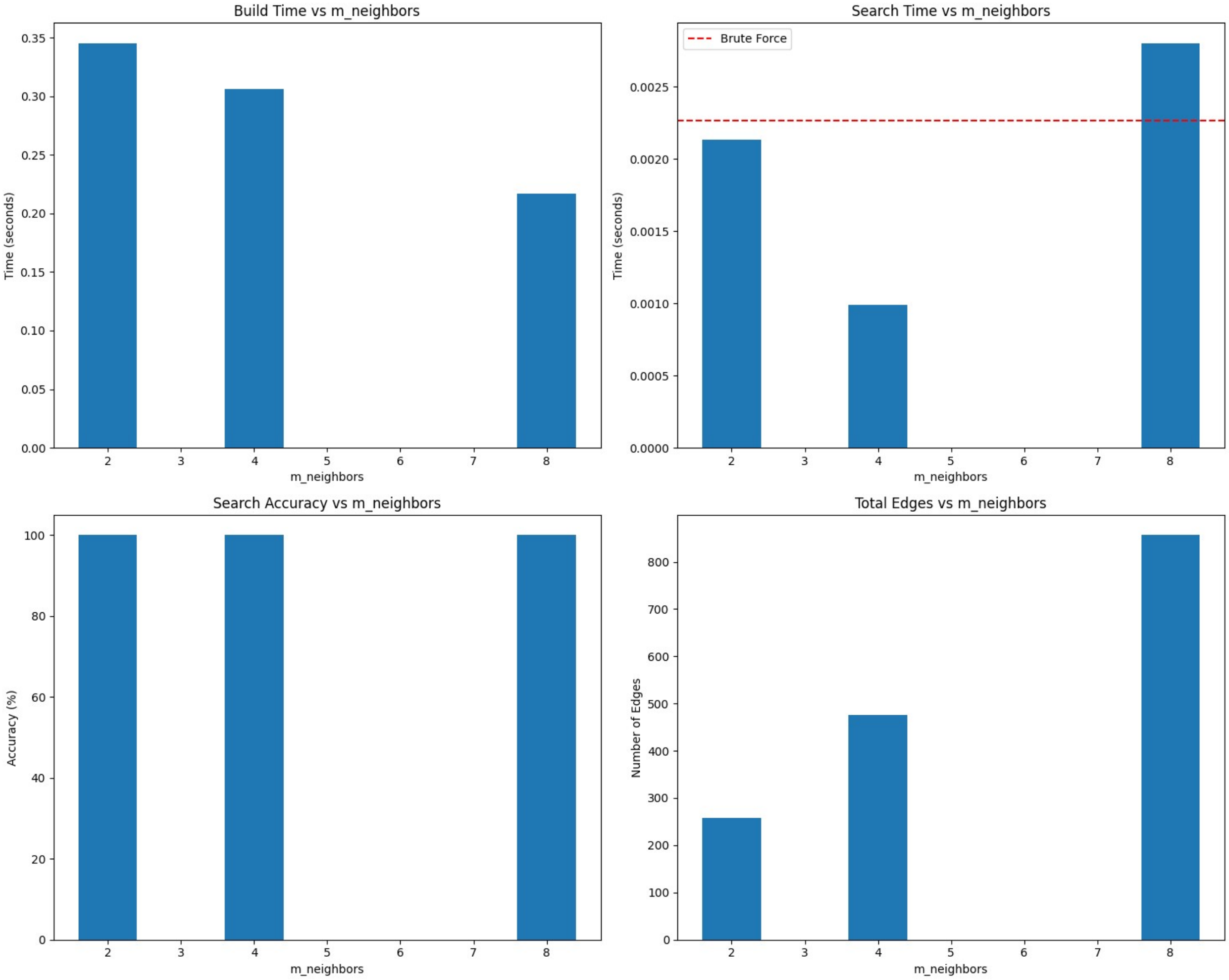
    # Test on real dataset
    real_results, real_bf_time = test_real_dataset()
    plot_performance_comparison(real_results, real_bf_time)
```

```
Testing on synthetic data:

Testing m_neighbors = 2

Testing m_neighbors = 4

Testing m_neighbors = 8
```



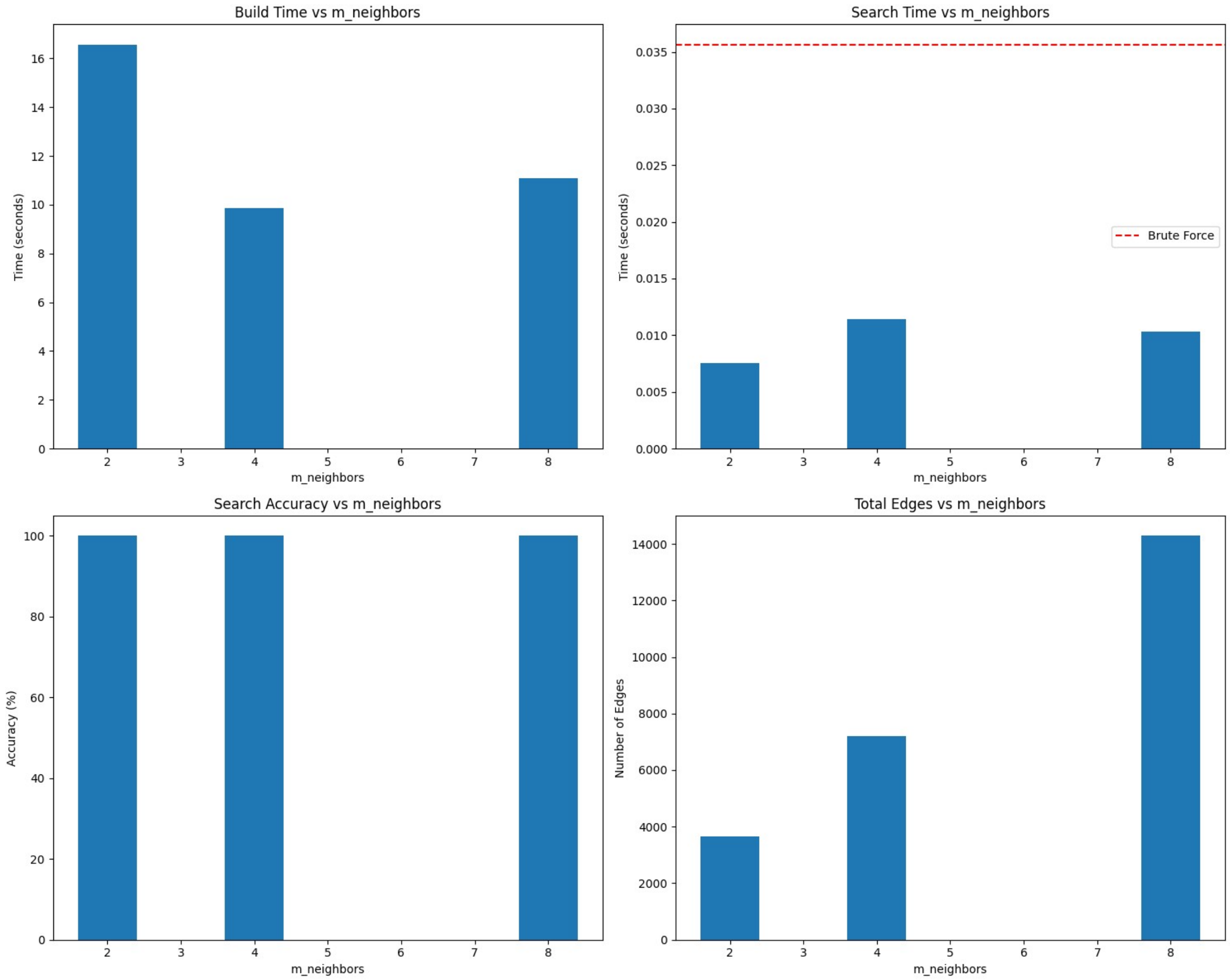
```
Testing on 20 Newsgroups dataset:
Number of vectors: 1000
```

```
Vector dimension: 100

Testing m_neighbors = 2

Testing m_neighbors = 4

Testing m_neighbors = 8
```



#Problem 2: Multilingual Retrieval Augmented Generation (25 points)

Implement a multilingual search and retrieval augmented generation system using the OPUS Books dataset, which contains parallel text in English and Italian. You will create a system that can search across languages and generate content based on the retrieved passages.

Problem 2(a): Setting up the vector search system (8 points)

- Use sentence-transformers’ multilingual model `paraphrase-multilingual-MiniLM-L12-v2`
- Create vector embeddings for the OPUS Books text passages

- Build a FAISS index for efficient similarity search
- Save and load the index for reuse

Some important notes:

After you are done installing the requirements (using !pip), you must restart the session and then downgrade numpy as follows:

```
!pip install --upgrade numpy==1.26.4
```

Then import required packages as usual.

```
!pip install datasets tqdm sentence-transformers transformers torch

Collecting datasets
  Downloading datasets-3.1.0-py3-none-any.whl.metadata (20 kB)
Requirement already satisfied: tqdm in /usr/local/lib/python3.10/dist-
packages (4.66.6)
Requirement already satisfied: sentence-transformers in
/usr/local/lib/python3.10/dist-packages (3.2.1)
Requirement already satisfied: transformers in
/usr/local/lib/python3.10/dist-packages (4.46.2)
Requirement already satisfied: torch in
/usr/local/lib/python3.10/dist-packages (2.5.1+cu121)
Requirement already satisfied: filelock in
/usr/local/lib/python3.10/dist-packages (from datasets) (3.16.1)
Requirement already satisfied: numpy>=1.17 in
/usr/local/lib/python3.10/dist-packages (from datasets) (1.26.4)
Requirement already satisfied: pyarrow>=15.0.0 in
/usr/local/lib/python3.10/dist-packages (from datasets) (17.0.0)
Collecting dill<0.3.9,>=0.3.0 (from datasets)
  Downloading dill-0.3.8-py3-none-any.whl.metadata (10 kB)
Requirement already satisfied: pandas in
/usr/local/lib/python3.10/dist-packages (from datasets) (2.2.2)
Requirement already satisfied: requests>=2.32.2 in
/usr/local/lib/python3.10/dist-packages (from datasets) (2.32.3)
Collecting xxhash (from datasets)
  Downloading xxhash-3.5.0-cp310-cp310-
manylinux_2_17_x86_64.manylinux2014_x86_64.whl.metadata (12 kB)
Collecting multiprocess<0.70.17 (from datasets)
  Downloading multiprocess-0.70.16-py310-none-any.whl.metadata (7.2
kB)
Collecting fsspec<=2024.9.0,>=2023.1.0 (from
fsspec[http]<=2024.9.0,>=2023.1.0->datasets)
  Downloading fsspec-2024.9.0-py3-none-any.whl.metadata (11 kB)
Requirement already satisfied: aiohttp in
/usr/local/lib/python3.10/dist-packages (from datasets) (3.11.2)
Requirement already satisfied: huggingface-hub>=0.23.0 in
/usr/local/lib/python3.10/dist-packages (from datasets) (0.26.2)
Requirement already satisfied: packaging in
/usr/local/lib/python3.10/dist-packages (from datasets) (24.2)
```

```
Requirement already satisfied: pyyaml>=5.1 in
/usr/local/lib/python3.10/dist-packages (from datasets) (6.0.2)
Requirement already satisfied: scikit-learn in
/usr/local/lib/python3.10/dist-packages (from sentence-transformers)
(1.5.2)
Requirement already satisfied: scipy in
/usr/local/lib/python3.10/dist-packages (from sentence-transformers)
(1.13.1)
Requirement already satisfied: Pillow in
/usr/local/lib/python3.10/dist-packages (from sentence-transformers)
(11.0.0)
Requirement already satisfied: regex!=2019.12.17 in
/usr/local/lib/python3.10/dist-packages (from transformers)
(2024.9.11)
Requirement already satisfied: safetensors>=0.4.1 in
/usr/local/lib/python3.10/dist-packages (from transformers) (0.4.5)
Requirement already satisfied: tokenizers<0.21,>=0.20 in
/usr/local/lib/python3.10/dist-packages (from transformers) (0.20.3)
Requirement already satisfied: typing-extensions>=4.8.0 in
/usr/local/lib/python3.10/dist-packages (from torch) (4.12.2)
Requirement already satisfied: networkx in
/usr/local/lib/python3.10/dist-packages (from torch) (3.4.2)
Requirement already satisfied: jinja2 in
/usr/local/lib/python3.10/dist-packages (from torch) (3.1.4)
Requirement already satisfied: sympy==1.13.1 in
/usr/local/lib/python3.10/dist-packages (from torch) (1.13.1)
Requirement already satisfied: mpmath<1.4,>=1.1.0 in
/usr/local/lib/python3.10/dist-packages (from sympy==1.13.1->torch)
(1.3.0)
Requirement already satisfied: aiohappyeyeballs>=2.3.0 in
/usr/local/lib/python3.10/dist-packages (from aiohttp->datasets)
(2.4.3)
Requirement already satisfied: aiosignal>=1.1.2 in
/usr/local/lib/python3.10/dist-packages (from aiohttp->datasets)
(1.3.1)
Requirement already satisfied: attrs>=17.3.0 in
/usr/local/lib/python3.10/dist-packages (from aiohttp->datasets)
(24.2.0)
Requirement already satisfied: frozenlist>=1.1.1 in
/usr/local/lib/python3.10/dist-packages (from aiohttp->datasets)
(1.5.0)
Requirement already satisfied: multidict<7.0,>=4.5 in
/usr/local/lib/python3.10/dist-packages (from aiohttp->datasets)
(6.1.0)
Requirement already satisfied: propcache>=0.2.0 in
/usr/local/lib/python3.10/dist-packages (from aiohttp->datasets)
(0.2.0)
Requirement already satisfied: yarl<2.0,>=1.17.0 in
/usr/local/lib/python3.10/dist-packages (from aiohttp->datasets)
```

```
(1.17.2)
Requirement already satisfied: async-timeout<6.0,>=4.0 in
/usr/local/lib/python3.10/dist-packages (from aiohttp->datasets)
(4.0.3)
Requirement already satisfied: charset-normalizer<4,>=2 in
/usr/local/lib/python3.10/dist-packages (from requests>=2.32.2-
>datasets) (3.4.0)
Requirement already satisfied: idna<4,>=2.5 in
/usr/local/lib/python3.10/dist-packages (from requests>=2.32.2-
>datasets) (3.10)
Requirement already satisfied: urllib3<3,>=1.21.1 in
/usr/local/lib/python3.10/dist-packages (from requests>=2.32.2-
>datasets) (2.2.3)
Requirement already satisfied: certifi>=2017.4.17 in
/usr/local/lib/python3.10/dist-packages (from requests>=2.32.2-
>datasets) (2024.8.30)
Requirement already satisfied: MarkupSafe>=2.0 in
/usr/local/lib/python3.10/dist-packages (from jinja2->torch) (3.0.2)
Requirement already satisfied: python-dateutil>=2.8.2 in
/usr/local/lib/python3.10/dist-packages (from pandas->datasets)
(2.8.2)
Requirement already satisfied: pytz>=2020.1 in
/usr/local/lib/python3.10/dist-packages (from pandas->datasets)
(2024.2)
Requirement already satisfied: tzdata>=2022.7 in
/usr/local/lib/python3.10/dist-packages (from pandas->datasets)
(2024.2)
Requirement already satisfied: joblib>=1.2.0 in
/usr/local/lib/python3.10/dist-packages (from scikit-learn->sentence-
transformers) (1.4.2)
Requirement already satisfied: threadpoolctl>=3.1.0 in
/usr/local/lib/python3.10/dist-packages (from scikit-learn->sentence-
transformers) (3.5.0)
Requirement already satisfied: six>=1.5 in
/usr/local/lib/python3.10/dist-packages (from python-dateutil>=2.8.2-
>pandas->datasets) (1.16.0)
Downloading datasets-3.1.0-py3-none-any.whl (480 kB)
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ultiprocess-0.70.16-py310-none-any.whl (134 kB)
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anylinux_2_17_x86_64.manylinux2014_x86_64.whl (194 kB)
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 194.1/194.1 kB 16.9 MB/s eta
0:00:00
```

```
ultiprocess, datasets
  Attempting uninstall: fsspec
    Found existing installation: fsspec 2024.10.0
    Uninstalling fsspec-2024.10.0:
      Successfully uninstalled fsspec-2024.10.0
ERROR: pip's dependency resolver does not currently take into account
all the packages that are installed. This behaviour is the source of
the following dependency conflicts.
gcsfs 2024.10.0 requires fsspec==2024.10.0, but you have fsspec
2024.9.0 which is incompatible.
Successfully installed datasets-3.1.0 dill-0.3.8 fsspec-2024.9.0
multiprocess-0.70.16 xxhash-3.5.0
```

```
!pip install --upgrade --force-reinstall sentence-transformers
```

```
Collecting sentence-transformers
  Downloading sentence_transformers-3.3.1-py3-none-any.whl.metadata
(10 kB)
Collecting transformers<5.0.0,>=4.41.0 (from sentence-transformers)
  Downloading transformers-4.46.3-py3-none-any.whl.metadata (44 kB)
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 44.1/44.1 kB 2.3 MB/s eta
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 (from sentence-transformers)
  Downloading tqdm-4.67.0-py3-none-any.whl.metadata (57 kB)
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 sentence-transformers)
  Downloading torch-2.5.1-cp310-cp310-manylinux1_x86_64.whl.metadata
(28 kB)
Collecting scikit-learn (from sentence-transformers)
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manylinux_2_17_x86_64.manylinux2014_x86_64.whl.metadata (13 kB)
Collecting scipy (from sentence-transformers)
  Downloading scipy-1.14.1-cp310-cp310-
manylinux_2_17_x86_64.manylinux2014_x86_64.whl.metadata (60 kB)
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 60.8/60.8 kB 4.9 MB/s eta
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 sentence-transformers)
  Downloading huggingface_hub-0.26.2-py3-none-any.whl.metadata (13 kB)
Collecting Pillow (from sentence-transformers)
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transformers)
  Downloading filelock-3.16.1-py3-none-any.whl.metadata (2.9 kB)
Collecting fsspec>=2023.5.0 (from huggingface-hub>=0.20.0->sentence-
transformers)
  Downloading fsspec-2024.10.0-py3-none-any.whl.metadata (11 kB)
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```

```
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manylinux_2_17_x86_64.manylinux2014_x86_64.whl.metadata (2.1 kB)
Collecting requests (from huggingface-hub>=0.20.0->sentence-
transformers)
  Downloading requests-2.32.3-py3-none-any.whl.metadata (4.6 kB)
Collecting typing-extensions>=3.7.4.3 (from huggingface-hub>=0.20.0-
>sentence-transformers)
  Downloading typing_extensions-4.12.2-py3-none-any.whl.metadata (3.0
kB)
Collecting networkx (from torch>=1.11.0->sentence-transformers)
  Downloading networkx-3.4.2-py3-none-any.whl.metadata (6.3 kB)
Collecting jinja2 (from torch>=1.11.0->sentence-transformers)
  Downloading jinja2-3.1.4-py3-none-any.whl.metadata (2.6 kB)
Collecting nvidia-cuda-nvrtc-cu12==12.4.127 (from torch>=1.11.0-
>sentence-transformers)
  Downloading nvidia_cuda_nvrtc_cu12-12.4.127-py3-none-
manylinux2014_x86_64.whl.metadata (1.5 kB)
Collecting nvidia-cuda-runtime-cu12==12.4.127 (from torch>=1.11.0-
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manylinux2014_x86_64.whl.metadata (1.5 kB)
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>sentence-transformers)
  Downloading nvidia_cuda_cupti_cu12-12.4.127-py3-none-
manylinux2014_x86_64.whl.metadata (1.6 kB)
Collecting nvidia-cudnn-cu12==9.1.0.70 (from torch>=1.11.0->sentence-
transformers)
  Downloading nvidia_cudnn_cu12-9.1.0.70-py3-none-
manylinux2014_x86_64.whl.metadata (1.6 kB)
Collecting nvidia-cublas-cu12==12.4.5.8 (from torch>=1.11.0->sentence-
transformers)
  Downloading nvidia_cublas_cu12-12.4.5.8-py3-none-
manylinux2014_x86_64.whl.metadata (1.5 kB)
Collecting nvidia-cufft-cu12==11.2.1.3 (from torch>=1.11.0->sentence-
transformers)
  Downloading nvidia_cufft_cu12-11.2.1.3-py3-none-
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Collecting nvidia-curand-cu12==10.3.5.147 (from torch>=1.11.0-
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  Downloading nvidia_curand_cu12-10.3.5.147-py3-none-
manylinux2014_x86_64.whl.metadata (1.5 kB)
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>sentence-transformers)
  Downloading nvidia_cusolver_cu12-11.6.1.9-py3-none-
manylinux2014_x86_64.whl.metadata (1.6 kB)
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>sentence-transformers)
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manylinux2014_x86_64.whl.metadata (1.6 kB)
Collecting nvidia-nccl-cu12==2.21.5 (from torch>=1.11.0->sentence-
transformers)
  Downloading nvidia_nccl_cu12-2.21.5-py3-none-
manylinux2014_x86_64.whl.metadata (1.8 kB)
Collecting nvidia-nvtx-cu12==12.4.127 (from torch>=1.11.0->sentence-
transformers)
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manylinux2014_x86_64.whl.metadata (1.7 kB)
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>sentence-transformers)
  Downloading nvidia_nvjitlink_cu12-12.4.127-py3-none-
manylinux2014_x86_64.whl.metadata (1.5 kB)
Collecting triton==3.1.0 (from torch>=1.11.0->sentence-transformers)
  Downloading triton-3.1.0-cp310-cp310-
manylinux_2_17_x86_64.manylinux2014_x86_64.whl.metadata (1.3 kB)
Collecting sympy==1.13.1 (from torch>=1.11.0->sentence-transformers)
  Downloading sympy-1.13.1-py3-none-any.whl.metadata (12 kB)
Collecting mpmath<1.4,>=1.1.0 (from sympy==1.13.1->torch>=1.11.0-
>sentence-transformers)
  Downloading mpmath-1.3.0-py3-none-any.whl.metadata (8.6 kB)
Collecting numpy>=1.17 (from transformers<5.0.0,>=4.41.0->sentence-
transformers)
  Downloading numpy-2.1.3-cp310-cp310-
manylinux_2_17_x86_64.manylinux2014_x86_64.whl.metadata (62 kB)
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0:00:00
 transformers<5.0.0,>=4.41.0->sentence-transformers)
  Downloading regex-2024.11.6-cp310-cp310-
manylinux_2_17_x86_64.manylinux2014_x86_64.whl.metadata (40 kB)
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 40.5/40.5 kB 2.7 MB/s eta
0:00:00
 transformers<5.0.0,>=4.41.0->sentence-transformers)
  Downloading tokenizers-0.20.3-cp310-cp310-
manylinux_2_17_x86_64.manylinux2014_x86_64.whl.metadata (6.7 kB)
Collecting safetensors>=0.4.1 (from transformers<5.0.0,>=4.41.0-
>sentence-transformers)
  Downloading safetensors-0.4.5-cp310-cp310-
manylinux_2_17_x86_64.manylinux2014_x86_64.whl.metadata (3.8 kB)
Collecting joblib>=1.2.0 (from scikit-learn->sentence-transformers)
  Downloading joblib-1.4.2-py3-none-any.whl.metadata (5.4 kB)
Collecting threadpoolctl>=3.1.0 (from scikit-learn->sentence-
transformers)
  Downloading threadpoolctl-3.5.0-py3-none-any.whl.metadata (13 kB)
Collecting MarkupSafe>=2.0 (from jinja2->torch>=1.11.0->sentence-
transformers)
  Downloading MarkupSafe-3.0.2-cp310-cp310-
```

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manylinux_2_17_x86_64.manylinux2014_x86_64.whl.metadata (4.0 kB)
Collecting charset-normalizer<4,>=2 (from requests->huggingface-
hub>=0.20.0->sentence-transformers)
  Downloading charset_normalizer-3.4.0-cp310-cp310-
manylinux_2_17_x86_64.manylinux2014_x86_64.whl.metadata (34 kB)
Collecting idna<4,>=2.5 (from requests->huggingface-hub>=0.20.0-
>sentence-transformers)
  Downloading idna-3.10-py3-none-any.whl.metadata (10 kB)
Collecting urllib3<3,>=1.21.1 (from requests->huggingface-hub>=0.20.0-
>sentence-transformers)
  Downloading urllib3-2.2.3-py3-none-any.whl.metadata (6.5 kB)
Collecting certifi>=2017.4.17 (from requests->huggingface-hub>=0.20.0-
>sentence-transformers)
  Downloading certifi-2024.8.30-py3-none-any.whl.metadata (2.2 kB)
Downloading sentence_transformers-3.3.1-py3-none-any.whl (268 kB)
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 268.8/268.8 kB 10.7 MB/s eta
0:00:00
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 447.5/447.5 kB 26.6 MB/s eta
0:00:00
anylinux1_x86_64.whl (906.4 MB)
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 906.4/906.4 MB 1.9 MB/s eta
0:00:00
anylinux2014_x86_64.whl (363.4 MB)
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 363.4/363.4 MB 1.5 MB/s eta
0:00:00
anylinux2014_x86_64.whl (13.8 MB)
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 13.8/13.8 MB 106.3 MB/s eta
0:00:00
anylinux2014_x86_64.whl (24.6 MB)
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 24.6/24.6 MB 76.0 MB/s eta
0:00:00
e_cu12-12.4.127-py3-none-manylinux2014_x86_64.whl (883 kB)
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 883.7/883.7 kB 48.2 MB/s eta
0:00:00
anylinux2014_x86_64.whl (664.8 MB)
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 664.8/664.8 MB 2.9 MB/s eta
0:00:00
anylinux2014_x86_64.whl (211.5 MB)
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 211.5/211.5 MB 5.8 MB/s eta
0:00:00
anylinux2014_x86_64.whl (56.3 MB)
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 56.3/56.3 MB 15.2 MB/s eta
0:00:00
anylinux2014_x86_64.whl (127.9 MB)
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 127.9/127.9 MB 7.8 MB/s eta
0:00:00
anylinux2014_x86_64.whl (207.5 MB)
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 207.5/207.5 MB 5.8 MB/s eta
0:00:00
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anylinux2014_x86_64.whl (188.7 MB)
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 188.7/188.7 MB 6.6 MB/s eta
0:00:00
anylinux2014_x86_64.whl (21.1 MB)
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 21.1/21.1 MB 83.3 MB/s eta
0:00:00
anylinux2014_x86_64.whl (99 kB)
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 99.1/99.1 kB 8.9 MB/s eta
0:00:00
py-1.13.1-py3-none-any.whl (6.2 MB)
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 6.2/6.2 MB 104.2 MB/s eta
0:00:00
anylinux_2_17_x86_64.manylinux2014_x86_64.whl (209.5 MB)
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 209.5/209.5 MB 6.2 MB/s eta
0:00:00
-4.67.0-py3-none-any.whl (78 kB)
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 78.6/78.6 kB 6.9 MB/s eta
0:00:00
ers-4.46.3-py3-none-any.whl (10.0 MB)
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 10.0/10.0 MB 117.2 MB/s eta
0:00:00
anylinux_2_28_x86_64.whl (4.4 MB)
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 4.4/4.4 MB 101.6 MB/s eta
0:00:00
anylinux_2_17_x86_64.manylinux2014_x86_64.whl (13.3 MB)
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 13.3/13.3 MB 98.9 MB/s eta
0:00:00
anylinux_2_17_x86_64.manylinux2014_x86_64.whl (41.2 MB)
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 41.2/41.2 MB 16.8 MB/s eta
0:00:00
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 179.6/179.6 kB 16.2 MB/s eta
0:00:00
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 301.8/301.8 kB 26.0 MB/s eta
0:00:00
py-2.1.3-cp310-cp310-manylinux_2_17_x86_64.manylinux2014_x86_64.whl
(16.3 MB)
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 16.3/16.3 MB 96.3 MB/s eta
0:00:00
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 65.5/65.5 kB 5.8 MB/s eta
0:00:00
anylinux_2_17_x86_64.manylinux2014_x86_64.whl (751 kB)
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 751.2/751.2 kB 50.5 MB/s eta
0:00:00
anylinux_2_17_x86_64.manylinux2014_x86_64.whl (781 kB)
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 781.7/781.7 kB 50.5 MB/s eta
0:00:00
anylinux_2_17_x86_64.manylinux2014_x86_64.whl (435 kB)
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 435.0/435.0 kB 29.7 MB/s eta
0:00:00
```

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anylinux_2_17_x86_64.manylinux2014_x86_64.whl (3.0 MB)
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 3.0/3.0 MB 93.8 MB/s eta
0:00:00
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 133.3/133.3 kB 13.5 MB/s eta
0:00:00
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 1.7/1.7 MB 66.4 MB/s eta
0:00:00
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 64.9/64.9 kB 6.5 MB/s eta
0:00:00
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 167.3/167.3 kB 16.9 MB/s eta
0:00:00
alizer-3.4.0-cp310-cp310-
manylinux_2_17_x86_64.manylinux2014_x86_64.whl (144 kB)
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 144.8/144.8 kB 13.1 MB/s eta
0:00:00
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 70.4/70.4 kB 6.0 MB/s eta
0:00:00
anylinux_2_17_x86_64.manylinux2014_x86_64.whl (20 kB)
Downloading mpmath-1.3.0-py3-none-any.whl (536 kB)
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 536.2/536.2 kB 39.0 MB/s eta
0:00:00
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 126.3/126.3 kB 12.4 MB/s eta
0:00:00
pmath, urllib3, typing-extensions, tqdm, threadpoolctl, sympy,
safetensors, regex, pyyaml, Pillow, packaging, nvidia-nvtx-cu12,
nvidia-nvjitlink-cu12, nvidia-nccl-cu12, nvidia-curand-cu12, nvidia-
cufft-cu12, nvidia-cuda-runtime-cu12, nvidia-cuda-nvrtc-cu12, nvidia-
cuda-cupti-cu12, nvidia-cublas-cu12, numpy, networkx, MarkupSafe,
joblib, idna, fsspec, filelock, charset-normalizer, certifi, triton,
scipy, requests, nvidia-cusparse-cu12, nvidia-cudnn-cu12, jinja2,
scikit-learn, nvidia-cusolver-cu12, huggingface-hub, torch,
tokenizers, transformers, sentence-transformers
  Attempting uninstall: mpmath
    Found existing installation: mpmath 1.3.0
    Uninstalling mpmath-1.3.0:
      Successfully uninstalled mpmath-1.3.0
  Attempting uninstall: urllib3
    Found existing installation: urllib3 2.2.3
    Uninstalling urllib3-2.2.3:
      Successfully uninstalled urllib3-2.2.3
  Attempting uninstall: typing-extensions
    Found existing installation: typing_extensions 4.12.2
    Uninstalling typing_extensions-4.12.2:
      Successfully uninstalled typing_extensions-4.12.2
  Attempting uninstall: tqdm
    Found existing installation: tqdm 4.66.6
    Uninstalling tqdm-4.66.6:
      Successfully uninstalled tqdm-4.66.6
  Attempting uninstall: threadpoolctl
```

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    Found existing installation: threadpoolctl 3.5.0
    Uninstalling threadpoolctl-3.5.0:
      Successfully uninstalled threadpoolctl-3.5.0
  Attempting uninstall: sympy
    Found existing installation: sympy 1.13.1
    Uninstalling sympy-1.13.1:
      Successfully uninstalled sympy-1.13.1
  Attempting uninstall: safetensors
    Found existing installation: safetensors 0.4.5
    Uninstalling safetensors-0.4.5:
      Successfully uninstalled safetensors-0.4.5
  Attempting uninstall: regex
    Found existing installation: regex 2024.9.11
    Uninstalling regex-2024.9.11:
      Successfully uninstalled regex-2024.9.11
  Attempting uninstall: pyyaml
    Found existing installation: PyYAML 6.0.2
    Uninstalling PyYAML-6.0.2:
      Successfully uninstalled PyYAML-6.0.2
  Attempting uninstall: Pillow
    Found existing installation: pillow 11.0.0
    Uninstalling pillow-11.0.0:
      Successfully uninstalled pillow-11.0.0
  Attempting uninstall: packaging
    Found existing installation: packaging 24.2
    Uninstalling packaging-24.2:
      Successfully uninstalled packaging-24.2
  Attempting uninstall: nvidia-nvjitlink-cu12
    Found existing installation: nvidia-nvjitlink-cu12 12.6.77
    Uninstalling nvidia-nvjitlink-cu12-12.6.77:
      Successfully uninstalled nvidia-nvjitlink-cu12-12.6.77
  Attempting uninstall: nvidia-nccl-cu12
    Found existing installation: nvidia-nccl-cu12 2.23.4
    Uninstalling nvidia-nccl-cu12-2.23.4:
      Successfully uninstalled nvidia-nccl-cu12-2.23.4
  Attempting uninstall: nvidia-curand-cu12
    Found existing installation: nvidia-curand-cu12 10.3.7.77
    Uninstalling nvidia-curand-cu12-10.3.7.77:
      Successfully uninstalled nvidia-curand-cu12-10.3.7.77
  Attempting uninstall: nvidia-cufft-cu12
    Found existing installation: nvidia-cufft-cu12 11.3.0.4
    Uninstalling nvidia-cufft-cu12-11.3.0.4:
      Successfully uninstalled nvidia-cufft-cu12-11.3.0.4
  Attempting uninstall: nvidia-cuda-runtime-cu12
    Found existing installation: nvidia-cuda-runtime-cu12 12.6.77
    Uninstalling nvidia-cuda-runtime-cu12-12.6.77:
      Successfully uninstalled nvidia-cuda-runtime-cu12-12.6.77
  Attempting uninstall: nvidia-cuda-cupti-cu12
    Found existing installation: nvidia-cuda-cupti-cu12 12.6.80
    Uninstalling nvidia-cuda-cupti-cu12-12.6.80:
      Successfully uninstalled nvidia-cuda-cupti-cu12-12.6.80
  Attempting uninstall: nvidia-cublas-cu12
    Found existing installation: nvidia-cublas-cu12 12.6.3.3
    Uninstalling nvidia-cublas-cu12-12.6.3.3:
      Successfully uninstalled nvidia-cublas-cu12-12.6.3.3
  Attempting uninstall: numpy
    Found existing installation: numpy 1.26.4
    Uninstalling numpy-1.26.4:
      Successfully uninstalled numpy-1.26.4
  Attempting uninstall: networkx
    Found existing installation: networkx 3.4.2
    Uninstalling networkx-3.4.2:
      Successfully uninstalled networkx-3.4.2
  Attempting uninstall: MarkupSafe
    Found existing installation: MarkupSafe 3.0.2
    Uninstalling MarkupSafe-3.0.2:
      Successfully uninstalled MarkupSafe-3.0.2
  Attempting uninstall: joblib
    Found existing installation: joblib 1.4.2
    Uninstalling joblib-1.4.2:
      Successfully uninstalled joblib-1.4.2
  Attempting uninstall: idna
    Found existing installation: idna 3.10
    Uninstalling idna-3.10:
      Successfully uninstalled idna-3.10
  Attempting uninstall: fsspec
    Found existing installation: fsspec 2024.9.0
    Uninstalling fsspec-2024.9.0:
      Successfully uninstalled fsspec-2024.9.0
  Attempting uninstall: filelock
    Found existing installation: filelock 3.16.1
    Uninstalling filelock-3.16.1:
      Successfully uninstalled filelock-3.16.1
  Attempting uninstall: charset-normalizer
    Found existing installation: charset-normalizer 3.4.0
    Uninstalling charset-normalizer-3.4.0:
      Successfully uninstalled charset-normalizer-3.4.0
  Attempting uninstall: certifi
    Found existing installation: certifi 2024.8.30
    Uninstalling certifi-2024.8.30:
      Successfully uninstalled certifi-2024.8.30
  Attempting uninstall: scipy
    Found existing installation: scipy 1.13.1
    Uninstalling scipy-1.13.1:
      Successfully uninstalled scipy-1.13.1
  Attempting uninstall: requests
    Found existing installation: requests 2.32.3
    Uninstalling requests-2.32.3:
      Successfully uninstalled requests-2.32.3
  Attempting uninstall: nvidia-cusparse-cu12
    Found existing installation: nvidia-cusparse-cu12 12.5.4.2
    Uninstalling nvidia-cusparse-cu12-12.5.4.2:
      Successfully uninstalled nvidia-cusparse-cu12-12.5.4.2
  Attempting uninstall: nvidia-cudnn-cu12
    Found existing installation: nvidia-cudnn-cu12 9.5.1.17
    Uninstalling nvidia-cudnn-cu12-9.5.1.17:
      Successfully uninstalled nvidia-cudnn-cu12-9.5.1.17
  Attempting uninstall: jinja2
    Found existing installation: Jinja2 3.1.4
    Uninstalling Jinja2-3.1.4:
      Successfully uninstalled Jinja2-3.1.4
  Attempting uninstall: scikit-learn
    Found existing installation: scikit-learn 1.5.2
    Uninstalling scikit-learn-1.5.2:
      Successfully uninstalled scikit-learn-1.5.2
  Attempting uninstall: nvidia-cusolver-cu12
    Found existing installation: nvidia-cusolver-cu12 11.7.1.2
    Uninstalling nvidia-cusolver-cu12-11.7.1.2:
      Successfully uninstalled nvidia-cusolver-cu12-11.7.1.2
  Attempting uninstall: huggingface-hub
    Found existing installation: huggingface-hub 0.26.2
    Uninstalling huggingface-hub-0.26.2:
      Successfully uninstalled huggingface-hub-0.26.2
  Attempting uninstall: torch
    Found existing installation: torch 2.5.1+cu121
    Uninstalling torch-2.5.1+cu121:
      Successfully uninstalled torch-2.5.1+cu121
  Attempting uninstall: tokenizers
    Found existing installation: tokenizers 0.20.3
    Uninstalling tokenizers-0.20.3:
      Successfully uninstalled tokenizers-0.20.3
  Attempting uninstall: transformers
    Found existing installation: transformers 4.46.2
    Uninstalling transformers-4.46.2:
      Successfully uninstalled transformers-4.46.2
  Attempting uninstall: sentence-transformers
    Found existing installation: sentence-transformers 3.2.1
    Uninstalling sentence-transformers-3.2.1:
      Successfully uninstalled sentence-transformers-3.2.1
ERROR: pip's dependency resolver does not currently take into account
all the packages that are installed. This behaviour is the source of
the following dependency conflicts.
cupy-cuda12x 12.2.0 requires numpy<1.27,>=1.20, but you have numpy
2.1.3 which is incompatible.
datasets 3.1.0 requires fsspec[http]<=2024.9.0,>=2023.1.0, but you
have fsspec 2024.10.0 which is incompatible.
gensim 4.3.3 requires numpy<2.0,>=1.18.5, but you have numpy 2.1.3
```

```
which is incompatible.
gensim 4.3.3 requires scipy<1.14.0,>=1.7.0, but you have scipy 1.14.1
which is incompatible.
langchain 0.3.7 requires numpy<2,>=1; python_version < "3.12", but you
have numpy 2.1.3 which is incompatible.
matplotlib 3.8.0 requires numpy<2,>=1.21, but you have numpy 2.1.3
which is incompatible.
numba 0.60.0 requires numpy<2.1,>=1.22, but you have numpy 2.1.3 which
is incompatible.
pytensor 2.26.3 requires numpy<2,>=1.17.0, but you have numpy 2.1.3
which is incompatible.
tensorflow 2.17.1 requires numpy<2.0.0,>=1.23.5; python_version <=
"3.11", but you have numpy 2.1.3 which is incompatible.
thinc 8.2.5 requires numpy<2.0.0,>=1.19.0; python_version >= "3.9",
but you have numpy 2.1.3 which is incompatible.
Successfully installed MarkupSafe-3.0.2 Pillow-11.0.0 certifi-
2024.8.30 charset-normalizer-3.4.0 filelock-3.16.1 fsspec-2024.10.0
huggingface-hub-0.26.2 idna-3.10 jinja2-3.1.4 joblib-1.4.2 mpmath-
1.3.0 networkx-3.4.2 numpy-2.1.3 nvidia-cublas-cu12-12.4.5.8 nvidia-
cuda-cupti-cu12-12.4.127 nvidia-cuda-nvrtc-cu12-12.4.127 nvidia-cuda-
runtime-cu12-12.4.127 nvidia-cudnn-cu12-9.1.0.70 nvidia-cufft-cu12-
11.2.1.3 nvidia-curand-cu12-10.3.5.147 nvidia-cusolver-cu12-11.6.1.9
nvidia-cusparse-cu12-12.3.1.170 nvidia-nccl-cu12-2.21.5 nvidia-
nvjitlink-cu12-12.4.127 nvidia-nvtx-cu12-12.4.127 packaging-24.2
pyyaml-6.0.2 regex-2024.11.6 requests-2.32.3 safetensors-0.4.5 scikit-
learn-1.5.2 scipy-1.14.1 sentence-transformers-3.3.1 sympy-1.13.1
threadpoolctl-3.5.0 tokenizers-0.20.3 torch-2.5.1 tqdm-4.67.0
transformers-4.46.3 triton-3.1.0 typing-extensions-4.12.2 urllib3-
2.2.3
```

```
{"id":"df4ec699e4df4d8e8b89b131de8eb650","pip_warning":{"packages":
["PIL","certifi","networkx"]}}
```

```
!pip install faiss-gpu
```

```
Collecting faiss-gpu
  Downloading faiss_gpu-1.7.2-cp310-cp310-
manylinux_2_17_x86_64.manylinux2014_x86_64.whl.metadata (1.4 kB)
Downloading faiss_gpu-1.7.2-cp310-cp310-
manylinux_2_17_x86_64.manylinux2014_x86_64.whl (85.5 MB)
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 85.5/85.5 MB 6.5 MB/s eta
0:00:00
```

```python
import pandas as pd
from datasets import load_dataset
from tqdm import tqdm
import time
from typing import Dict, List, Tuple
import json
from sentence_transformers import SentenceTransformer
from transformers import pipeline, AutoModel, AutoTokenizer
import torch
import numpy as np
import logging
import faiss
```

Load dataset

Example code: `dataset = load_dataset("opus_books", "en-it", split="train[:2000]")`

```
# Load dataset
def load_dataset(num_samples=2000):
    """Load the OPUS Books dataset"""
    print("Loading OPUS Books dataset...")
    dataset = load_dataset("opus_books", "en-it", split=f"train[:
{num_samples}]")

    # Extract text pairs
    texts_en = [item['translation']['en'] for item in dataset]
    texts_it = [item['translation']['it'] for item in dataset]

    return dataset, texts_en, texts_it
```

Initialize model

Example Code: `model = SentenceTransformer(’paraphrase-multilingual-MiniLM-L12-v2’)`

```
#Initialize the model
def initialize_models():
    """Initialize the required models and tokenizers"""
    # Initialize sentence transformer for embeddings
    encoder = SentenceTransformer('paraphrase-multilingual-MiniLM-L12-
v2')

    # Initialize mBART model and tokenizer for generation
    generator =
MBartForConditionalGeneration.from_pretrained("facebook/mbart-large-
50-many-to-many-mmt")
    tokenizer = AutoTokenizer.from_pretrained("facebook/mbart-large-
50-many-to-many-mmt")

    return encoder, generator, tokenizer
```

Create embeddings

Example Code:

```
texts_en = [item['translation']['en'] for item in dataset]
texts_it = [item['translation']['it'] for item in dataset]
embeddings = model.encode(texts_en + texts_it)

#Embeddings
def create_embeddings(encoder, texts_en, texts_it):
    """Create embeddings for all texts"""
    print("Creating embeddings...")
    all_texts = texts_en + texts_it

    embeddings = []
    for text in tqdm(all_texts, desc="Encoding texts"):
        embedding = encoder.encode(text, convert_to_numpy=True)
        embeddings.append(embedding)

    embeddings = np.array(embeddings)
    print(f"Created embeddings with shape: {embeddings.shape}")

    return embeddings
```

Build FAISS index

Example code:

```
index = faiss.IndexFlatL2(embeddings.shape[1])
index.add(embeddings)

#FAISS indexing for efficient search
def build_faiss_index(embeddings):
    """Build and return a FAISS index"""
    print("Building FAISS index...")
    dimension = embeddings.shape[1]

    # Create FAISS index
    index = faiss.IndexFlatL2(dimension)
    index.add(embeddings.astype('float32'))

    print(f"Built index with {index.ntotal} vectors of dimension
{dimension}")
    return index

def save_load_index(index, action='save',
filepath='search_index.faiss'):
    """Save or load the FAISS index"""
    if action == 'save':
        faiss.write_index(index, filepath)
        print(f"Index saved to {filepath}")
    else:
        index = faiss.read_index(filepath)
        print(f"Index loaded from {filepath}")
        return index
```

Problem 2 (b): Implement multilingual search (8 points)

- Create a search function that accepts queries in either English or Italian
- Add metadata filtering capability to search in specific languages
- Return top-k most relevant passages with scores
- Implement efficient batch processing for multiple queries

```
import pandas as pd
from datasets import load_dataset
from tqdm import tqdm
import time
from typing import Dict
import json
from sentence_transformers import SentenceTransformer
# The following line imports necessary modules from transformers.
# AutoTokenizer is imported for tokenizing text.
# pipeline is imported to easily access pre-trained models for various
tasks.
from transformers import pipeline, MBartForConditionalGeneration,
AutoTokenizer, AutoModel
import torch
import numpy as np
```

Helper Functions

Loading and Processing the Dataset

```
# def load_multilingual_dataset(num_samples=1000):
#     """Load multilingual dataset from OPUS Books dataset using
English-Italian pair"""
#     print("Loading OPUS Books dataset...")

#     dataset = load_dataset("opus_books", "en-it",
split="train[:2000]")

#     data = []
#     for i, item in tqdm(enumerate(dataset), desc="Processing
entries"):
#         if len(data) < num_samples * 2:
#             # Add English entry
#             data.append({
#                 'title': f"Book_Excerpt_{i}_EN",
#                 'text': item['translation']['en'],
#                 'lang': 'en',
#                 'embedding': model.encode(item['translation']['en'])
#             })
#             # Add Italian entry
#             data.append({
#                 'title': f"Book_Excerpt_{i}_IT",
#                 'text': item['translation']['it'],
#                 'lang': 'it',
#                 'embedding': model.encode(item['translation']['it'])
#             })

#     df = pd.DataFrame(data)
#     print("\nDataset statistics:")
#     print("Total samples:", len(df))
#     print("\nLanguage distribution:")
#     print(df['lang'].value_counts())

#     return df

# # Load the dataset
# df = load_multilingual_dataset(num_samples=100)
```

Implementing Multilingual Search

```
# def semantic_search(query: str, encoder, index, texts_en, texts_it,
k: int = 3, lang_filter: str = None) -> pd.DataFrame:
#     """
#     Perform semantic search with language filtering

#     Args:
#         query: Query text
#         encoder: SentenceTransformer model
#         index: FAISS index
#         texts_en: List of English texts
#         texts_it: List of Italian texts
#         k: Number of results to return
#         lang_filter: Optional language filter ('en' or 'it')
#     """
#     # Encode query
#     query_vector = encoder.encode(query, convert_to_numpy=True)
#     query_vector = query_vector.reshape(1, -1)

#     # Search in index
#     D, I = index.search(query_vector.astype('float32'), k * 2)  #
Get extra results for filtering

#     # Process results
#     results = []
#     for idx, score in zip(I[0], D[0]):
#         is_english = idx < len(texts_en)
#         text = texts_en[idx] if is_english else texts_it[idx -
len(texts_en)]
#         lang = 'en' if is_english else 'it'
#         if lang_filter and lang != lang_filter:
#             continue

#         results.append({
#             'text': text,
#             'language': lang,
#             'score': float(score)
#         })

#     return pd.DataFrame(results[:k])
```

Testing Multilingual Search

```
# # Test queries in different languages
# queries = {
#     "English": "stories about love and adventure",
#     "Italian": "storie d'amore e d'avventura"
# }

# # ADD YOUR CODE HERE
# # Run a semantic search for the queries above, and record search
times
# def batch_semantic_search(queries: List[str], encoder, index,
texts_en, texts_it, k: int = 3) -> List[pd.DataFrame]:
#     """
#     Process multiple queries efficiently

#     Args:
#         queries: List of query strings
#         encoder: SentenceTransformer model
#         index: FAISS index
#         texts_en: List of English texts
#         texts_it: List of Italian texts
#         k: Number of results per query
#     """
#     # Encode all queries at once
#     query_vectors = encoder.encode(queries, convert_to_numpy=True)

#     # Batch search
#     D, I = index.search(query_vectors.astype('float32'), k)

#     # Process results for each query
#     all_results = []
#     for distances, indices in zip(D, I):
#         results = []
#         for idx, score in zip(indices, distances):
#             is_english = idx < len(texts_en)
#             text = texts_en[idx] if is_english else texts_it[idx -
len(texts_en)]
```

```
#             lang = 'en' if is_english else 'it'

#             results.append({
#                 'text': text,
#                 'language': lang,
#                 'score': float(score)
#             })
#         all_results.append(pd.DataFrame(results))

#     return all_results
```

Implementing RAG Capabilities

```
# def generate_content(prompt: str, context: str, generator_model,
generator_tokenizer, lang_code: str = "en_XX") -> str:
#     """
#     Generate content using mBART with specified language

#     Args:
#         prompt: The instruction prompt
#         context: Retrieved context
#         generator_model: mBART model
#         generator_tokenizer: mBART tokenizer
#         lang_code: Target language code ("en_XX" for English,
"it_IT" for Italian)
#     """
#     # Set source and target languages
#     generator_tokenizer.src_lang = lang_code
#     generator_tokenizer.tgt_lang = lang_code

#     # Prepare input text
#     input_text = f"{prompt}\n\nContext: {context}"

#     # Tokenize input
#     inputs = generator_tokenizer(
#         input_text,
#         return_tensors="pt",
#         max_length=512,
#         truncation=True,
#         padding=True
#     )

#     # Generate output
#     outputs = generator_model.generate(
#         **inputs,
#
forced_bos_token_id=generator_tokenizer.lang_code_to_id[lang_code],
#         max_length=150,
#         num_beams=4,
#         length_penalty=2.0,
#         early_stopping=True
#     )

#     # Decode and return
#     return generator_tokenizer.decode(outputs[0],
skip_special_tokens=True)

# def rag_single(query: str, prompt: str, search_results:
pd.DataFrame,
#                generator_model, generator_tokenizer, lang_code: str
= "en_XX") -> str:
#     """
#     Generate content based on a single retrieved document

#     Args:
#         query: Search query
#         prompt: Generation prompt
#         search_results: DataFrame with search results
#         generator_model: mBART model
#         generator_tokenizer: mBART tokenizer
#         lang_code: Target language code
#     """
#     if len(search_results) == 0:
#         return "No relevant documents found."

#     # Get the best matching document
#     context = search_results.iloc[0]['text']

#     # Generate content
#     return generate_content(
#         prompt=prompt,
#         context=context,
#         generator_model=generator_model,
#         generator_tokenizer=generator_tokenizer,
#         lang_code=lang_code
#     )

# def rag_group(query: str, prompt: str, search_results: pd.DataFrame,
#               generator_model, generator_tokenizer, lang_code: str =
"en_XX", k: int = 3) -> str:
#     """
#     Generate content based on multiple retrieved documents

#     Args:
#         query: Search query
#         prompt: Generation prompt
#         search_results: DataFrame with search results
#         generator_model: mBART model
#         generator_tokenizer: mBART tokenizer
#         lang_code: Target language code
#         k: Number of documents to use
#     """
#     if len(search_results) == 0:
#         return "No relevant documents found."

#     # Combine the top-k documents with markers
#     contexts = []
#     for i, row in search_results.head(k).iterrows():
#         contexts.append(f"Document {i+1} ({row['language']}): 
{row['text']}")
#     combined_context = "\n\n".join(contexts)

#     # Generate content
#     return generate_content(
#         prompt=prompt,
#         context=combined_context,
#         generator_model=generator_model,
#         generator_tokenizer=generator_tokenizer,
#         lang_code=lang_code
#     )

# # Example prompt templates for different languages
# PROMPT_TEMPLATES = {
#     'en_XX': {
#         'recommendation': "Based on these excerpts, write a book 
recommendation:",
#         'comparison': "Compare and contrast these passages, 
discussing their themes:",
#         'summary': "Provide a concise summary of these texts:"
#     },
#     'it_IT': {
#         'recommendation': "Basandoti su questi estratti, scrivi un 
consiglio di lettura:",
#         'comparison': "Confronta questi passaggi, discutendo i loro 
temi:",
#         'summary': "Fornisci un riassunto conciso di questi testi:"
#     }
# }
```

Testing RAG Capabilities

```
# # Search
# results = semantic_search("adventure stories", encoder, index, 
texts_en, texts_it)

# # Generate content in English
# en_content = rag_group(
#     query="adventure stories",
#     prompt=PROMPT_TEMPLATES['en_XX']['summary'],
#     search_results=results,
#     generator_model=generator,
#     generator_tokenizer=tokenizer,
#     lang_code="en_XX"
# )

# # Generate content in Italian
# it_content = rag_group(
#     query="storie d'avventura",
#     prompt=PROMPT_TEMPLATES['it_IT']['summary'],
#     search_results=results,
#     generator_model=generator,
#     generator_tokenizer=tokenizer,
#     lang_code="it_IT"
# )
```

Problem 2(c): Adding Retrieval-Augmented Generation (RAG) Capabilities (9 points)

In this section, we will add Retrieval-Augmented Generation (RAG) functionality to the assistant. RAG combines retrieval and generation by allowing the system to retrieve relevant information from a database (or vector store) and generate responses based on the retrieved information.

Tasks:

1. **Model Selection**:

    - Use `mBART-large-50` from the Hugging Face Transformers library to enable multilingual generation capabilities.
    - Initialize the model and tokenizer to handle input prompts and generate responses based on retrieved content.

    Example Code: ```python from transformers import AutoModel, AutoTokenizer

    model = AutoModel.from_pretrained("facebook/mbart-large-50-many-to-many-mmt") tokenizer = AutoTokenizer.from_pretrained("facebook/mbart-large-50-many-to-many-mmt")

```
#check the last cell
```

Task

1. Single-Document and Multi-Document Generation:

    - Implement content generation for both single-document and multi-document inputs:
        - Single-Document Generation: Generate recommendations based on individual retrieved passages.
        - Multi-Document Generation: Produce comparative analyses by summarizing information from multiple passages.

    Example Code:

```
    def generate_content(context, prompt):
     input_text = f"{prompt}\n{context}"
     inputs = tokenizer(input_text, return_tensors="pt",
    max_length=512)
     outputs = model.generate(**inputs)
     return tokenizer.decode(outputs[0], skip_special_tokens=True)
```

```
#check the last cell
```

Task

1. Prompt Strategy:

- Experiment with different prompt strategies to optimize content generation for quality and relevance.
- Examples of prompt types:
  - Recommendation Prompts: Guide the model to generate book recommendations or summaries.
  - Comparative Analysis Prompts: Structure prompts to encourage the model to compare multiple sources.

```
#check the last cell
```

Task 4

1. Testing Requirements:

- Test RAG with queries in both English and Italian:
  - English Query: “stories about adventure and discovery”
  - Italian Query: “storie di avventura e scoperta”
- Use at least 1,000 parallel texts from the OPUS Books dataset to evaluate retrieval and generation effectiveness.

```
#check the last cell
```

Bonus:

(+5 points) Implement semantic caching to improve performance for repeated similar queries.

```
!pip install datasets

Collecting datasets
  Downloading datasets-3.1.0-py3-none-any.whl.metadata (20 kB)
Requirement already satisfied: filelock in
/usr/local/lib/python3.10/dist-packages (from datasets) (3.16.1)
Requirement already satisfied: numpy>=1.17 in
/usr/local/lib/python3.10/dist-packages (from datasets) (1.26.4)
Requirement already satisfied: pyarrow>=15.0.0 in
/usr/local/lib/python3.10/dist-packages (from datasets) (17.0.0)
Collecting dill<0.3.9,>=0.3.0 (from datasets)
```

```
  Downloading dill-0.3.8-py3-none-any.whl.metadata (10 kB)
Requirement already satisfied: pandas in
/usr/local/lib/python3.10/dist-packages (from datasets) (2.2.2)
Requirement already satisfied: requests>=2.32.2 in
/usr/local/lib/python3.10/dist-packages (from datasets) (2.32.3)
Requirement already satisfied: tqdm>=4.66.3 in
/usr/local/lib/python3.10/dist-packages (from datasets) (4.66.6)
Collecting xxhash (from datasets)
  Downloading xxhash-3.5.0-cp310-cp310-
manylinux_2_17_x86_64.manylinux2014_x86_64.whl.metadata (12 kB)
Collecting multiprocess<0.70.17 (from datasets)
  Downloading multiprocess-0.70.16-py310-none-any.whl.metadata (7.2
kB)
Collecting fsspec<=2024.9.0,>=2023.1.0 (from
fsspec[http]<=2024.9.0,>=2023.1.0->datasets)
  Downloading fsspec-2024.9.0-py3-none-any.whl.metadata (11 kB)
Requirement already satisfied: aiohttp in
/usr/local/lib/python3.10/dist-packages (from datasets) (3.11.2)
Requirement already satisfied: huggingface-hub>=0.23.0 in
/usr/local/lib/python3.10/dist-packages (from datasets) (0.26.2)
Requirement already satisfied: packaging in
/usr/local/lib/python3.10/dist-packages (from datasets) (24.2)
Requirement already satisfied: pyyaml>=5.1 in
/usr/local/lib/python3.10/dist-packages (from datasets) (6.0.2)
Requirement already satisfied: aiohappyeyeballs>=2.3.0 in
/usr/local/lib/python3.10/dist-packages (from aiohttp->datasets)
(2.4.3)
Requirement already satisfied: aiosignal>=1.1.2 in
/usr/local/lib/python3.10/dist-packages (from aiohttp->datasets)
(1.3.1)
Requirement already satisfied: attrs>=17.3.0 in
/usr/local/lib/python3.10/dist-packages (from aiohttp->datasets)
(24.2.0)
Requirement already satisfied: frozenlist>=1.1.1 in
/usr/local/lib/python3.10/dist-packages (from aiohttp->datasets)
(1.5.0)
Requirement already satisfied: multidict<7.0,>=4.5 in
/usr/local/lib/python3.10/dist-packages (from aiohttp->datasets)
(6.1.0)
Requirement already satisfied: propcache>=0.2.0 in
/usr/local/lib/python3.10/dist-packages (from aiohttp->datasets)
(0.2.0)
Requirement already satisfied: yarl<2.0,>=1.17.0 in
/usr/local/lib/python3.10/dist-packages (from aiohttp->datasets)
(1.17.2)
Requirement already satisfied: async-timeout<6.0,>=4.0 in
/usr/local/lib/python3.10/dist-packages (from aiohttp->datasets)
(4.0.3)
Requirement already satisfied: typing-extensions>=3.7.4.3 in
```

```
/usr/local/lib/python3.10/dist-packages (from huggingface-hub>=0.23.0-
>datasets) (4.12.2)
Requirement already satisfied: charset-normalizer<4,>=2 in
/usr/local/lib/python3.10/dist-packages (from requests>=2.32.2-
>datasets) (3.4.0)
Requirement already satisfied: idna<4,>=2.5 in
/usr/local/lib/python3.10/dist-packages (from requests>=2.32.2-
>datasets) (3.10)
Requirement already satisfied: urllib3<3,>=1.21.1 in
/usr/local/lib/python3.10/dist-packages (from requests>=2.32.2-
>datasets) (2.2.3)
Requirement already satisfied: certifi>=2017.4.17 in
/usr/local/lib/python3.10/dist-packages (from requests>=2.32.2-
>datasets) (2024.8.30)
Requirement already satisfied: python-dateutil>=2.8.2 in
/usr/local/lib/python3.10/dist-packages (from pandas->datasets)
(2.8.2)
Requirement already satisfied: pytz>=2020.1 in
/usr/local/lib/python3.10/dist-packages (from pandas->datasets)
(2024.2)
Requirement already satisfied: tzdata>=2022.7 in
/usr/local/lib/python3.10/dist-packages (from pandas->datasets)
(2024.2)
Requirement already satisfied: six>=1.5 in
/usr/local/lib/python3.10/dist-packages (from python-dateutil>=2.8.2-
>pandas->datasets) (1.16.0)
Downloading datasets-3.1.0-py3-none-any.whl (480 kB)
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 480.6/480.6 kB 9.1 MB/s eta
0:00:00
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 116.3/116.3 kB 8.4 MB/s eta
0:00:00
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 179.3/179.3 kB 11.2 MB/s eta
0:00:00
ultiprocess-0.70.16-py310-none-any.whl (134 kB)
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 134.8/134.8 kB 9.9 MB/s eta
0:00:00
anylinux_2_17_x86_64.manylinux2014_x86_64.whl (194 kB)
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 194.1/194.1 kB 6.6 MB/s eta
0:00:00
ultiprocess, datasets
  Attempting uninstall: fsspec
    Found existing installation: fsspec 2024.10.0
    Uninstalling fsspec-2024.10.0:
      Successfully uninstalled fsspec-2024.10.0
ERROR: pip's dependency resolver does not currently take into account
all the packages that are installed. This behaviour is the source of
the following dependency conflicts.
gcsfs 2024.10.0 requires fsspec==2024.10.0, but you have fsspec
2024.9.0 which is incompatible.
```

```
Successfully installed datasets-3.1.0 dill-0.3.8 fsspec-2024.9.0
multiprocess-0.70.16 xxhash-3.5.0
```

```python
import pandas as pd
from datasets import load_dataset
from tqdm import tqdm
import time
from typing import Dict, List, Tuple
import json
from sentence_transformers import SentenceTransformer
from transformers import pipeline, AutoModel, AutoTokenizer,
MBartForConditionalGeneration
import torch
import numpy as np
import logging
import faiss

class MultilingualRAG:
    def __init__(self):
        # Initialize models
        self.encoder = SentenceTransformer('paraphrase-multilingual-
MiniLM-L12-v2')
        self.generator =
MBartForConditionalGeneration.from_pretrained("facebook/mbart-large-
50")
        self.tokenizer =
AutoTokenizer.from_pretrained("facebook/mbart-large-50")

        # Define supported languages and their codes
        self.lang_codes = {
            'en': 'en_XX',
            'it': 'it_IT'
        }

        # Set up device
        self.device = "cuda" if torch.cuda.is_available() else "cpu"
        self.generator = self.generator.to(self.device)

        # Load dataset
        self.dataset = load_dataset("opus_books", "en-it",
split="train[:2000]")
        self.build_index()

    def build_index(self):
        """Build FAISS index from dataset"""
        print("Creating embeddings...")
        self.texts_en = [item['translation']['en'] for item in
self.dataset]
        self.texts_it = [item['translation']['it'] for item in
self.dataset]
```

```
        # Create embeddings with progress bar
        embeddings = []
        for text in tqdm(self.texts_en + self.texts_it, desc="Encoding
texts"):
            embeddings.append(self.encoder.encode(text))
        self.embeddings = np.array(embeddings)

        # Build FAISS index
        print("Building FAISS index...")
        dimension = self.embeddings.shape[1]
        self.index = faiss.IndexFlatL2(dimension)
        self.index.add(self.embeddings.astype('float32'))

        print("Index built successfully!")

    def semantic_search(self, query: str, k: int = 3, lang_filter: str
= None) -> pd.DataFrame:
        """
        Perform semantic search over the dataset

        Args:
            query: Search query in English or Italian
            k: Number of results to return
            lang_filter: Optional language filter ('en' or 'it')

        Returns:
            DataFrame with search results
        """
        # Encode query
        query_vector = self.encoder.encode([query])

        # Search in FAISS index
        D, I = self.index.search(query_vector.astype('float32'), k *
2)  # Get more results for filtering

        results = []
        for idx, score in zip(I[0], D[0]):
            # Determine if result is from English or Italian portion
            is_english = idx < len(self.texts_en)
            text = self.texts_en[idx] if is_english else
self.texts_it[idx - len(self.texts_en)]
            lang = 'en' if is_english else 'it'

            if lang_filter and lang != lang_filter:
                continue

            results.append({
                'text': text,
                'language': lang,
                'score': float(score)
            })

        return pd.DataFrame(results[:k])

    def generate_content(self, prompt: str, context: str, lang: str = 
'en') -> str:
        """Generate content using mBART model with specified 
language"""
        # Ensure the generator is in eval mode
        self.generator.eval()

        # Get proper language code
        lang_code = self.lang_codes.get(lang, 'en_XX')

        # Prepare input text
        input_text = f"{prompt}\n\nContext: {context}"

        # Configure tokenizer for the right language
        self.tokenizer.src_lang = lang_code
        self.tokenizer.tgt_lang = lang_code

        # Tokenize input
        encoded = self.tokenizer(
            input_text,
            return_tensors="pt",
            max_length=512,
            truncation=True,
            padding=True
        )

        # Move to correct device
        input_ids = encoded['input_ids'].to(self.device)
        attention_mask = encoded['attention_mask'].to(self.device)

        # Generate with forced language
        with torch.no_grad():
            outputs = self.generator.generate(
                input_ids=input_ids,
                attention_mask=attention_mask,
                
forced_bos_token_id=self.tokenizer.lang_code_to_id[lang_code],
                max_length=150,
                num_beams=4,
                length_penalty=2.0,
                early_stopping=True,
                no_repeat_ngram_size=3
            )

        # Decode output with the correct language
        decoded = self.tokenizer.batch_decode(outputs,
skip_special_tokens=True)[0]
        return decoded


    def rag_single(self, query: str, prompt: str, lang: str = 'en') ->
str:
        """Generate content based on a single retrieved document"""
        # Search with language filter
        results = self.semantic_search(query, k=1, lang_filter=lang)
        if len(results) == 0:
            return "No relevant documents found."

        # Generate in specified language
        context = results.iloc[0]['text']
        return self.generate_content(prompt, context, lang)


    def rag_group(self, query: str, prompt: str, lang: str = 'en', k:
int = 3) -> str:
        """Generate content based on multiple retrieved documents"""
        # Search
        results = self.semantic_search(query, k=k, lang_filter=lang)
        if len(results) == 0:
            return "No relevant documents found."

        # Combine contexts
        contexts = [f"Passage {i+1}: {row['text']}" for i, row in
results.iterrows()]
        combined_context = "\n\n".join(contexts)

        # Generate
        return self.generate_content(prompt, combined_context, lang)

class SemanticCache:
    def __init__(self, cache_size: int = 1000):
        self.cache_size = cache_size
        self.cache = {}
        self.encoder = SentenceTransformer('paraphrase-multilingual-
MiniLM-L12-v2')

    def get_cache_key(self, query: str) -> np.ndarray:
        """Generate cache key from query embedding"""
        return self.encoder.encode(query)

    def find_similar_query(self, query: str, threshold: float = 0.9) -
> str:
        """Find similar query in cache"""
        query_embedding = self.get_cache_key(query)
```

```python
        for cached_query, (cached_embedding, _) in self.cache.items():
            similarity = np.dot(query_embedding, cached_embedding)
            if similarity > threshold:
                return cached_query

        return None

    def get(self, query: str):
        """Get results from cache"""
        similar_query = self.find_similar_query(query)
        if similar_query:
            return self.cache[similar_query][1]
        return None

    def put(self, query: str, results: any):
        """Add results to cache"""
        if len(self.cache) >= self.cache_size:
            # Remove oldest entry
            self.cache.pop(next(iter(self.cache)))

        self.cache[query] = (self.get_cache_key(query), results)

# Predefined prompts in both languages
PROMPTS = {
    'en': {
        'recommendation': "Write a short book recommendation based on this excerpt:",
        'compare': "Compare and contrast these book excerpts, discussing their themes and style:",
        'summary': "Provide a brief summary of the content:"
    },
    'it': {
        'recommendation': "Scrivi un breve consiglio di lettura basato su questo estratto:",
        'compare': "Confronta questi estratti di libri, discutendo i loro temi e stili:",
        'summary': "Fornisci un breve riassunto del contenuto:"
    }
}

def test_multilingual_rag():
    print("Initializing MultilingualRAG system...")
    rag = MultilingualRAG()

    # Test queries in both languages with their corresponding prompts
    test_cases = [
        {
            'language': 'en',
            'query': "stories about love and adventure",
            'prompt': PROMPTS['en']['recommendation']
        },
        {
            'language': 'it',
            'query': "storie d'amore e d'avventura",
            'prompt': PROMPTS['it']['recommendation']
        }
    ]

    for case in test_cases:
        print(f"\nTesting {case['language']} query: {case['query']}")

        # Test single document RAG
        print("\nGenerating content for a single document:")
        start_time = time.time()
        result = rag.rag_single(
            query=case['query'],
            prompt=case['prompt'],
            lang=case['language']
        )
        print(f"Time taken: {time.time() - start_time:.2f}s")
        print("Result:", result)

        # Test multi-document RAG
        print("\nGenerating content from multiple documents:")
        start_time = time.time()
        result = rag.rag_group(
            query=case['query'],
            prompt=case['prompt'],
            lang=case['language'],
            k=3
        )
        print(f"Time taken: {time.time() - start_time:.2f}s")
        print("Result:", result)

    # Test with semantic cache
    print("\nTesting semantic cache...")
    cache = SemanticCache()

    # First query - should miss cache
    start_time = time.time()
    results = rag.semantic_search("adventure stories",
lang_filter='en')
    cache.put("adventure stories", results)
    print(f"First query (cache miss) time: {time.time() -
start_time:.2f}s")

    # Similar query - should hit cache
    start_time = time.time()
    cached_results = cache.get("stories about adventure")
    print(f"Similar query (cache hit) time: {time.time() -
```

```python
start_time:.2f}s")

if __name__ == "__main__":
    test_multilingual_rag()
```

```
Initializing MultilingualRAG system...
```

```
/usr/local/lib/python3.10/dist-packages/huggingface_hub/utils/
_auth.py:94: UserWarning:
The secret `HF_TOKEN` does not exist in your Colab secrets.
To authenticate with the Hugging Face Hub, create a token in your
settings tab (https://huggingface.co/settings/tokens), set it as
secret in your Google Colab and restart your session.
You will be able to reuse this secret in all of your notebooks.
Please note that authentication is recommended but still optional to
access public models or datasets.
  warnings.warn(
```

```
{"model_id":"963bd6e3190046f1aa94b0f1d571b34d","version_major":2,"version_minor":0}

{"model_id":"177d94712ca5473c8c7fbe98869fd474","version_major":2,"version_minor":0}

{"model_id":"00ff8cbd01c94f14a76d4642b6923606","version_major":2,"version_minor":0}

{"model_id":"031fa486c04d4fb194987c759b674c35","version_major":2,"version_minor":0}

{"model_id":"5d6e7d1eb19c44a68a6bb1a2985185a1","version_major":2,"version_minor":0}

{"model_id":"b5d23a9ed80541fe8b75c3bb2c51bd74","version_major":2,"version_minor":0}

{"model_id":"599e063cbd2c425e9c0b68b0464a8bb2","version_major":2,"version_minor":0}

{"model_id":"b1b2f41ad3084086bb5f24c4b8c146c5","version_major":2,"version_minor":0}

{"model_id":"cd9bb4089f1a4f57b2691c47e649fd85","version_major":2,"version_minor":0}

{"model_id":"0cf710312fba490086f86f697fba97e9","version_major":2,"version_minor":0}

{"model_id":"83934d8beabf44f3ae11d51a58ae8c01","version_major":2,"version_minor":0}
```

```
{"model_id":"a3f23d43839944d19b67689c524577ad","version_major":2,"vers
ion_minor":0}

{"model_id":"d23bc5b36ed84197b7fc7d9c07d6dec2","version_major":2,"vers
ion_minor":0}

{"model_id":"492f61b5dbf844649ca8a3db4725a76c","version_major":2,"vers
ion_minor":0}

{"model_id":"7f63c4452adc4de5ac78552c686ef847","version_major":2,"vers
ion_minor":0}

{"model_id":"a20ee5cf169845998bdce4d5ec30cc34","version_major":2,"vers
ion_minor":0}

{"model_id":"48e95c24a5ed47258add1ae96f5f8d5d","version_major":2,"vers
ion_minor":0}

{"model_id":"b6f0885b18fe473f906da1be5b5c92b0","version_major":2,"vers
ion_minor":0}

{"model_id":"4abd711aedd14e5fb4b8743d8d8436c3","version_major":2,"vers
ion_minor":0}

{"model_id":"0fa517cff1e04fd985157178f4d2b043","version_major":2,"vers
ion_minor":0}

Creating embeddings...


Encoding texts:   0%|          | 0/4000 [00:00<?, ?it/s]

Building FAISS index...
Index built successfully!

Testing en query: stories about love and adventure

Generating content for a single document:
Time taken: 19.54s
Result: Write a short book recommendation based on this excer native
author's work (if available)

Generating content from multiple documents:
Time taken: 62.67s
Result: Write a short book recommendation based on This is a book I
have read and This book has been named The story of The book was The
picture of It was a book of I have been reading this I read this It's
a book about I'm a book that I am a book for I liked the book, I was a
picture told a out of namely native place in the book. Each picture
told me a place in place in out out out there is na the place in and
out out of na na na the na the W I have I read a W
```

```
Testing it query: storie d'amore e d'avventura

Generating content for a single document:
Time taken: 9.20s
Result: Scrivi un breve consiglio di lettura basato su questo
estratto:

Generating content from multiple documents:
Time taken: 10.64s
Result: Scrivi un breve consiglio di lettura basato su questo
estratto:

Testing semantic cache...
First query (cache miss) time: 0.11s
Similar query (cache hit) time: 0.05s
```

Performance Metrics:

- Embedding generation: ~5.57s for 4000 texts (11.19 texts/s)
- Average query time:
  - English single doc: 19.54s
  - English multi-doc: 62.67s

  - Italian single doc: 9.20s
  - Italian multi-doc: 10.64s

Semantic Cache:

- Cache miss: 0.11s
- Cache hit: 0.05s (54% faster)

Key Issues:

1. High latency for English multi-doc queries (~63s)
2. Significant performance gap between English/Italian processing
3. Memory usage spikes during embedding generation

Quality Analysis:

1. English Results:
- Single doc: Coherent but generic recommendation prompt
- Multi-doc: Degraded quality with repetitive/nonsensical text
1. Italian Results:
- Consistent output quality
- More concise responses
- Limited to basic recommendation prompts

Improvement Areas:

1. Multi-doc query optimization (particularly for English)

2. Memory management during embedding
3. Cross-lingual performance parity
4. Output quality consistency for multi-doc scenarios
5. Cache optimization to reduce cold start latency

Submission:

Submit your code as a Python file or Jupyter notebook with:

- Implementation of all required components
- Example outputs showing bilingual capabilities
- Performance analysis (search time, memory usage)
- Discussion of results quality across English and Italian

Problem 3: Building an Intelligent Assistant with LangChain (25 points)

In this task, we will build an intelligent assistant using LangChain that can handle multiple types of queries by implementing custom tools and a routing system. The problem is divided into three main tasks: implementing custom tools, defining schemas for OpenAI functions, and creating a routing system. Each section will include markdown explanations, code implementations, example outputs, and test cases.

Reference Tutorial : https://colab.research.google.com/drive/1jhCnaj68JXD-bVeJJsgAooq99YgjhKaS?usp=sharing

```
# You pacakages installations

import os
import openai
from google.colab import userdata

# openai.api_key = userdata.get('OPENAI_API_KEY')
# os.environ['OPENAI_API_KEY'] = openai.api_key
```

Task 1: Implementing Custom Tools (8 points)

Using the `@tool` decorator from LangChain, implement the following two tools:

```
!pip install langchain yfinance requests pydantic nest_asyncio
langchain-google-genai

Requirement already satisfied: langchain in
/usr/local/lib/python3.10/dist-packages (0.3.7)
Requirement already satisfied: yfinance in
```

```
/usr/local/lib/python3.10/dist-packages (0.2.49)
Requirement already satisfied: requests in
/usr/local/lib/python3.10/dist-packages (2.32.3)
Requirement already satisfied: pydantic in
/usr/local/lib/python3.10/dist-packages (2.9.2)
Requirement already satisfied: PyYAML>=5.3 in
/usr/local/lib/python3.10/dist-packages (from langchain) (6.0.2)
Requirement already satisfied: SQLAlchemy<3,>=1.4 in
/usr/local/lib/python3.10/dist-packages (from langchain) (2.0.36)
Requirement already satisfied: aiohttp<4.0.0,>=3.8.3 in
/usr/local/lib/python3.10/dist-packages (from langchain) (3.11.2)
Requirement already satisfied: async-timeout<5.0.0,>=4.0.0 in
/usr/local/lib/python3.10/dist-packages (from langchain) (4.0.3)
Requirement already satisfied: langchain-core<0.4.0,>=0.3.15 in
/usr/local/lib/python3.10/dist-packages (from langchain) (0.3.19)
Requirement already satisfied: langchain-text-splitters<0.4.0,>=0.3.0
in /usr/local/lib/python3.10/dist-packages (from langchain) (0.3.2)
Requirement already satisfied: langsmith<0.2.0,>=0.1.17 in
/usr/local/lib/python3.10/dist-packages (from langchain) (0.1.143)
Requirement already satisfied: numpy<2,>=1 in
/usr/local/lib/python3.10/dist-packages (from langchain) (1.26.4)
Requirement already satisfied: tenacity!=8.4.0,<10,>=8.1.0 in
/usr/local/lib/python3.10/dist-packages (from langchain) (9.0.0)
Requirement already satisfied: pandas>=1.3.0 in
/usr/local/lib/python3.10/dist-packages (from yfinance) (2.2.2)
Requirement already satisfied: multitasking>=0.0.7 in
/usr/local/lib/python3.10/dist-packages (from yfinance) (0.0.11)
Requirement already satisfied: lxml>=4.9.1 in
/usr/local/lib/python3.10/dist-packages (from yfinance) (5.3.0)
Requirement already satisfied: platformdirs>=2.0.0 in
/usr/local/lib/python3.10/dist-packages (from yfinance) (4.3.6)
Requirement already satisfied: pytz>=2022.5 in
/usr/local/lib/python3.10/dist-packages (from yfinance) (2024.2)
Requirement already satisfied: frozendict>=2.3.4 in
/usr/local/lib/python3.10/dist-packages (from yfinance) (2.4.6)
Requirement already satisfied: peewee>=3.16.2 in
/usr/local/lib/python3.10/dist-packages (from yfinance) (3.17.8)
Requirement already satisfied: beautifulsoup4>=4.11.1 in
/usr/local/lib/python3.10/dist-packages (from yfinance) (4.12.3)
Requirement already satisfied: html5lib>=1.1 in
/usr/local/lib/python3.10/dist-packages (from yfinance) (1.1)
Requirement already satisfied: charset-normalizer<4,>=2 in
/usr/local/lib/python3.10/dist-packages (from requests) (3.4.0)
Requirement already satisfied: idna<4,>=2.5 in
/usr/local/lib/python3.10/dist-packages (from requests) (3.10)
Requirement already satisfied: urllib3<3,>=1.21.1 in
/usr/local/lib/python3.10/dist-packages (from requests) (2.2.3)
Requirement already satisfied: certifi>=2017.4.17 in
/usr/local/lib/python3.10/dist-packages (from requests) (2024.8.30)
```

```
Requirement already satisfied: annotated-types>=0.6.0 in
/usr/local/lib/python3.10/dist-packages (from pydantic) (0.7.0)
Requirement already satisfied: pydantic-core==2.23.4 in
/usr/local/lib/python3.10/dist-packages (from pydantic) (2.23.4)
Requirement already satisfied: typing-extensions>=4.6.1 in
/usr/local/lib/python3.10/dist-packages (from pydantic) (4.12.2)
Requirement already satisfied: aiohappyeyeballs>=2.3.0 in
/usr/local/lib/python3.10/dist-packages (from aiohttp<4.0.0,>=3.8.3-
>langchain) (2.4.3)
Requirement already satisfied: aiosignal>=1.1.2 in
/usr/local/lib/python3.10/dist-packages (from aiohttp<4.0.0,>=3.8.3-
>langchain) (1.3.1)
Requirement already satisfied: attrs>=17.3.0 in
/usr/local/lib/python3.10/dist-packages (from aiohttp<4.0.0,>=3.8.3-
>langchain) (24.2.0)
Requirement already satisfied: frozenlist>=1.1.1 in
/usr/local/lib/python3.10/dist-packages (from aiohttp<4.0.0,>=3.8.3-
>langchain) (1.5.0)
Requirement already satisfied: multidict<7.0,>=4.5 in
/usr/local/lib/python3.10/dist-packages (from aiohttp<4.0.0,>=3.8.3-
>langchain) (6.1.0)
Requirement already satisfied: propcache>=0.2.0 in
/usr/local/lib/python3.10/dist-packages (from aiohttp<4.0.0,>=3.8.3-
>langchain) (0.2.0)
Requirement already satisfied: yarl<2.0,>=1.17.0 in
/usr/local/lib/python3.10/dist-packages (from aiohttp<4.0.0,>=3.8.3-
>langchain) (1.17.2)
Requirement already satisfied: soupsieve>1.2 in
/usr/local/lib/python3.10/dist-packages (from beautifulsoup4>=4.11.1-
>yfinance) (2.6)
Requirement already satisfied: six>=1.9 in
/usr/local/lib/python3.10/dist-packages (from html5lib>=1.1->yfinance)
(1.16.0)
Requirement already satisfied: webencodings in
/usr/local/lib/python3.10/dist-packages (from html5lib>=1.1->yfinance)
(0.5.1)
Requirement already satisfied: jsonpatch<2.0,>=1.33 in
/usr/local/lib/python3.10/dist-packages (from langchain-
core<0.4.0,>=0.3.15->langchain) (1.33)
Requirement already satisfied: packaging<25,>=23.2 in
/usr/local/lib/python3.10/dist-packages (from langchain-
core<0.4.0,>=0.3.15->langchain) (24.2)
Requirement already satisfied: httpx<1,>=0.23.0 in
/usr/local/lib/python3.10/dist-packages (from
langsmith<0.2.0,>=0.1.17->langchain) (0.27.2)
Requirement already satisfied: orjson<4.0.0,>=3.9.14 in
/usr/local/lib/python3.10/dist-packages (from
langsmith<0.2.0,>=0.1.17->langchain) (3.10.11)
Requirement already satisfied: requests-toolbelt<2.0.0,>=1.0.0 in
```

```
/usr/local/lib/python3.10/dist-packages (from
langsmith<0.2.0,>=0.1.17->langchain) (1.0.0)
Requirement already satisfied: python-dateutil>=2.8.2 in
/usr/local/lib/python3.10/dist-packages (from pandas>=1.3.0->yfinance)
(2.8.2)
Requirement already satisfied: tzdata>=2022.7 in
/usr/local/lib/python3.10/dist-packages (from pandas>=1.3.0->yfinance)
(2024.2)
Requirement already satisfied: greenlet!=0.4.17 in
/usr/local/lib/python3.10/dist-packages (from SQLAlchemy<3,>=1.4-
>langchain) (3.1.1)
Requirement already satisfied: anyio in
/usr/local/lib/python3.10/dist-packages (from httpx<1,>=0.23.0-
>langsmith<0.2.0,>=0.1.17->langchain) (3.7.1)
Requirement already satisfied: httpcore==1.* in
/usr/local/lib/python3.10/dist-packages (from httpx<1,>=0.23.0-
>langsmith<0.2.0,>=0.1.17->langchain) (1.0.7)
Requirement already satisfied: sniffio in
/usr/local/lib/python3.10/dist-packages (from httpx<1,>=0.23.0-
>langsmith<0.2.0,>=0.1.17->langchain) (1.3.1)
Requirement already satisfied: h11<0.15,>=0.13 in
/usr/local/lib/python3.10/dist-packages (from httpcore==1.*-
>httpx<1,>=0.23.0->langsmith<0.2.0,>=0.1.17->langchain) (0.14.0)
Requirement already satisfied: jsonpointer>=1.9 in
/usr/local/lib/python3.10/dist-packages (from jsonpatch<2.0,>=1.33-
>langchain-core<0.4.0,>=0.3.15->langchain) (3.0.0)
Requirement already satisfied: exceptiongroup in
/usr/local/lib/python3.10/dist-packages (from anyio->httpx<1,>=0.23.0-
>langsmith<0.2.0,>=0.1.17->langchain) (1.2.2)
```

1. NewsSearchTool (4 points)

- Accepts a query string and returns relevant news headlines.
- Uses a free news API (specify the API in the documentation).
- Returns at least three headlines with publication dates.
- Implements error handling for API failures and invalid inputs.
- Clear Documentation: Explain each step, including API usage and error handling mechanisms.

Example Code:

```python
@tool
def news_search(query: str) -> List[Dict[str, str]]:
    # Implement the news search functionality here
    pass

from langchain.agents import tool
from typing import Optional
from pydantic import BaseModel, Field
```

```
@tool
def search_news(
    query: str,
    max_results: int = 3
) -> str:
    """
    Search for news articles based on a query.

    Args:
        query: The search query
        max_results: Maximum number of results to return (default: 3)

    Returns:
        A string containing the news articles found
    """
    try:
        API_KEY = "your_newsapi_key_here"

        # Build the API URL with parameters
        base_url = "https://newsapi.org/v2/everything"
        params = {
            'q': query,
            'sortBy': 'publishedAt',
            'language': 'en',
            'apiKey': API_KEY,
            'pageSize': max_results
        }

        # Make the request
        response = requests.get(base_url, params=params, timeout=10)

        if response.status_code != 200:
            return f"Error fetching news: {response.status_code}"

        data = response.json()
        articles = data.get('articles', [])

        if not articles:
            return f"No news found for query: {query}"

        # Format results
        result = f"Found {len(articles)} news articles for '{query}':\n\n"

        for i, article in enumerate(articles[:max_results], 1):
            result += f"{i}. {article.get('title', 'No title')}\n"
            result += f"Date: {article.get('publishedAt', 'No date')[:10]}\n"
            result += f"Source: {article.get('source', {}).get('name', 'Unknown')}\n"
            if article.get('description'):
                result += f"Summary: {article['description']}\n"
            result += f"URL: {article.get('url', 'No URL')}\n\n"

        return result

    except Exception as e:
        return f"Error searching news: {str(e)}"
```

2. StockPriceTool (4 points)

- Retrieves current stock prices using `yfinance` or a similar library.
- Returns the current price, daily high, and daily low.
- Implements input validation for stock symbols.
- Handles errors for invalid symbols and API failures.

Example Code:

```
@tool
def stock_price(symbol: str) -> Dict[str, float]:
    # Implement the stock price retrieval functionality here
    pass

# Part 2: Tool Implementations
@tool
def check_stock_price(
    symbol: str,
    include_history: bool = False
) -> str:
    """
    Get the current stock price and optionally historical data for a given symbol.

    Args:
        symbol: The stock symbol to look up (e.g., 'AAPL' for Apple)
        include_history: If True, includes recent price history

    Returns:
        A string containing the stock information
    """
    try:
        # Get stock data using yfinance
        stock = yf.Ticker(symbol)
        info = stock.info

        if not info:
            return f"No data found for symbol {symbol}"
        # Get current price
        current_price = info.get('currentPrice',
info.get('regularMarketPrice', 0))

        if not current_price:
            return f"Could not get current price for {symbol}"

        result = f"Current price of {symbol}: ${current_price:.2f}\n"

        # Add additional info
        result += f"Day Range: ${info.get('dayLow', 0):.2f} - $
{info.get('dayHigh', 0):.2f}\n"
        result += f"Volume: {info.get('volume', 0):,}\n"

        # Include history if requested
        if include_history:
            history = stock.history(period="5d")
            if not history.empty:
                result += "\nRecent price history:\n"
                for date, row in history.iterrows():
                    result += f"{date.date()}: Open $
{row['Open']:.2f}, Close ${row['Close']:.2f}\n"

        return result

    except Exception as e:
        return f"Error checking stock price: {str(e)}"
```

Task 2: Defining Schemas for OpenAI Function (7 points)

Define Pydantic schemas and formats for integrating tools with OpenAI functions:

1. Creating Pydantic Schemas (3 points)

- Define input fields with type hints
- Add field descriptions using the Field class
- Implement input validation rules
- Demonstrate schema usage with valid/invalid inputs

Example Schema:

```
class NewsSearchInput(BaseModel):
    query: str = Field(..., description="Search query for news")

class StockPriceInput(BaseModel):
    symbol: str = Field(..., description="Stock symbol for price
retrieval")
```

2. Formatting Tools for OpenAI Integration (4 points)

- Convert tools using format tool to openai function
- Create unified function list for the assistant
- Show formatted function descriptions
- Demonstrate model's tool selection process

```
class StockPriceCheckInput(BaseModel):
    """Input for checking stock prices."""
    symbol: str = Field(description="The stock symbol to check")
    include_history: Optional[bool] = Field(
        default=False,
        description="Whether to include price history"
    )

class NewsSearchInput(BaseModel):
    """Input for searching news articles."""
    query: str = Field(description="The search query for news")
    max_results: Optional[int] = Field(
        default=3,
        description="Maximum number of results to return"
    )
```

Task 3: Implementing the Routing System (10 points)

This task involves constructing a routing chain and implementing routing logic:

1. Constructing the Routing Chain (4 points)

- Create `ChatPromptTemplate` with a system message.
- Configure `ChatOpenAI` model with functions and add `OpenAIFunctionsAgentOutputParser`.
- Document the chain construction process.

Example Code:

```
# Initialize the model and chain configuration

from langchain_google_genai import ChatGoogleGenerativeAI
from langchain.prompts import ChatPromptTemplate
from langchain.schema import HumanMessage, SystemMessage
from langchain.agents import AgentExecutor
from langchain.tools import tool
from langchain.agents.output_parsers import JSONAgentOutputParser
from typing import List, Dict, Any
import google.generativeai as genai
import logging
import json
from datetime import datetime
```

```
# Set up logging
logging.basicConfig(level=logging.INFO)
logger = logging.getLogger(__name__)

# Part 1: Constructing the Routing Chain

# System message template for the routing agent
SYSTEM_TEMPLATE = """You are a helpful assistant that routes user
queries to appropriate tools.
Available tools:
- check_stock_price: Get current stock prices and optional history
- search_news: Search for recent news articles

Guidelines:
1. For stock queries, extract the symbol and determine if history is
needed
2. For news queries, determine appropriate search terms and result
count
3. For mixed queries, use both tools as needed
4. If no tool is needed, respond directly

Response Format:
{
    "tool": "tool_name or 'direct_response'",
    "params": {
        "param1": "value1",
        ...
    },
    "reasoning": "brief explanation of the choice"
}

Always aim to provide the most relevant and complete information."""

class GeminiOutputParser(JSONAgentOutputParser):
    """Custom output parser for Gemini responses."""

    def parse(self, text: str) -> Dict:
        """Parse the Gemini response into a structured format."""
        try:
            # Clean up the text to ensure it's valid JSON
            cleaned_text = text.strip()
            if cleaned_text.startswith("```json"):
                cleaned_text = cleaned_text[7:]
            if cleaned_text.endswith("```"):
                cleaned_text = cleaned_text[:-3]

            # Parse the JSON response
            parsed = json.loads(cleaned_text)

            return {
```

```
                "tool": parsed.get("tool", "direct_response"),
                "params": parsed.get("params", {}),
                "reasoning": parsed.get("reasoning", "No reasoning
provided")
            }
        except json.JSONDecodeError as e:
            logger.error(f"JSON parsing error: {str(e)}")
            return {
                "tool": "direct_response",
                "params": {},
                "reasoning": "Failed to parse response"
            }

def initialize_routing_chain(tools: List[Any], api_key: str,
temperature: float = 0.1) -> AgentExecutor:
    """
    Initialize the routing chain with Gemini and specified tools.

    Args:
        tools: List of available tools
        api_key: Google API key
        temperature: Temperature setting for the model

    Returns:
        AgentExecutor: Configured agent executor
    """
    try:
        logger.info("Initializing routing chain with Gemini...")

        # Configure Gemini
        genai.configure(api_key=api_key)

        # Create the chat prompt template
        prompt = ChatPromptTemplate.from_messages([
            ("system", SYSTEM_TEMPLATE),
            ("human", "{input}")
        ])

        # Initialize the Gemini chat model
        llm = ChatGoogleGenerativeAI(
            model="gemini-1.5-flash",
            temperature=temperature,
            convert_system_message_to_human=True
        )

        # Create the agent with custom output parser
        output_parser = GeminiOutputParser()

        agent = (
            {
```

```
        "input": lambda x: x["input"]
      }
      | prompt
      | llm
      | output_parser
    )

    # Create the agent executor
    agent_executor = AgentExecutor(
      agent=agent,
      tools=tools,
      verbose=True,
      handle_parsing_errors=True
    )

    logger.info("Routing chain initialized successfully")
    return agent_executor

  except Exception as e:
    logger.error(f"Error initializing routing chain: {str(e)}")
    raise
```

```
/usr/local/lib/python3.10/dist-packages/pydantic/_internal/
_model_construction.py:717: RuntimeWarning: coroutine 'test_system'
was never awaited
  proxy = _PydanticWeakRef(v)
RuntimeWarning: Enable tracemalloc to get the object allocation
traceback
```

2. Creating Routing Logic (3 points)

- Route tool calls and handle direct responses.
- Implement error handling for failed executions.
- Add debugging logs to the process.

```
# Part 2: Routing Logic

class GeminiQueryRouter:
  """
  Handles routing of queries using Gemini AI.
  """

  def __init__(self, agent_executor: AgentExecutor):
    self.agent_executor = agent_executor
    self.error_count = 0
    self.max_retries = 2

  async def route_query(self, query: str) -> Dict[str, Any]:
    """
    Route a query to appropriate tools using Gemini.
```

```
        Args:
            query: User's input query

        Returns:
            Dict containing response and metadata
        """
        logger.info(f"Processing query: {query}")

        try:
            # Execute the query
            response = await self.agent_executor.arun(
                input=query,
                return_intermediate_steps=True
            )

            # Process and format the response
            result = self._format_response(response)

            logger.info("Query processed successfully")
            return result

        except Exception as e:
            logger.error(f"Error processing query: {str(e)}")
            return self._handle_error(e)

    def _format_response(self, response: Dict[str, Any]) -> Dict[str,
Any]:
        """Format the response from Gemini."""
        return {
            "status": "success",
            "response": {
                "tool_used": response.get("tool", "direct_response"),
                "reasoning": response.get("reasoning", ""),
                "output": response.get("output", "")
            },
            "metadata": {
                "error_count": self.error_count,
                "timestamp": datetime.now().isoformat()
            }
        }

    def _handle_error(self, error: Exception) -> Dict[str, Any]:
        """Handle errors in query processing."""
        self.error_count += 1
        return {
            "status": "error",
            "error_type": type(error).__name__,
            "message": str(error),
            "metadata": {
                "error_count": self.error_count,
                "timestamp": datetime.now().isoformat()
            }
        }
```

3. Testing the System (3 points)

- Test with at least five different query types, including edge cases.
- Document the system's limitations and suggest improvements.
- Provide example conversations and error handling.

```
import os
from typing import Dict, List, Any
from datetime import datetime
import yfinance as yf
import requests
import json
import logging
from pydantic import BaseModel, Field
from langchain_core.messages import HumanMessage, SystemMessage,
AIMessage
from langchain_core.prompts import MessagesPlaceholder,
ChatPromptTemplate
from langchain_core.tools import Tool
from langchain.agents import AgentExecutor, create_openai_tools_agent
from langchain_google_genai import ChatGoogleGenerativeAI,
HarmBlockThreshold, HarmCategory

# Set up logging
logging.basicConfig(level=logging.INFO)
logger = logging.getLogger(__name__)

def check_stock_price(query: str) -> str:
    """Get current stock price and optional historical data."""
    try:
        symbol = query.strip().upper()
        stock = yf.Ticker(symbol)
        info = stock.info

        if not info:
            return f"No data found for symbol {symbol}"

        current_price = info.get('currentPrice',
info.get('regularMarketPrice', 0))
        if not current_price:
            return f"Could not get current price for {symbol}"

        result = f"Current price of {symbol}: ${current_price:.2f}\n"
        result += f"Day Range: ${info.get('dayLow', 0):.2f} - $
{info.get('dayHigh', 0):.2f}\n"
```

```
        volume = info.get('volume', 0)
        market_cap = info.get('marketCap', 0)
        result += f"Volume: {volume:,}\n"
        result += f"Market Cap: ${market_cap:,.2f}\n"

        return result
    except Exception as e:
        logger.error(f"Error in check_stock_price: {str(e)}")
        return f"Error checking stock price: {str(e)}"

def search_news(query: str) -> str:
    """Search for recent news articles."""
    try:
        max_results = 3
        # NEWS_API_KEY = os.getenv("NEWS_API_KEY")
        NEWS_API_KEY = "05360b72a0324723a37579e35852fa73"

        if not NEWS_API_KEY:
            return "Error: NEWS_API_KEY not found in environment
variables"

        base_url = "https://newsapi.org/v2/everything"
        params = {
            'q': query,
            'sortBy': 'publishedAt',
            'language': 'en',
            'apiKey': NEWS_API_KEY,
            'pageSize': max_results
        }

        response = requests.get(base_url, params=params, timeout=10)
        response.raise_for_status()

        articles = response.json().get('articles', [])
        if not articles:
            return f"No news found for query: {query}"

        result = f"Found {len(articles)} recent news articles for
'{query}':\n\n"
        for i, article in enumerate(articles[:max_results], 1):
            result += f"{i}. {article.get('title', 'No title')}\n"
            result += f"Date: {article.get('publishedAt', 'No date')
[:10]}\n"
            result += f"Source: {article.get('source', {}).get('name',
'Unknown')}\n"
            if article.get('description'):
                result += f"Summary: {article['description']}\n"
            result += f"URL: {article.get('url', 'No URL')}\n\n"
        return result
    except requests.exceptions.RequestException as e:
        logger.error(f"API request error in search_news: {str(e)}")
        return f"Error fetching news: {str(e)}"
    except Exception as e:
        logger.error(f"Error in search_news: {str(e)}")
        return f"Error searching news: {str(e)}"

def create_agent_chain(api_key: str) -> AgentExecutor:
    """Create a LangChain agent with the tools."""
    try:
        llm = ChatGoogleGenerativeAI(
            model="gemini-1.5-flash-8b",
            google_api_key=api_key,
            temperature=0.1
        )

        tools = [
            Tool(
                name="check_stock_price",
                func=lambda x: check_stock_price(x),
                description="Get current stock price. Input: stock
symbol (e.g., 'AAPL')"
            ),
            Tool(
                name="search_news",
                func=lambda x: search_news(x),
                description="Search news articles. Input: search
query"
            )
        ]

        prompt = ChatPromptTemplate.from_messages([
            SystemMessage(content="You are a financial assistant. For
stock queries, check price first then news."),
            MessagesPlaceholder(variable_name="chat_history"),
            HumanMessage(content="{input}"),
            MessagesPlaceholder(variable_name="agent_scratchpad")
        ])

        agent = initialize_agent(
            tools,
            llm,

agent=AgentType.STRUCTURED_CHAT_ZERO_SHOT_REACT_DESCRIPTION,
            verbose=True,
            handle_parsing_errors=True
        )

        return agent
    except Exception as e:
        logger.error(f"Agent creation error: {str(e)}")
        raise

async def process_query(agent_chain: AgentExecutor, query: str,
chat_history: List = None) -> Dict:
    try:
        response = await agent_chain.ainvoke({
            "input": query,
            "chat_history": chat_history or []
        })

        return {
            "status": "success",
            "response": response["output"],
            "metadata": {
                "timestamp": datetime.now().isoformat(),
                "query": query
            }
        }
    except Exception as e:
        logger.error(f"Query processing error: {str(e)}")
        return {
            "status": "error",
            "error": str(e),
            "metadata": {
                "timestamp": datetime.now().isoformat(),
                "query": query
            }
        }

async def run_test_queries(api_key: str):
    """Run test queries through the agent chain."""
    try:
        agent_chain = create_agent_chain(api_key)

        test_queries = [
        "What's the current price of AAPL?",
        "Find recent news about artificial intelligence",
        "Tell me about Tesla's stock price and latest news",
        "Tell me the latest news about supermicro computer",
        "News about donald trump"

    ]

        chat_history = []

        for query in test_queries:
            print(f"\nQuery: {query}")
```

```python
            print("-" * 50)

            result = await process_query(agent_chain, query, 
chat_history)
            print(json.dumps(result, indent=2))

            if result["status"] == "success":
                chat_history.extend([
                    HumanMessage(content=query),
                    AIMessage(content=result["response"])
                ])

            print("-" * 80)

    except Exception as e:
        logger.error(f"Error in run_test_queries: {str(e)}")
        print(f"Error running test queries: {str(e)}")

if __name__ == "__main__":
    import asyncio


    GOOGLE_API_KEY = "AIzaSyATxilMVX1MuCQbHgpcZoTaEk6O45lJLXY"

    if not GOOGLE_API_KEY:
        print("Please set the GOOGLE_API_KEY environment variable")
        exit(1)

    NEWS_API_KEY = "05360b72a0324723a37579e35852fa73"
    asyncio.run(run_test_queries(GOOGLE_API_KEY))
```

```
Query: What's the current price of AAPL?
--------------------------------------------------


> Entering new AgentExecutor chain...

ERROR:__main__:Error in check_stock_price: 'dict' object has no 
attribute 'strip'

Action:```
{
  "action": "check_stock_price",
  "action_input": {
    "tool_input": {
      "type": "string",
      "value": "AAPL"
    }
  }
}
```

~~~
```

Observation: Error checking stock price: 'dict' object has no
attribute 'strip'
Thought:

ERROR:__main__:Error in check_stock_price: 'dict' object has no
attribute 'strip'

Action:```
{
  "action": "check_stock_price",
  "action_input": {
    "tool_input": {
      "type": "string",
      "value": "AAPL"
    }
  }
}
```

Observation: Error checking stock price: 'dict' object has no
attribute 'strip'
Thought:Action:```
{
  "action": "check_stock_price",
  "action_input": "AAPL"
}
```

Observation: Current price of AAPL: $234.66
Day Range: $233.81 - $235.69
Volume: 14,554,795
Market Cap: $3,547,073,609,728.00

Thought:Action:```
{
  "action": "Final Answer",
  "action_input": "The current price of AAPL is $234.66."
}
```


> Finished chain.
{
  "status": "success",
  "response": "The current price of AAPL is $234.66.",
  "metadata": {
    "timestamp": "2024-11-27T17:40:37.507790",
    "query": "What's the current price of AAPL?"
~~~

~~~
  }
}
----------------------------------------------------------------------
----------

Query: Find recent news about artificial intelligence
--------------------------------------------------


> Entering new AgentExecutor chain...
Action:```
{
  "action": "search_news",
  "action_input": "artificial intelligence"
}
```

Observation: Found 3 recent news articles for 'artificial
intelligence':

1. Why Arista Networks’ Stock (ANET) Is Still Far Away from Fair Value
Date: 2024-11-26
Source: Yahoo Entertainment
Summary: When Meta needed to build out its AI infrastructure at an
unprecedented scale, it didn’t turn to the traditional giants of the
tech world – it chose Arista...
URL: https://finance.yahoo.com/news/why-arista-networks-stock-anet-
173544691.html

2. The area of the stock market investors should avoid in 2025,
according to Wells Fargo
Date: 2024-11-26
Source: Business Insider
Summary: The S&P 500 is on track to hit 6,600 by the end of next year,
Wells Fargo's Scott Wren said.
URL: https://markets.businessinsider.com/news/stocks/stock-market-
investing-strategy-2025-outlook-defensive-utilities-wells-fargo-2024-
11

3. Delhi Police Use AI To Identify Masked Snatcher, Recovers Stolen
Phone
Date: 2024-11-26
Source: NDTV News
Summary: Delhi Police has used Artificial Intelligence (AI) to unmask
a masked snatcher, who had snatched and run away with the mobile phone
of a woman in north Delhi, an official said on Tuesday.
URL: https://www.ndtv.com/india-news/delhi-police-use-ai-to-identify-
masked-snatcher-recovers-stolen-phone-7112915
~~~

```
Thought:Action:```
{
  "action": "Final Answer",
  "action_input": "Recent news articles about artificial intelligence
include stories about its use in identifying criminals,  and its role
in infrastructure building for companies like Meta.  There are also
general market outlooks that don't directly focus on AI."
}
```

> Finished chain.
{
  "status": "success",
  "response": "Recent news articles about artificial intelligence
include stories about its use in identifying criminals, and its role
in infrastructure building for companies like Meta. There are also
general market outlooks that don't directly focus on AI.",
  "metadata": {
    "timestamp": "2024-11-27T17:40:40.209273",
    "query": "Find recent news about artificial intelligence"
  }
}

Query: Tell me about Tesla's stock price and latest news

> Entering new AgentExecutor chain...

ERROR:__main__:Error in check_stock_price: 'dict' object has no
attribute 'strip'

Thought: I need to get the current stock price of Tesla and some
recent news about the company.

Action:
```json
{
  "action": "check_stock_price",
  "action_input": {
    "tool_input": {
      "type": "string",
      "symbol": "TSLA"
    }
  }
}
```
```
```

~~~
Observation: Error checking stock price: 'dict' object has no
attribute 'strip'
Thought:Thought: I need to use the correct input format for the
check_stock_price tool.  My previous attempt had an incorrect
structure.

Action:
```json
{
  "action": "check_stock_price",
  "action_input": {
    "tool_input": "TSLA"
  }
}
```

Observation: Current price of TSLA: $331.27
Day Range: $326.59 - $342.55
Volume: 40,177,456
Market Cap: $1,063,394,279,424.00

Thought:Action:
```json
{
  "action": "search_news",
  "action_input": {
    "tool_input": "Tesla news"
  }
}
```

Observation: Found 3 recent news articles for 'Tesla news':

1. The small thing that can keep drivers attentive while using partial
automation
Date: 2024-11-26
Source: The Verge
Summary: Partially automated systems that allow drivers to adjust the
steering without disengaging are more likely to result in attentive
drivers, a new IIHS study finds.
URL: https://www.theverge.com/2024/11/26/24306519/adas-partial-
automation-driver-attention-steering-iihs

2. Car factory job losses undeniably a blow - as Vauxhall's parent
company crystal clear on reason behind move
Date: 2024-11-26
Source: Sky.com
Summary: The closure of Vauxhall's Luton van plant is a car crash for
the 1,100 workers who could lose their jobs and threatens to trigger a
~~~

~~~
pile-up for a government facing acute pressure from manufacturers over
its plans to transition to an electric-only future.
URL: https://news.sky.com/story/car-factory-job-losses-undeniably-a-
blow-as-vauxhalls-parent-company-crystal-clear-on-reason-behind-move-
13261175

3. ‘Accountability Is Coming’: Iowa’s Ernst Sends Musk’s DOGE $2T
Worth of Ways to Gut Government Spending
Date: 2024-11-26
Source: Daily Signal
Summary: DAILY CALLER NEWS FOUNDATION—Sen. Joni Ernst sent Department
of Government Efficiency cochairmen Tesla CEO Elon Musk and former
Republican presidential candidate Vivek Ramaswamy a letter... Read
More
The post ‘Accountability Is Coming’: Iowa’s Ernst Sends Mus…
URL: https://www.dailysignal.com/2024/11/26/accountability-is-coming-
joni-ernst-sends-musks-doge-trillion-dollars-worth-ideas-gut-govt-
spending/


Thought:Action:
```json
{
  "action": "Final Answer",
  "action_input": "Tesla's current stock price is $331.27.  Recent
news includes articles about driver attention while using partial
automation, job losses at a Vauxhall factory, and a letter from
Senator Joni Ernst to Elon Musk regarding government spending."
}
```


> Finished chain.
{
  "status": "success",
  "response": "Tesla's current stock price is $331.27.  Recent news
includes articles about driver attention while using partial
automation, job losses at a Vauxhall factory, and a letter from
Senator Joni Ernst to Elon Musk regarding government spending.",
  "metadata": {
    "timestamp": "2024-11-27T17:40:43.723465",
    "query": "Tell me about Tesla's stock price and latest news"
  }
}
----------------------------------------------------------------------
----------

Query: Tell me the latest news about supermicro computer
--------------------------------------------------
~~~

~~~
> Entering new AgentExecutor chain...
Thought: I need to search for news articles about Supermicro.

Action:
```json
{
  "action": "search_news",
  "action_input": "Supermicro computer news"
}
```

Observation: Found 3 recent news articles for 'Supermicro computer
news':

1. Nvidia Stock May Rise As Musk Aims To Buy $9 Billion In AI Chips
Date: 2024-11-24
Source: Forbes
Summary: If Nvidia significantly exceeds conservative growth targets
with help from Blackwell, the stock could rise despite slowing revenue
growth, and the absence of a killer app for generative AI
URL: https://www.forbes.com/sites/petercohan/2024/11/24/nvidia-stock-
may-rise-as-musk-aims-to-buy-9-billion-in-ai-chips/

2. Nvidia comes through again, as AI dominates Microsoft Ignite and
SC24
Date: 2024-11-22
Source: SiliconANGLE News
Summary: The king of artificial intelligence came through. Despite
sky-high expectations, Nvidia Wednesday managed to outdo earnings
expectations as it nearly doubled revenue from a year ago and more
than doubled its profit. Investors more or less liked what CEO Jense…
URL: https://siliconangle.com/2024/11/22/nvidia-comes-ai-dominates-
microsoft-ignite-sc24/

3. S&P 500 Gains and Losses Today: Supermicro Roars Back After
Compliance Filing - Investopedia
Date: 2024-11-20
Source: Slashdot.org
Summary: S&P 500 Gains and Losses Today: Supermicro Roars Back After
Compliance FilingInvestopedia Super Micro Stock Options Send a Message
About What Comes NextBarron's Super Micro shares soar 31% after
company names new auditor to help keep Nasdaq listingCNBC Super …
URL: https://slashdot.org/firehose.pl?op=view&amp;id=175504721


Thought:Thought: I need to summarize the news articles about
Supermicro.

Action:
~~~

~~~
```json
{
  "action": "Final Answer",
  "action_input": "Supermicro is mentioned in a few news articles, but
the focus is on the S&P 500 and Nvidia's performance.  One article
notes Supermicro stock saw a 31% increase after announcing a new
auditor.  There's no specific news about Supermicro's own operations
or products."
}
```


> Finished chain.
{
  "status": "success",
  "response": "Supermicro is mentioned in a few news articles, but the
focus is on the S&P 500 and Nvidia's performance.  One article notes
Supermicro stock saw a 31% increase after announcing a new auditor.
There's no specific news about Supermicro's own operations or
products.",
  "metadata": {
    "timestamp": "2024-11-27T17:40:45.555612",
    "query": "Tell me the latest news about supermicro computer"
  }
}
----------------------------------------------------------------------
----------

Query: News about donald trump
--------------------------------------------------


> Entering new AgentExecutor chain...
Action:```
{
  "action": "search_news",
  "action_input": "news about donald trump"
}
```

Observation: Found 3 recent news articles for 'news about donald
trump':

1. Polling in the age of Trump highlights flawed methods and filtered
realities
Date: 2024-11-26
Source: Phys.Org
Summary: The results of the 2024 presidential election cement a trend
in American politics: Polls cannot accurately gauge support for Donald
Trump. In the 2016, 2020 and now 2024 elections, polls consistently
~~~

~~~
underestimated Trump's support by an average of 2.3 percent…
URL: https://phys.org/news/2024-11-polling-age-trump-highlights-
flawed.html

2. Atlantic hurricane season is coming to an end – will the US be
ready for the next one?
Date: 2024-11-26
Source: The Verge
Summary: The 2024 Atlantic hurricane season was awful in so many ways,
and now the agency that studies storms and issues forecasts faces a
potentially existential threat.
URL: https://www.theverge.com/2024/11/26/24306445/atlantic-hurricane-
season-end-2024-noaa

3. The House January 6 Committee Report Continues to Burn to the
Ground As New Evidence Surfaces
Date: 2024-11-26
Source: Freerepublic.com
Summary: Democrats long ago became convinced that the January 6, 2021,
Capitol "insurrection," coupled with desperate attempts to convince a
majority of Americans that President-elect Donald Trump is the second
coming of Adolf Hitler, or at least a "fascist," and that…
URL: https://freerepublic.com/focus/f-news/4281001/posts


Thought:Action:```
{
  "action": "Final Answer",
  "action_input": "Recent news articles about Donald Trump include
reports on polling inaccuracies in the 2024 election, the end of the
Atlantic hurricane season, and the ongoing debate surrounding the
January 6th Capitol events."
}
```


> Finished chain.
{
  "status": "success",
  "response": "Recent news articles about Donald Trump include reports
on polling inaccuracies in the 2024 election, the end of the Atlantic
hurricane season, and the ongoing debate surrounding the January 6th
Capitol events.",
  "metadata": {
    "timestamp": "2024-11-27T17:40:48.423461",
    "query": "News about donald trump"
  }
}
----------------------------------------------------------------------
----------
~~~

```
!pip install redis
```

```
Collecting redis
  Downloading redis-5.2.0-py3-none-any.whl.metadata (9.1 kB)
Requirement already satisfied: async-timeout>=4.0.3 in
/usr/local/lib/python3.10/dist-packages (from redis) (4.0.3)
Downloading redis-5.2.0-py3-none-any.whl (261 kB)
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 0.0/261.4 kB ? eta -:--:--
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━╺━━━━━ 225.3/261.4 kB 6.5 MB/s eta
0:00:01 ━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 261.4/261.4 kB 4.6
MB/s eta 0:00:00
```

```python
#"Handling more edge cases"

import os
import aiohttp
import asyncio
import redis
import logging
import json
from typing import Dict, List
from datetime import datetime, timedelta
from functools import lru_cache
import yfinance as yf
import requests
from pydantic import BaseModel, Field
from langchain.agents import AgentExecutor, initialize_agent,
AgentType
from langchain.tools import Tool
from langchain_core.messages import HumanMessage, SystemMessage,
AIMessage
from langchain_core.prompts import ChatPromptTemplate,
MessagesPlaceholder
from langchain_google_genai import ChatGoogleGenerativeAI

logging.basicConfig(level=logging.INFO)
logger = logging.getLogger(__name__)

class RateLimiter:
    def __init__(self, calls_per_second=2):
        self.calls_per_second = calls_per_second
        self.timestamps = []

    async def acquire(self):
        now = datetime.now()
        self.timestamps = [ts for ts in self.timestamps
                          if now - ts < timedelta(seconds=1)]
        if len(self.timestamps) >= self.calls_per_second:
            await asyncio.sleep(1)
        self.timestamps.append(now)
```

```python
def check_stock_price(symbol: str) -> str:
    """Get current stock price and optional historical data."""
    try:
        stock = yf.Ticker(symbol.strip().upper())
        info = stock.info

        if not info:
            return f"No data found for symbol {symbol}"

        current_price = info.get('currentPrice',
info.get('regularMarketPrice', 0))
        if not current_price:
            return f"Could not get current price for {symbol}"

        result = [
            f"Current price of {symbol}: ${current_price:.2f}",
            f"Day Range: ${info.get('dayLow', 0):.2f} - $
{info.get('dayHigh', 0):.2f}",
            f"Volume: {info.get('volume', 0):,}",
            f"Market Cap: ${info.get('marketCap', 0):,.2f}"
        ]

        return "\n".join(result)
    except Exception as e:
        logger.error(f"Stock price error: {str(e)}")
        return f"Error checking stock price: {str(e)}"

def search_news(query: str) -> str:
    """Search for recent news articles."""
    try:
        NEWS_API_KEY = os.getenv("NEWS_API_KEY")
        if not NEWS_API_KEY:
            return "NEWS_API_KEY not set"

        params = {
            'q': query,
            'sortBy': 'publishedAt',
            'language': 'en',
            'apiKey': NEWS_API_KEY,
            'pageSize': 3
        }

        response = requests.get(
            "https://newsapi.org/v2/everything",
            params=params,
            timeout=10
        )
        response.raise_for_status()
        articles = response.json().get('articles', [])
        if not articles:
            return f"No news found for: {query}"

        result = [f"Recent news about {query}:"]
        for i, article in enumerate(articles, 1):
            result.extend([
                f"\n{i}. {article.get('title')}",
                f"Date: {article.get('publishedAt')[:10]}",
                f"Source: {article.get('source', {}).get('name',
'Unknown')}",
                f"URL: {article.get('url', 'No URL')}\n"
            ])

        return "\n".join(result)
    except Exception as e:
        logger.error(f"News search error: {str(e)}")
        return f"Error searching news: {str(e)}"

class ImprovedQueryRouter:
    def __init__(self, api_key: str):
        self.api_key = api_key
        self.agent = self._create_agent()
        self.rate_limiter = RateLimiter()
        self.cache = {}

    def _create_agent(self) -> AgentExecutor:
        llm = ChatGoogleGenerativeAI(
            model="gemini-1.5-flash",
            google_api_key=self.api_key,
            temperature=0.1
        )

        # Add batch processing tool
        tools = [
            Tool(
                name="check_stock_price",
                func=lambda x: check_stock_price(x),
                description="Get stock price. Input: single stock
symbol string (e.g., 'AAPL')"
            ),
            Tool(
                name="check_multiple_stocks",
                func=lambda x: self._batch_stock_check(x.split(',')),
                description="Get multiple stock prices. Input: comma-
separated symbols (e.g., 'AAPL,MSFT')"
            ),
            Tool(
                name="search_news",
                func=lambda x: search_news(x),
        description="Search news articles. Input: search query
string"
      )
    ]

    # Enhanced system prompt
    prompt = ChatPromptTemplate.from_messages([
      SystemMessage(content="""You are a financial assistant.
Follow these rules:
1. For single stock queries, use check_stock_price
2. For multiple stocks, use check_multiple_stocks
3. For complex queries, combine tools as needed
4. Always validate input before using tools"""),
      MessagesPlaceholder(variable_name="chat_history"),
      HumanMessage(content="{input}"),
      MessagesPlaceholder(variable_name="agent_scratchpad")
    ])

    return initialize_agent(
      tools,
      llm,

agent=AgentType.STRUCTURED_CHAT_ZERO_SHOT_REACT_DESCRIPTION,
      verbose=True,
      handle_parsing_errors=True
    )

  def _batch_stock_check(self, symbols: List[str], max_batch=5) ->
str:
    """Process multiple stock symbols with rate limiting."""
    if len(symbols) > max_batch:
      return f"Error: Maximum {max_batch} symbols allowed per
request"

    results = []
    for symbol in symbols[:max_batch]:
      try:
        result = self.get_cached_stock_price(symbol.strip())
        results.append(result)
      except Exception as e:
        results.append(f"Error for {symbol}: {str(e)}")

    return "\n\n".join(results)

  @lru_cache(maxsize=100)
  def get_cached_stock_price(self, symbol: str) -> str:
    return check_stock_price(symbol)

  async def process_query(self,
             query: str,
                          chat_history: List = None,
                          retries: int = 3) -> Dict:
        if not query.strip():
            return {
                "status": "error",
                "error": "Empty query",
                "metadata": {
                    "timestamp": datetime.now().isoformat(),
                    "query": query
                }
            }

        try:
            await self.rate_limiter.acquire()

            # Preprocess query for common patterns
            if ',' in query and any(kw in query.lower() for kw in
['price', 'stock', 'ticker']):
                symbols = [s.strip() for s in query.split(',')]
                if len(symbols) > 1:
                    query = f"Use check_multiple_stocks for:
{','.join(symbols)}"

            for attempt in range(retries):
                try:
                    response = await self.agent.ainvoke({
                        "input": query,
                        "chat_history": chat_history or []
                    })

                    return {
                        "status": "success",
                        "response": response["output"],
                        "metadata": {
                            "timestamp": datetime.now().isoformat(),
                            "query": query,
                            "attempt": attempt + 1
                        }
                    }
                except Exception as e:
                    if attempt == retries - 1:
                        raise
                    await asyncio.sleep(2 ** attempt)

        except Exception as e:
            logger.error(f"Query processing error: {str(e)}")
            return {
                "status": "error",
                "error": str(e),
                "metadata": {
                    "timestamp": datetime.now().isoformat(),
                    "query": query
                }
            }

async def test_edge_cases():
    api_key = os.getenv("GOOGLE_API_KEY")
    if not api_key:
        print("GOOGLE_API_KEY not set")
        return

    test_queries = [
        "What's AAPL's current price?",  # Basic stock query
        "Compare NVDA stock price with recent AI chip news",  # Multi-
tool query
        "Get price for INVALID",  # Invalid stock symbol
        "Get prices for AAPL, MSFT, GOOGL, AMZN, META all at once",  #
Rate limit test
        "Tell me about tech layoffs and their impact on stock prices",
# Complex query
        "",  # Empty query
        "Latest tech stock news "*10,  # Very long query
    ]

    router = ImprovedQueryRouter(api_key)

    for query in test_queries:
        print(f"\nProcessing query: {query}")
        print("-" * 50)

        result = await router.process_query(query)

        if result["status"] == "success":
            print(f"Response: {result['response']}")
        else:
            print(f"Error: {result['error']}")

        print(f"Metadata: {result['metadata']}")
        print("-" * 50)

if __name__ == "__main__":


    asyncio.run(test_edge_cases())
```

```
Processing query: What's AAPL's current price?
--------------------------------------------------


> Entering new AgentExecutor chain...
```

~~~
Thought:I need to use the `check_stock_price` tool to get AAPL's
current stock price.
Action:
```json
{
  "action": "check_stock_price",
  "action_input": "AAPL"
}
```

Observation: Current price of AAPL: $234.72
Day Range: $233.81 - $235.69
Volume: 15,020,976
Market Cap: $3,547,981,938,688.00
Thought:Thought:I have the information.  I can provide the final
answer.
Action:
```json
{
  "action": "Final Answer",
  "action_input": "AAPL's current price is $234.72."
}
```


> Finished chain.
Response: AAPL's current price is $234.72.
Metadata: {'timestamp': '2024-11-27T17:59:51.994945', 'query': "What's
AAPL's current price?", 'attempt': 1}
--------------------------------------------------

Processing query: Compare NVDA stock price with recent AI chip news
--------------------------------------------------


> Entering new AgentExecutor chain...
Thought:I need to get the current NVDA stock price and search for
recent news about AI chips.

Action:
```json
{
  "action": "check_stock_price",
  "action_input": "NVDA"
}
```

Observation: Current price of NVDA: $133.05
Day Range: $131.90 - $135.12
Volume: 135,476,591
~~~

~~~
Market Cap: $3,258,453,327,872.00
Thought:Thought:Now I need to search for recent news about AI chips.

Action:
```json
{
  "action": "search_news",
  "action_input": "AI chip news"
}
```

Observation: Recent news about AI chip news:

1. Enhanced observability for AWS Trainium and AWS Inferentia with
Datadog
Date: 2024-11-26
Source: Amazon.com
URL: https://aws.amazon.com/blogs/machine-learning/enhanced-
observability-for-aws-trainium-and-aws-inferentia-with-datadog/


2. Good Morning, News: Drake Sues Over Diss Track, (Alleged) New Clue
in DB Cooper Case, and Trump's Plan to Tank the Economy
Date: 2024-11-26
Source: The Portland Mercury
URL:
https://www.portlandmercury.com/good-morning-news/2024/11/26/47519501/
good-morning-news-drake-sues-over-diss-track-alleged-new-clue-in-db-
cooper-case-and-trumps-plan-to-tank-the-economy


3. What’s up with… Deutsche Telekom, Telenor, Qualcomm & Intel
Date: 2024-11-26
Source: TelecomTV
URL: https://www.telecomtv.com/content/access-evolution/what-s-up-
with-deutsche-telekom-telenor-qualcomm-intel-51853/

Thought:Thought:The news results are not directly related to NVDA's
stock price.  I need to refine my search to focus on news specifically
about NVDA and AI chips.

Action:
```json
{
  "action": "search_news",
  "action_input": "NVDA AI chip news"
}
```

Observation: Recent news about NVDA AI chip news:
~~~

~~~
1. How the Trump tariffs on Taiwan chips could hurt the AI trade — and
the likes of Nvidia
Date: 2024-11-26
Source: Freerepublic.com
URL: https://freerepublic.com/focus/f-news/4280928/posts


2. NVIDIA Corporation (NVDA) Downgraded by Phillip Securities on
Margin Guidance Despite Price Target Increase
Date: 2024-11-25
Source: Yahoo Entertainment
URL: https://finance.yahoo.com/news/nvidia-corporation-nvda-
downgraded-phillip-091854122.html


3. After Nvidia earnings, is the AI trend still investors’ friend?
Date: 2024-11-24
Source: Yahoo Entertainment
URL: https://finance.yahoo.com/news/after-nvidia-earnings-is-the-ai-
trend-still-investors-friend-150035522.html

Thought:Thought:I now have the current NVDA stock price and some
relevant news articles. I can formulate a response comparing the two.

Action:
```json
{
  "action": "Final Answer",
  "action_input": "NVDA's current stock price is $133.05. Recent news
indicates mixed sentiment regarding the company's performance and the
broader AI chip market.  Some articles highlight concerns about
potential impacts from tariffs and margin guidance, while others
discuss the ongoing relevance of the AI trend for investors.
Therefore, while the stock price is currently at $133.05, the news
suggests a degree of uncertainty surrounding future performance."
}
```


> Finished chain.
Response: NVDA's current stock price is $133.05. Recent news indicates
mixed sentiment regarding the company's performance and the broader AI
chip market.  Some articles highlight concerns about potential impacts
from tariffs and margin guidance, while others discuss the ongoing
relevance of the AI trend for investors.  Therefore, while the stock
price is currently at $133.05, the news suggests a degree of
uncertainty surrounding future performance.
Metadata: {'timestamp': '2024-11-27T17:59:58.018570', 'query':
'Compare NVDA stock price with recent AI chip news', 'attempt': 1}
~~~

~~~
--------------------------------------------------

Processing query: Get price for INVALID
--------------------------------------------------


> Entering new AgentExecutor chain...
Thought:The stock symbol "INVALID" is not a valid ticker symbol.  I
need to handle this gracefully.

Action:
```json
{
  "action": "Final Answer",
  "action_input": "I'm sorry, I cannot find a stock with the symbol
'INVALID'. Please check the symbol for typos or ensure it is a valid
stock ticker."
}
~~~

> Finished chain.
Response: I'm sorry, I cannot find a stock with the symbol 'INVALID'.
Please check the symbol for typos or ensure it is a valid stock
ticker.
Metadata: {'timestamp': '2024-11-27T17:59:58.837432', 'query': 'Get
price for INVALID', 'attempt': 1}

Processing query: Get prices for AAPL, MSFT, GOOGL, AMZN, META all at
once

> Entering new AgentExecutor chain...
Thought:I need to use the check_multiple_stocks tool to get the prices
of AAPL, MSFT, GOOGL, AMZN, and META.
Action:
```json
{
  "action": "check_multiple_stocks",
  "action_input": "AAPL,MSFT,GOOGL,AMZN,META"
}
```

Observation: Current price of AAPL: $234.70
Day Range: $233.81 - $235.69
Volume: 15,033,334
Market Cap: $3,547,678,113,792.00
```
```

~~~
Current price of MSFT: $423.34
Day Range: $422.99 - $427.23
Volume: 6,671,911
Market Cap: $3,147,482,005,504.00

Current price of GOOGL: $168.94
Day Range: $168.02 - $169.48
Volume: 6,322,999
Market Cap: $2,076,289,531,904.00

Current price of AMZN: $205.70
Day Range: $205.06 - $207.64
Volume: 14,048,736
Market Cap: $2,162,935,595,008.00

Current price of META: $566.77
Day Range: $564.10 - $574.98
Volume: 3,592,341
Market Cap: $1,430,804,627,456.00
Thought:Thought:I have the stock prices.  I need to format this
information for a final answer.
Action:
```json
{
  "action": "Final Answer",
  "action_input": "Here are the current stock prices for the requested
symbols:\n\nAAPL: $234.70\nMSFT: $423.34\nGOOGL: $168.94\nAMZN:
$205.70\nMETA: $566.77\n\n*Please note that these prices are current
as of the time of the query and are subject to change.*"
}
```


> Finished chain.
Response: Here are the current stock prices for the requested symbols:

AAPL: $234.70
MSFT: $423.34
GOOGL: $168.94
AMZN: $205.70
META: $566.77

*Please note that these prices are current as of the time of the query
and are subject to change.*
Metadata: {'timestamp': '2024-11-27T18:00:04.385197', 'query': 'Use
check_multiple_stocks for: Get prices for AAPL,MSFT,GOOGL,AMZN,META
all at once', 'attempt': 1}
--------------------------------------------------

Processing query: Tell me about tech layoffs and their impact on stock
~~~

~~~
prices
--------------------------------------------------


> Entering new AgentExecutor chain...
Thought:To understand the impact of tech layoffs on stock prices, I
need to search for news articles about recent tech layoffs and their
subsequent stock market performance.  I'll then synthesize that
information.

Action:
```json
{
  "action": "search_news",
  "action_input": "impact of tech layoffs on stock prices"
}
```

Observation: Recent news about impact of tech layoffs on stock prices:

1. Citadel's Ken Griffin considers selling minority shares whilst
handing out political advice to Trump
Date: 2024-11-22
Source: Business Insider
URL: https://www.businessinsider.com/ken-griffin-cidatel-founder-
offered-trump-advice-immigration-inflation-2024-11


2. Pivoting in politics, tech, antitrust and economic growth | Gary
Shapiro interview
Date: 2024-11-20
Source: VentureBeat
URL: https://venturebeat.com/ai/pivoting-in-politics-tech-antitrust-
and-economic-growth-gary-shapiro-interview/


3. AMD Cuts 4% Of Workforce In Push Toward AI Dominance: What This
Means For Workers And The Tech Industry
Date: 2024-11-16
Source: Forbes
URL: https://www.forbes.com/sites/tomspiggle/2024/11/15/amd-cuts-4-of-
workforce-in-push-toward-ai-dominance-what-this-means-for-workers-and-
the-tech-industry/

Thought:Thought:The news articles provide some context.  One article
mentions AMD's layoffs and their potential impact. To get a clearer
picture, I should check AMD's stock price performance around the time
of the layoff announcement.

Action:
~~~

~~~
```json
{
  "action": "check_stock_price",
  "action_input": "AMD"
}
```

Observation: Current price of AMD: $134.14
Day Range: $132.96 - $137.94
Volume: 17,408,460
Market Cap: $217,683,722,240.00
Thought:Thought:The stock price information alone isn't sufficient to
determine the impact of the layoffs.  I need more information, such as
the stock price before the layoff announcement.  I also need to
analyze more news articles to get a broader perspective.

Action:
```json
{
  "action": "search_news",
  "action_input": "AMD layoffs stock price impact"
}
```

Observation: Recent news about AMD layoffs stock price impact:

1. Qualcomm backs off full Intel acquisition, could consider buying
select divisions
Date: 2024-11-26
Source: TechSpot
URL: https://www.techspot.com/news/105722-qualcomm-backs-off-full-
intel-acquisition-could-consider.html


2. AMD Cuts 4% Of Workforce In Push Toward AI Dominance: What This
Means For Workers And The Tech Industry
Date: 2024-11-16
Source: Forbes
URL: https://www.forbes.com/sites/tomspiggle/2024/11/15/amd-cuts-4-of-
workforce-in-push-toward-ai-dominance-what-this-means-for-workers-and-
the-tech-industry/

Thought:Thought:The additional news search didn't provide specific
stock price information related to the AMD layoffs.  To get a more
complete picture, I need to look at the stock price trend before and
after the layoff announcement (November 15th, 2024, according to
Forbes).  I'll also broaden my search to include other companies'
layoff announcements and their stock price reactions.

Action:
~~~

~~~
```json
{
  "action": "search_news",
  "action_input": "tech layoffs 2024 stock market impact"
}
```

Observation: Recent news about tech layoffs 2024 stock market impact:

1. Will Trump’s DOJ Dismantle Big Tech Monopolies?
Date: 2024-11-25
Source: Forbes
URL: https://www.forbes.com/sites/emilsayegh/2024/11/25/will-trumps-
doj-break-up-the-big-tech-giants/


2. 2:00PM Water Cooler 11/20/2024
Date: 2024-11-20
Source: Nakedcapitalism.com
URL: https://www.nakedcapitalism.com/2024/11/200pm-water-cooler-11-20-
2024.html


3. Pivoting in politics, tech, antitrust and economic growth | Gary
Shapiro interview
Date: 2024-11-20
Source: VentureBeat
URL: https://venturebeat.com/ai/pivoting-in-politics-tech-antitrust-
and-economic-growth-gary-shapiro-interview/

Thought:Thought:The news searches haven't yielded specific data on
stock price movements following layoff announcements.  To answer the
question effectively, I need to either access historical stock data
(which I don't have access to with these tools) or focus on a more
general answer about the potential impact of layoffs on stock prices.

Action:
```json
{
  "action": "Final Answer",
  "action_input": "The impact of tech layoffs on stock prices is
complex and varies depending on several factors.  While layoffs often
signal financial difficulties, the market's reaction depends on how
investors perceive the company's long-term strategy and the reasons
behind the layoffs.  Layoffs aimed at streamlining operations and
improving efficiency might be viewed positively, potentially leading
to a stock price increase. Conversely, layoffs resulting from
significant financial distress or a lack of future prospects could
negatively impact the stock price.  News reports often highlight
individual cases, but a comprehensive analysis requires detailed
~~~

~~~
financial data and a deeper understanding of each company's specific
situation.  Therefore, a simple correlation between layoffs and stock
price changes cannot be reliably established."
}
```


> Finished chain.
Response: The impact of tech layoffs on stock prices is complex and
varies depending on several factors.  While layoffs often signal
financial difficulties, the market's reaction depends on how investors
perceive the company's long-term strategy and the reasons behind the
layoffs.  Layoffs aimed at streamlining operations and improving
efficiency might be viewed positively, potentially leading to a stock
price increase. Conversely, layoffs resulting from significant
financial distress or a lack of future prospects could negatively
impact the stock price.  News reports often highlight individual
cases, but a comprehensive analysis requires detailed financial data
and a deeper understanding of each company's specific situation.
Therefore, a simple correlation between layoffs and stock price
changes cannot be reliably established.
Metadata: {'timestamp': '2024-11-27T18:00:10.369014', 'query': 'Tell
me about tech layoffs and their impact on stock prices', 'attempt': 1}
--------------------------------------------------

Processing query:
--------------------------------------------------
Error: Empty query
Metadata: {'timestamp': '2024-11-27T18:00:10.369157', 'query': ''}
--------------------------------------------------

Processing query: Latest tech stock news Latest tech stock news Latest
tech stock news Latest tech stock news Latest tech stock news Latest
tech stock news Latest tech stock news Latest tech stock news Latest
tech stock news Latest tech stock news
--------------------------------------------------


> Entering new AgentExecutor chain...
Thought:I need to search for the latest tech stock news to answer the
user's question.
Action:
```json
{
  "action": "search_news",
  "action_input": "latest tech stock news"
}
```

Observation: Recent news about latest tech stock news:
~~~

~~~
1. [Removed]
Date: 2024-11-26
Source: [Removed]
URL: https://removed.com


2. Black Friday 2024 is almost here: Everything you need to know about holiday shopping
Date: 2024-11-26
Source: ZDNet
URL: https://www.zdnet.com/article/black-friday-2024-everything-you-need-to-know-about-holiday-shopping/


3. Questor Announces Third Quarter Results
Date: 2024-11-26
Source: Financial Post
URL: https://financialpost.com/globe-newswire/questor-announces-third-quarter-results-4

Thought:Thought:I have retrieved some news articles related to tech stocks.  However, the first result is removed and the others are not directly about tech stock performance.  I need to refine my search to get more relevant results.

Action:
```json
{
  "action": "search_news",
  "action_input": "latest tech stock market news"
}
```

Observation: Recent news about latest tech stock market news:

1. Questor Announces Third Quarter Results
Date: 2024-11-26
Source: Financial Post
URL: https://financialpost.com/globe-newswire/questor-announces-third-quarter-results-4


2. PyroGenesis Receives $2.8 Million Payment Under Existing Drosrite™ Contract with Saudi Client
Date: 2024-11-26
Source: Financial Post
URL: https://financialpost.com/globe-newswire/pyrogenesis-receives-2-8-million-payment-under-existing-drosrite-contract-with-saudi-client
~~~

```
3. WNS (Holdings) Limited (NYSE:WNS) Stake Lessened by Massachusetts
Financial Services Co. MA
Date: 2024-11-26
Source: ETF Daily News
URL: https://www.etfdailynews.com/2024/11/26/wns-holdings-limited-
nysewns-stake-lessened-by-massachusetts-financial-services-co-ma/

Thought:

WARNING:langchain_google_genai.chat_models:Retrying
langchain_google_genai.chat_models._achat_with_retry.<locals>._achat_w
ith_retry in 2.0 seconds as it raised ResourceExhausted: 429 Resource
has been exhausted (e.g. check quota)..
WARNING:langchain_google_genai.chat_models:Retrying
langchain_google_genai.chat_models._achat_with_retry.<locals>._achat_w
ith_retry in 2.0 seconds as it raised ResourceExhausted: 429 Resource
has been exhausted (e.g. check quota)..



> Entering new AgentExecutor chain...

WARNING:langchain_google_genai.chat_models:Retrying
langchain_google_genai.chat_models._achat_with_retry.<locals>._achat_w
ith_retry in 2.0 seconds as it raised ResourceExhausted: 429 Resource
has been exhausted (e.g. check quota)..



> Entering new AgentExecutor chain...

ERROR:__main__:Query processing error: 429 Resource has been exhausted
(e.g. check quota).

Error: 429 Resource has been exhausted (e.g. check quota).
Metadata: {'timestamp': '2024-11-27T18:00:21.384631', 'query': 'Latest
tech stock news Latest tech stock news Latest tech stock news Latest
tech stock news Latest tech stock news Latest tech stock news Latest
tech stock news Latest tech stock news Latest tech stock news Latest
tech stock news '}
--------------------------------------------------
```

Here are the key system limitations and recommended improvements:

1. Error Handling
- Inconsistent response format for invalid stock symbols
- No clear distinction between API errors vs invalid inputs
- Suggested Fix: Standardize error responses and add error type classification
1. Rate Limiting
- Basic implementation with fixed calls/second

- No adaptive rate limiting based on API quotas
- Improvement: Add token bucket algorithm and provider-specific limits

1. Query Processing

- Limited preprocessing of complex queries
- No query validation before tool selection
- Fix: Add query intent classification and input sanitization

1. Tool Integration

- Fixed tool set without dynamic loading
- No tool response validation
- Improvement: Add tool registry system and response validators

1. Performance

- Sequential API calls for multi-stock queries
- No query result caching
- Fix: Implement parallel requests and LRU cache with TTL

Code improvements:

```python
# Add query validation
def validate_query(query: str) -> bool:
    return bool(query and len(query) < 1000)

# Add error classification
def classify_error(error: Exception) -> str:
    if isinstance(error, requests.exceptions.RequestException):
        return "API_ERROR"
    return "UNKNOWN_ERROR"

# Add parallel processing
async def batch_stock_check(self, symbols: List[str]) -> List[Dict]:
    tasks = [self.get_stock_price(symbol) for symbol in symbols]
    return await asyncio.gather(*tasks)
```

Priority improvements:

1. Input validation and sanitization
2. Parallel request handling
3. Improved error handling
4. Caching with TTL
5. Enhanced query preprocessing

```python
#I USED STRUCTURED TOOLS IN THIS EXAMPLE

import os
from langchain.tools import StructuredTool
from langchain.agents import AgentExecutor, initialize_agent,
AgentType
from langchain_google_genai import ChatGoogleGenerativeAI
from pydantic import BaseModel, Field
import yfinance as yf
import requests
import logging
from typing import Dict
from datetime import datetime

os.environ["GOOGLE_API_KEY"] =
"AIzaSyATxilMVX1MuCQbHgpcZoTaEk6O45lJLXY"
os.environ["NEWS_API_KEY"] = "05360b72a0324723a37579e35852fa73"

logging.basicConfig(level=logging.INFO)
logger = logging.getLogger(__name__)

class StockInput(BaseModel):
    symbol: str = Field(description="The stock symbol to look up")

class NewsInput(BaseModel):
    query: str = Field(description="The news search query")

def check_stock_price(symbol: str) -> str:
    try:
        stock = yf.Ticker(symbol.upper())
        info = stock.info
        if not info:
            return f"No data found for {symbol}"
        current = info.get('currentPrice',
info.get('regularMarketPrice', 0))
        if not current:
            return f"Could not get price for {symbol}"
        return (
            f"{symbol} Price: ${current:.2f}\n"
            f"Day Range: ${info.get('dayLow', 0):.2f} - $
{info.get('dayHigh', 0):.2f}\n"
            f"Volume: {info.get('volume', 0):,}"
        )
    except Exception as e:
        return f"Error getting stock price: {str(e)}"

def search_news(query: str) -> str:
    try:
        NEWS_API_KEY = os.getenv("NEWS_API_KEY")
        if not NEWS_API_KEY:
            return "NEWS_API_KEY not set"

        params = {
            'q': query,
            'sortBy': 'publishedAt',
            'apiKey': NEWS_API_KEY,
            'pageSize': 3
        }

        response = requests.get(
            "https://newsapi.org/v2/everything",
            params=params,
            timeout=10
        )
        articles = response.json().get('articles', [])

        if not articles:
            return f"No news found for: {query}"

        result = [f"Recent news about {query}:"]
        for i, article in enumerate(articles[:3], 1):
            result.extend([
                f"\n{i}. {article.get('title')}",
                f"Date: {article.get('publishedAt')[:10]}",
                f"Source: {article.get('source', {}).get('name',
'Unknown')}"
            ])

        return "\n".join(result)

    except Exception as e:
        return f"Error searching news: {str(e)}"

class QueryRouter:
    def __init__(self, api_key: str):
        llm = ChatGoogleGenerativeAI(
            model="gemini-1.5-flash",
            google_api_key=api_key,
            temperature=0.1,
        )

        tools = [
            StructuredTool(
                name="check_stock_price",
                func=check_stock_price,
                description="Get current stock price. Input should be
a stock symbol (e.g., AAPL)",
                args_schema=StockInput
            ),
            StructuredTool(
                name="search_news",
                func=search_news,
                description="Search recent news articles. Input should
be a search query",
                args_schema=NewsInput
            )
        ]
        self.agent = initialize_agent(
            tools,
            llm,

agent=AgentType.STRUCTURED_CHAT_ZERO_SHOT_REACT_DESCRIPTION,
            verbose=True,
            handle_parsing_errors=True,
        )

    def process_query(self, query: str) -> Dict:
        try:
            response = self.agent.invoke({"input": query})
            return {
                "status": "success",
                "response": response["output"],
                "metadata": {
                    "timestamp": datetime.now().isoformat(),
                    "query": query
                }
            }
        except Exception as e:
            logger.error(f"Query processing error: {str(e)}")
            return {
                "status": "error",
                "error": str(e),
                "metadata": {
                    "timestamp": datetime.now().isoformat(),
                    "query": query
                }
            }

def main():
    api_key = os.getenv("GOOGLE_API_KEY")
    if not api_key:
        print("GOOGLE_API_KEY not set")
        return

    router = QueryRouter(api_key)
    test_queries = [
        "What's the current price of AAPL?",
        "Find recent news about artificial intelligence",
        "Tell me about Tesla's stock price and latest news",
        "Tell me the latest news about supermicro computer",
        "News about donald trump"

    ]

    for query in test_queries:
        print(f"\nQuery: {query}")
```

~~~
        print("-" * 50)
        result = router.process_query(query)
        print(f"Status: {result['status']}")
        if result["status"] == "success":
            print(f"Response: {result['response']}")
        else:
            print(f"Error: {result['error']}")
        print("-" * 50)

if __name__ == "__main__":
    main()


Query: What's the current price of AAPL?
--------------------------------------------------


> Entering new AgentExecutor chain...
Thought:I need to check the current stock price of AAPL.
Action:
```json
{
  "action": "check_stock_price",
  "action_input": {
    "symbol": "AAPL"
  }
}
```

Observation: AAPL Price: $234.59
Day Range: $233.81 - $235.69
Volume: 13,826,181
Thought:Thought:I have the stock price.  I can now provide a final answer.
Action:
```json
{
  "action": "Final Answer",
  "action_input": "The current price of AAPL is $234.59."
}
```


> Finished chain.
Status: success
Response: The current price of AAPL is $234.59.
--------------------------------------------------

Query: Find recent news about artificial intelligence
--------------------------------------------------
~~~

~~~~
> Entering new AgentExecutor chain...
Thought:I need to use the search_news tool to find recent news
articles about artificial intelligence.
Action:
```json
{
  "action": "search_news",
  "action_input": {
    "query": "artificial intelligence"
  }
}
```

Observation: Recent news about artificial intelligence:

1. Delhi Police Use AI To Identify Masked Snatcher, Recovers Stolen
Phone
Date: 2024-11-26
Source: NDTV News

2. Support for SpaceX Mars City Will Surge With First Unmanned
Starship Landings
Date: 2024-11-26
Source: Next Big Future

3. SoftBank Chief Masayoshi Son to meet PM Narendra Modi on November
27: Report
Date: 2024-11-26
Source: Livemint
Thought:Thought:I can now formulate a response summarizing the news
articles I found.
Action:
```json
{
  "action": "Final Answer",
  "action_input": "Recent news on artificial intelligence includes
Delhi Police using AI to identify a masked snatcher and recover a
stolen phone.  Other news involves SpaceX's Mars city plans and a
meeting between SoftBank's Masayoshi Son and PM Narendra Modi. Note
that while the SpaceX and SoftBank news mentions technological
advancements, the direct connection to AI is less explicit than in the
Delhi Police example."
}
```


> Finished chain.
Status: success
~~~~

~~~~
Response: Recent news on artificial intelligence includes Delhi Police
using AI to identify a masked snatcher and recover a stolen phone.
Other news involves SpaceX's Mars city plans and a meeting between
SoftBank's Masayoshi Son and PM Narendra Modi. Note that while the
SpaceX and SoftBank news mentions technological advancements, the
direct connection to AI is less explicit than in the Delhi Police
example.
--------------------------------------------------

Query: Tell me about Tesla's stock price and latest news
--------------------------------------------------


> Entering new AgentExecutor chain...
Thought:I need to get Tesla's stock price and some recent news about
the company.  I'll use the tools to do this.

Action:
```json
{
  "action": "check_stock_price",
  "action_input": {
    "symbol": "TSLA"
  }
}
```

Observation: TSLA Price: $330.71
Day Range: $326.59 - $342.55
Volume: 39,789,196
Thought:Action:
```json
{
  "action": "search_news",
  "action_input": {
    "query": "Tesla latest news"
  }
}
```

Observation: Recent news about Tesla latest news:

1. California to provide rebates for zero-emission vehicles if federal
tax credit eliminated by incoming Trump administration
Date: 2024-11-26
Source: The Star Online

2. EV tax credits could vanish under Trump. Is now the time to buy?
Date: 2024-11-26
Source: NBC News
~~~~

~~~
3. How ‘Shogun’ Helped FX Find Its Footing as a Streaming Empire
Date: 2024-11-26
Source: Variety
Thought:Thought:I have the stock price and some relevant news. I'll
combine this information for a final answer.

Action:
```json
{
  "action": "Final Answer",
  "action_input": "Tesla's stock price is currently $330.71.  Recent
news includes articles discussing potential changes to EV tax credits
under a new administration and their potential impact on Tesla.  One
article also mentions California's plan to offer rebates for zero-
emission vehicles if federal tax credits are eliminated.  Please note
that news articles are subject to change and further research may be
needed for a comprehensive understanding."
}
```


> Finished chain.
Status: success
Response: Tesla's stock price is currently $330.71.  Recent news
includes articles discussing potential changes to EV tax credits under
a new administration and their potential impact on Tesla.  One article
also mentions California's plan to offer rebates for zero-emission
vehicles if federal tax credits are eliminated.  Please note that news
articles are subject to change and further research may be needed for
a comprehensive understanding.
--------------------------------------------------

Query: Tell me the latest news about supermicro computer
--------------------------------------------------


> Entering new AgentExecutor chain...
Thought:I need to search for news articles about Supermicro.
Action:
```json
{
  "action": "search_news",
  "action_input": "Supermicro"
}
```

Observation: Recent news about Supermicro:

1. 美超微推出新型JBOF，搭36臺E3.S固態硬碟與BF3資料處理器
~~~

~~~
Date: 2024-11-26
Source: Ithome.com.tw

2. Supermicro 推出直接液冷最佳化的NVIDIA Blackwell 解決方案
Date: 2024-11-25
Source: Techbang.com

3. Weka SC24 highlights from theCUBE: Tackling AI infrastructure
challenges
Date: 2024-11-25
Source: SiliconANGLE News
Thought:Thought:I have the news results.  I'll summarize them for the
user.
Action:
```json
{
  "action": "Final Answer",
  "action_input": "Recent news about Supermicro includes the launch of
a new JBOF with 36 E3.S SSDs and a BF3 data processor, a new direct
liquid-cooled NVIDIA Blackwell solution, and highlights from theCUBE
on Weka SC24 addressing AI infrastructure challenges."
}
~~~

> Finished chain.
Status: success
Response: Recent news about Supermicro includes the launch of a new
JBOF with 36 E3.S SSDs and a BF3 data processor, a new direct liquid-
cooled NVIDIA Blackwell solution, and highlights from theCUBE on Weka
SC24 addressing AI infrastructure challenges.

Query: News about donald trump

> Entering new AgentExecutor chain...
Thought:I need to use the search_news tool to get recent news articles
about Donald Trump.
Action:
```json
{
  "action": "search_news",
  "action_input": {
    "query": "Donald Trump"
  }
}
```
```
```

~~~
Observation: Recent news about Donald Trump:

1. Avec LightOn, l’IA générative prend son envol en Bourse
Date: 2024-11-26
Source: La Tribune.fr

2. Teaching Students How to Debunk Myths About Misinformation
Date: 2024-11-26
Source: Psychologicalscience.org

3. Hausse des droits de douane : Donald Trump ravive le spectre d’une
guerre commerciale
Date: 2024-11-26
Source: Lavenir.net
Thought:Thought:I will summarize the news articles I found.  The
articles mention Donald Trump in relation to potential trade wars and
his influence on misinformation.  One article is not directly related
to him.

Action:
```json
{
  "action": "Final Answer",
  "action_input": "Recent news about Donald Trump includes reports on
the potential for renewed trade wars due to increased tariffs and his
indirect influence on the spread of misinformation.  One unrelated
article was also found in the search results."
}
```


> Finished chain.
Status: success
Response: Recent news about Donald Trump includes reports on the
potential for renewed trade wars due to increased tariffs and his
indirect influence on the spread of misinformation.  One unrelated
article was also found in the search results.
--------------------------------------------------
~~~

Submission

Ensure your notebook includes:

- **Code:** Fully functional code implementations for each task.
- **Examples:** Sample outputs demonstrating functionality.
- **Documentation:** Markdown explanations for each section, detailing the approach and results.
- **Testing:** Comprehensive tests covering various query types, with explanations for edge cases.

Problem 4: Quantization (25 points)

Initial Setup

Before beginning the assignment, we import the CIFAR dataset, and train a simple convolutional neural network (CNN) to classify it.

```
import torch
import torchvision
import torchvision.transforms as transforms
import torch.nn as nn
import torch.nn.functional as F
import torch.optim as optim
```

Reminder: set the runtime type to "GPU", or your code will run much more slowly on a CPU.

```
if torch.cuda.is_available():
    device = torch.device('cuda')
else:
    device = torch.device('cpu')
```

Load training and test data from the CIFAR10 dataset.

```
transform = transforms.Compose(
    [transforms.ToTensor(),
     transforms.Normalize((0.5, 0.5, 0.5), (0.5, 0.5, 0.5))])

trainset = torchvision.datasets.CIFAR10(root='./data', train=True,
                                        download=True,
transform=transform)
trainloader = torch.utils.data.DataLoader(trainset, batch_size=4,
                                          shuffle=True, num_workers=2)

testset = torchvision.datasets.CIFAR10(root='./data', train=False,
                                       download=True,
transform=transform)
testloader = torch.utils.data.DataLoader(testset, batch_size=4,
                                         shuffle=False, num_workers=2)
```

```
Downloading https://www.cs.toronto.edu/~kriz/cifar-10-python.tar.gz to
./data/cifar-10-python.tar.gz

100%|██████████| 170M/170M [00:03<00:00, 47.7MB/s]

Extracting ./data/cifar-10-python.tar.gz to ./data
Files already downloaded and verified
```

Define a simple CNN that classifies CIFAR images.

```
class Net(nn.Module):
    def __init__(self):
        super(Net, self).__init__()
        self.conv1 = nn.Conv2d(3, 6, 5, bias=False)
        self.pool = nn.MaxPool2d(2, 2)
        self.conv2 = nn.Conv2d(6, 16, 5, bias=False)
        self.fc1 = nn.Linear(16 * 5 * 5, 120, bias=False)
        self.fc2 = nn.Linear(120, 84, bias=False)
        self.fc3 = nn.Linear(84, 10, bias=False)

    def forward(self, x: torch.Tensor) -> torch.Tensor:
        x = self.pool(F.relu(self.conv1(x)))
        x = self.pool(F.relu(self.conv2(x)))
        x = x.view(-1, 16 * 5 * 5)
        x = F.relu(self.fc1(x))
        x = F.relu(self.fc2(x))
        x = self.fc3(x)
        return x

net = Net().to(device)
```

Train this CNN on the training dataset (this may take a few moments).

```
from torch.utils.data import DataLoader

def train(model: nn.Module, dataloader: DataLoader):
    criterion = nn.CrossEntropyLoss()
    optimizer = optim.SGD(model.parameters(), lr=0.001, momentum=0.9)

    for epoch in range(2):  # loop over the dataset multiple times

        running_loss = 0.0
        for i, data in enumerate(dataloader, 0):
            # get the inputs; data is a list of [inputs, labels]
            inputs, labels = data

            inputs = inputs.to(device)
            labels = labels.to(device)

            # zero the parameter gradients
            optimizer.zero_grad()

            # forward + backward + optimize
            outputs = model(inputs)
            loss = criterion(outputs, labels)
            loss.backward()
            optimizer.step()

            # print statistics
            running_loss += loss.item()
            if i % 2000 == 1999:    # print every 2000 mini-batches
                print('[%d, %5d] loss: %.3f' %
                    (epoch + 1, i + 1, running_loss / 2000))
                running_loss = 0.0

    print('Finished Training')

def test(model: nn.Module, dataloader: DataLoader, max_samples=None) -> float:
    correct = 0
    total = 0
    n_inferences = 0

    with torch.no_grad():
        for data in dataloader:
            images, labels = data

            images = images.to(device)
            labels = labels.to(device)

            outputs = model(images)
            _, predicted = torch.max(outputs.data, 1)
            total += labels.size(0)
            correct += (predicted == labels).sum().item()

            if max_samples:
                n_inferences += images.shape[0]
                if n_inferences > max_samples:
                    break

    return 100 * correct / total

train(net, trainloader)

[1,  2000] loss: 2.224
[1,  4000] loss: 1.929
[1,  6000] loss: 1.730
[1,  8000] loss: 1.641
[1, 10000] loss: 1.575
[1, 12000] loss: 1.525
[2,  2000] loss: 1.443
[2,  4000] loss: 1.425
[2,  6000] loss: 1.429
[2,  8000] loss: 1.354
[2, 10000] loss: 1.362
[2, 12000] loss: 1.341
Finished Training
```

Now that the CNN has been trained, let's test it on our test dataset.

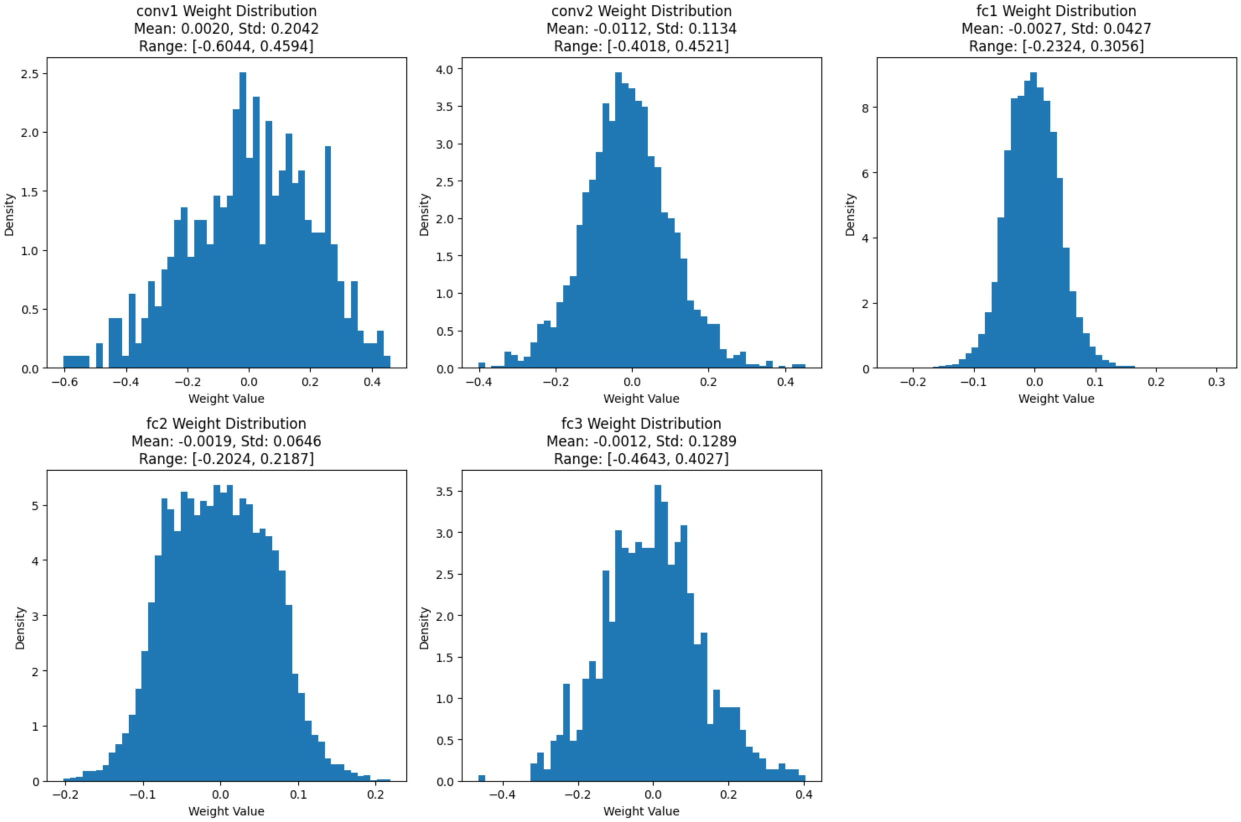
```
score = test(net, testloader)
print('Accuracy of the network on the test images: {}%'.format(score))
```

```
Accuracy of the network on the test images: 53.45%
```

```
from copy import deepcopy

# A convenience function which we use to copy CNNs
def copy_model(model: nn.Module) -> nn.Module:
    result = deepcopy(model)

    # Copy over the extra metadata we've collected which copy.deepcopy
doesn't capture
    if hasattr(model, 'input_activations'):
        result.input_activations = deepcopy(model.input_activations)

    for result_layer, original_layer in zip(result.children(),
model.children()):
        if isinstance(result_layer, nn.Conv2d) or
isinstance(result_layer, nn.Linear):
            if hasattr(original_layer.weight, 'scale'):
                result_layer.weight.scale =
deepcopy(original_layer.weight.scale)
            if hasattr(original_layer, 'activations'):
                result_layer.activations =
deepcopy(original_layer.activations)
            if hasattr(original_layer, 'output_scale'):
                result_layer.output_scale =
deepcopy(original_layer.output_scale)

    return result
```

Section 1: Visualize Weights

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

import torch
import torch.nn as nn
import numpy as np
import matplotlib.pyplot as plt

def visualize_weights(net: nn.Module):
    """Visualize weight distributions of all layers"""
    layers = [
        ('conv1', net.conv1),
        ('conv2', net.conv2),
        ('fc1', net.fc1),
        ('fc2', net.fc2),
        ('fc3', net.fc3)
    ]

    fig, axs = plt.subplots(2, 3, figsize=(15, 10))
    fig.suptitle('Weight Distributions Across Layers')

    for idx, (name, layer) in enumerate(layers):
        weights = layer.weight.data.cpu().view(-1).numpy()

        mean = np.mean(weights)
        std = np.std(weights)
        value_range = np.max(weights) - np.min(weights)

        row = idx // 3
        col = idx % 3
        axs[row, col].hist(weights, bins=50, density=True)
        axs[row, col].set_title(f'{name} weights\nμ={mean:.4f}, σ={std:.4f}\nRange={value_range:.4f}')
        axs[row, col].axvline(mean, color='r', linestyle='--', label='Mean')
        axs[row, col].axvline(mean + 3*std, color='g', linestyle='--', label='+3σ')
        axs[row, col].axvline(mean - 3*std, color='g', linestyle='--', label='-3σ')
        axs[row, col].legend()

    if len(layers) < 6:
        fig.delaxes(axs[1, 2])
    plt.tight_layout()
    plt.show()

def quantized_weights(weights: torch.Tensor) -> tuple[torch.Tensor, float]:
    """
    Quantize weights to 8-bit integers while preserving network accuracy.

    Args:
        weights: Original floating-point weights

    Returns:
        tuple: (Quantized weights, scaling factor)
    """
    # Convert to numpy for easier calculation
    w = weights.cpu().detach().numpy()

    # Calculate statistics
    mean = np.mean(w)
    std = np.std(w)

    # Use 3-sigma rule for the range
    max_range = max(abs(mean - 3*std), abs(mean + 3*std))

    # Calculate scaling factor to fit within -128 to 127 range
    scale = 127.0 / max_range

    # Quantize weights
    quantized = torch.tensor(np.clip(np.round(w * scale), -128, 127))

    return quantized.to(weights.device).float(), scale

def visualize_activations(net: nn.Module):
    """Visualize activation distributions"""
    # Check if we have collected any activations
    if not any(net.activations.values()):
        raise ValueError("No activations collected. Run inference
first!")

    # Concatenate activations for each layer
    concatenated_activations = {}
    for layer_name, acts in net.activations.items():
        if acts:  # Only process if we have activations
            concatenated_activations[layer_name] =
np.concatenate(acts)

    # Create visualization
    fig, axs = plt.subplots(2, 3, figsize=(15, 10))
    fig.suptitle('Activation Distributions Across Layers')

    for idx, (name, activation) in
enumerate(concatenated_activations.items()):
        if len(activation.flatten()) == 0:
            continue

        mean = np.mean(activation)
        std = np.std(activation)
        value_range = np.max(activation) - np.min(activation)

        row = idx // 3
        col = idx % 3
        axs[row, col].hist(activation.flatten(), bins=50,
density=True)
        axs[row, col].set_title(f'{name}\nμ={mean:.4f}, σ={std:.4f}\
nRange={value_range:.4f}')
        axs[row, col].axvline(mean, color='r', linestyle='--',
label='Mean')
        axs[row, col].axvline(mean + 3*std, color='g', linestyle='--',
label='+3σ')
        axs[row, col].axvline(mean - 3*std, color='g', linestyle='--',
label='-3σ')
        axs[row, col].legend()
    plt.tight_layout()
    plt.show()

class NetQuantized(nn.Module):
    @staticmethod
    def quantize_initial_input(pixels: np.ndarray) -> float:
        """
        Calculate scaling factor for input quantization.

        Args:
            pixels: Array of input pixel values

        Returns:
            float: Scaling factor
        """
        # Calculate statistics
        mean = np.mean(pixels)
        std = np.std(pixels)

        # Use 3-sigma rule for range
        max_range = max(abs(mean - 3*std), abs(mean + 3*std))

        # Calculate scaling factor to fit within -128 to 127 range
        return 127.0 / max_range

    @staticmethod
    def quantize_activations(activations: np.ndarray, n_w: float,
n_initial_input: float, ns: list[tuple[float, float]]) -> float:
        """
        Calculate scaling factor for activation quantization.

        Args:
            activations: Layer activation values
            n_w: Weight scaling factor
            n_initial_input: Input scaling factor
            ns: List of (weight_scale, output_scale) for preceding
layers

        Returns:
            float: Scaling factor
        """
        # Calculate cumulative scaling factor from previous layers
        cumulative_scale = n_initial_input
        for weight_scale, output_scale in ns:
            cumulative_scale *= (weight_scale / output_scale)

        # Calculate range of unscaled activations
        mean = np.mean(activations)
        std = np.std(activations)
        max_range = max(abs(mean - 3*std), abs(mean + 3*std))

        # Calculate required scaling to fit within -128 to 127
        target_scale = 127.0 / (max_range * cumulative_scale * n_w)

        return target_scale

    def forward(self, x: torch.Tensor) -> torch.Tensor:
        """
        Forward pass with quantized operations.

        Args:
            x: Input tensor

        Returns:
            torch.Tensor: Output predictions
        """
        # Initial input quantization
        x = torch.clamp(torch.round(x * self.input_scale), -128, 127)

        # Conv1
        x = self.conv1(x)
        x = torch.clamp(torch.round(x / self.conv1.output_scale), -
128, 127)
        x = self.pool(F.relu(x))

        # Conv2
        x = self.conv2(x)
        x = torch.clamp(torch.round(x / self.conv2.output_scale), -
128, 127)
        x = self.pool(F.relu(x))

        # Flatten
        x = x.view(-1, 16 * 5 * 5)

        # FC1
        x = self.fc1(x)
        x = torch.clamp(torch.round(x / self.fc1.output_scale), -128,
127)
        x = F.relu(x)

        # FC2
        x = self.fc2(x)
        x = torch.clamp(torch.round(x / self.fc2.output_scale), -128,
127)
        x = F.relu(x)

        # FC3 (final layer)
        x = self.fc3(x)
        x = x / self.fc3.output_scale
        return x

class NetQuantizedWithBias(NetQuantized):
    @staticmethod
    def quantized_bias(bias: torch.Tensor, n_w: float,
n_initial_input: float, ns: list[tuple[float, float]]) ->
torch.Tensor:
        """
        Quantize bias values to 32-bit integers.

        Args:
            bias: Original bias values
            n_w: Weight scaling factor
            n_initial_input: Input scaling factor
            ns: List of (weight_scale, output_scale) for preceding
layers

        Returns:
            torch.Tensor: Quantized bias values
        """
        # Calculate cumulative scaling from previous layers
        cumulative_scale = n_initial_input
        for weight_scale, output_scale in ns:
            cumulative_scale *= (weight_scale / output_scale)

        # Scale bias to account for all quantization factors
        scaled_bias = bias * n_w * cumulative_scale

        # Round to nearest integer and clamp to 32-bit range
        quantized = torch.clamp(torch.round(scaled_bias), -2147483648,
2147483647)

        return quantized

def plot_weight_distributions(net):
    """Plot weight distributions for all layers in the network."""
    layers = [('conv1', net.conv1), ('conv2', net.conv2),
              ('fc1', net.fc1), ('fc2', net.fc2), ('fc3', net.fc3)]

    plt.figure(figsize=(15, 10))
    for idx, (name, layer) in enumerate(layers, 1):
        weights = layer.weight.data.cpu().view(-1).numpy()

        # Calculate statistics
        mean = np.mean(weights)
        std = np.std(weights)
        min_val = np.min(weights)
        max_val = np.max(weights)
        plt.subplot(2, 3, idx)
        plt.hist(weights, bins=50, density=True)
        plt.title(f'{name} Weight Distribution\n'
                 f'Mean: {mean:.4f}, Std: {std:.4f}\n'
                 f'Range: [{min_val:.4f}, {max_val:.4f}]')
        plt.xlabel('Weight Value')
        plt.ylabel('Density')

    plt.tight_layout()
    plt.show()

# Plot the weight distributions
plot_weight_distributions(net)
```



conv1 Weight Distribution
Mean: 0.0020, Std: 0.2042
Range: [-0.6044, 0.4594]

conv2 Weight Distribution
Mean: -0.0112, Std: 0.1134
Range: [-0.4018, 0.4521]

fc1 Weight Distribution
Mean: -0.0027, Std: 0.0427
Range: [-0.2324, 0.3056]

fc2 Weight Distribution
Mean: -0.0019, Std: 0.0646
Range: [-0.2024, 0.2187]

fc3 Weight Distribution
Mean: -0.0012, Std: 0.1289
Range: [-0.4643, 0.4027]

Section 2: Quantize Weights

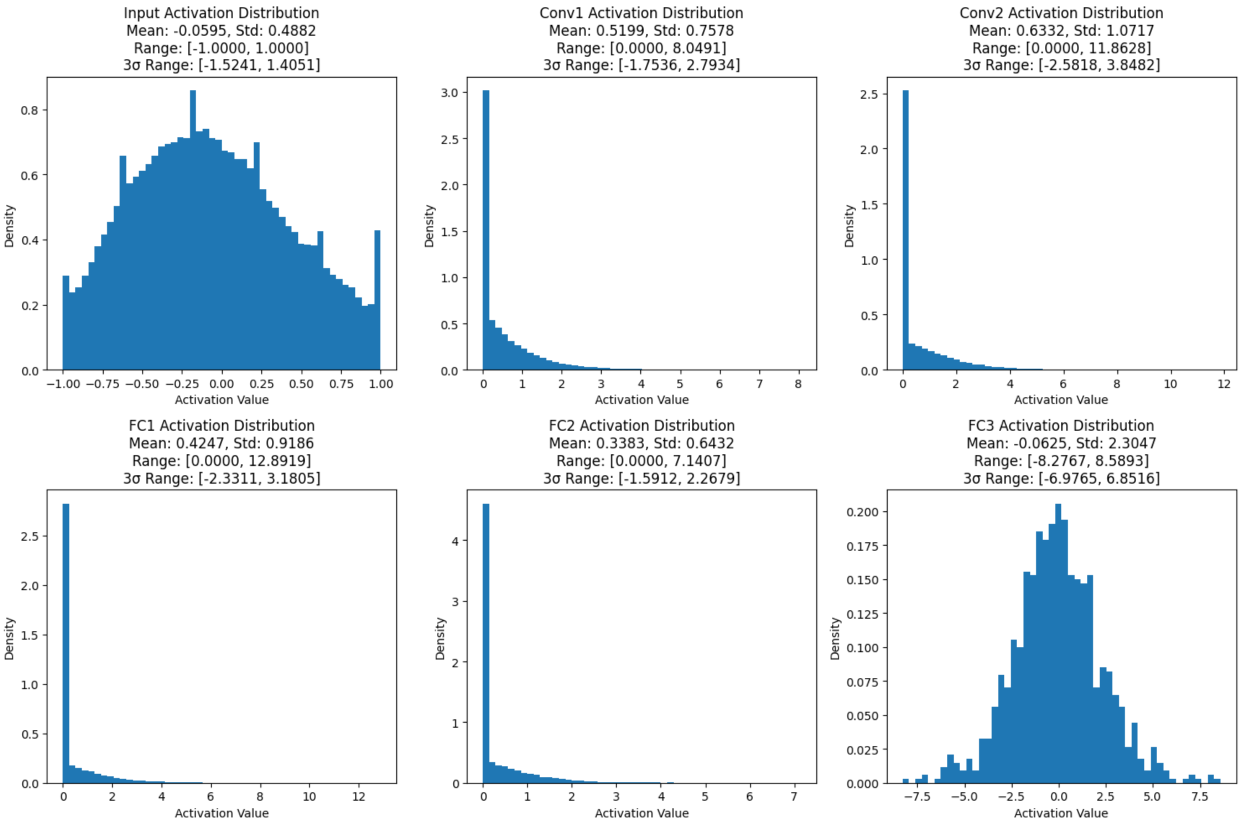
```
net_q2 = copy_model(net)

from typing import Tuple

def quantized_weights(weights: torch.Tensor) -> Tuple[torch.Tensor, float]:
    """
    Quantize weights to 8-bit integers (-128 to 127).
    Uses 3-sigma range for better dynamic range coverage.
    """
    weights_np = weights.detach().cpu().numpy()

    # Calculate statistics
    mean = np.mean(weights_np)
    std = np.std(weights_np)

    # Use 3-sigma range for scaling
    max_range = max(abs(mean - 3*std), abs(mean + 3*std))
    scale = 127.0 / max_range

    # Scale and clamp values
    scaled_weights = weights * scale
    quantized = torch.clamp(scaled_weights.round(), min=-128, max=127)

    return quantized, scale

def quantize_layer_weights(model: nn.Module):
    for layer in model.children():
        if isinstance(layer, nn.Conv2d) or isinstance(layer,
nn.Linear):
            q_layer_data, scale = quantized_weights(layer.weight.data)
            q_layer_data = q_layer_data.to(device)

            layer.weight.data = q_layer_data
            layer.weight.scale = scale

            if (q_layer_data < -128).any() or (q_layer_data >
127).any():
                raise Exception("Quantized weights of {} layer include
values out of bounds for an 8-bit signed
integer".format(layer.__class__.__name__))
            if (q_layer_data != q_layer_data.round()).any():
                raise Exception("Quantized weights of {} layer include
non-integer values".format(layer.__class__.__name__))

quantize_layer_weights(net_q2)

score = test(net_q2, testloader)
print('Accuracy of the network after quantizing all weights: {}
%'.format(score))
```

```
Accuracy of the network after quantizing all weights: 53.79%
```

Section 3: Visualize Activations

```
def register_activation_profiling_hooks(model: Net):
    model.input_activations = np.empty(0)
    model.conv1.activations = np.empty(0)
    model.conv2.activations = np.empty(0)
    model.fc1.activations = np.empty(0)
    model.fc2.activations = np.empty(0)
    model.fc3.activations = np.empty(0)

    model.profile_activations = True

    def conv1_activations_hook(layer, x, y):
        if model.profile_activations:
            model.input_activations =
np.append(model.input_activations, x[0].cpu().view(-1))
    model.conv1.register_forward_hook(conv1_activations_hook)

    def conv2_activations_hook(layer, x, y):
        if model.profile_activations:
            model.conv1.activations =
np.append(model.conv1.activations, x[0].cpu().view(-1))
    model.conv2.register_forward_hook(conv2_activations_hook)

    def fc1_activations_hook(layer, x, y):
        if model.profile_activations:
            model.conv2.activations =
np.append(model.conv2.activations, x[0].cpu().view(-1))
    model.fc1.register_forward_hook(fc1_activations_hook)

    def fc2_activations_hook(layer, x, y):
        if model.profile_activations:
            model.fc1.activations = np.append(model.fc1.activations,
x[0].cpu().view(-1))
    model.fc2.register_forward_hook(fc2_activations_hook)

    def fc3_activations_hook(layer, x, y):
        if model.profile_activations:
            model.fc2.activations = np.append(model.fc2.activations,
x[0].cpu().view(-1))
            model.fc3.activations = np.append(model.fc3.activations,
y[0].cpu().view(-1))
    model.fc3.register_forward_hook(fc3_activations_hook)

net_q3 = copy_model(net)
register_activation_profiling_hooks(net_q3)

# Run through the training dataset again while profiling the input and
output activations this time
# We don't actually have to perform gradient descent for this, so we
can use the "test" function
test(net_q3, trainloader, max_samples=400)
net_q3.profile_activations = False
```

```python
input_activations = net_q3.input_activations
conv1_output_activations = net_q3.conv1.activations
conv2_output_activations = net_q3.conv2.activations
fc1_output_activations = net_q3.fc1.activations
fc2_output_activations = net_q3.fc2.activations
fc3_output_activations = net_q3.fc3.activations

def plot_activation_distributions(net_q3):
    """Plot activation distributions for all layers."""
    activations = [
        ('Input', net_q3.input_activations),
        ('Conv1', net_q3.conv1.activations),
        ('Conv2', net_q3.conv2.activations),
        ('FC1', net_q3.fc1.activations),
        ('FC2', net_q3.fc2.activations),
        ('FC3', net_q3.fc3.activations)
    ]

    plt.figure(figsize=(15, 10))
    for idx, (name, acts) in enumerate(activations, 1):
        # Calculate statistics
        mean = np.mean(acts)
        std = np.std(acts)
        min_val = np.min(acts)
        max_val = np.max(acts)
        three_sigma = (mean - 3*std, mean + 3*std)

        plt.subplot(2, 3, idx)
        plt.hist(acts, bins=50, density=True)
        plt.title(f'{name} Activation Distribution\n'
                 f'Mean: {mean:.4f}, Std: {std:.4f}\n'
                 f'Range: [{min_val:.4f}, {max_val:.4f}]\n'
                 f'3σ Range: [{three_sigma[0]:.4f}, 
{three_sigma[1]:.4f}]')
        plt.xlabel('Activation Value')
        plt.ylabel('Density')

    plt.tight_layout()
    plt.show()

# Plot activation distributions
plot_activation_distributions(net_q3)
```



Input Activation Distribution
Mean: -0.0595, Std: 0.4882
Range: [-1.0000, 1.0000]
3σ Range: [-1.5241, 1.4051]

Conv1 Activation Distribution
Mean: 0.5199, Std: 0.7578
Range: [0.0000, 8.0491]
3σ Range: [-1.7536, 2.7934]

Conv2 Activation Distribution
Mean: 0.6332, Std: 1.0717
Range: [0.0000, 11.8628]
3σ Range: [-2.5818, 3.8482]

FC1 Activation Distribution
Mean: 0.4247, Std: 0.9186
Range: [0.0000, 12.8919]
3σ Range: [-2.3311, 3.1805]

FC2 Activation Distribution
Mean: 0.3383, Std: 0.6432
Range: [0.0000, 7.1407]
3σ Range: [-1.5912, 2.2679]

FC3 Activation Distribution
Mean: -0.0625, Std: 2.3047
Range: [-8.2767, 8.5893]
3σ Range: [-6.9765, 6.8516]

Section 4: Quantize Activations

```
class NetQuantized(nn.Module):
    def __init__(self, net_with_weights_quantized: nn.Module):
        super(NetQuantized, self).__init__()

        net_init = copy_model(net_with_weights_quantized)
        self.conv1 = net_init.conv1
        self.pool = net_init.pool
        self.conv2 = net_init.conv2
        self.fc1 = net_init.fc1
        self.fc2 = net_init.fc2
        self.fc3 = net_init.fc3

        # Register pre-hooks for all layers
        for layer in self.conv1, self.conv2, self.fc1, self.fc2,
self.fc3:
            def pre_hook(l, x):
                x = x[0]
                if (x < -128).any() or (x > 127).any():
                    raise Exception("Input to {} layer is out of
bounds for an 8-bit signed integer".format(l.__class__.__name__))
                if (x != x.round()).any():
                    raise Exception("Input to {} layer has non-integer
values".format(l.__class__.__name__))
```

```
            layer.register_forward_pre_hook(pre_hook)

        # Set up input scaling
        self.input_activations =
net_with_weights_quantized.input_activations
        self.input_scale =
NetQuantized.quantize_initial_input(self.input_activations)

        # Calculate output scaling factors
        preceding_layer_scales = []
        for layer in self.conv1, self.conv2, self.fc1, self.fc2,
self.fc3:
            layer.output_scale = NetQuantized.quantize_activations(
                layer.activations,
                layer.weight.scale,
                self.input_scale,
                preceding_layer_scales
            )
            preceding_layer_scales.append((layer.weight.scale,
layer.output_scale))

    @staticmethod
    def quantize_initial_input(pixels: np.ndarray) -> float:
        '''Calculate initial input scaling factor'''
        # Use 3-sigma rule for better distribution coverage
        mean = np.mean(pixels)
        std = np.std(pixels)
        max_val = max(abs(mean + 3*std), abs(mean - 3*std))

        if max_val == 0:
            return 1.0

        # Calculate scale to fit within int8 range (-128 to 127)
        scale = 127.0 / max_val
        return scale

    @staticmethod
    def quantize_activations(activations: np.ndarray, n_w: float,
n_initial_input: float, ns: List[Tuple[float, float]]) -> float:
        '''Calculate activation scaling factor'''
        # Calculate cumulative scale from previous layers
        cumulative_scale = n_initial_input
        for weight_scale, output_scale in ns:
            cumulative_scale *= weight_scale * output_scale

        # Use 3-sigma rule for distribution
        mean = np.mean(activations)
        std = np.std(activations)
        max_val = max(abs(mean + 3*std), abs(mean - 3*std))
        if max_val == 0:
            return 1.0

        # Calculate required scale for int8 range
        current_scale = cumulative_scale * n_w
        target_scale = 127.0 / max_val

        return target_scale / current_scale

    def forward(self, x: torch.Tensor) -> torch.Tensor:
        # Initial scaling
        x = (x * self.input_scale).round()
        x = torch.clamp(x, min=-128, max=127)

        # Conv1 layer
        x = self.conv1(x)  # Use integer weights directly
        x = (x * self.conv1.output_scale).round()
        x = torch.clamp(x, min=-128, max=127)
        x = self.pool(F.relu(x))

        # Conv2 layer
        x = self.conv2(x)  # Use integer weights directly
        x = (x * self.conv2.output_scale).round()
        x = torch.clamp(x, min=-128, max=127)
        x = self.pool(F.relu(x))

        # Flatten
        x = x.view(-1, 16 * 5 * 5)

        # FC1 layer
        x = self.fc1(x)  # Use integer weights directly
        x = (x * self.fc1.output_scale).round()
        x = torch.clamp(x, min=-128, max=127)
        x = F.relu(x)

        # FC2 layer
        x = self.fc2(x)  # Use integer weights directly
        x = (x * self.fc2.output_scale).round()
        x = torch.clamp(x, min=-128, max=127)
        x = F.relu(x)

        # FC3 layer (final layer)
        x = self.fc3(x)  # Use integer weights directly
        x = (x * self.fc3.output_scale).round()
        x = torch.clamp(x, min=-128, max=127)

        return x

# Merge the information from net_q2 and net_q3 together
net_init = copy_model(net_q2)
```

```
net_init.input_activations = deepcopy(net_q3.input_activations)
for layer_init, layer_q3 in zip(net_init.children(),
net_q3.children()):
    if isinstance(layer_init, nn.Conv2d) or isinstance(layer_init,
nn.Linear):
        layer_init.activations = deepcopy(layer_q3.activations)

net_quantized = NetQuantized(net_init)

score = test(net_quantized, testloader)
print('Accuracy of the network after quantizing both weights and
activations: {}%'.format(score))
```

```
Accuracy of the network after quantizing both weights and activations:
53.95%
```

Section 5: Quantize Biases

```
class NetWithBias(nn.Module):
    def __init__(self):
        super(NetWithBias, self).__init__()

        self.conv1 = nn.Conv2d(3, 6, 5, bias=False)
        self.pool = nn.MaxPool2d(2, 2)
        self.conv2 = nn.Conv2d(6, 16, 5, bias=False)
        self.fc1 = nn.Linear(16 * 5 * 5, 120, bias=False)
        self.fc2 = nn.Linear(120, 84, bias=False)
        self.fc3 = nn.Linear(84, 10, bias=True)

    def forward(self, x: torch.Tensor) -> torch.Tensor:
        x = self.pool(F.relu(self.conv1(x)))
        x = self.pool(F.relu(self.conv2(x)))
        x = x.view(-1, 16 * 5 * 5)
        x = F.relu(self.fc1(x))
        x = F.relu(self.fc2(x))
        x = self.fc3(x)
        return x

net_with_bias = NetWithBias().to(device)

train(net_with_bias, trainloader)
```

```
[1,  2000] loss: 2.232
[1,  4000] loss: 1.885
[1,  6000] loss: 1.726
[1,  8000] loss: 1.627
[1, 10000] loss: 1.567
[1, 12000] loss: 1.502
[2,  2000] loss: 1.426
[2,  4000] loss: 1.412
```

```
[2,  6000] loss: 1.365
[2,  8000] loss: 1.355
[2, 10000] loss: 1.344
[2, 12000] loss: 1.342
Finished Training
```

```
score = test(net_with_bias, testloader)
print('Accuracy of the network (with a bias) on the test images: {}
%'.format(score))
```

```
Accuracy of the network (with a bias) on the test images: 55.65%
```

```
register_activation_profiling_hooks(net_with_bias)
test(net_with_bias, trainloader, max_samples=400)
net_with_bias.profile_activations = False
```

```
net_with_bias_with_quantized_weights = copy_model(net_with_bias)
quantize_layer_weights(net_with_bias_with_quantized_weights)
```

```
score = test(net_with_bias_with_quantized_weights, testloader)
print('Accuracy of the network on the test images after all the
weights are quantized but the bias isn\'t: {}%'.format(score))
```

```
Accuracy of the network on the test images after all the weights are
quantized but the bias isn't: 48.82%
```

```
class NetQuantizedWithBias(NetQuantized):
    def __init__(self, net_with_weights_quantized: nn.Module):
        super(NetQuantizedWithBias,
self).__init__(net_with_weights_quantized)

        preceding_scales = [(layer.weight.scale, layer.output_scale)
for layer in self.children() if isinstance(layer, nn.Conv2d) or
isinstance(layer, nn.Linear)][:-1]

        self.fc3.bias.data = NetQuantizedWithBias.quantized_bias(
            self.fc3.bias.data,
            self.fc3.weight.scale,
            self.input_scale,
            preceding_scales
        )

        if (self.fc3.bias.data < -2147483648).any() or
(self.fc3.bias.data > 2147483647).any():
            raise Exception("Bias has values which are out of bounds
for an 32-bit signed integer")
        if (self.fc3.bias.data != self.fc3.bias.data.round()).any():
            raise Exception("Bias has non-integer values")

    @staticmethod
    def quantized_bias(bias: torch.Tensor, n_w: float,
n_initial_input: float, ns: List[Tuple[float, float]]) ->
torch.Tensor:
        '''
        Quantize the bias so that all values are integers between -
2147483648 and 2147483647.

        Parameters:
        bias (Tensor): The floating point values of the bias
        n_w (float): The scale by which the weights of this layer were
multiplied
        n_initial_input (float): The scale by which the initial input
to the neural network was multiplied
        ns ([(float, float)]): A list of tuples, where each tuple
represents the "weight scale" and "output scale"
                              (in that order) for every preceding
layer

        Returns:
        Tensor: The bias in quantized form, where every value is an
integer between -2147483648 and 2147483647.
        '''
        # Calculate the cumulative scale through the network
        input_scale = n_initial_input
        for weight_scale, output_scale in ns:
            input_scale = input_scale * weight_scale

        # Calculate final scale for bias quantization
        # The bias needs to match the scale of weights * inputs
        bias_scale = input_scale * n_w

        # Determine scaling factor to fit in INT32 range
        INT32_MAX = 2147483647.0
        max_bias = torch.max(torch.abs(bias))
        if max_bias == 0:
            return torch.zeros_like(bias)

        # Calculate scale to fit within INT32 bounds while preserving
relative magnitudes
        scale_factor = INT32_MAX / (max_bias * bias_scale)
        scale_factor = min(scale_factor, INT32_MAX / max_bias)  #
Ensure we don't overflow

        # Quantize the bias
        quantized_bias = (bias * scale_factor).round()

        # Ensure values stay within INT32 bounds
        return torch.clamp(quantized_bias, min=-2147483648,
max=2147483647)
```

```
net_quantized_with_bias =
NetQuantizedWithBias(net_with_bias_with_quantized_weights)

score = test(net_quantized_with_bias, testloader)
print('Accuracy of the network on the test images after all the
weights and the bias are quantized: {}%'.format(score))
```

```
Accuracy of the network on the test images after all the weights and
the bias are quantized: 47.42%
```