UCF Center for Research in Computer Vision

CAP6412
Advanced Computer Vision
Spring 2025

Mubarak Shah

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HEC-245

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CAP6412, Spring 2025

- **Instructor**: Dr. Mubarak Shah
- **Email:** shah@crcv.ucf.edu
- **Office**: HEC 245
- **GTA**: Swetha Sirnam <Swetha.Sirnam@ucf.edu>
- **Time**: Mondays and Wednesdays 3:00 to 4:15PM
- **Location: HEC 103/**Zoom/Panopto
- Join URL: https://ucf.zoom.us/j/93604767693?pwd=1i2C8bsbUaWr8xmP3hQwINGwzuta5B.1
- **Office Hours:** Mondays 2:00 to 3:00PM; Wednesdays 4:15 to 5:00PM; Fridays 1:00 to 2:00; and by appointment
- **Pre-requisite**: CAP5415
- Course webpage: https://www.crcv.ucf.edu/courses/cap6412-spring-2025/

Course Objectives

- To expose graduate students to
  - Visual Language Models (VLM)
  - Diffusion Models
  - And issues of these models related to
    - Bias
    - Privacy
    - Trust
    - Toxicity

Students Learning Outcomes

- Students should be knowledgeable in Visual-language and Diffusion models
- Students should be able to:
  - Read and understand a research paper.
  - Write a comprehensive review of the paper.
  - To identify strong and weak points of the paper.
  - To prepare a detailed presentation about the paper and deliver it in the class
  - To generate own ideas to solve the same problem
  - To work on research project and write a research paper

Grading Policy

- Assignments: 45%
- Presentation: 10%
- Reports : 10%
- Projects: 35%

Each group member will be evaluated by other members of the group; the final grade on presentations and project will be scaled accordingly

No Mid Term, Final, Homework

- **Late Policy**
- 0 for late Reports/Presentations
- 20% off per day, up to 4 days, for Assignments/Projects

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Project Timeline

- Three in-class presentations (see class schedule)
  - Project ideas / proposal [2%]
  - Update-1 [3%]
  - Update-2 [5%]
  - Final presentation/Paper [25%]

Assignments

- Google Colab to carry out the assignments throughout the course

- PyTorch Colab Documentation:
  https://pytorch.org/tutorials/beginner/colab.html
- HuggingFace Sample Notebooks:
  https://huggingface.co/docs/transformers/en/notebooks

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Papers/ Reports

- We will discuss one paper in each class
- All students will read the assigned paper before the class and write a report
- One group of students will make presentation, and all students will participate in discussion
- Presentation should not be more than 30 minutes
- You can select the paper you want to present from the list on the course webpage
- Reports will be due just before the class meeting through Web Courses

- Schedule Table: https://www.crcv.ucf.edu/courses/cap6412-spring-2025/schedule/

Reports (one page)

- Parts of Report
  - Very short Summary
  - Good points
  - Weak points
  - Questions
  - Ideas

- Reports will not be graded
- We will follow the honor system, by submitting report you will pledge that you have read the paper, have written report yourself, have not copied word by word from the paper and from any other student or leveraged resources like ChatGPT etc

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Statement of Academic Integrity

- The UCF Golden Rule (http://goldenrule.sdes.ucf.edu/) will be observed in the class. Plagiarism and Cheating of any kind on an examination, quiz, or assignment will result at least in an "F" for that assignment (and may, depending on the severity of the case, lead to an "F" for the entire course) and may be subject to appropriate referral to the Office of Student Conduct for further action. I will assume for this course that you will adhere to the academic creed of this University and will maintain the highest standards of academic integrity. In other words, don't cheat by giving answers to others or taking them from anyone else. I will also adhere to the highest standards of academic integrity, so please do not ask me to change (or expect me to change) your grade illegitimately or to bend or break rules for one person that will not apply to everyone.

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Paper presentation review/Rehearsal Schedule

- **For Monday presentation**
  - **Slide Review**: Wednesday 4:15 a week before the scheduled presentation
  - **Rehearsal**: Friday a week before the scheduled presentation 1:00PM during Office hours
- **For Wednesday presentation**
  - **Slide Review** : A week before the scheduled presentation : Friday 1:00PM during Office hours
  - **Rehearsal**: A week of presentation on Monday 2:00PM during Office hours

Textbook

There is no textbook for this class. We will discuss recent research papers.

A good deep learning textbook:

- Ian Goodfellow, Yoshua Bengio, Aaron Courville. Deep Learning. https://www.deeplearningbook.org/
- Alex Smola, Introduction to Machine Learning

https://alex.smola.org/drafts/thebook.pdf

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Research Paper

- Each paper has following parts
  1. Title
  2. Abstract
  3. Introduction
  4. Rest of the paper
     - Related Work
     - Method
     - Results
     - Conclusion

- Each part is equally important (25% each!)

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How to read a research paper?

- You must read the paper several times to understand it.
  - When you read the paper first time,
    - if you do not understand something do not get stuck,
    - keep reading assuming you will figure out that later.
  - When you read it the second time, you will understand much more, and the third time even more ...
- Read the abstract first then look at the figures with captions and then conclusion

How to read a research paper?

- Try first to get a general idea of the paper
  - What problem is being solved?
  - What are the main steps?
  - How can I implement the method?,
  - Even though I do not understand why each step is performed the way it is performed
- Try to relate the method to other methods you know, and conceptually find similarities and differences.

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How to read a research paper?

- In the first reading it may be a good idea to skip the related work.
- Do not use dictionary to just look up the meaning of technical terms
- Try to understand each concept in isolation, and then integrate them to understand the whole paper.

Useful Blogs about how to read a paper?

- https://web.stanford.edu/class/ee384m/Handouts/HowtoReadPaper.pdf

- https://blogs.lse.ac.uk/impactofsocialsciences/2016/05/09/how-to-read-and-understand-a-scientific-paper-a-guide-for-non-scientists/

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Visual-Language Models: Short Introduction

- Material from
  - Survey paper: Muhammad Awais, Muzammal Naseer, Salman Khan, Rao Muhammad Anwer, Hisham Cholakkal, Mubarak Shah, Ming-Hsuan Yang, Fahad Khan, *Foundational Models Defining a New Era in Vision: A Survey and Outlook,* https://arxiv.org/pdf/2307.13721.pdf
  - A Dive into Vision-Language Models: https://huggingface.co/blog/vision_language_pretraining
  - Beginner's Guide to Large Language Models | by Digitate | Medium https://medium.com/@igniobydigitate/a-beginners-guide-to-large-language-models-e5e9e63d84a
  - Introduction to Visual-Language Model | by Navendu Brajesh | Medium https://medium.com/@navendubrajesh/vision-language-models-an-introduction-37853f535415
  - https://huggingface.co/blog/vision_language_pretraining

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Relevant Resources: Visual Language Models

- https://huggingface.co/blog/vision_language_pretraining
- https://medium.com/@navendubrajesh/vision-language-models-an-introduction-37853f535415
- https://www.kaggle.com/code/jhoward/getting-started-with-llms/
- https://landing.ai/news/landing-ai-announces-new-capability-to-build-domain-specific-large-vision
- models/?utm_campaign=mv_pr_lvm&utm_medium=organicsocial&utm_source=linkedIn&utm_content=pr_lvm
- https://www.promptingguide.ai/techniques/rag
- https://huggingface.co/blog/vision_language_pretraining

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Relevant Resources: Diffusion Models

- Survey paper
  - Diffusion Models in Vision: A Survey, Florinel-Alin Croitoru, Vlad Hondru, Radu Tudor Ionescu, Member, IEEE, and Mubarak Shah https://arxiv.org/pdf/2209.04747.pdf
- https://www.youtube.com/watch?v=cS6JQpEY9cs
- [1]https://maciejdomagala.github.io/generative_models/2022/06/06/The-recent-rise- of-diffusion-based-models.html
- [2] https://lilianweng.github.io/posts/2021-07-11-diffusion-models/
- [3] https://developer.nvidia.com/blog/improving-diffusion-models-as-an-alternative-to- gans-part-1/
- https://yang-song.net/blog/2021/score/
- https://www.youtube.com/watch?v=cS6JQpEY9cs

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Computer Vision Tasks

- Object Classification
- Object Detection
- Object Segmentation
- Instant Segmentation
- Object Retrieval
- Semantic Segmentation
- Action Classification
- Object Tracking
- ….

Limitation

- Computer Vision techniques output images, bounding boxes, classes,..
- They don’t communicate through text
- Humans are good at communicating with language and text

Computer Vision Tasks requiring language

- Images
  - Image Captioning
  - Visual Question & Answering
  - Image-to-Text Retrieval
  - Text-to-Image Retrieval
  - Text-guided image generation
- Video
  - Video Captioning
  - Video Q&A
  - Video-text Retrieval
  - …

Image Captioning



O Vinyals et al. Show and Tell: A Neural Image Caption Generator, 2014

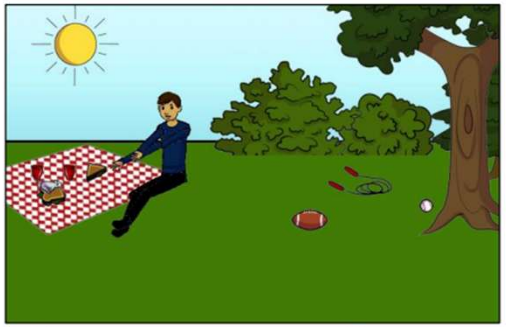
VQA



What color are her eyes?
What is the mustache made of?



How many slices of pizza are there?
Is this a vegetarian pizza?



Is this person expecting company?
What is just under the tree?

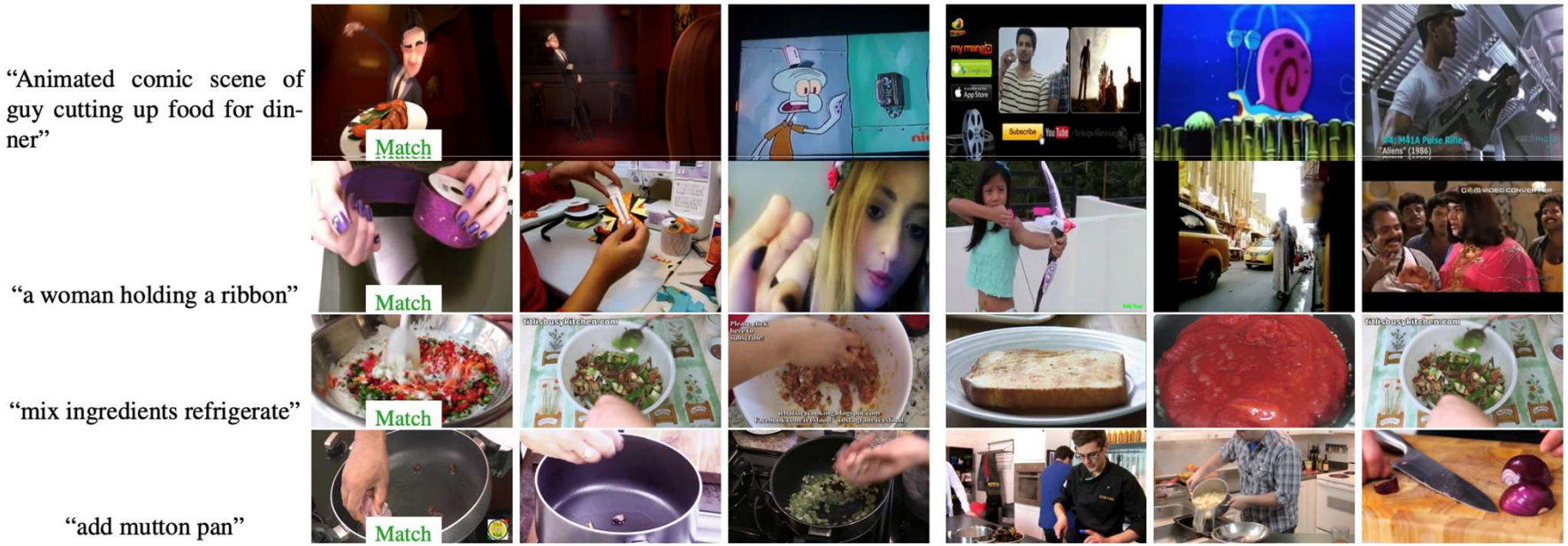


Does it appear to be rainy?
Does this person have 20/20 vision?

VQA: Visual Question Answering, Aishwarya Agrawal, Jiasen Lu, Stanislaw Antol, Margaret Mitchell, C. Lawrence Zitnick, Dhruv Batra, Devi Parikh, 2015

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Text to Video Retrieval



Sirnam, Swetha; Rizve, Mamshad Nayeem; Kuhne, Hilde; Shah, Mubarak
Preserving Modality Structure Improves Multi-Modal Learning, ICCV, 2023

Natural Language Processing (NLP)

- Search engines
- Spam filtering
- Machine translation
- Sentiment analysis
- Document summarization
- …..

Natural Language Processing (NLP)

- Limitations
  - Not able to decode visual cues
  - Linguistic Ambiguities
  - Verifying interpretations against real-world visual references

Language Models

- Understand and Generate text
- Learn from raw text
- Transformer architecture

Source: Beginner's Guide to Large Language Models | by Digitate | Medium

Large Language Models

- Pre-trained on large datasets
- They have large number of parameters

LLM Datasets

- Common Crawl consists of ~60% of training data.
- WebText2 (Open AI, from Reddit) consists of ~22% of training data.
- Books1 consists of ~8 % of training data.
- Books2 consists of ~ 8% of training data.
- Wikipedia consists of ~ 3% of training data.

Source: Beginner's Guide to Large Language Models | by Digitate | Medium

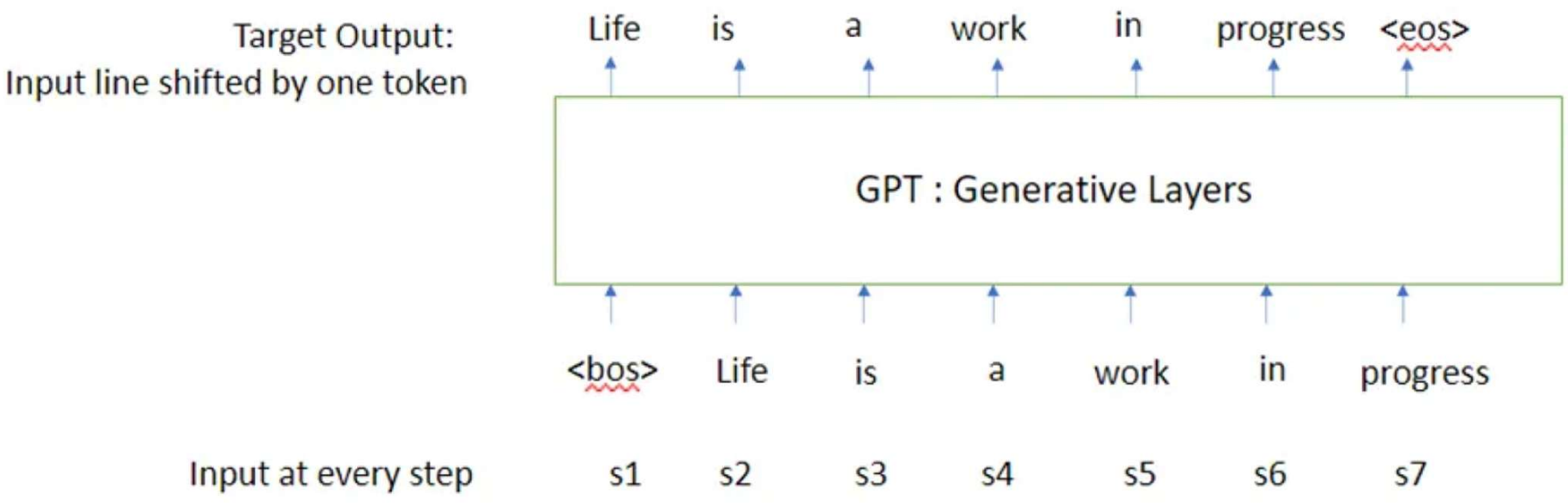
LLMs

- **LaMDA**: Developed by google, trained on 1.56 trillion words of public dialog data. It powers the BARD chatbot!
- **LLaMA**: Developed by Meta, a relatively small model (7B parameters) yet accurate as compared to GPT3.
- **BLOOM**: open source and multilingual model, trained data from 46 natural languages and 13 programming languages.
- **Galactica**: Developed by Meta, can store, combine, and reason about scientific knowledge.
- **Codex:** model that powers GitHub Copilot. Proficient in more than a dozen programming languages, Codex can now interpret simple commands in natural language and execute them.
- **PaLM-E**: Developed by google, a LLM focused on robot sensor data.
- **Chinchilla**: Developed by Deepmind, considerably simplifies downstream utilization because it requires much less computer power for inference and fine-tuning.

Source: Beginner's Guide to Large Language Models | by Digitate | Medium

LLM	Developer	Multimodal?	Access
GPT	OpenAI	Yes	Chatbot and API
Gemini	Google	Yes	Chatbot and API
Gemma	Google	No	Open
Llama	Meta	No	Chatbot and open
Claude	Anthropic	Yes	Chatbot and API
Command	Cohere	No	API
Falcon	Technology Innovation Institute	No	Open
DBRX	Databricks and Mosaic	No	Open
Mixtral 8×7B and 8×22B	Mistral AI	No	Open source
Phi-3	Microsoft	No	Open
Grok	xAI	No	Chatbot and open

GPT (Generative Pre-trained Transformer)



Source: Beginner's Guide to Large Language Models | by Digitate | Medium

Pre-Training

- Self-Supervised
- Auto-regressive
- Unidirectional
- It understands the relationship between various words in the given context

Source: Beginner's Guide to Large Language Models | by Digitate | Medium

Limitations of LLMs

- LLMs are large
- LLMs are Black box
- LLMs can have bias
- LLMs can do hallucinations
- LLMs may have IP issue

Source: Beginner's Guide to Large Language Models | by Digitate | Medium

Applications of LLMs

- Code generation
- Content generation tools
- Copywriting
- Conversational tools
- Educational tools
- Enterprise search
- Information retrieval

Source: Beginner's Guide to Large Language Models | by Digitate | Medium

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Visual Language Models

- Vision systems are fundamental to understanding our world
- However, humans are good in communicating through language
- Complex relations between objects and their locations can be better described in human language (text)
- Visual-Language models bridge the gap between vision and language
- VLMs understand both images and text
- The output of VLM can be modified through human-provided prompts, e.g.,
  - segmenting a particular object by providing a **bounding box**,
  - having interactive dialogues by asking **questions** about an image or video scene
  - manipulating the robot's behavior through **language instructions**

Muhammad Awais, Muzammal Naseer, Salman Khan, Rao Muhammad Anwer, Hisham Cholakkal, Mubarak Shah, Ming-Hsuan Yang, Fahad Khan, *Foundational Models Defining a New Era in Vision: A Survey and Outlook,* https://arxiv.org/pdf/2307.13721.pdf

Language and Senses

- Humans are the only known species where much of knowledge learning happens symbolically through language.
- In addition to information received directly from Five senses.
  - Vision
  - Hearing
  - Touch
  - Taste
  - Smell

Source: Wikipedia

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Large Multi-model Models (LMMs)

- Image
- Video
- Text
- Audio (speech, music)
- Physiological signals
- ….

Contrastive Learning Image Pre-training (CLIP)



Input Image

$\vec{H}_i$

Image Representation

A dog lying in grass

Input Text

$\vec{H}_t$

Text Representation

$$maximize(\frac{\vec{H}_i \cdot \vec{H}_t}{\|\vec{H}_i\| \times \|\vec{H}_t\|})$$

Learning Transferable Visual Models From Natural Language Supervision

Alec Radford, Jong Wook Kim, Chris Hallacy, Aditya Ramesh, Gabriel Goh, Sandhini Agarwal, Girish Sastry, Amanda Askell, Pamela Mishkin, Jack Clark, Gretchen Krueger, Ilya Sutskever

Contrastive Learning Image Pre-training (CLIP)



Input Image

$\vec{H}_i$

Image Representation

A dog lying in grass

Input Text

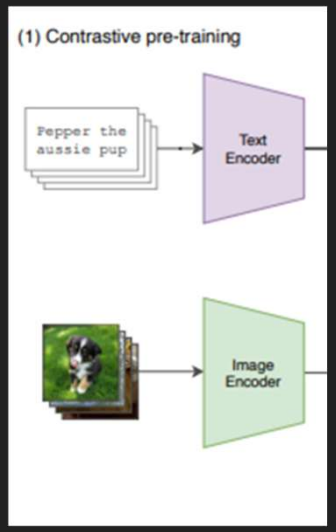
$\vec{H}_t$

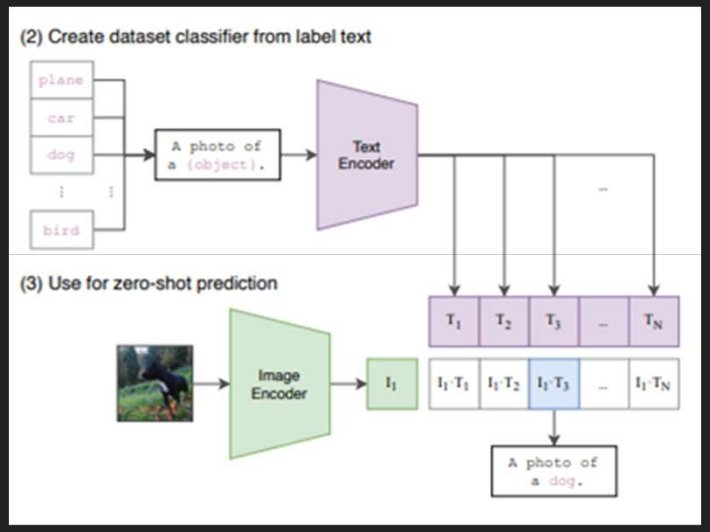
Text Representation

$$minimize(\frac{\vec{H}_i \cdot \vec{H}_t}{\|\vec{H}_i\| \times \|\vec{H}_t\|})$$

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Contrastive Language Image Pre-training (CLIP)





GPT-4

Example of GPT-4 visual input:

User: What is funny about this image? Describe it panel by panel.



Source: https://www.reddit.com/r/hmmm/comments/ubab5v/hmmm/

GPT-4: The image shows a package for a "Lightning Cable" adapter with three panels.

Panel 1: A smartphone with a VGA connector (a large, blue, 15-pin connector typically used for computer monitors) plugged into its charging port.

Panel 2: The package for the "Lightning Cable" adapter with a picture of a VGA connector on it.

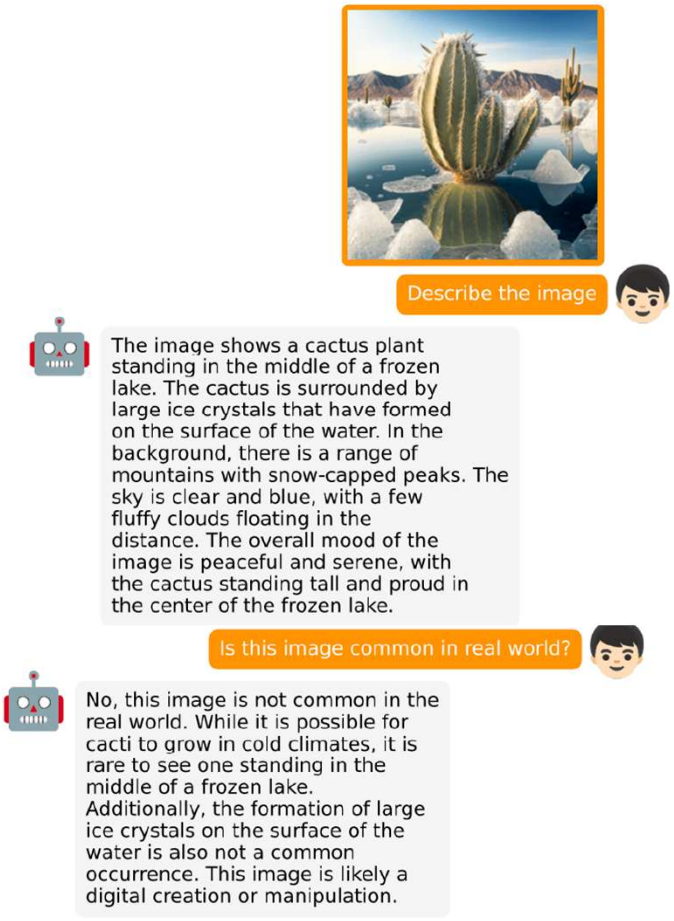
Panel 3: A close-up of the VGA connector with a small Lightning connector (used for charging iPhones and other Apple devices) at the end.

The humor in this image comes from the absurdity of plugging a large, outdated VGA connector into a small, modern smartphone charging port.

https://cdn.openai.com/papers/gpt-4.pdf

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Mini-GPT4



MiniGPT-4: Enhancing Vision-Language Understanding with Advanced Large Language Models, Deyao Zhu, Jun Chen, Xiaoqian Shen, Xiang Li, Mohamed Elhoseiny

LLaVa

Visual input example, Extreme Ironing:



Source: https://www.barnorama.com/wp-content/uploads/2016/12/03-Confusing-Pictures.jpg

User: What is unusual about this image?

LLaVA: The unusual aspect of this image is a man ironing clothes on the back of a minivan or van. This is not a typical place to perform this activity, as one would usually iron clothes in a more stationary and safe location, such as a home, using a regular ironing board. The scene depicted in the image is peculiar as it involves a makeshift ironing setup on a vehicle, which can be both unsafe and unconventional. Additionally, it is not clear how the man is able to maintain balance and stability while ironing clothes in such an unstable environment.

[*Start a new conversation, and clear the history*]

User: What's happening in the scene?

LLaVA: The image depicts a man standing on top of a yellow SUV in a busy city street. He is holding a portable ladder, seemingly ironing clothes while standing on the vehicle. Around the scene, there are other cars, a traffic light, and a fire hydrant. Additionally, there are two other people in the vicinity, one close to the man on the car and another further away. The man on the ladder appears to be attracting attention due to his unconventional choice of ironing his clothes on top of a moving car. The city street around him is bustling with activity, adding to the unique nature of the scene.

Visual Instruction Tuning

Haotian Liu, Chunyuan Li, Qingyang Wu, Yong Jae Lee

LLaVA



What's the ending of this movie?

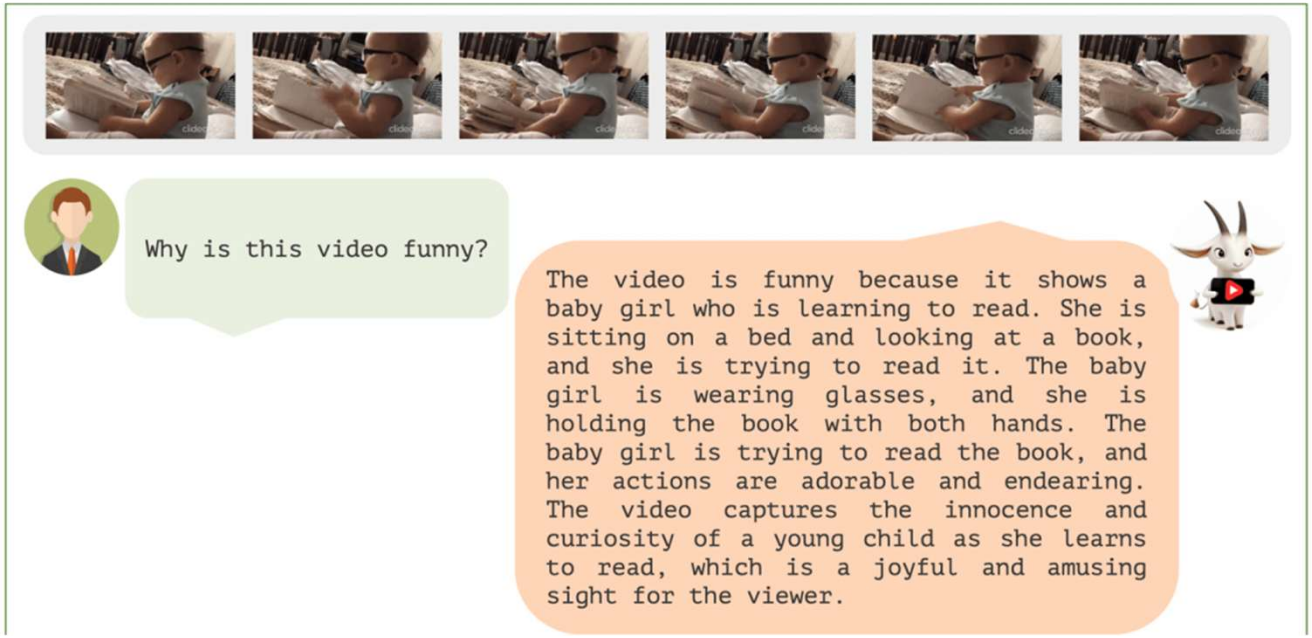
In the image, a young woman is leaning on a man in front of a beautiful sunset, with both of them standing on a boat. They appear to be enjoying a romantic moment together. The scene suggests that they could be depicted as the characters Jack and Rose from the popular movie Titanic. In the movie, their romance blossoms aboard the fictional ocean liner Titanic, with the pair ultimately sharing a passionate kiss as the ship sinks into the ocean. The ending of the movie is known for its emotional and heartfelt scenes, where the characters are forced to say goodbye to each other as they are separated by the sinking ship. The image evokes a sense of romance and nostalgia, paying tribute to the iconic love story portrayed in the movie Titanic.

Visual Instruction Tuning

Haotian Liu, Chunyuan Li, Qingyang Wu, Yong Jae Lee

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Video ChatGPT



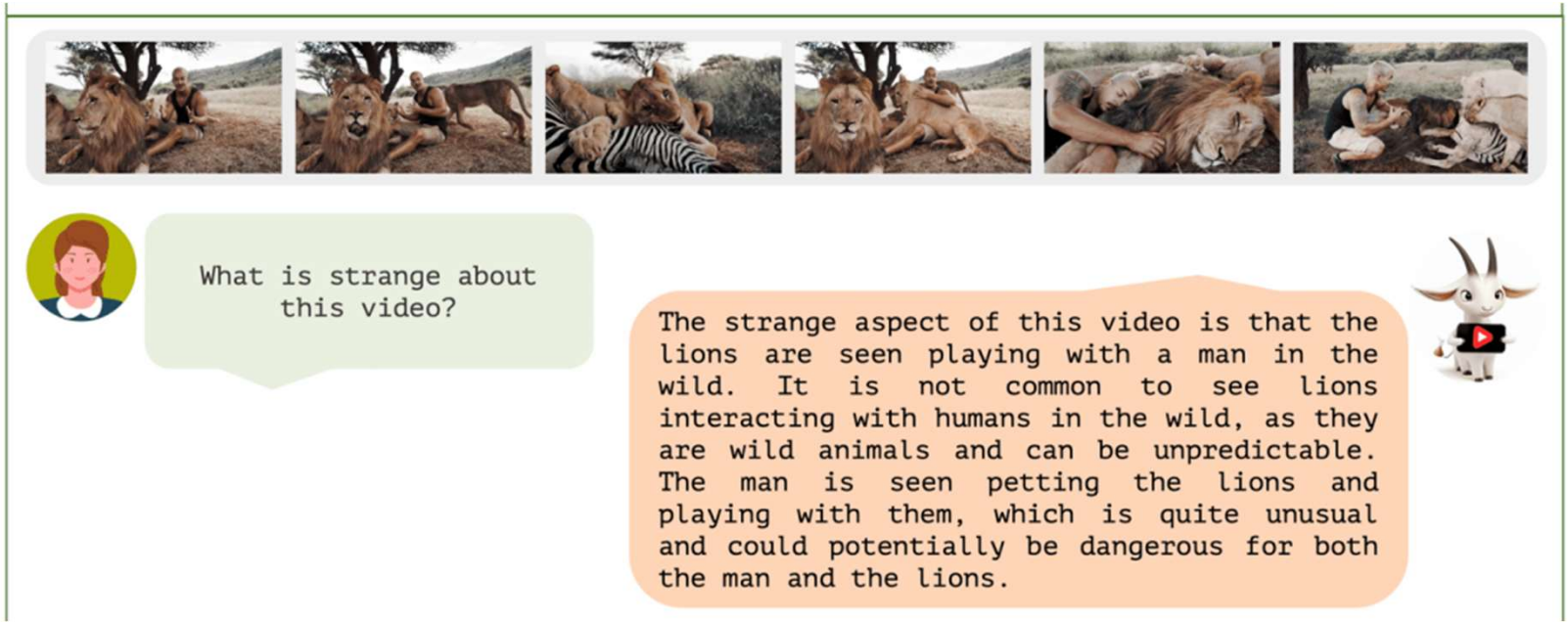
Video-ChatGPT: Towards Detailed Video Understanding via Large Vision and Language Models
Muhammad Maaz, Hanoona Rasheed, Salman Khan, Fahad Shahbaz Khan

Video ChatGPT



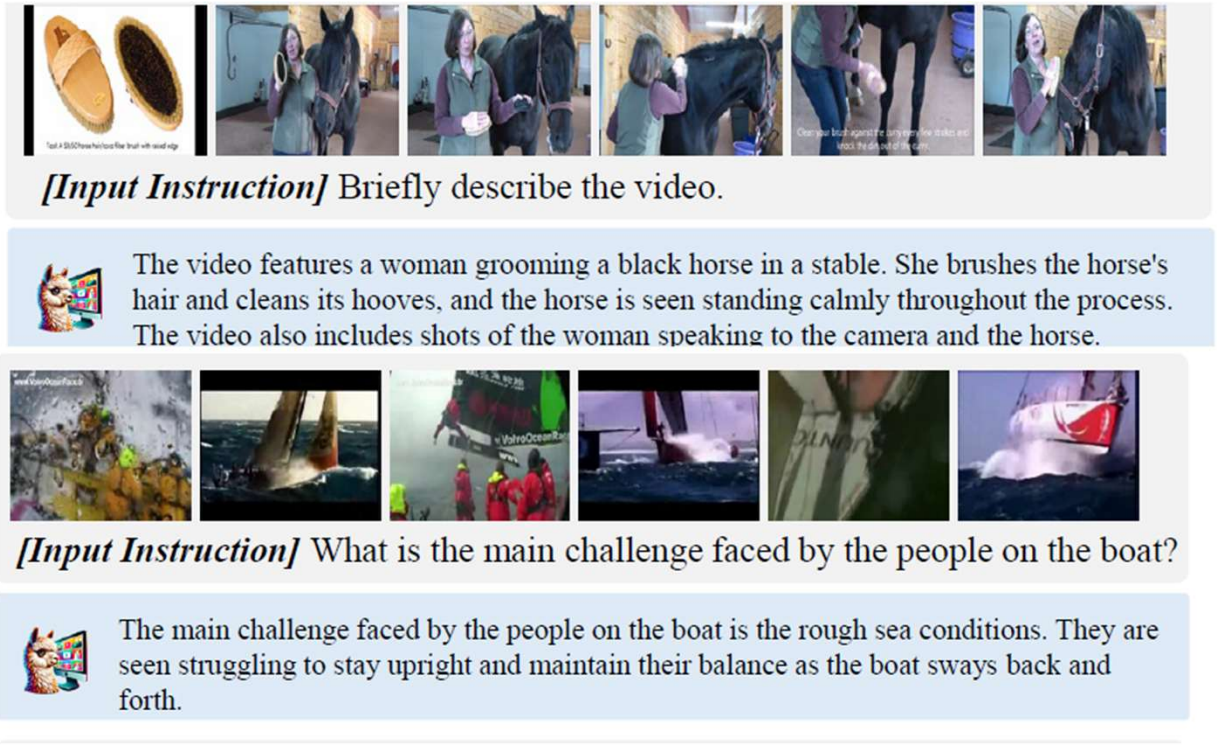
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Video ChatGPT



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PG-Video-LLaVA



PG-Video-LLaVA: Pixel Grounding Large Video-Language Models

Shehan Munasinghe, Rusiru Thushara, Muhammad Maaz, Hanoona Abdul Rasheed, Salman Khan, Mubarak Shah, Fahad I

PG-Video-LLaVA



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PG-Video-LLaVA

