

PandaGPT: One Model To Instruction-Follow Them All

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<https://panda-gpt.github.io/>

Abstract

We present PandaGPT, an approach to empower large language models with visual and auditory instruction-following capabilities. Our pilot experiments show that PandaGPT can perform complex tasks such as detailed image description generation, writing stories inspired by videos, and answering questions about audios. More interestingly, PandaGPT can take multimodal inputs simultaneously and compose their semantics naturally. For example, PandaGPT can connect how objects look in an image/video and how they sound in an audio. To do so, PandaGPT combines the multimodal encoders from ImageBind and the large language models from Vicuna. Notably, only aligned image-text pairs are required for the training of PandaGPT. Thanks to the strong capability of ImageBind in embedding data from different modalities into the same space, PandaGPT displays emergent, i.e. zero-shot, cross-modal behaviors for data other than image and text (e.g., video, audio, depth, thermal, and IMU). We hope that PandaGPT serves as an initial step toward building AGI that can perceive and understand inputs in different modalities holistically, as we humans do.

1 Introduction

Humans possess remarkable abilities to perceive and understand information from diverse sensory modalities, such as seeing a painting and hearing an audio guide. Analogously, to learn simultaneously, holistically, and directly from many different forms of information holds great promise for enabling machines to have a more comprehensive and better understanding of the world. To this end, there has been an emergent interest in developing artificial intelligence (AI) systems capable of perceiving and understanding information from multiple modalities simultaneously in a manner similar to humans.

However, much of the prior research has focused on tackling individual modalities in isolation. For

instance, while significant progress has been made in text-to-image retrieval and generation (Radford et al., 2021), visually-grounded instruction following (Liu et al., 2023; Zhu et al., 2023), and speech understanding and generation (Zhang et al., 2023a), these advances have largely been confined to separate combinations of text and other modalities or, at best, a few visual modalities (e.g., image and video). These models are limited in their ability to connect information from different modalities and lack the capacity to perceive and understand multimodal inputs holistically, thereby neglecting the inherent richness and complementary nature of multimodal data.

In this paper, we present PandaGPT, the first general-purpose model capable of instruction-following data from six modalities. PandaGPT leverages the power of multimodal encoders from ImageBind (Girdhar et al., 2023) and the expressive language models from Vicuna (Chiang et al., 2023), demonstrating impressive and emergent cross-modal capabilities across six modalities, namely, image/video, text, audio, depth, thermal, and inertial measurement units (IMU). Crucially, PandaGPT achieves these capabilities despite being only trained on aligned image-text pairs, thanks to the shared embedding space provided by ImageBind.

This integration of multimodal information enables PandaGPT to perform a wide range of tasks, including generating detailed descriptions of images, composing engaging stories inspired by videos, and providing accurate answers to questions about audio inputs. Most interestingly, the core innovation of PandaGPT lies in its ability to naturally compose the semantics of multimodal inputs, which enables a rich set of compositional multimodal tasks across different modalities. For example, it can seamlessly connect the visual appearance of objects in a photo with their corresponding sounds in an audio clip, producing a cohesive and comprehensive understanding of the scene. These cross-modal capabilities empower the model to go

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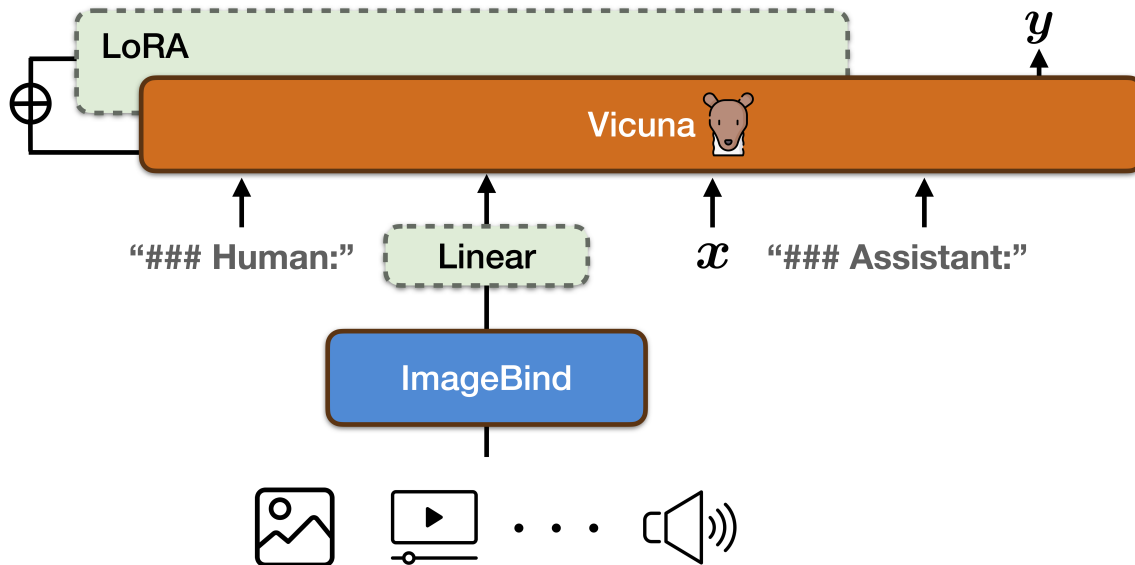


Figure 1: Illustration of PandaGPT. During training, we only train the linear projection matrix and the additional LoRA weights (as indicated with dashed boxes) while keeping the parameters of ImageBind and Vicuna frozen.

beyond traditional unimodal analysis. We hope PandaGPT serves as an initial step toward building AGI that can perceive and understand inputs in different modalities holistically, as humans do.

2 Related Work

Large Language Models. Large language models (LLMs) pre-trained over massive unlabeled text have dominated the field of natural language processing (NLP) today (Radford et al., 2018; Devlin et al., 2019; Radford et al., 2019; Brown et al., 2020; Su et al., 2021, 2022b). With alignment techniques such as supervised instruction tuning (Sanh et al., 2021; Wei et al., 2021; Mishra et al., 2021) and reinforcement learning from human feedback (Stiennon et al., 2020; Ouyang et al., 2022), LLMs exhibit surprisingly effective zero- and few-shot generalization abilities to perform almost any NLP tasks. The most successful examples could be OpenAI’s ChatGPT (OpenAI, 2023b) and GPT4 (OpenAI, 2023a), which have made a profound impact on the entire AI research community and beyond. There also have been enormous open-source efforts to replicate the success, such as BLOOM (Scao et al., 2022), LLaMA (Touvron et al., 2023), Alpaca (Taori et al., 2023), Vicuna (Chiang et al., 2023), OpenAlpaca (Su et al., 2023) among many others.

Multi-modal Alignment. Feature alignment among multiple modalities has attracted great interest for its applications such as cross-modal retrieval (Frome et al., 2013; Faghri et al., 2017; Alayrac

et al., 2020). Recently, CLIP (Radford et al., 2021) learns a joint embedding space for image and text. Flamingo (Alayrac et al., 2022), BLIP-2 (Li et al., 2023), and MAGIC (Su et al., 2022a) bridge powerful pre-trained vision-only and language-only models and show strong zero-shot abilities. AudioCLIP (Guzhov et al., 2022) adds audio into the CLIP framework for audio classification. ImageBind (Girdhar et al., 2023) learn a joint embedding across six different modalities (image/video, text, audio, depth, thermal, and IMU data) using image-paired data only. More recently, there has been a surge of interest to combine multi-modal alignment and large language models for multi-modal instruction following. LLaVa (Liu et al., 2023), Mini-GPT4 (Zhu et al., 2023), and VideoLLaMA (Zhang et al., 2023b) enable visually-grounded instruction following. DetGPT (Pi et al., 2023) proposes reasoning-based object detection. SpeechGPT (Zhang et al., 2023a) adds speech understanding and generation abilities to LLMs. However, these advances have largely been confined to separate combinations of text and other modalities (e.g., image/video or audio).

3 Method

PandaGPT combines the multi-modal encoders from ImageBind (Girdhar et al., 2023) and the large language models from Vicuna (Chiang et al., 2023), achieving impressive capabilities in vision- and audio-grounded instruction following tasks. To align the feature space of multimodal encoders from ImageBind and large language models from

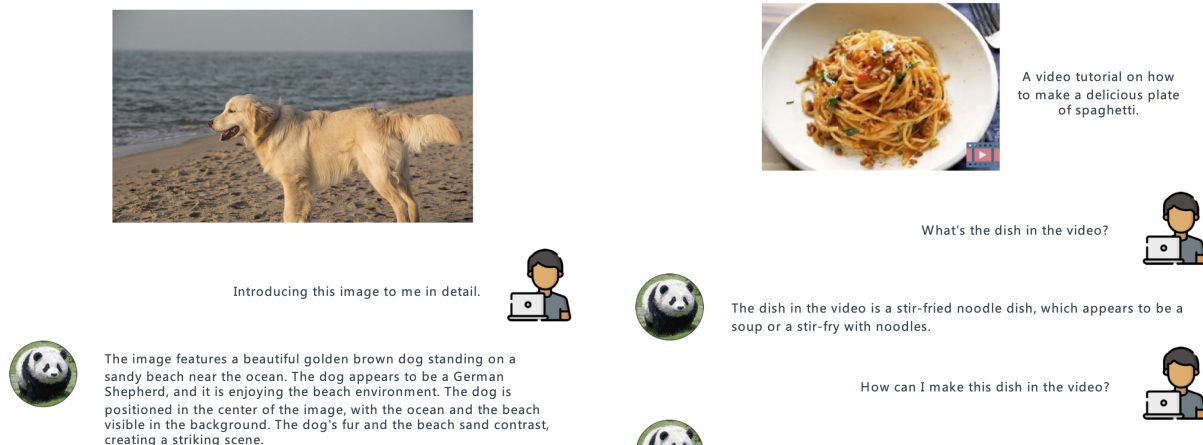


Figure 2: Example showing PandaGPT’s capability in image-grounded question answering.

Vicuna¹, we train PandaGPT using 160k image-language instruction-following data released by Liu et al. (2023) and Zhu et al. (2023). Each training instance consists of an image \mathcal{I} and a multi-turn conversation data $(\mathbf{x}_1, \mathbf{y}_1, \dots, \mathbf{x}_n, \mathbf{y}_n)$, where \mathbf{x}_i and \mathbf{y}_i are the human’s instruction and the system’s response at the i -th turn, respectively. To reduce the number of trainable parameters, we only train (i) a linear projection matrix f to connect the representation produced by ImageBind to Vicuna; and (ii) additional LoRA (Hu et al., 2021) weights on the Vicuna’s attention modules.² Figure 1 illustrates the architecture of PandaGPT.

The training objective of PandaGPT is defined as

$$\mathcal{L}(\theta_f, \theta_l) = \prod_{i=1}^n p_{\theta}(\mathbf{y}_i | \mathbf{x}_{<i}, \mathbf{y}_{<i-1}, f(h_{\mathcal{I}})), \quad (1)$$

where θ_f and θ_l correspond to the learnable parameters of the linear projection matrix and LoRA weights. The $h_{\mathcal{I}}$ is the image representation produced by ImageBind and $\theta = \{\theta_f, \theta_l, \theta_1, \theta_2\}$, where θ_1 and θ_2 are frozen parameters of ImageBind and Vicuna, respectively. Note that the loss is only computed from the part of system responses during training. We train PandaGPT on the image-language instruction-following dataset for two epochs using a learning rate of $5e-4$ with linear decay. The maximum sequence length for Vicuna-13B is set to 400 based on our computation resources ($8 \times A100$ 40G GPUs). The training takes around 7 hours to complete.

¹We use the version-0 of Vicuna-13B as our base language model.

²The total number of trainable parameters is around 0.4% of the parameters of Vicuna.



The dish in the video is a stir-fried noodle dish, which appears to be a soup or a stir-fry with noodles.



To make this dish, follow these steps:

1. Cook the noodles according to the package instructions.
2. In a large pot or wok, heat some oil over medium heat.
3. Add the chopped onions and stir-fry until they are translucent.
4. Add the chopped carrots and stir-fry for a few more minutes.
5. Add the broccoli and stir-fry until it is tender.
6. Add the noodles to the pot, stirring to coat them with the vegetables and oil.
7. Add the sauce to the pot, stirring to combine with the ingredients.
8. Cook the mixture over medium heat for a few minutes, stirring occasionally, until the sauce thickens.
9. Serve the dish hot, garnished with chopped green onions or other desired toppings.

Note: The specific ingredients and sauce used in the video may vary, so adjust the recipe according to your preferences or the ingredients available.

Figure 3: Example showing PandaGPT’s capability in image/video-inspired creative writing.

It is worth noting that the current version of PandaGPT is only trained with aligned image-text data. However, by leveraging the binding property across six modalities (image/video, text, audio, depth, thermal, and IMU) inherited from ImageBind, PandaGPT demonstrates emergent, i.e. zero-shot, cross-modal capabilities across all of the modalities.

4 Capabilities of PandaGPT

Compared to existing multimodal instruction-following models trained individually for one particular modality, PandaGPT can understand and combine the information in different forms together, including image/video, text, audio, depth (3D), thermal (infrared radiation), and inertial measurement units (IMU) readings. We find that the capabilities of PandaGPT include but are not limited to:

- **image/video-grounded question answering:** see examples of Figure 2, 6, and 7.
- **image/video-inspired creative writing:** see examples of Figure 3.
- **visual and auditory reasoning:** see examples of Figure 4, 8, and 9.
- **multimodal arithmetic:** PandaGPT is also capable of working with input composed across



Figure 4: Example showing PandaGPT’s capability in visual reasoning.

modalities. By arithmetically adding information from different modalities as input, PandaGPT can produce results that reflect concepts from different parts. See Figure 5 and 10 for examples of image and audio arithmetic, and see Figure 11 and 12 for examples of video and audio arithmetic.

5 Conclusion and Limitations

In this study, we present PandaGPT, the first general-purpose model capable of instruction-following data from six modalities. The training of PandaGPT is designed in a parameter-efficient way on a 160k vision-language instruction-following dataset. Through extensive and concrete examples, we demonstrate that PandaGPT possesses strong vision-language capabilities and such capabilities are transferable to other modalities in an emergent, i.e. zero-shot, way.

Despite the amazing capabilities in handling multiple modalities and their combinations. There are multiple ways to further improve PandaGPT.

1. The training of PandaGPT can be enriched by using other alignment data, for instance, other modalities paired with text (e.g., audio-text pairs).
2. We only use one embedding vector from Im-

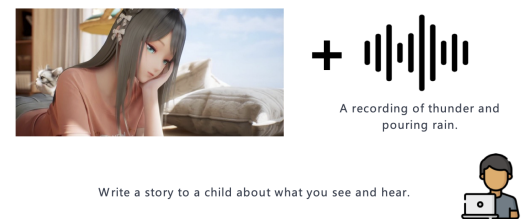


Figure 5: Example showing PandaGPT’s capability in multimodal arithmetic (Image and Audio).

ageBind for the content in other modalities than text. More research into fine-grained feature extraction such as cross-modal attention mechanisms could be beneficial for the improvement of performance.

3. PandaGPT currently only allows multimodal information to be used as input, future possibilities include generating richer multimedia content (e.g., creating images and response in audio).
4. New benchmarks to evaluate the composition ability of multimodal inputs is demanded.
5. PandaGPT can also exhibit several common deficiencies of existing language models, including hallucination, toxicity, and stereotypes.

Lastly, we would like to note that PandaGPT is a research prototype and cannot be readily used for real-world applications.

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A More Examples of PandaGPT



Who's this guy?



The guy in the image is Elon Musk, a well-known entrepreneur, inventor, and CEO of multiple companies, including SpaceX and Tesla. He is often associated with innovative projects and technological advancements.

Can you list some other companies he's involved with?



In addition to SpaceX and Tesla, Elon Musk is also involved with several other companies, including Neuralink, The Boring Company, and OpenAI.

Figure 6: Example showing PandaGPT's capability in image-grounded question answering.



A video of a Super-hero Movie.

Who are the people in this video?



The people in this video are a group of superheroes, including characters like Iron Man, Captain America, and the Hulk.

I wanna know if Spider-Man showed up in the video.



Yes, Spider-Man is present in the video along with the other superheroes.

Figure 7: Example showing PandaGPT's capability in video-grounded question answering.



A dog barking audio.

Tell me what you hear about this audio.



In the audio, a dog is barking loudly, possibly due to being excited or startled. The dog's barking is heard in the background, with the sound gradually getting louder as the audio progresses. The dog's barking is the main focus of the audio, and it is clear that the dog is the source of the noise.

Can you guess what might be the reason why dogs in the audio start barking?



While it is impossible to know the exact reason for the dogs barking in the audio, there are several possibilities that could explain the sudden increase in barking. Some possible reasons include:

1. Playfulness: Dogs often bark when they are playing or engaging in playful activities with their owners or other dogs.
2. Excitement: Dogs may bark when they are excited or curious about something new, such as a visitor, a toy, or a treat.
3. Fear or anxiety: Dogs may bark when they are scared or anxious, such as when they hear strange noises or see unfamiliar people or animals.
4. Separation anxiety: Dogs may bark when they are left alone or feel anxious about being separated from their owners.
5. Communication: Dogs may bark to communicate their needs, such as wanting attention, food, or to play.

These are just a few examples of the many reasons why dogs might bark. It is important to consider the context of the situation and the dog's behavior to determine the exact cause of the barking in this particular audio.

Figure 8: Example showing PandaGPT's capability in auditory reasoning.



The audio of a gunshot.

Describe what you hear from this audio.



The audio is a sound of a gunshot, with the distinctive cracking sound of the bullet being fired and the muffled echoes from the surrounding environment.

This is so scary, how can we avoid encountering such a thing?



To avoid encountering dangerous situations like gunshots, it is essential to prioritize safety and awareness. Here are some suggestions:

1. Stay informed: Keep yourself updated on local news, crime reports, and any potential threats in your area.
2. Be aware of your surroundings: Pay attention to your environment and any unusual or suspicious activities.
3. Avoid potentially dangerous situations: Avoid walking alone in isolated or high-crime areas, especially at night.
4. Learn self-defense techniques: Knowing how to protect yourself in case of an emergency can be a valuable skill.
5. Report any suspicious activity: If you witness or experience something unusual, immediately report it to the authorities.
6. Install security systems: Installing security systems like alarms, cameras, and locks can help protect you and your property.
7. Maintain a strong support system: Stay connected with friends, family, and neighbors to ensure that you have a network of people who can help you in case of an emergency.

By following these guidelines, you can minimize the risk of encountering the gunshot.

Figure 9: Example showing PandaGPT's capability in auditory reasoning.



A recording of calm ocean waves.

Write a story to a child about what you see and hear.



In the image, there is a woman standing on a rock near the water, looking out at the ocean. The ocean is calm and reflects the sky, creating a serene atmosphere. The woman is enjoying the view and listening to the soothing sound of the waves crashing against the shore. As she stands there, she notices a bird flying by, adding a touch of life and movement to the scene. The woman feels peaceful and content, taking in the beauty of the ocean and the natural world around her.

What color is the woman's hair?



The woman has blonde hair.

Figure 10: Example showing PandaGPT's capability in multimodal arithmetic (Image and Audio).



A video about a couple taking a stroll together.



A recording of thunder and pouring rain.

Now, I am closing my eyes. Please describe what you can see and hear for me.



As you close your eyes, you can still see the image of the two people walking down the street at night, carrying umbrellas to protect themselves from the rain. The streetlights illuminate the scene, casting a warm glow on the people and the surrounding area. You can hear the sound of the rain falling gently on the umbrellas, creating a soothing and calming atmosphere. The sound of footsteps on the pavement complements the overall ambiance of the scene.

Figure 11: Example showing PandaGPT's capability in multimodal arithmetic (Video and Audio).



A video about a couple taking a stroll together.



A recording of calm ocean waves.

Now, I am closing my eyes. Please describe what you can see and hear for me.



As you close your eyes, you can still see the image of the beach with the ocean waves and the path leading to the water. You can also hear the sound of the waves crashing against the shore, as well as the sound of footsteps on the path. The atmosphere is serene and peaceful, with the sun setting in the background, casting a warm glow over the scene

Figure 12: Example showing PandaGPT's capability in multimodal arithmetic (Video and Audio).