

AURELIA: Test-time Reasoning Distillation in Audio-Visual LLMs

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Introduction and Motivation

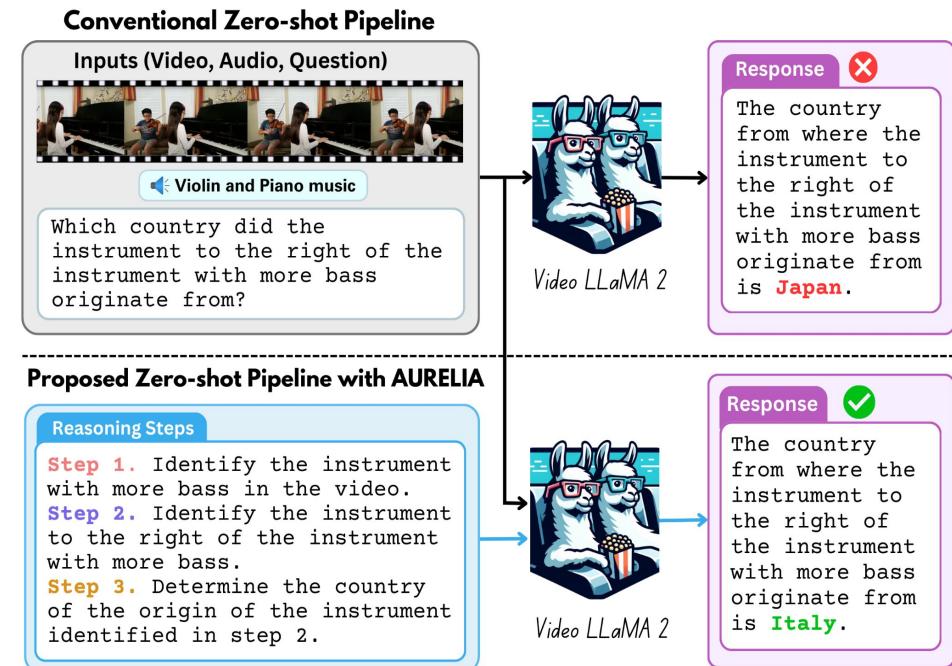
- Audio-Visual (AV) reasoning is crucial for capturing abstract nuances that text or images alone cannot convey.
- Current AVLLMs are prone to cultural, contextual, and perceptual biases in training data, relying on dominant visual or auditory cues over true reasoning.
- Recent advances in reasoning remain largely unexplored for AV models.

Contributions

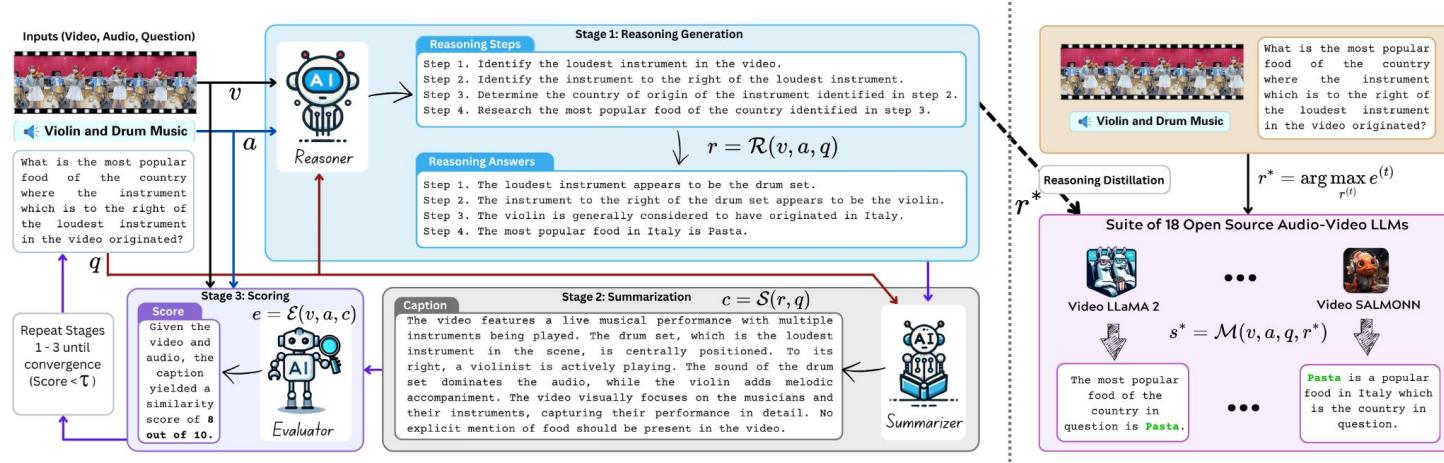
- We introduce **AURELIA**, a test-time multi-agent reasoning distillation framework for addressing challenges in audio-visual cross-modal comprehension by mitigating visual and auditory biases without the need for additional training
- Using our pipeline, we build **AVReasonBench** with 4,500 samples across six tasks, plus new *AV-GeoIQ*, *AV-Compositional*, and *AV-Meme* subsets.

Overview of AURELIA

- AURELIA systematically breaks down the problem into intermediate reasoning steps, guiding the model toward more accurate and interpretable answer.



AURELIA Framework



- **Multi-Agent Framework:** AURELIA employs an interactive Actor-Critique setup where a **Reasoning Generator** proposes structured, step-by-step reasoning based on input audio, video, and query. A **Summarizer** Agent condenses these steps into a coherent caption, and an **Evaluator** Agent scores how well this reasoning aligns with the given AV input. **Feedback** refines the reasoning iteratively until it surpasses a quality threshold or exhausts iterations.

AURELIA Framework: Properties

- **Zero-Shot Reasoning Distillation:** Rather than requiring new training or fine-tuning, AURELIA distills the refined reasoning steps into AVLLMs at inference time, enabling improved reasoning without modifying model weights.
- **Bias Mitigation via Structured Reasoning:** By breaking the problem into logical steps, AURELIA helps AVLLMs move away from relying on superficial visual or auditory cues, addressing cultural and perceptual biases.

AVReasonBench

- Leveraging AURELIA, we build **AVReasonBench**, a benchmark with 4,500 audio-visual question–answer samples, each paired with detailed reasoning. It includes six task categories such as commonsense, music understanding, humor, and a new **AV-GeoIQ** for geo-cultural reasoning.

Task ID	Question Category	Task Name	Class	Number
1	Country Recognition	AV-GeoIQ	17	21
2	Famous Landmark	AV-GeoIQ	18	23
3	Popular Dish/Food	AV-GeoIQ	16	19
4	Currency	AV-GeoIQ	12	13
5	Continent	AV-GeoIQ	5	17
6	Flag Specifics	AV-GeoIQ	10	15
7	Popular Dance Form	AV-GeoIQ	N/A	20
8	Geographical	AV-GeoIQ	N/A	31
9	Language	AV-GeoIQ	11	13
10	Commonsense Reasoning	AV-GeoIQ, AV-Meme, AV-Dance Match	N/A	165
11	Musical Performances	Music-AVQA, AV-GeoIQ	N/A	1014
12	Dynamic Scene	AVSD	N/A	931
13	Meme and Humor	AV-Meme	N/A	50
14	Dance Performances	AV-Dance Match	N/A	100
15	Indoor/Kitchen Scenarios	VALOR	N/A	945
16	Compositional	AV-Comp	N/A	968
17	Miscellaneous	AV-GeoIQ, AVSD, VALOR	N/A	159

Experimental Results: Quantitative

- By leveraging the zeroshot reasoning distillation through AURELIA, we observe consistent boost in the performance of all the AVLLMs

Models	AV-QA		AV-Captioning	AV-Compositional	AV-GeoIQ	AV-Meme	DM-Match
	Music-AVQA	AVSD					
<i>Closed-Source Models</i>							
Gemini 1.5 Pro	70.6 / 68.9	74.7 / 72.5	84.9 / 82.7	38.9 / 36.8	71.2 / 68.0	52.0 / 49.0	43.4 / 41.5
<i>Open-Source Models in ZS</i>							
PandaGPT (13B)	35.8 / 33.7	29.1 / 26.1	67.8 / 64.7	28.8 / 24.1	17.2 / 12.5	25.0 / 21.0	30.2 / 27.0
Macaw-LLM (7B)	34.7 / 31.8	38.4 / 34.3	67.7 / 65.9	26.1 / 24.3	17.2 / 14.0	18.0 / 14.0	24.5 / 20.0
VideoLLaMA (7B)	39.1 / 36.6	40.0 / 36.7	68.4 / 66.2	28.8 / 25.8	19.3 / 16.5	18.0 / 16.0	26.6 / 23.0
ImageBind-LLM	44.2 / 43.9	42.7 / 39.2	69.0 / 66.9	28.8 / 25.4	18.0 / 13.0	17.7 / 15.0	26.2 / 22.5
X-InstructBLIP (13B)	47.8 / 44.5	43.9 / 40.1	69.5 / 66.1	27.5 / 25.9	27.6 / 14.5	18.7 / 15.0	27.3 / 24.5
AV-LLM (13B)	48.2 / 45.2	55.4 / 52.6	70.1 / 67.6	29.6 / 26.1	18.0 / 14.5	24.4 / 20.0	29.4 / 27.0
OneLLM (7B)	49.9 / 47.6	52.3 / 49.8	71.6 / 68.1	29.7 / 26.3	20.9 / 17.0	24.5 / 18.0	28.8 / 26.5
AVicuna (7B)	51.6 / 49.6	56.2 / 53.1	71.2 / 67.9	29.6 / 26.6	19.7 / 16.5	28.4 / 23.0	29.6 / 27.0
CREMA (4B)	56.8 / 52.6	62.3 / 58.6	73.8 / 68.4	31.6 / 27.0	23.8 / 19.0	29.0 / 26.0	31.5 / 28.5
VideoLLaMA2 (7B)	-	-	70.4 / 68.3	29.7 / 26.8	25.7 / 22.0	27.5 / 23.0	28.4 / 25.5
AnyGPT (7B)	53.7 / 50.7	59.2 / 56.9	72.5 / 68.1	28.8 / 26.2	25.7 / 22.5	24.0 / 19.0	28.9 / 25.5
NExt-GPT (7B)	53.5 / 50.9	58.4 / 56.3	68.7 / 67.9	28.0 / 26.4	23.8 / 22.0	19.5 / 16.0	32.3 / 28.0
Unified-IO-2 L (6.8B)	58.3 / 55.1	60.0 / 57.9	73.8 / 70.1	31.8 / 27.2	25.6 / 21.5	26.5 / 22.0	29.3 / 27.5
Unified-IO-2 XL	61.3 / 57.2	59.7 / 58.6	73.7 / 71.8	30.0 / 28.5	24.7 / 22.5	29.0 / 26.0	29.6 / 27.0
Bay-CAT (7B)	55.6 / 53.8	58.3 / 56.5	71.9 / 69.5	31.9 / 28.2	24.4 / 20.5	22.0 / 18.0	29.8 / 27.5
Video-SALMONN (7B)	56.8 / 54.9	58.7 / 57.2	71.1 / 70.2	29.8 / 27.5	24.7 / 22.0	21.0 / 17.0	27.5 / 26.5
VITA (7B)	59.0 / 58.6	61.2 / 60.1	73.8 / 72.9	30.1 / 29.2	26.7 / 25.5	44.0 / 41.0	29.2 / 27.5
<i>Open-Source Models with AURELIA</i>							
PandaGPT (13B)	41.9 ^{+24.33%}	32.7 ^{+25.38%}	72.9 ^{+12.67%}	28.6 ^{+18.67%}	25.0 ^{+100%}	25.0 ^{+19.04%}	31.0 ^{+14.81%}
Macaw-LLM (7B)	41.6 ^{+30.81%}	38.1 ^{+11.07%}	73.5 ^{+11.53%}	29.3 ^{+20.57%}	25.5 ^{+82.14%}	24.0 ^{+71.42%}	28.5 ^{+42.5%}
VideoLLaMA (7B)	45.8 ^{+25.13%}	41.5 ^{+13.07%}	74.2 ^{+12.08%}	29.6 ^{+14.72%}	28.5 ^{+72.72%}	28.0 ^{+75.0%}	29.0 ^{+26.08%}
ImageBind-LLM	49.7 ^{+13.21%}	44.2 ^{+12.75%}	72.8 ^{+8.81%}	30.1 ^{+18.50%}	28.0 ^{+100%}	23.0 ^{+53.33%}	31.0 ^{+37.77%}
X-InstructBLIP (13B)	52.3 ^{+17.52%}	46.9 ^{+16.95%}	72.6 ^{+9.83%}	29.8 ^{+15.05%}	29.0 ^{+100%}	27.0 ^{+8.00%}	30.0 ^{+22.45%}
AV-LLM (13B)	52.7 ^{+16.59%}	57.9 ^{+10.07%}	73.4 ^{+8.57%}	31.1 ^{+19.15%}	28.5 ^{+83.87%}	29.0 ^{+45.0%}	34.0 ^{+25.92%}
OneLLM (7B)	54.1 ^{+13.65%}	55.3 ^{+11.04%}	73.9 ^{+8.51%}	30.7 ^{+16.73%}	29.0 ^{+70.93%}	29.0 ^{+61.11%}	33.5 ^{+26.41%}
AVicuna (7B)	55.3 ^{+11.49%}	57.8 ^{+8.85%}	73.1 ^{+7.65%}	30.4 ^{+14.28%}	29.5 ^{+79.09%}	34.0 ^{+47.80%}	34.5 ^{+27.78%}
CREMA (4B)	59.8 ^{+13.68%}	67.2 ^{+14.67%}	74.2 ^{+8.47%}	31.9 ^{+18.14%}	32.5 ^{+71.05%}	40.0 ^{+53.84%}	34.0 ^{+19.29%}
VideoLLaMA2 (7B)	-	-	74.7 ^{+9.37%}	31.6 ^{+17.91%}	38.0 ^{+72.72%}	35.0 ^{+40.0%}	34.5 ^{+35.29%}
AnyGPT (7B)	56.2 ^{+10.84%}	62.5 ^{+9.84%}	73.3 ^{+7.63%}	31.4 ^{+19.84%}	35.5 ^{+57.77%}	33.0 ^{+73.68%}	33.0 ^{+29.41%}
NExt-GPT (7B)	57.8 ^{+13.55%}	60.8 ^{+7.99%}	73.5 ^{+8.25%}	31.8 ^{+20.45%}	36.0 ^{+63.63%}	32.0 ^{+100%}	33.5 ^{+19.64%}
Unified-IO-2 L (6.8B)	61.9 ^{+12.34%}	62.0 ^{+7.08%}	74.6 ^{+6.41%}	32.4 ^{+19.11%}	36.5 ^{+69.76%}	35.0 ^{+59.09%}	33.5 ^{+21.81%}
Unified-IO-2 XL (6.8B)	62.3 ^{+8.91%}	62.8 ^{+7.16%}	75.6 ^{+5.29%}	33.6 ^{+17.89%}	38.5 ^{+71.11%}	40.0 ^{+53.84%}	34.0 ^{+25.92%}
Bay-CAT (7B)	58.5 ^{+8.73%}	61.1 ^{+8.14%}	75.0 ^{+7.91%}	32.7 ^{+15.95%}	34.0 ^{+65.85%}	35.0 ^{+94.40%}	32.5 ^{+18.18%}
Video-SALMONN (7B)	59.8 ^{+8.92%}	61.7 ^{+7.86%}	75.2 ^{+7.12%}	32.5 ^{+18.18%}	37.5 ^{+70.45%}	32.0 ^{+88.23%}	33.0 ^{+24.52%}
VITA (7B)	62.6 ^{+6.82%}	66.5 ^{+10.64%}	78.8 ^{+8.09%}	33.8 ^{+15.75%}	39.0 ^{+52.94%}	50.0 ^{+21.95%}	35.0 ^{+27.27%}

Experimental Results: Qualitative

- Compared to vanilla zero-shot inference, AURELIA augments the target model with reasoning capabilities, leading to the improved answers.

AV-QA

How many instruments are sounding in the video?

GT Answer: Three

Zero-shot Response

Identifying the instruments in the video

Violin and an accordian are the instruments in the video

Identifying number of instruments in the video

There are two sounding instruments in the video X

Zero-shot with AURELIA

Step 1. Identify all the **visible instruments** being played in the video.
Step 2. Determine if any instruments are being played that are **not visible** in the video based on the audio.

Violin and **Accordian** are the visible instruments being played in the video. **Piano** is being played, based on the audio, but is not directly visible being played in the video. Number of sounding instruments in the video are **three**. ✓

DM-Match

Please select the audio [audio1], [audio2], [audio3], or [audio4] that you think best corresponds to the dance in [video1]? Audio 1: Blues music, Audio 2: Folk music, Audio 3: Jazz music, Audio 4: Hip-hop music

GT Answer: Audio 4

Zero-shot Response

Identifying the scenario in the video

There are two people in the video who are moving

Identifying which type of music is suitable for the scenario

Audio 3: Jazz music X

Zero-shot with AURELIA

Step 1. Identify the **tempo** by analyzing the movement speed.
Step 2. Recognize **dance style** characteristics (e.g., salsa, hip-hop, waltz).
Step 3. Identify whether the **steps align** naturally with the audio's rhythm

The tempo is **very fast**, after analyzing the movement speed. Dance style characteristics resemble **hip-hop** music. **Yes**, steps naturally **align** with the rhythm of the audio. **Audio 4: Hip-hop music** ✓

AV-Compositional

What is the sequence of events in the video? A. A drone whirring followed by a crashing sound
B. A drone crashing followed by a whirring sound C. Condenser followed by Louver

GT Answer: A drone whirring followed by a crashing sound

Zero-shot Response

Identify the object flying in the video

A drone is seen flying in the video

What happens after the drone crashes?

B. A drone crashing followed by a whirring sound X

Zero-shot with AURELIA

Step 1. Identify the **object** being controlled in the video.
Step 2. Describe the **initial state** or position of this object.
Step 3. Note down all **sounds** from the video.
Step 3. Describe the final state or position of this object and any **sound** it makes.

The object being controlled is a **drone**. The drone is initially **flying**. There is a **whirring sound** coming from the video. In the end, the drone crashes, making a **crashing sound**. Sequence of events in the video is a **drone whirring followed by a crashing sound**. ✓

AV-GeoIQ

Which continent is country located from which the maker of the sounding object is?

GT Answer: Asia

Zero-shot Response

Identifying the object making sound

The object making the sound is a **clock**

Identifying where the object was discovered.

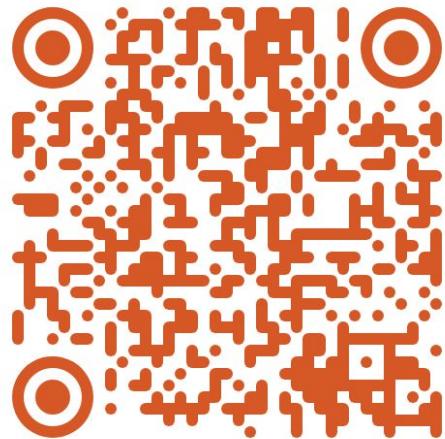
Clock was introduced in America. X

Zero-shot with AURELIA

Step 1. Identify the **object** making the sound.
Step 2. Identify the **brand name** of the object.
Step 3. Determine the **country of origin** for that brand.
Step 4. Identify the **continent** where that country is located.

The object making the sound is an **alarm clock**. The brand name on the clock is **Casio**. Casio is a **Japanese** company. Japan is located in **Asia**. ✓

Thank You!



Project Page