



SQA3D: Situated Question Answering in 3D Scenes

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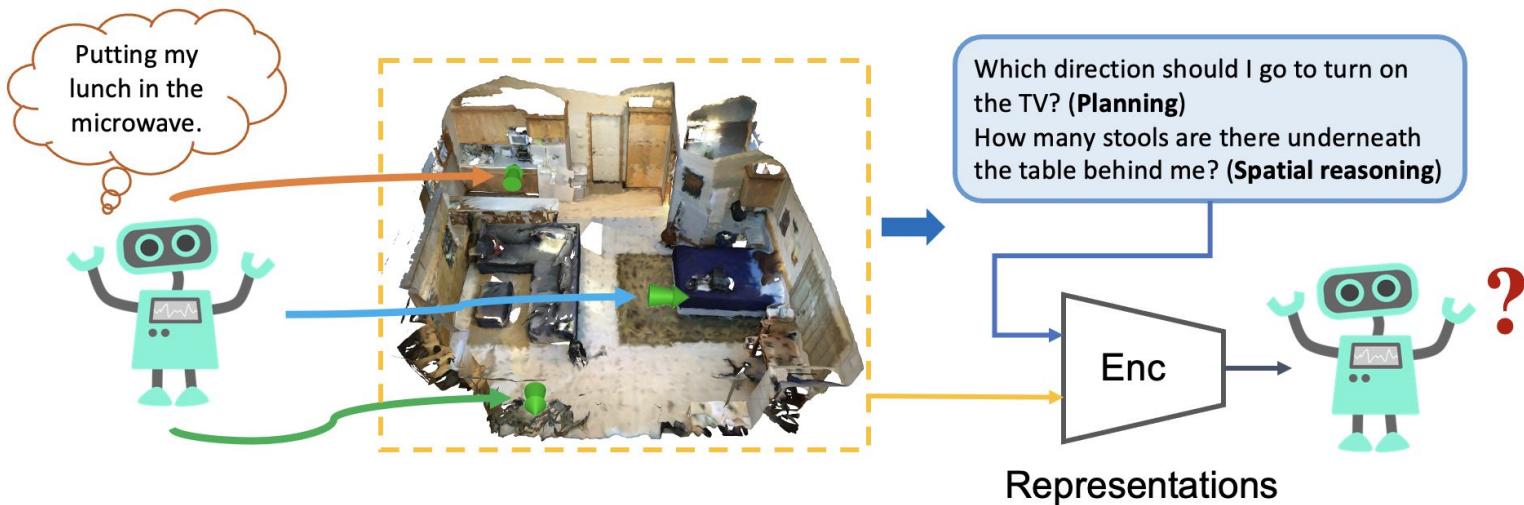
Motivation

We study the problem of **embodied scene understanding** to bridge the gap between *embodied AI* and *3D scene understanding*: an agent need to understand its surroundings (situations) from a *dynamic & egocentric* view, then accomplish reasoning & planning tasks *accordingly* (situated reasoning).



Motivation

We believe, truly **generalist representations** should support such challenging **situation understanding** and **situated reasoning** in embodied, **3D** scenes.

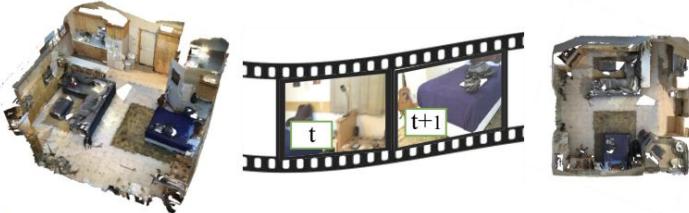


What is SQA3D?

Description s_{txt} : Sitting at the edge of the bed and facing the couch.

Question q : Can I go straight to the coffee table in front of me?

Scene context \mathcal{S} : 3D scan, egocentric video, bird-eye view (BEV) picture, etc.



Answer a : No

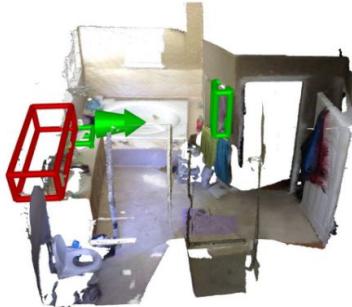
Location (optional): $\langle s_{pos}, s_{rot} \rangle$



Given a **scene context** (3D scan, egocentric video, BEV pictures...), the agent needs to understand its situation from a **description**, then answer a **question**.

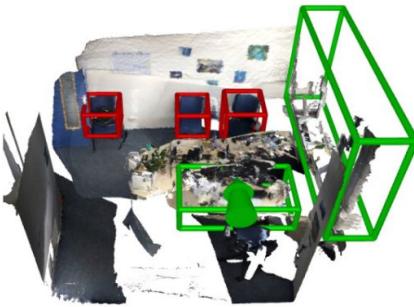
Examples from SQA3D

Embodied activities



s^{txt}: Standing in front of the sink and facing the towels.
q: Can I see myself in the mirror?
a: No

Navigation



s^{txt}: Working by the desk and the window is on my right.
q: How many chairs will I pass by to open the window from other side of the desk?
a: Three

Common sense



s^{txt}: Just looking for some food in the fridge.
q: Which direction should I go to heat my lunch?
a: Right

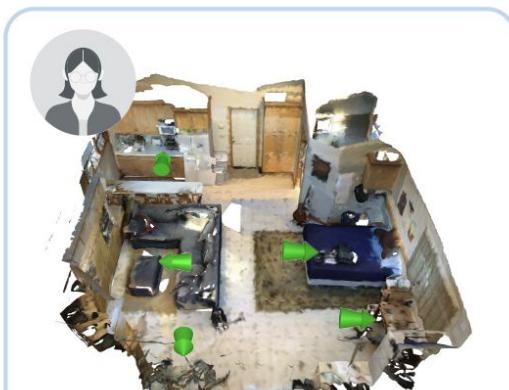
Multi-hop reasoning



s^{txt}: Playing computer games and the window is on my right.
q: How many monitors are there on the desk that the chair on my left is facing?
a: One

The **green boxes** indicate relevant objects in situation description while **red boxes** are for the questions. The virtual avatar marks the actual location of the agent.

Building SQA3D



I. Situation Identification

Participants are asked to pick (s_{pos} , s_{rot}) ➔ and write description s_{txt} .



II. Question Preparation

Participants are asked to write question q given the situation depicted in both ➔ and s_{txt} .



III. Answer Collection & Human Study

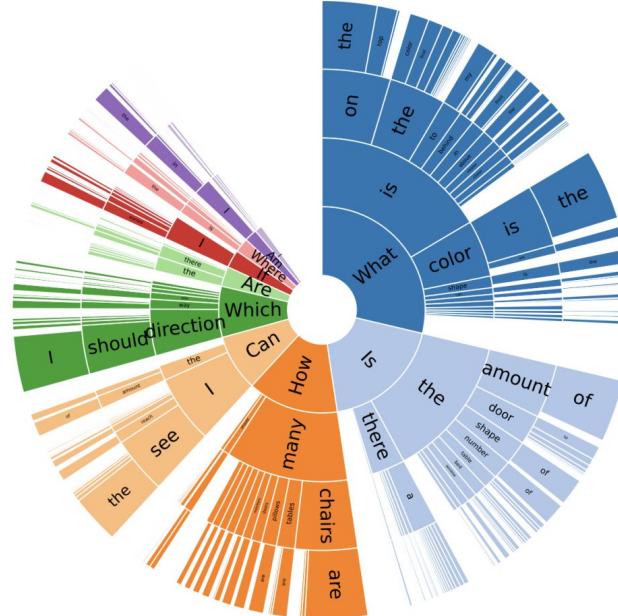
More participants are asked to answer question q given the situation depicted **only** in s_{txt} .

We recruit our workforces from Amazon Mechanical Turk (AMT). A multi-staged collection strategy is adopted to ensure manageable workload and higher data quality.

Dataset statistics



Statistic	Value
Total s^{txt} (train/val/test)	16,229/1,997/2,143
Total q (train/val/test)	26,623/3,261/3,519
Unique q (train/val/test)	20,183/2,872/3,036
Total scenes (train/val/test)	518/65/67
Total objects (train/val/test)	11,723/1,550/1,652
Average s^{txt} length	17.49
Average q length	10.49



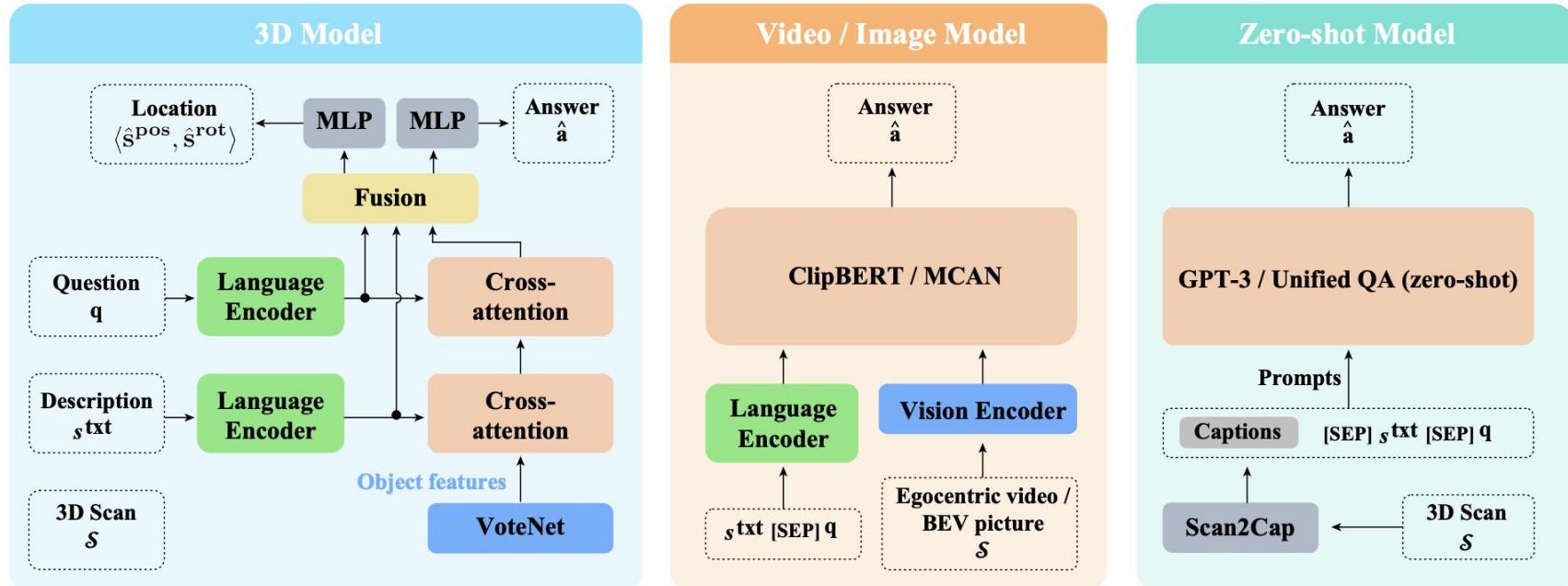
Compared to counterparts with template-based text, SQA3D offers more **diverse** questions thanks to our AMT workforces.

Comparison to related benchmarks

dataset	task	situated?	3D type	text collection	navig- ation?	common sense?	multi-hop reasoning?	#scenes	#tasks
ScanNet (Dai et al., 2017)	seg.	✗	scan	n/a	✗	✗	✗	800 rooms	1.5k
ScanRefer (Chen et al., 2020)	det.	✗	scan	human	✗	✗	✗	800 rooms	52k
ReferIt3D (Achlioptas et al., 2020)	det.	✗	scan	human	✗	✗	✗	707 rooms	41k
ScanQA (Azuma et al., 2022)	q.a.	✗	scan	template	✗	✗	✗	800 rooms	41k
3D-QA (Ye et al., 2021)	q.a.	✗	scan	human	✗	✗	✗	806 rooms	5.8k
CLEVR3D (Yan et al., 2021)	q.a.	✗	scan	template	✗	✗	✓	478 rooms	60k
MP3D-R2R (Anderson et al., 2018)	nav.	✓	*nav.	human	✓	✗	✗	190 floors	22k
MP3D-EQA (Wijmans et al., 2019a)	q.a.	✓	*nav.	template	✓	✗	✗	146 floors	1.1k
SQA3D (Ours)	q.a.	✓	scan	human	✓	✓	✓	650 rooms	33.4k

To the best of our knowledge, SQA3D is the **largest** dataset combines the best of both worlds: **situated reasoning, human-written text, and diverse & challenging problems**.

Models for SQA3D?



Canonical question answering models for 3D scan, video and image input are evaluated. We further explore **zero-shot large models** (GPT-3, Unified QA) by converting the 3D scene into *captions*.

Benchmarking: quantitative results

\mathcal{S}	Format	test set						Avg.	
		What	Is	How	Can	Which	Others		
Blind test	-	SQ→A	26.75	63.34	43.44	69.53	37.89	43.41	43.65
ScanQA (w/o s^{txt})	3D scan	VQ→A	28.58	65.03	47.31	66.27	43.87	42.88	45.27
ScanQA	3D scan	VSQ→A	31.64	63.80	46.02	69.53	43.87	45.34	46.58
ScanQA + aux. task	3D scan	VSQ→AL	33.48	66.10	42.37	69.53	43.02	46.40	47.20
MCAN	BEV	VSQ→A	28.86	59.66	44.09	68.34	40.74	40.46	43.42
ClipBERT	Ego. video	VSQ→A	30.24	60.12	38.71	63.31	42.45	42.71	43.31
Unified QA _{Large}	ScanRefer	VSQ→A	33.01	50.43	31.91	56.51	45.17	41.11	41.00
Unified QA _{Large}	ReferIt3D	VSQ→A	27.58	47.99	34.05	59.47	40.91	39.77	38.71
GPT-3	ScanRefer	VSQ→A	39.67	45.99	40.47	45.56	36.08	38.42	41.00
GPT-3	ReferIt3D	VSQ→A	28.90	46.42	28.05	40.24	30.11	36.07	34.57
Human (amateur)	3D scan	VSQ→A	88.53	93.84	88.44	95.27	87.22	88.57	90.06

*aux. task: we introduce an additional location prediction task to encourage better situation understanding.

Benchmarking: quantitative results

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Blind test	-	SQ→A	26.75	63.34	43.44	69.53	37.89	43.41	43.65
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GROBERT	BEV	VSQ→A	20.24	60.12	38.71	63.31	42.45	42.71	43.31
UnifiedQA	ScanRefer	VSQ→A	33.01	50.43	31.01	56.51	45.17	41.11	41.00
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Situation understanding. Models with better situation understanding (w/ s^{txt} , w/ aux. task) generally deliver better results.

*aux. task: we introduce an additional location prediction task to encourage better situation understanding.

Benchmarking: quantitative results

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ScanQA (w/o s^{txt})	3D scan	VQ→A	28.58	65.03	47.31	66.27	43.87	42.88	45.27
ScanQA	3D scan	VSQ→A	31.64	63.80	46.02	69.53	43.87	45.34	46.58
ScanQA + aux. task	3D scan	VSQ→AL	33.48	66.10	42.37	69.53	43.02	46.40	47.20
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Representation of 3D scenes. 3D scan could still be better representation of 3D scenes than egocentric videos and BEV pictures.

Benchmarking: quantitative results

\mathcal{S}	Format		test set						Avg.
			What	Is	How	Can	Which	Others	
Blind test	-	SQ→A	26.75	63.34	43.44	69.53	37.89	43.41	43.65
ScanQA (w/o ext)	3D scan	YOLO	28.58	65.03	47.31	66.27	43.87	42.88	45.27
ScanQA	3D scan	VSQ→A	31.04	63.80	40.11	69.29	43.87	43.34	40.58
CLIP	3D scan	CLIP	28.86	59.66	44.09	68.34	40.74	40.46	43.42
ClipBERT	Ego. video	VSQ→A	30.24	60.12	38.71	63.31	42.45	42.71	43.31
Unified QA _{Large}	ScanRefer	VSQ→A	33.01	50.43	31.91	56.51	45.17	41.11	41.00
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Zero-shot models. These models indeed have great potential in common sense reasoning, spatial language understanding, etc. But they could be *bottlenecked by 3D captions*.

Benchmarking: quantitative results

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			What	Is	How	Can	Which	Others	
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MCAN	BEV	VSQ→A	28.86	59.66	44.09	68.34	40.74	40.46	43.42
Human vs. machine. Amateur human participants that only learn from a handful of examples promptly master our tasks and the gap to the best model is still large (47.2% vs 90.06%).									
GPT-3	ReferIt3D	VSQ→A	28.90	46.42	28.05	40.24	30.11	36.07	34.57
Human (amateur)	3D scan	VSQ→A	88.53	93.84	88.44	95.27	87.22	88.57	90.06

Benchmarking: qualitative results & failure modes

	s^{txt} : I am picking up my <u>backpack</u> with a <u>chair</u> to my left within reach. q : How many <u>chairs</u> are behind me?	s^{txt} : I am sitting on the rightmost side of my <u>couch</u> , and there is an <u>end table</u> to my right. q : The <u>coffee table</u> that is furthest from me is surrounded by what?	s^{txt} : I am entering the room. q : What is the color of the <u>backpack</u> on my 10 o'clock <u>chair</u> ?	s^{txt} : I am working at the <u>counter</u> with <u>cabinets</u> over my head and the <u>wall</u> on my left is within reach. q : If I walked backwards, what would I hit behind me?
ScanQA (w/o s^{txt})	 a : One ✗	 a : Unknown ✗	 a : Black ✗	 a : Front ✗
ScanQA	 a : One ✗	 a : Couch ✓	 a : Black ✗	 a : Wall ✓
ScanQA + aux. task	 a : Two ✓	 a : Couch ✓	 a : Red ✓	 a : Wall ✓

Most-attended bbox is highlighted in red. Our best model (ScanQA + aux. task) are more likely to attend to the relevant objects and provide the correct answer.

ScanQA (w/o s^{txt})

ScanQA

ScanQA + aux. task

GT answer

s^{txt} : I am sitting on the armchair in front of the window.
 q : What is above the armchair that is far away in front of me?



a : Light \times



a : Picture \times



a : TV \times



a : Bulletin board \checkmark

s^{txt} : I am facing an ottoman with a couch to my right within reach and an armchair to my left.
 q : What color is the armchair to my left?



a : Black \times



a : Red \times



a : Brown \times



a : White \checkmark

s^{txt} : I am facing the table and there is a coffee table and a foosball table to my left.
 q : Which way should I go to sit on the couch?



a : Left \times



a : Forward \times



a : Left \times



a : Right \checkmark

s^{txt} : I am facing an end table and there is a couch on my left within reach.
 q : How many chairs does the table on my left have?



a : Four \times



a : Four \times



a : Four \times



a : Zero \checkmark

When the model **fails** to attend to the relevant objects, there is a good chance it will also provide the **wrong** answer.

Takeaway

We present SQA3D, a new benchmark for **embodied scene understanding**, aiming at bridging the gap between 3D scene understanding and embodied AI.

SQA3D is the **largest** dataset combines the best of both worlds: situated reasoning, human-written text, and diverse & challenging problems.

State-of-the-art multi-modal QA models and zero-shot large models struggle on SQA3D and the gap to amateur human participants is also considerable.

Code & benchmark will be online soon!

SQA3D: Situated Question Answering in 3D Scenes

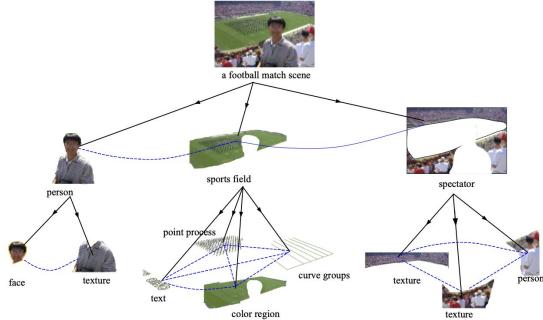


add open word here

open word + situation understanding + situated reasoning

aux task

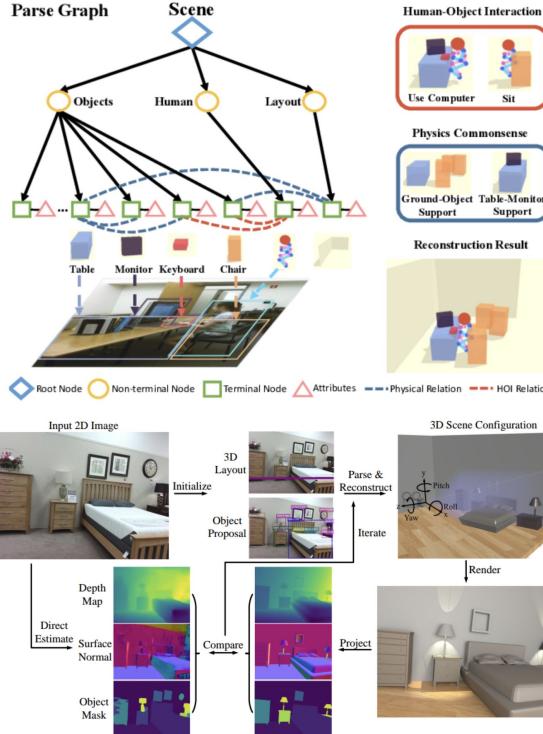
Motivation: AI Baby can **reason** & **generalize** in egocentric (embodied), 3D scenes



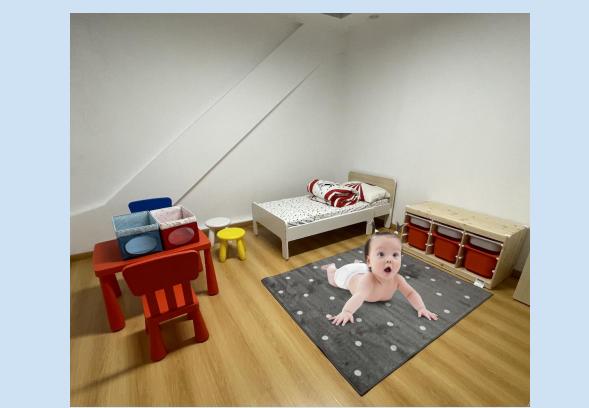
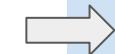
Is the umbrella upside down?
yes no



2D image understanding
and reasoning



Third-person 3D
scene understanding



- The stools behind me are more than the boxes to my right? **(egocentric, spatial, number sense)**
- Can I still move to the right? **(affordance)**
- I'm sleepy, where should I go? **(functionality)**

Reasoning in egocentric,
embodied 3D scenes