CS 839: Foundation Models
Multimodal Models

Fred Sala

University of Wisconsin-Madison

Oct. 24, 2023

Announcements

- **Logistics:**
  - HW2 out tonight (due Nov. 7).
  - Sign-up sheet for project also.
- Class roadmap:

Tuesday Oct. 24	Multimodal and Specialized Foundation Models
Thursday Oct. 26	Knowledge
Tuesday Oct. 31	Scaling & Scaling Laws
Thursday Nov. 2	Security, Privacy, Toxicity
Tuesday Nov. 7	The Future

Outline

- **Multimodal Models Intro + One-Encoder Models**
  - Short history, adapting models to incorporate multiple modalities, BERT-like vision-language models, ViTs
- **Two-Encoder and Other VLMs**
  - Contrastive training, CLIP, joint training, few-shot models
- **Other Modalities and Domains**
  - Audio, video, code generation, RL

Outline

- **Multimodal Models Intro + One-Encoder Models**
  - Short history, adapting models to incorporate multiple modalities, BERT-like vision-language models, ViTs
- **Two-Encoder and Other VLMs**
  - Contrastive training, CLIP, joint training, few-shot models
- **Other Modalities and Domains**
  - Audio, video, code generation, RL

Short History of Multimodal Models

Multimodal models pre-date foundation models

- Image-captioning models, VQA models, esc…
  - But it has become more popular

- Ex: **joint embedding spaces**

(Weston, Bengio, Usunier '11)

Image	One-vs-Rest	WSABIE
	surf, bora, belize, sea world, balena, wale, tahiti, delfini, surfing, mahi mahi	delfini, orca, **dolphin**, mar, delfin, dauphin, whale, cancun, killer whale, sea world
	**eiffel tower**, tour eiffel, snowboard, blue sky, empire state building, luxor, eiffel, lighthouse, jump, adventure	**eiffel tower**, statue, eiffel, mole antoneliana, la tour eiffel, londra, cctv tower, big ben, calatrava, tokyo tower
	falco, barack, daniel craig, **obama**, barack obama, kanye west, pharrell williams, 50 cent, barrack obama, bono	barrack obama, barack obama, barack hussein obama, barack obama, james marsden, jay z, **obama**, nelly, falco, barack

Making LLMs Multimodal

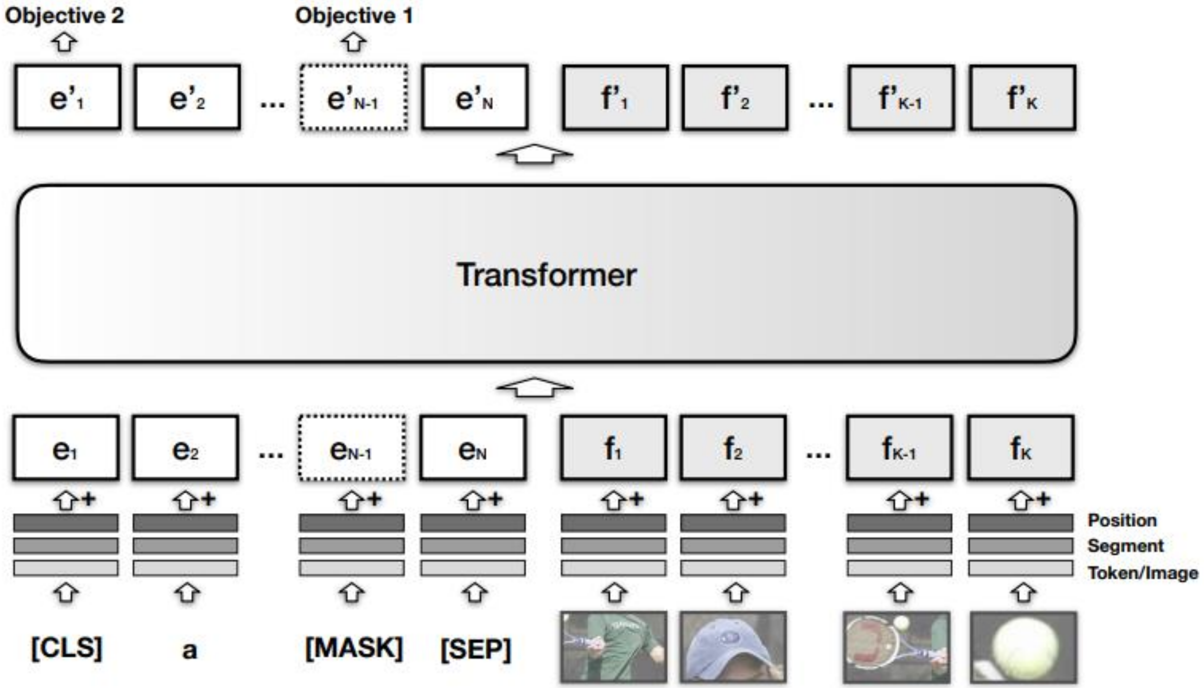
How do we use a language architecture for multiple modalities?

VisualBERT: take all the ideas from BERT, add images

- Use bounding boxes from image detector + image embedder

A person hits a ball with a tennis racket

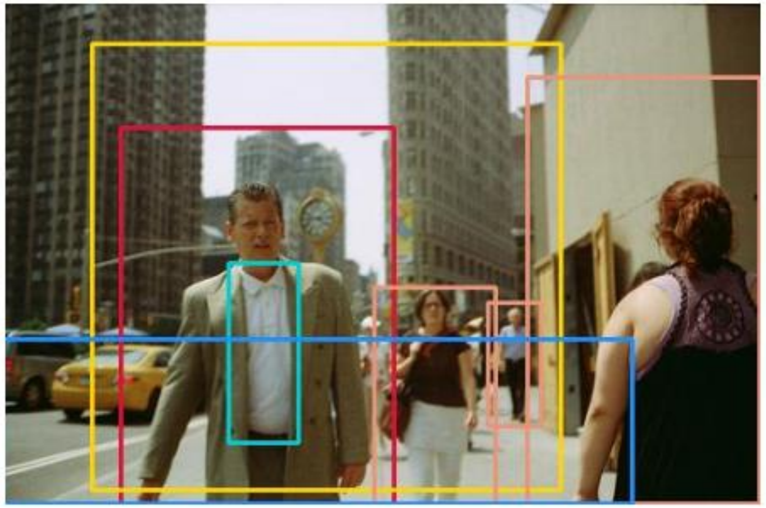
Li et al ‘19

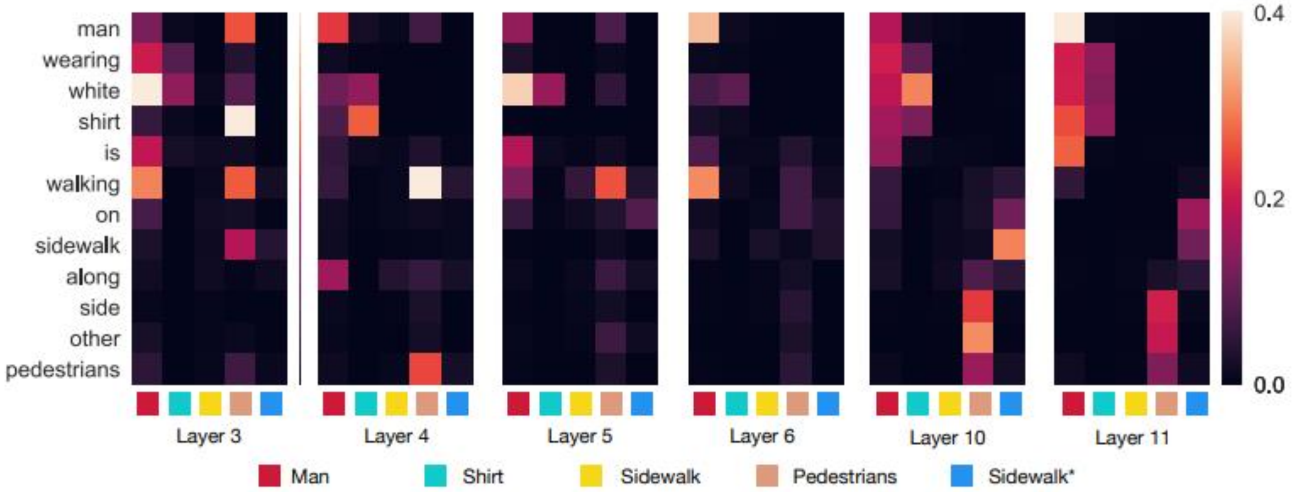


Making LLMs Multimodal: **VisualBERT**

VisualBERT: take all the ideas from BERT, add images

- What about training? Recall BERT training…
  - Masked language modeling + image (text is masked, image same)
  - Sentence-image prediction
- Results (Li et al, ‘19)





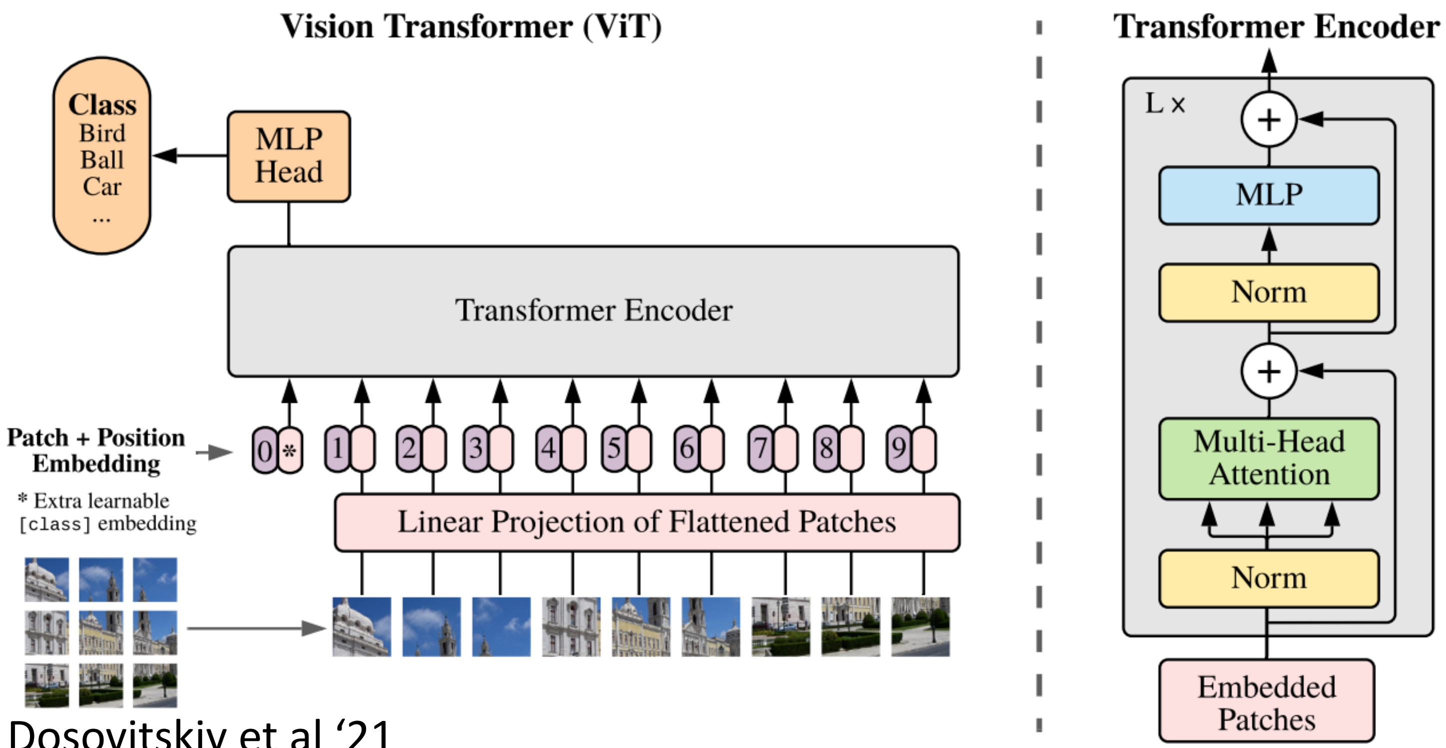
How Do We Get Image Embeddings?

Transformers for Image Recognition at Scale

by A Dosovitskiy · 2020 · Cited by 23217 —), **Vision Transformer**

Could always user resnets, etc., but…

- Didn't Transformers make a big difference for text?
- Can also use for vision: **ViT.** Just use patches!

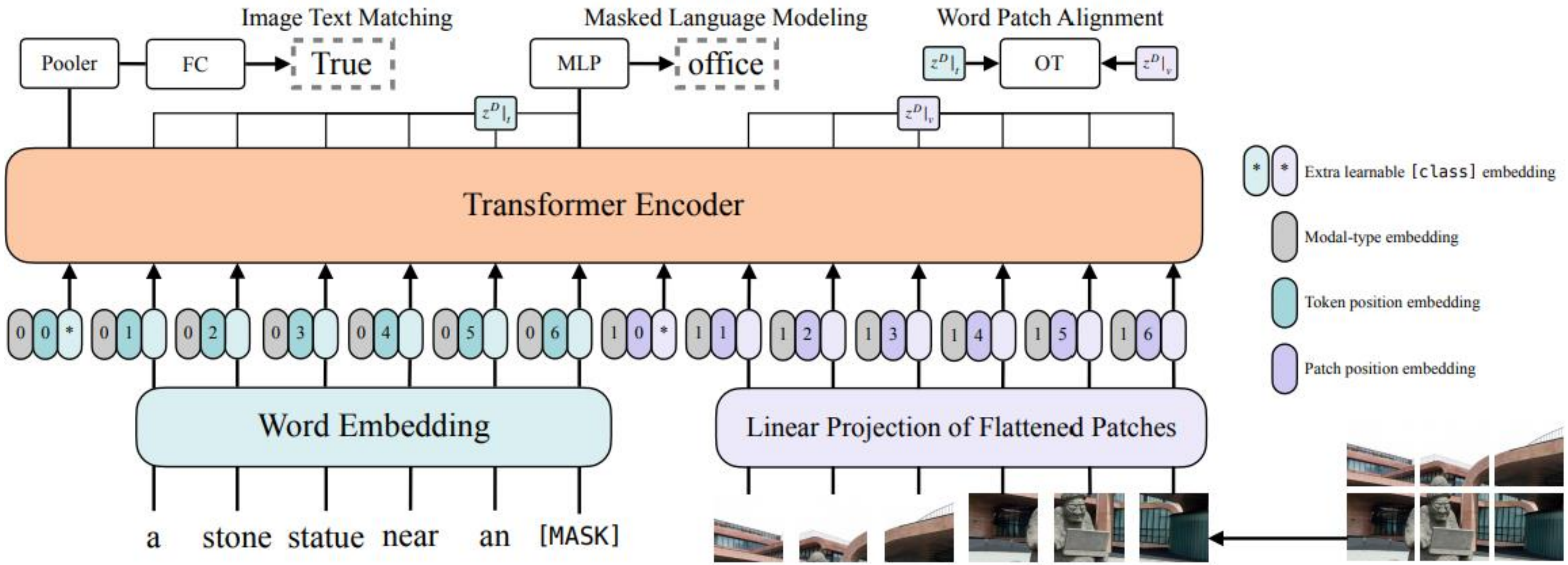


Dosovitskiy et al '21

Put It Together

Multimodal with language and vision transformers: **ViLT**

- Kim et al ‘21



Variations…

Lots of different approaches!

- Du et al ‘22, “A Survey of Vision-Language Pre-Trained Models”

VL-PTM	Text encoder	Vision encoder	Fusion scheme	Pre-training tasks	Multimodal datasets for pre-training
Fusion Encoder					
VisualBERT [2019]	BERT	Faster R-CNN	Single stream	MLM+ITM	COCO
Uniter [2020]	BERT	Faster R-CNN	Single stream	MLM+ITM+WRA+MRFR+MRC	CC+COCO+VG+SBU
OSCAR [2020c]	BERT	Faster R-CNN	Single stream	MLM+ITM	CC+COCO+SBU+Flickr30k+VQA
InterBert [2020]	BERT	Faster R-CNN	Single stream	MLM+MRC+ITM	CC+COCO+SBU
ViLBERT [2019]	BERT	Faster R-CNN	Dual stream	MLM+MRC+ITM	CC
LXMERT [2019]	BERT	Faster R-CNN	Dual stream	MLM+ITM+MRC+MRFR+VQA	COCO+VG+VQA
VL-BERT [2019]	BERT	Faster R-CNN+ ResNet	Single stream	MLM+MRC	CC
Pixel-BERT [2020]	BERT	ResNet	Single stream	MLM+ITM	COCO+VG
Unified VLP [2020]	UniLM	Faster R-CNN	Single stream	MLM+seq2seq LM	CC
UNIMO [2020b]	BERT, RoBERTa	Faster R-CNN	Single stream	MLM+seq2seq LM+MRC+MRFR+CMCL	COCO+CC+VG+SBU
SOHO [2021]	BERT	ResNet + Visual Dictionary	Single stream	MLM+MVM+ITM	COCO+VG
VL-T5 [2021]	T5, BART	Faster R-CNN	Single stream	MLM+VQA+ITM+VG+GC	COCO+VG
XGPT [2021]	transformer	Faster R-CNN	Single stream	IC+MLM+DAE+MRFR	CC
Visual Parsing [2021]	BERT	Faster R-CNN + Swin transformer	Dual stream	MLM+ITM+MFR	COCO+VG
ALBEF [2021a]	BERT	ViT	Dual stream	MLM+ITM+CMCL	CC+COCO+VG+SBU
SimVLM [2021b]	ViT	ViT	Single stream	PrefixLM	C4+ALIGN
WenLan [2021]	RoBERTa	Faster R-CNN + EffcientNet	Dual stream	CMCL	RUC-CAS-WenLan
ViLT [2021]	ViT	Linear Projection	Single stream	MLM+ITM	CC+COCO+VG+SBU
Dual Encoder					
CLIP [2021]	GPT2	ViT, ResNet		CMCL	self-collected
ALIGN [2021]	BERT	EffcientNet		CMCL	self-collected
DeCLIP [2021b]	GPT2, BERT	ViT, ResNet, RegNetY-64GF		CMCL+MLM+CL	CC+self-collected
Fusion Encoder+ Dual Encoder					
VLMo [2021a]	BERT	ViT	Single stream	MLM+ITM+CMCL	CC+COCO+VG+SBU
FLAVA [2021]	ViT	ViT	Single stream	MMM+ITM+CMCL	CC+COCO+VG+SBU+RedCaps

Datasets

Trained on? Datasets with image-text pairs

Dataset	Year	Num. of Image-Text Pairs	Language	Public
SBU Caption [92] [link]	2011	1M	English	✓
COCO Caption [93] [link]	2016	1.5M	English	✓
Yahoo Flickr Creative Commons 100 Million (YFCC100M) [94] [link]	2016	100M	English	✓
Visual Genome (VG) [95] [link]	2017	5.4 M	English	✓
Conceptual Captions (CC3M) [96] [link]	2018	3.3M	English	✓
Localized Narratives (LN) [97] [link]	2020	0.87M	English	✓
Conceptual 12M (CC12M) [98] [link]	2021	12M	English	✓
Wikipedia-based Image Tex (WIT) [99] [link]	2021	37.6M	108 Languages	✓
Red Caps (RC) [100] [link]	2021	12M	English	✓
LAION400M [28] [link]	2021	400M	English	✓
LAION5B [27] [link]	2022	5B	Over 100 Languages	✓
WuKong [101] [link]	2022	100M	Chinese	✓
CLIP [14]	2021	400M	English	✗
ALIGN [24]	2021	1.8B	English	✗
FILIP [25]	2021	300M	English	✗
WebLI [102]	2022	12B	109 Languages	✗

Zhang et al '23

Break & Questions

Outline

- **Multimodal Models Intro + One-Encoder Models**
  - Short history, adapting models to incorporate multiple modalities, BERT-like vision-language models, ViTs
- **Two-Encoder and Other VLMs**
  - Contrastive training, CLIP, joint training, few-shot models
- **Other Modalities and Domains**
  - Audio, video, code generation, RL

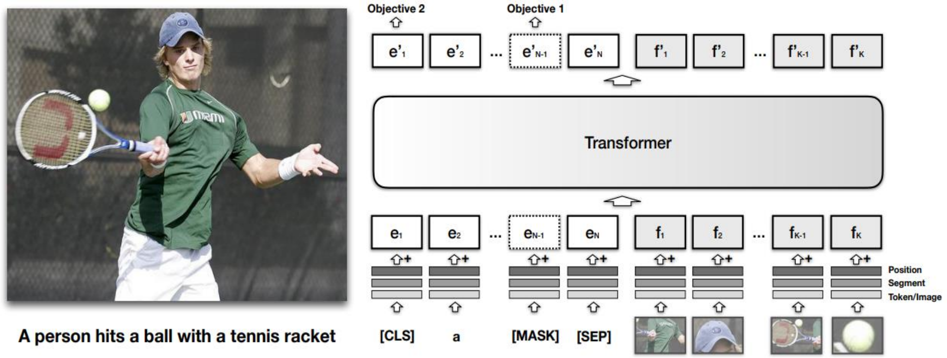
Contrastive Vision-Language Models

So far, trained the modalities together

- I.e., text and images were both inputs to a transformer
- This is “fusion”, but we could do it **later**…

- I.e., produce two representations separately, then produce some means of connecting/tying them together

- **Contrastive** approach



Li et al ‘19

VLMs: **Constrastive Training**

Training approach: contrastive

- Loss example: InfoNCE (noise contrastive estimation) loss:

$$\mathcal{L}_I^{\text{InfoNCE}} = -\frac{1}{B}\sum_{i=1}^{B} \log \frac{\exp\left(z_i^I \cdot z_+^I/\tau\right)}{\sum_{j=1, j\neq i}^{B+1} \exp(z_i^I \cdot z_j^I/\tau)}$$

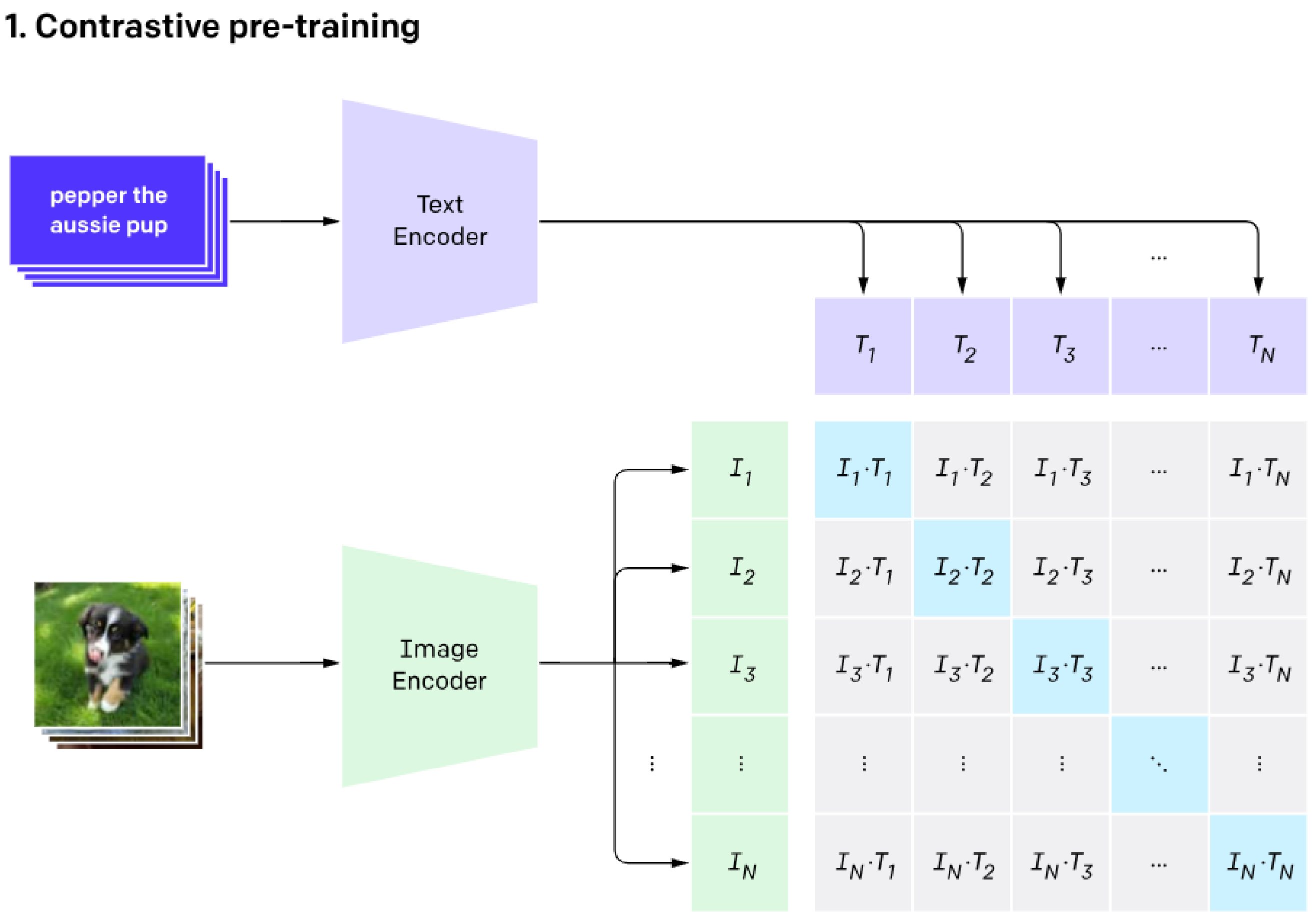
- To train a text and image encoder simultaneously, symmetrize:

$$\mathcal{L}_{I\to T} = -\frac{1}{B}\sum_{i=1}^{B} \log \frac{\exp\left(z_i^I \cdot z_i^T/\tau\right)}{\sum_{j=1}^{B} \exp(z_i^I \cdot z_j^T/\tau)}$$

$$\mathcal{L}_{T\to I} = -\frac{1}{B}\sum_{i=1}^{B} \log \frac{\exp\left(z_i^T \cdot z_i^I/\tau\right)}{\sum_{j=1}^{B} \exp(z_i^T \cdot z_j^I/\tau)}$$

VLMs: **CLIP**

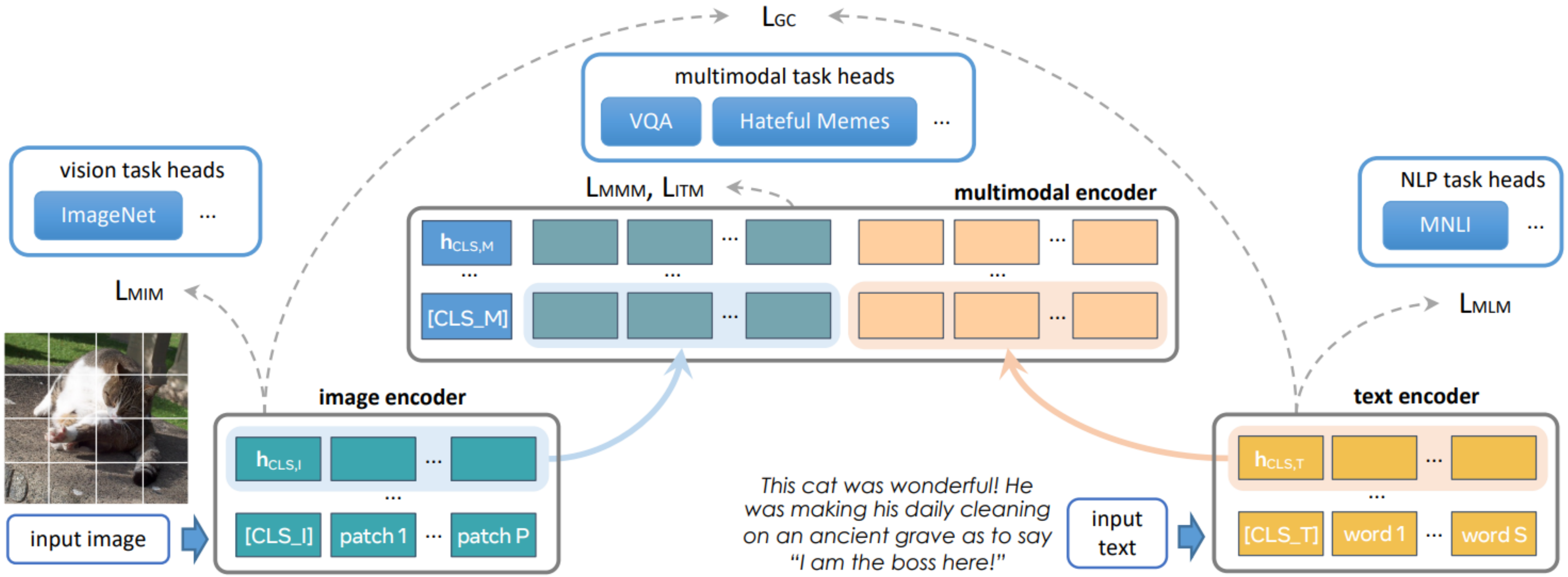
A simple but easily scalable constrastive VLM



VLMs: **FLAVA**

Foundational Language And Vision Alignment Model (FLAVA)

- Combines everything
- Pretrain **separately** and **jointly**

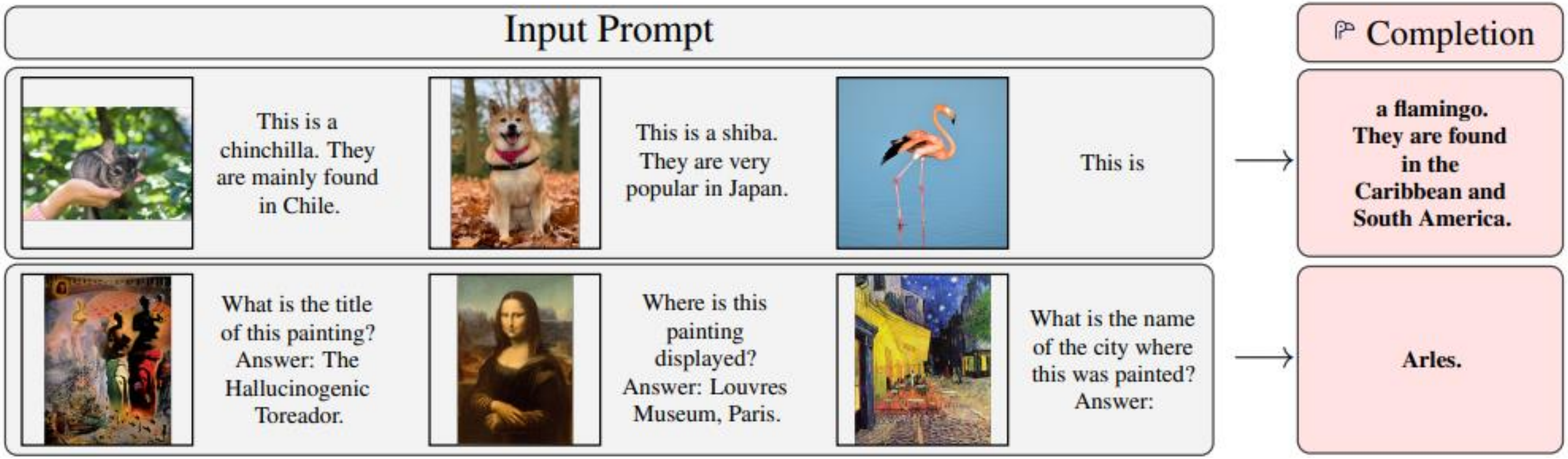


Singh et al '22

Few-Shot VLMs

The models we've talked about are either meant to
- Do zero-shot prediction, OR
- Be fine-tuned for a particular task

- What about **few-shot** (like in LLMs) for VLMs?

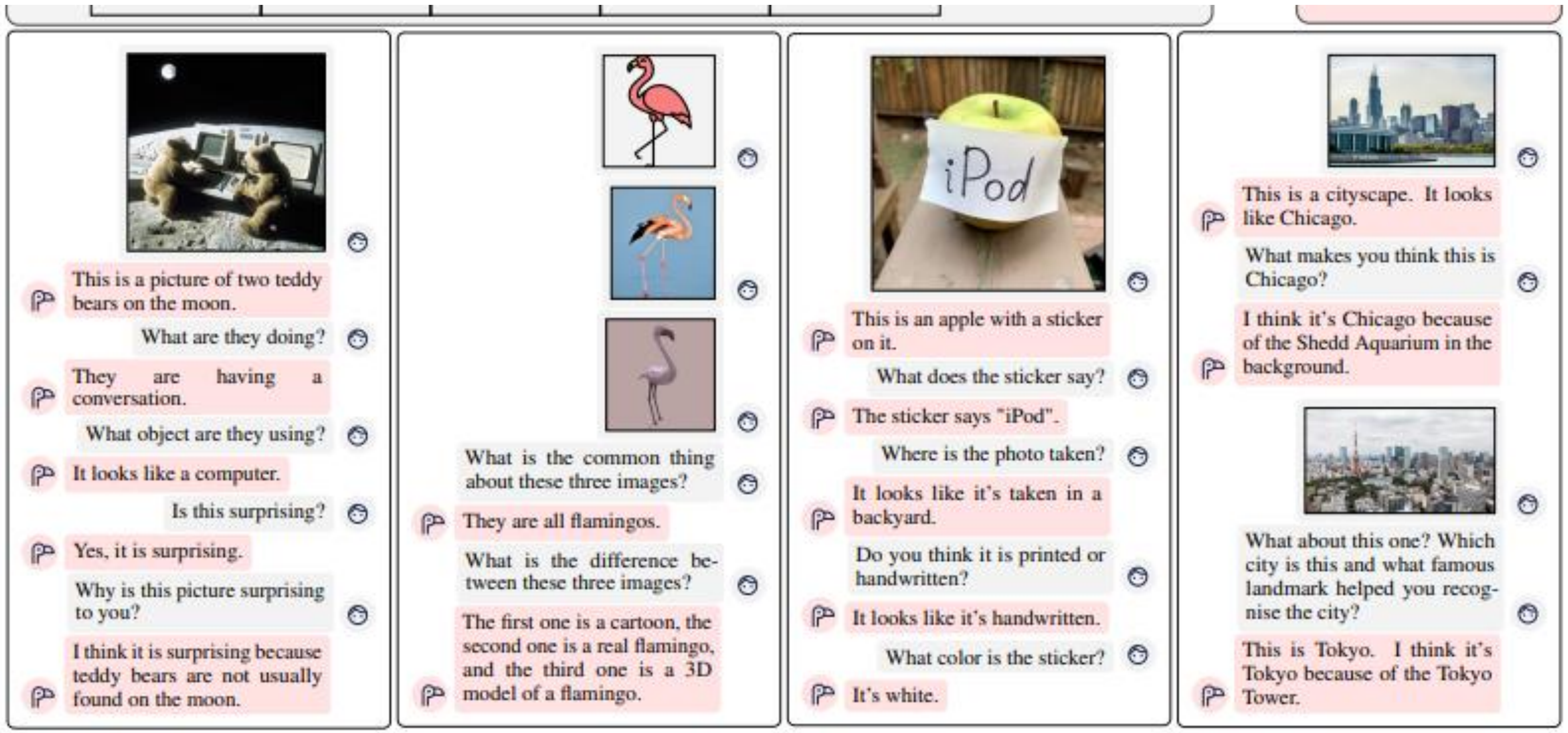


Alayrac et al '22

Few-Shot VLMs: **Flamingo**

Flamingo: 80B parameter model (based on an LLM)

- Multi-image!
- More complex interleaved architecture



Alayrac et al '22

Break & Questions

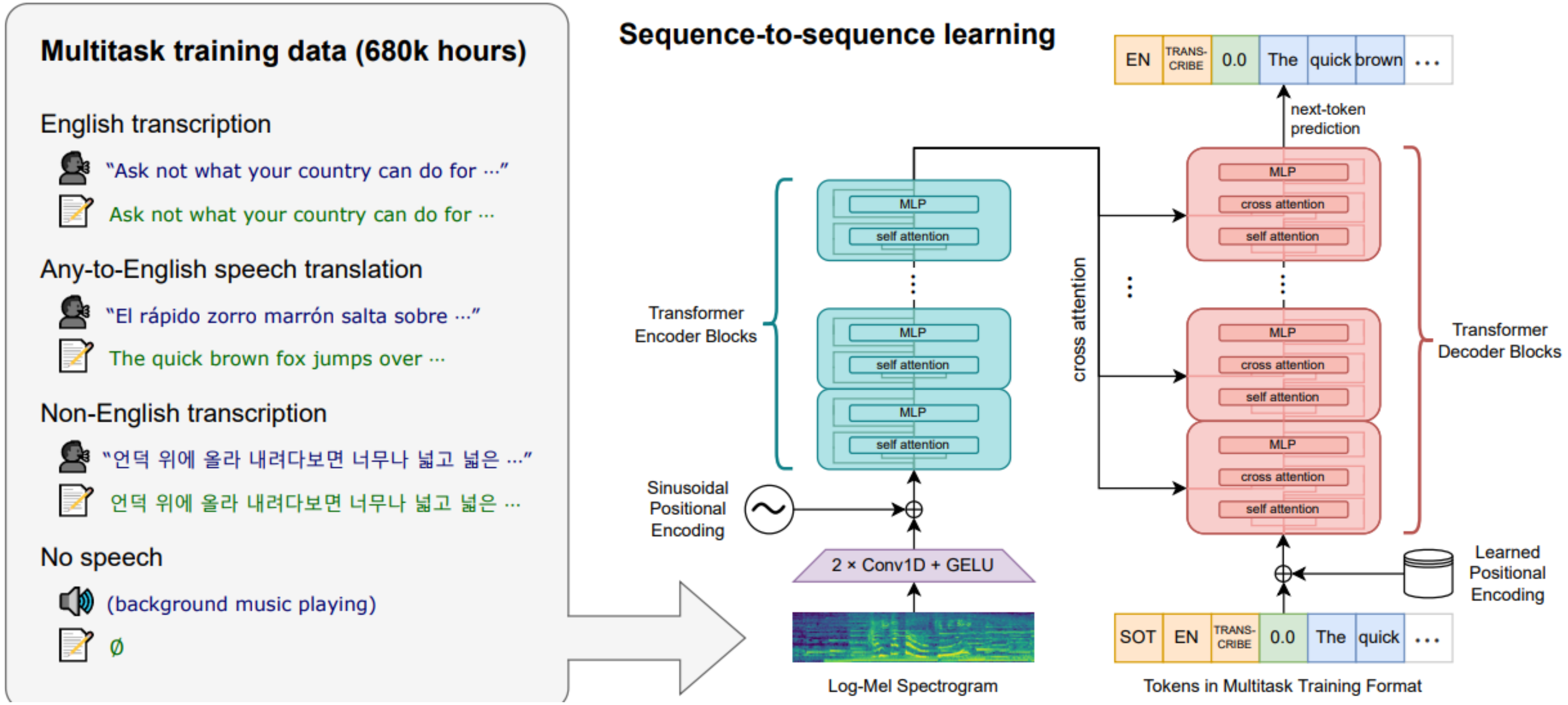
Outline

- **Multimodal Models Intro + One-Encoder Models**
  - Short history, adapting models to incorporate multiple modalities, BERT-like vision-language models, ViTs
- **Two-Encoder and Other VLMs**
  - Contrastive training, CLIP, joint training, few-shot models
- **Other Modalities and Domains**
  - Audio, video, code generation, RL

Other Modalities: Audio

Can do similar things with all sorts of other modalities

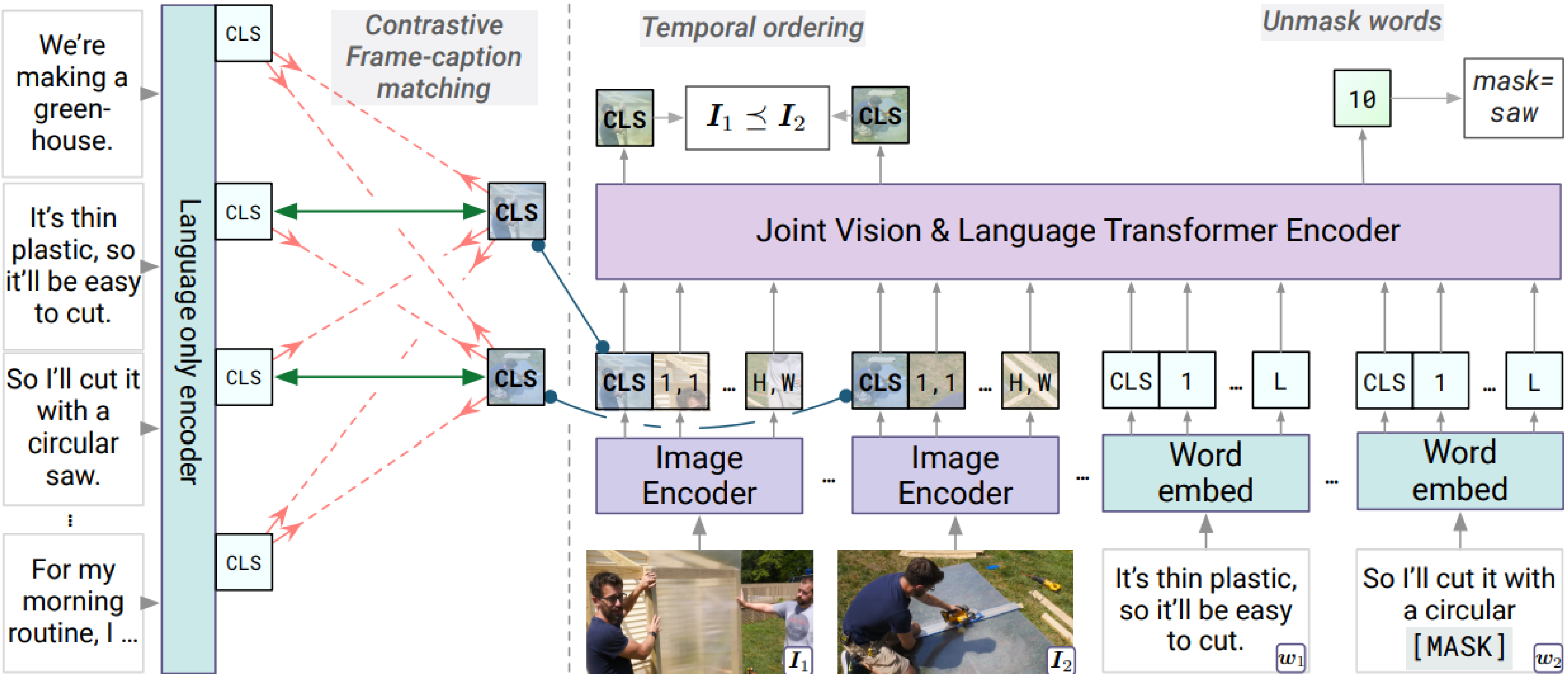
- Audio: can always convert to image and apply directly
- **Ex: Whisper.** 680K hours of audio supervision



Radford et al '22

Other Modalities: **Audio + Video + Text**

Merlot: video + text + audio



Zellers et al '21

Code Models: **Codex**

Start with GPT-3 and fine-tune on large-scale code.

- Data: “0 from 54 million public software repositories hosted on GitHub, containing 179 GB of unique Python files under 1 MB. “
- Plus pre-processing. Filter out
  - High-chance of autogenerated
  - Long average line length
- ~160GB of data.
- **Eval**: pass @ k
  - k samples per prob, correct if any pass

	PASS@k $k=1$	$k=10$	$k=100$
GPT-NEO 125M	0.75%	1.88%	2.97%
GPT-NEO 1.3B	4.79%	7.47%	16.30%
GPT-NEO 2.7B	6.41%	11.27%	21.37%
GPT-J 6B	11.62%	15.74%	27.74%
TABNINE	2.58%	4.35%	7.59%
CODEX-12M	2.00%	3.62%	8.58%
CODEX-25M	3.21%	7.1%	12.89%
CODEX-42M	5.06%	8.8%	15.55%
CODEX-85M	8.22%	12.81%	22.4%
CODEX-300M	13.17%	20.37%	36.27%
CODEX-679M	16.22%	25.7%	40.95%
CODEX-2.5B	21.36%	35.42%	59.5%
CODEX-12B	28.81%	46.81%	72.31%

Chen et al ‘21

Code Models: **StarCoder**

Codex (and descendants) are not open source.

Lots of open variants. Trained on open dataset: “The Stack”

- “From the 358 programming languages… we selected 86 languages”
- 15B model
- 1T tokens for pretraining
- 35B Python tokens
  for fine-tuning

Model	HumanEval	MBPP
LLaMA-7B	10.5	17.7
LaMDA-137B	14.0	14.8
LLaMA-13B	15.8	22.0
CodeGen-16B-Multi	18.3	20.9
LLaMA-33B	21.7	30.2
CodeGeeX	22.9	24.4
LLaMA-65B	23.7	37.7
PaLM-540B	26.2	36.8
CodeGen-16B-Mono	29.3	35.3
StarCoderBase	30.4	49.0
code-cushman-001	33.5	45.9
StarCoder	33.6	**52.7**
StarCoder-Prompted	**40.8**	49.5

Foundation Models in Robotics

Can use language models for planning/robotics, but

- Not "grounded" since not aware of the environment
- Can mix together with RL concepts

Ahn et al '22

Foundation Models in Robotics: **SayCan**

Can use language models for planning/robotics, but

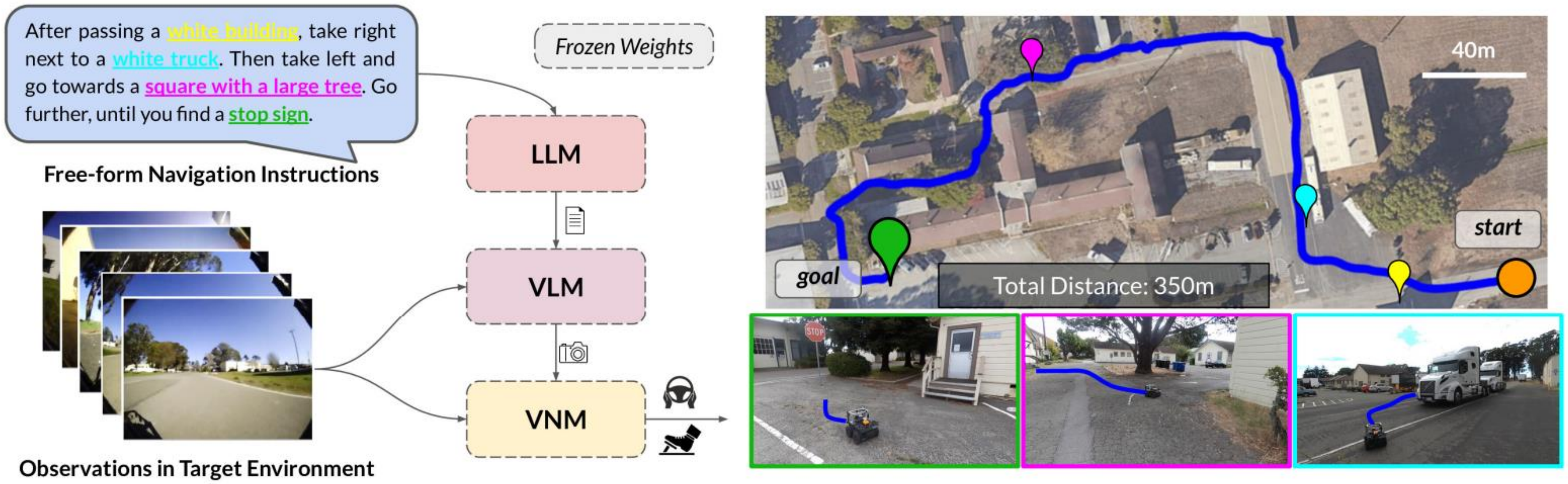
- Not “grounded” since not aware of the environment
- Can mix together with RL concepts
- Basic idea (Ahn et al ’22)

$$\pi = \arg\max_{\pi \in \Pi} p(\underbrace{c_\pi | s, \ell_\pi}_{\substack{\text{Prob. of completing} \\ \text{skill/step from state s}}}) p(\underbrace{\ell_\pi | i}_{\substack{\text{LLM-provided} \\ \text{prob of next} \\ \text{step being valid}}})$$

Foundation Models in Robotics: **Navigation**

For navigation:

- Connect multiple FMs (language, vision, action)
- **Inputs**: observations, instructions
- **Output**: plan

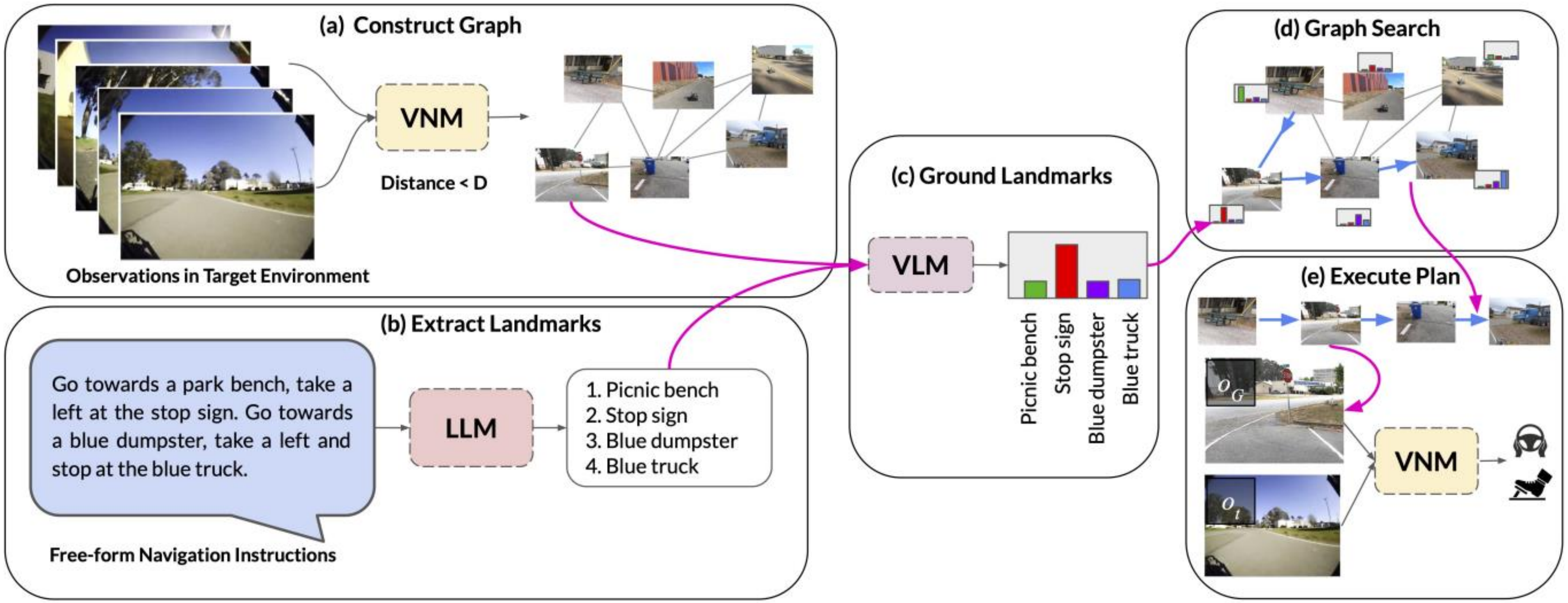


Shah et al '22

Foundation Models in Robotics: **Navigation**

For navigation:

- Connect multiple FMs (language, vision, action)



Shah et al '22

Bibliography

- Weston, Bengio, Usunier '11: Jason Weston, Samy Bengio, Nicolas Usunier, "Wsabie: Scaling Up To Large Vocabulary Image Annotation" (https://research.google/pubs/pub37180/)
- Li et al '19: Liunian Harold Li, Mark Yatskar, Da Yin, Cho-Jui Hsieh, Kai-Wei Chang, "VisualBERT: A Simple and Performant Baseline for Vision and Language" (https://arxiv.org/abs/1908.03557)
- Dosovitskiy et al '20: Alexey Dosovitskiy, Lucas Beyer, Alexander Kolesnikov, Dirk Weissenborn, Xiaohua Zhai, Thomas Unterthiner, Mostafa Dehghani, Matthias Minderer, Georg Heigold, Sylvain Gelly, Jakob Uszkoreit, Neil Houlsby, "An Image is Worth 16x16 Words: Transformers for Image Recognition at Scale" (https://arxiv.org/abs/2010.11929)
- Kim et al '21: Wonjae Kim, Bokyung Son, Ildoo Kim, "ViLT: Vision-and-Language Transformer Without Convolution or Region Supervision" (https://arxiv.org/abs/2102.03334)
- Du et al '22: Yifan Du, Zikang Liu, Junyi Li, Wayne Xin Zhao, "A Survey of Vision-Language Pre-Trained Models" https://arxiv.org/abs/2202.10936)
- Zhang et al '23: Jingyi Zhang, Jiaxing Huang, Sheng Jin, Shijian Lu, "Vision-Language Models for Vision Tasks: A Survey" (https://arxiv.org/abs/2304.00685)
- Singh et al '22: Amanpreet Singh, Ronghang Hu, Vedanuj Goswami, Guillaume Couairon, Wojciech Galuba, Marcus Rohrbach, Douwe Kiela, "FLAVA: A Foundational Language And Vision Alignment Model" (https://arxiv.org/pdf/2112.04482.pdf)
- Alayrac et al '22: Jean-Baptiste Alayrac and others, "Flamingo: a Visual Language Model for Few-Shot Learning" (https://arxiv.org/abs/2204.14198)
- Radford et al '22: Alec Radford and others, "Robust Speech Recognition via Large-Scale Weak Supervision" (https://cdn.openai.com/papers/whisper.pdf)
- Zellers et al '21: Rowan Zellers, Ximing Lu, Jack Hessel, Youngjae Yu, Jae Sung Park, Jize Cao, Ali Farhadi, Yejin Choi, "MERLOT: Multimodal Neural Script Knowledge Models" (https://arxiv.org/abs/2106.02636)
- Ahn et al '21: Michael Ahn and others, "Do As I Can, Not As I Say: Grounding Language in Robotic Affordances" (https://arxiv.org/pdf/2204.01691.pdf)

Thank You!