Yiming LEI, Jingqi LI, Zilong LI, Yuan CAO, Hongming SHAN, 2024. Prompt learning in computer vision: a survey. *Frontiers of Information Technology & Electronic Engineering*, 25(1):42-63. https://doi.org/10.1631/FITEE.2300389

Prompt learning in computer vision: a survey

Key words: Prompt learning; Visual prompt tuning (VPT); Image generation; Image classification; Artificial intelligence generated content (AIGC)

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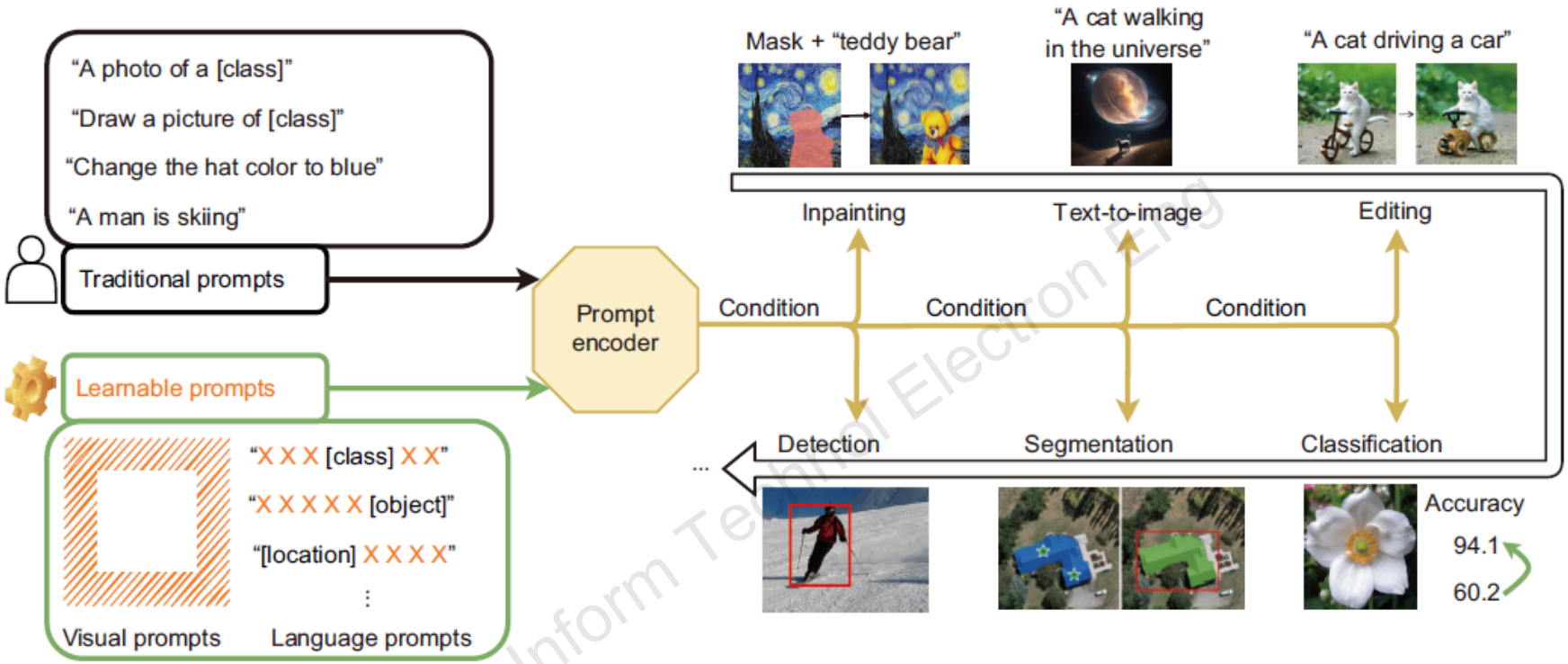
Motivation

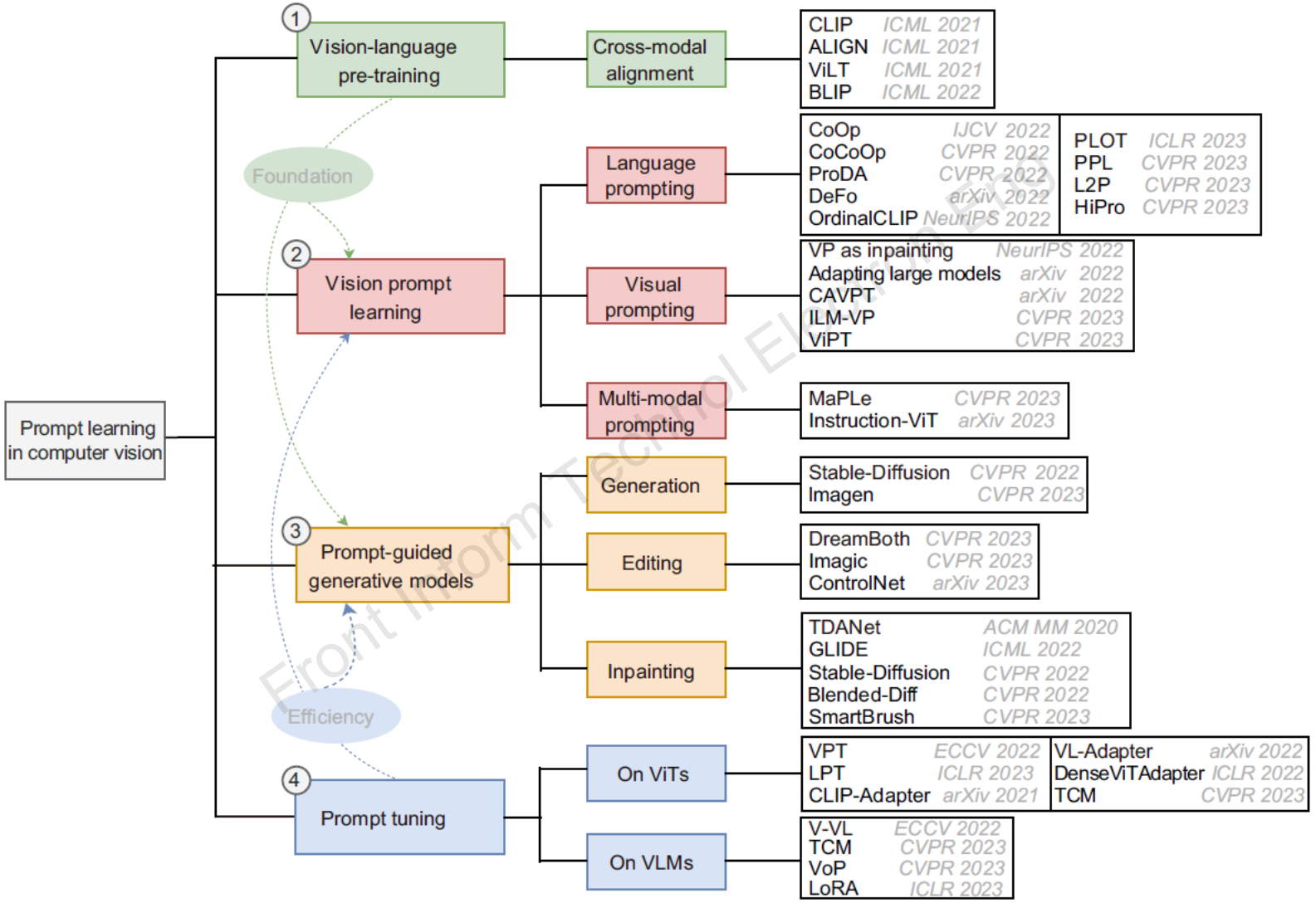
- Recently, prompt learning has attracted broad attention since the large pre-trained vision-language models (VLM) exploded such as contrastive language-image pre-training (CLIP). Prompt learning has inspired large amounts of studies and applications such as zero/few-shot learning, image restoration, and image segmentation.
- Empowered by prompt learning in both vision and language areas, artificial intelligence generated content (AIGC) becomes a hot topic for its amazing ability in generating various kinds of contents such as images, videos, and texts.
- We intend to make a comprehensive survey about prompt learning applied in computer vision (CV) community including introduction of VLM, popular prompt learning methods and prompt-guided generative models, prompt tuning, and promising directions.

Pipeline of prompt learning in CV



- Vision and language prompts act as conditions for various tasks
  - Traditional prompts are with pre-defined forms like those used in CLIP.
  - Learnable prompts are formulated as learnable parameters that will be updated during training or fine-tuning.

Overview of this survey



- The four parts interact with each other in real applications.

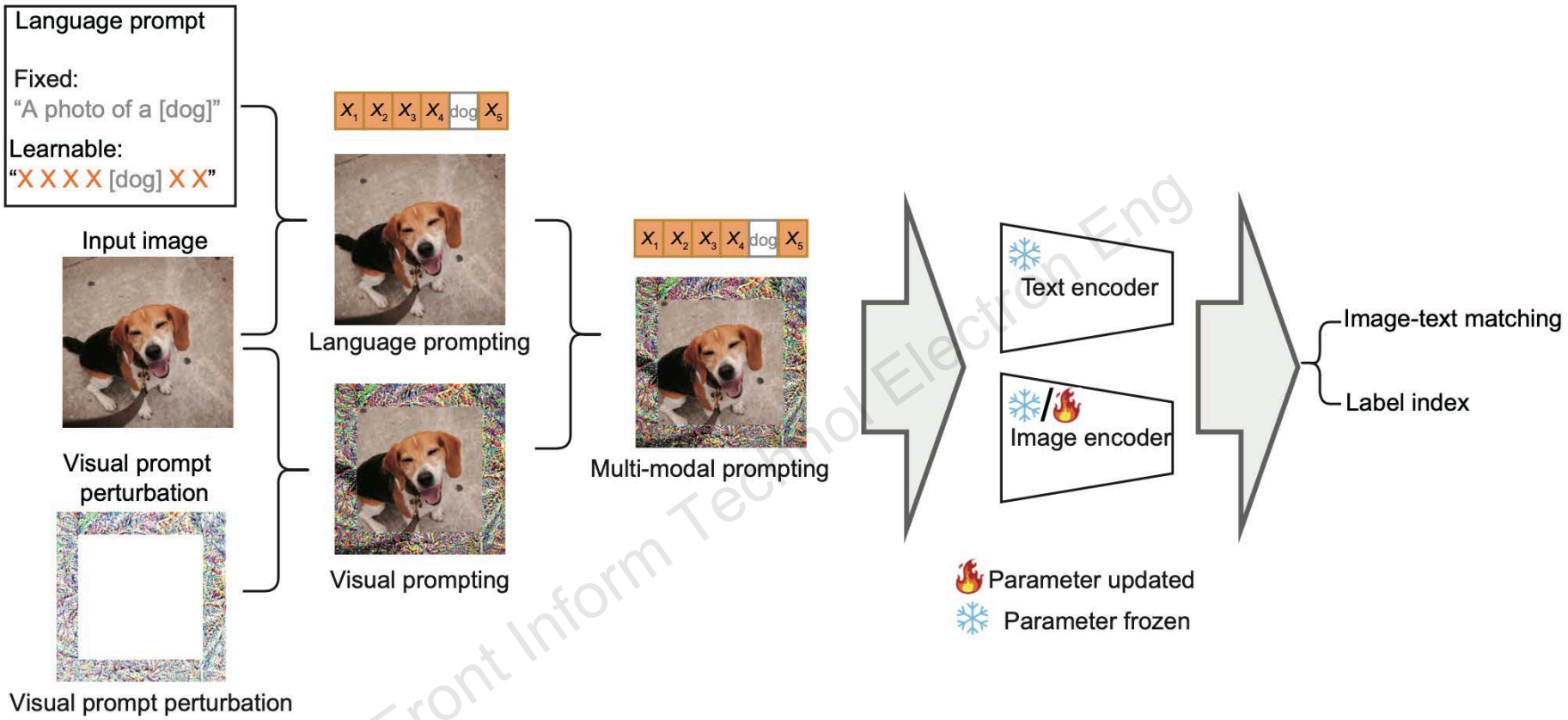
Summary of prompting methods

Method	Task	Language	Visual	Remark
CLIP (Radford et al., 2021)	Pre-train	✓	✗	Vision-language matching for pre-training
ALIGN (Jia C et al., 2021)	Pre-train	✓	✗	Vision-language matching with noisy data
BLIP (Li JN et al., 2022)	Pre-train	✓	✗	Removing noisy data with a bootstrapping captioner
CoOp (Zhou KY et al., 2022b)	Adapt.	✓	✗	Learnable prompts for adapting large-scale models
CoCoOp (Zhou KY et al., 2022a)	Adapt.	✓	✗	Conditional prompting for generalizing to new classes
DeFo (Wang F et al., 2023)	Adapt.	✓	✗	No class tokens in learnable prompts
PLOT (Chen GY et al., 2023)	Adapt.	✓	✗	Optimal transport
VP (Bahng et al., 2022)	Adapt.	✗	✓	Visual prompting with image perturbations
MAE-VQGAN (Bar et al., 2022)	Adapt.	✗	✓	Recovering visual prompt images via inpainting
Painter (Wang XL et al., 2023)	Seg./Det.	✗	✓	Proposing task prompts for many tasks
EVP (Liu WH et al., 2023)	Seg.	✗	✓	Task-aware explicit prompts for structure segmentation
ILM-VP (Chen AC et al., 2023)	Cls.	✗	✓	Visual prompting enhances traditional CNNs
BlackVIP (Oh et al., 2023)	Cls.	✗	✓	Predicting visual prompts for transfer learning
OrdinalCLIP (Li WH et al., 2022)	Ordinal reg.	✗	✓	Modeling ordinal regression as image-text matching
CLIP-Lung (Lei et al., 2023a)	Cls.	✗	✓	Channel-wise conditional prompts
MaPLe (Khattak et al., 2023)	Cls.	✓	✓	Predicting visual prompts for transfer learning
Instruction-ViT (Xiao et al., 2023)	Cls.	✓	✓	Tuning ViTs with multi-modal prompts
SAM (Kirillov et al., 2023)	Seg.	✓	✓	Prompts: points, boxes, texts

"Adapt.," "Seg.," "Det.," "Cls.," and "reg." are short for "Adaptation," "Segmentation," "Detection," "Classification," and "regression," respectively

- Selected prompt learning methods including pre-training, downstream task adaptation, classification, and segmentation.

Hierarchical relationships prompting methods

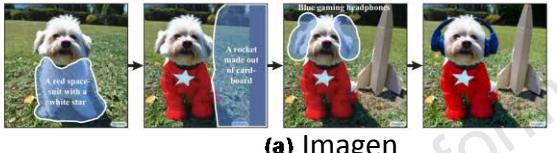


- Learnable prompts include both language and pixel tokens, and they can be combined after feeding into text and image encoders.

Prompt-guided generative models

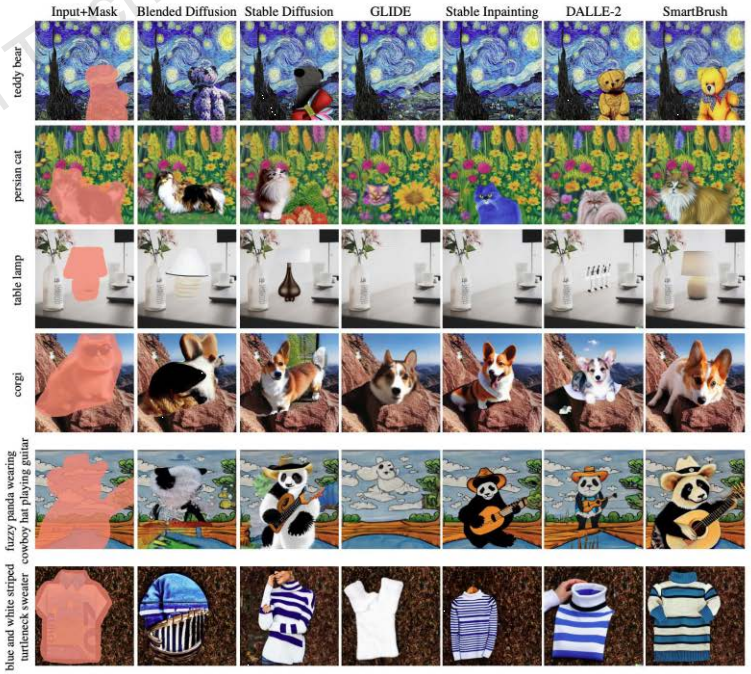
Method	Task	Language	Visual	Remark
Stable-Diffusion (Rombach et al., 2022)	Generation	✓	✓	Diffusion-based, many kinds of prompts
Imagen (Wang S et al., 2023)	Generation	✓	✗	Diffusion-based
GLIDE (Nichol et al., 2022)	Generation	✓	✗	Text-conditional image synthesis
GigaGAN (Kang et al., 2023)	Generation	✓	✗	A new GAN-based model trained with prompts
DreamBooth (Ruiz et al., 2023)	Editing	✓	✗	Unique prompt for a specific subject
ControlNet (Zhang LM et al., 2023)	Editing	✓	✗	Task-specific conditions, robust to small datasets
Blended-Diff (Avrahami et al., 2022)	Inpainting	✓	✗	Task-specific conditions, robust to small datasets
SmartBrush (Xie et al., 2023)	Inpainting	✓	✗	Continuous guidance, multi-level masks

- Summary of highly-cited generative models involving diffusion models and prompt guidance.



(a) Imagen

(b) Blended-Diff



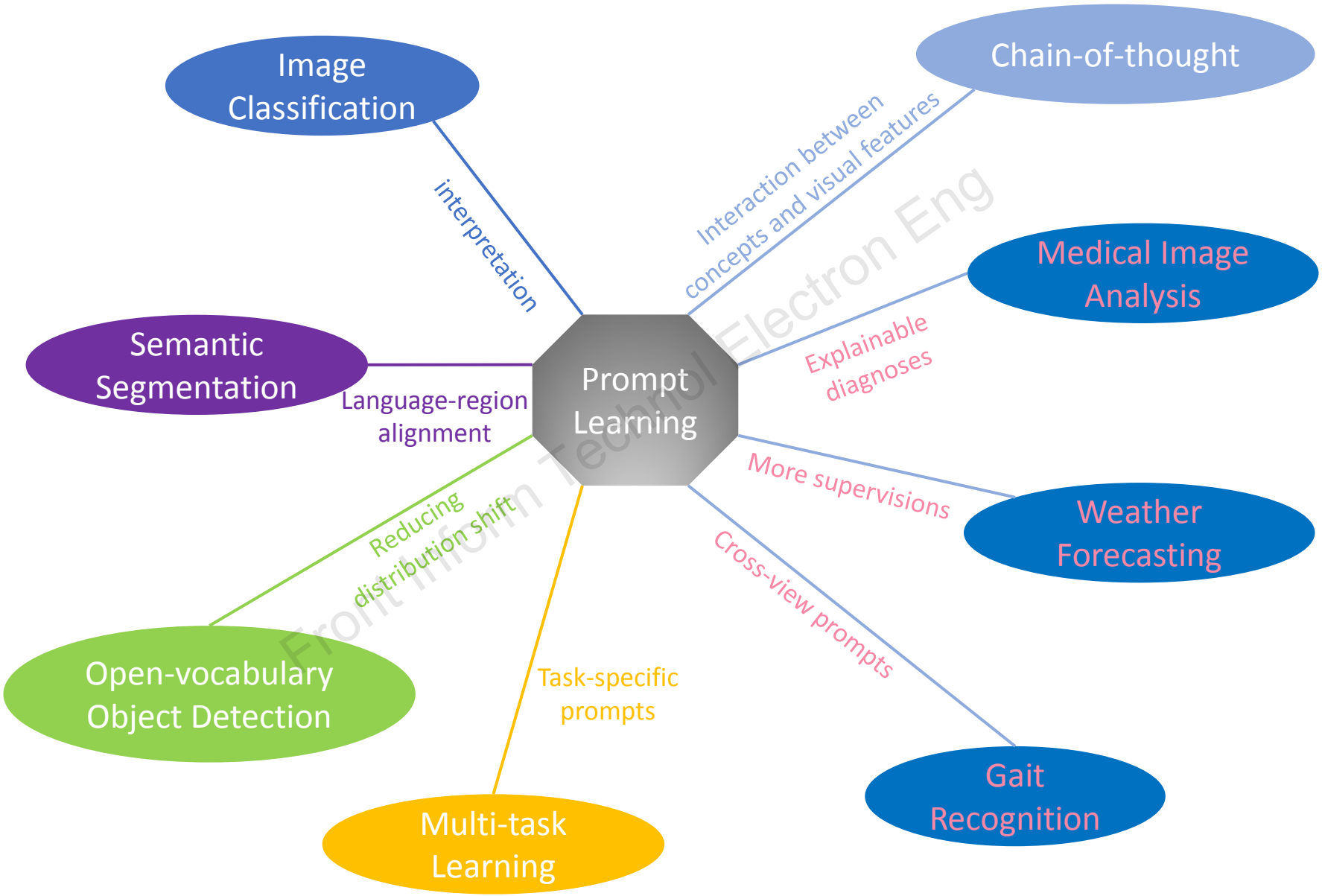
(c) SmartBrush

Prompt tuning

Method	Task	Language	Visual	Remark
VPT (Jia ML et al., 2022)	ViTs	✓	✗	Less than 1% of backbone parameters to tune
LPT (Dong et al., 2023)	ViTs	✓	✗	Prompt tuning for long-tailed classification
TCM (Yu WW et al., 2023)	VLMs	✓	✗	Scene text detection with two prompt generators
V-VL (Ju et al., 2022)	VLMs	✓	✗	Video understanding using learnable prompts
VoP (Huang ST et al., 2023)	VLMs	✓	✗	Video understanding, prompts in intermediate layers
DenseVitAdapter (Chen Z et al., 2023)	VLMs	✓	✗	Injecting task- and input-specific knowledge
CLIP-Adapter (Gao et al., 2021)	VLMs	✓	✗	Modality-agnostic adapter
VL-Adapter (Sung et al., 2022)	VLMs	✓	✗	Unifying various image-text and video-text downstream tasks
LoRA (Hu et al., 2022)	VLMs	✓	✗	Parameter-efficient training on downstream tasks

- We summarized the prompt tuning techniques into two categories: for vision Transformers (ViTs) and for VLMs.
  - For ViTs, it is imperative to study parameter-efficient tuning methods for pre-trained models.
  - For VLMs, prompt tuning can be investigated to efficiently fine-tune VLMs for transferring powerful vision and language representations.

Future directions



Conclusions

- Prompt learning strategies in image-text cross-modal frameworks have overcome shortcomings like weak generalizability of traditional prompt engineering.
- For efficiently applying large VLMs for downstream prompt-guided learning, we discussed prompt tuning methods tailored for better adaptation of large-scale ViTs.
- Prompt-guided generative models trigger a wide variety of applications such as image generation, image editing, and image inpainting.
- Prompt learning has great potential in enhancing existing studies and leading to new multi-modal directions.

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