Multi-Modal Semantic Communication Through Transformer-Aided Compression

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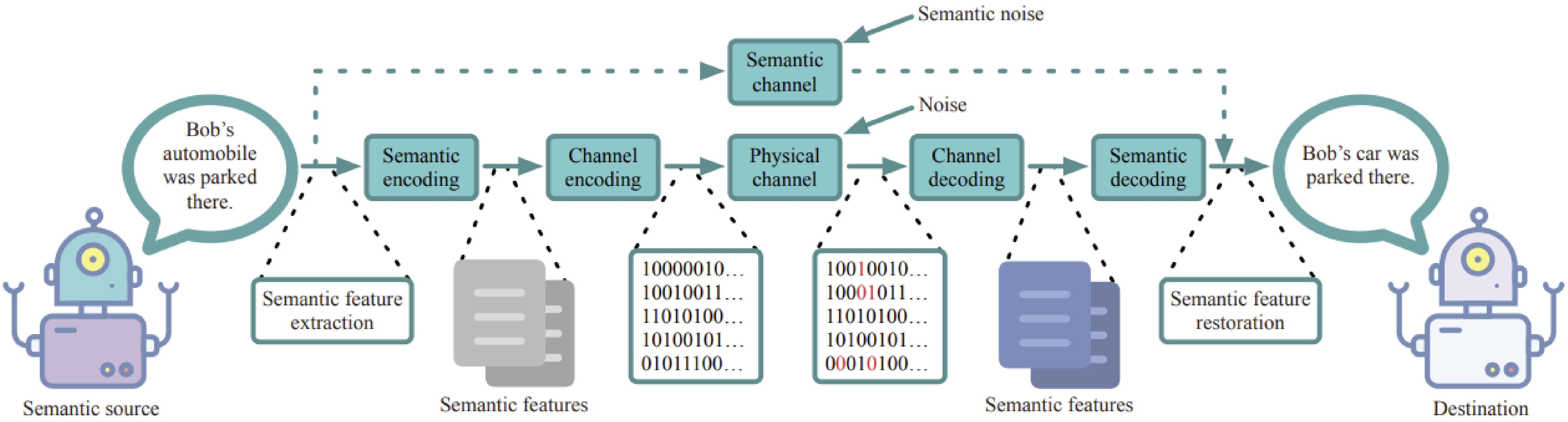
Introduction

- **Semantic communications** is to extract the "meanings" or "features" of sent information from a source and "interpret" the semantic information at a destination.



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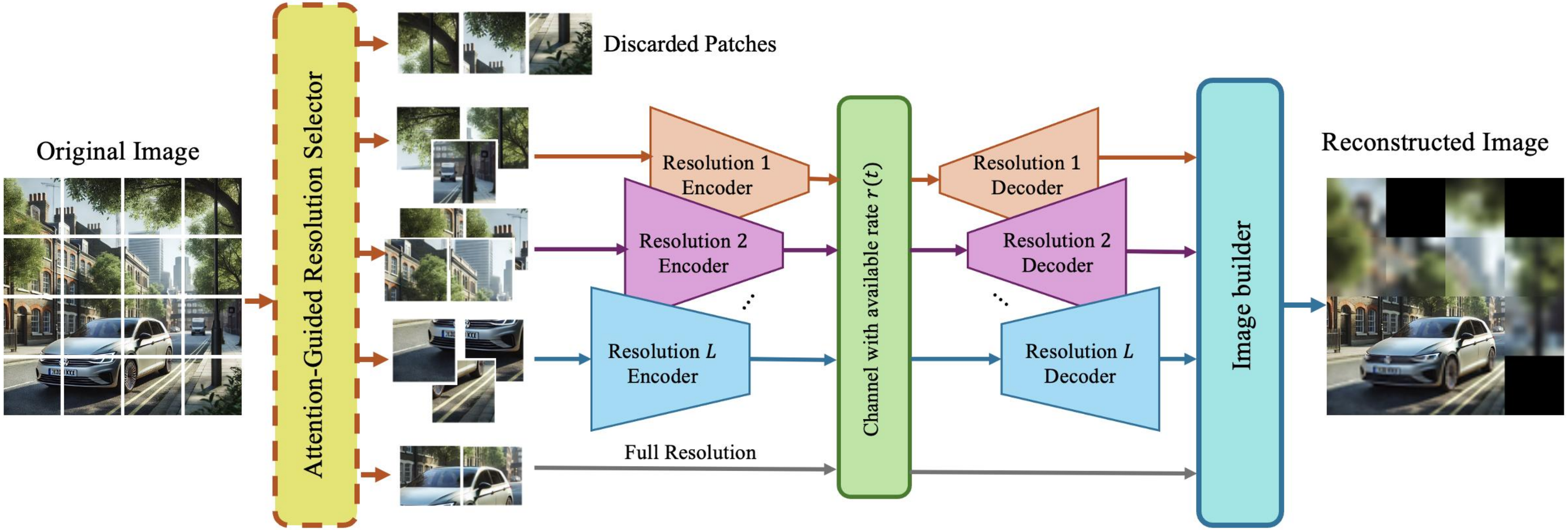
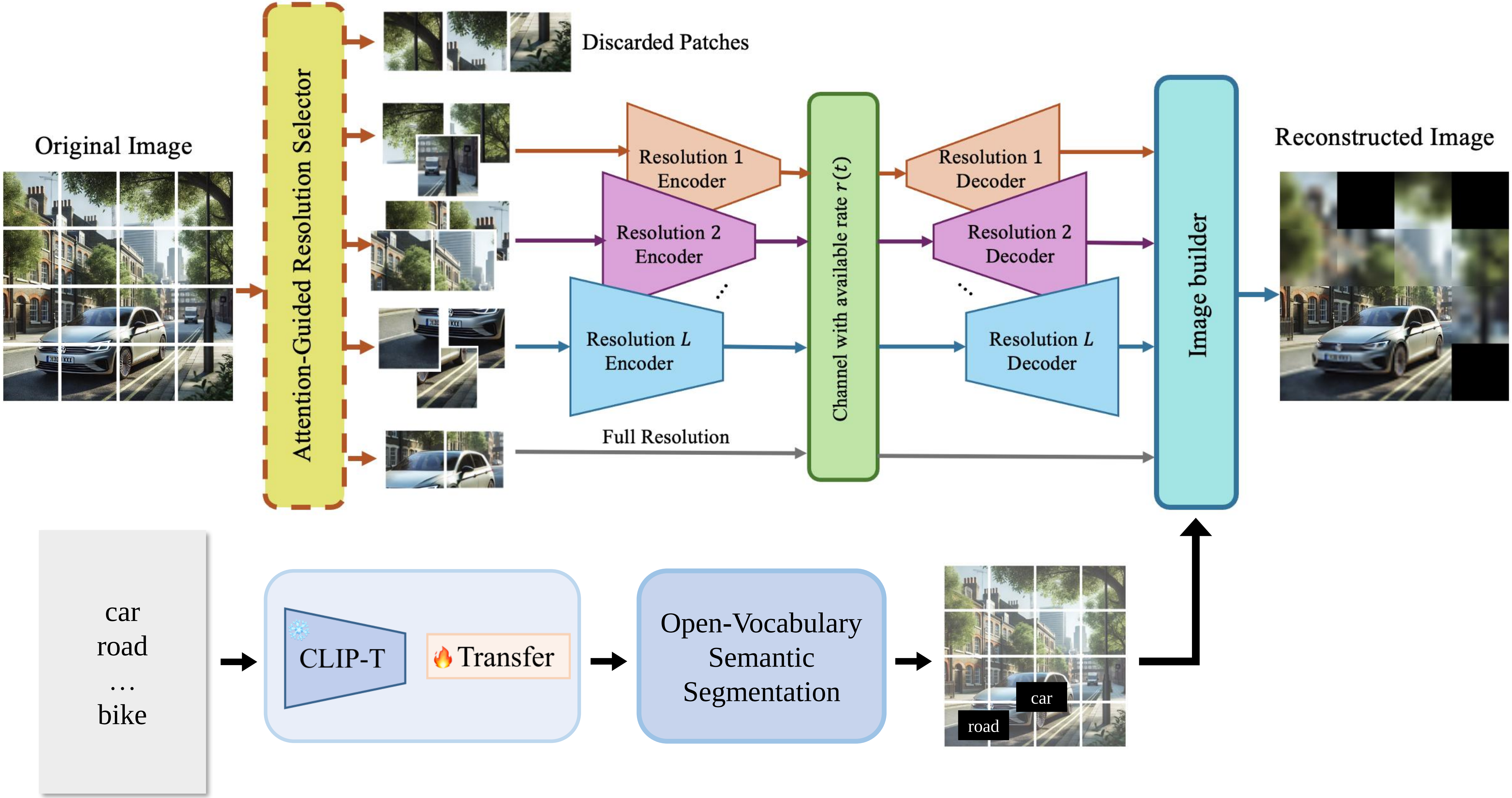
Introduction

- Goal: Transmit multi-resolution data in limited bandwidth conditions.
- Developed a transformer-based framework for channel-adaptive communication.





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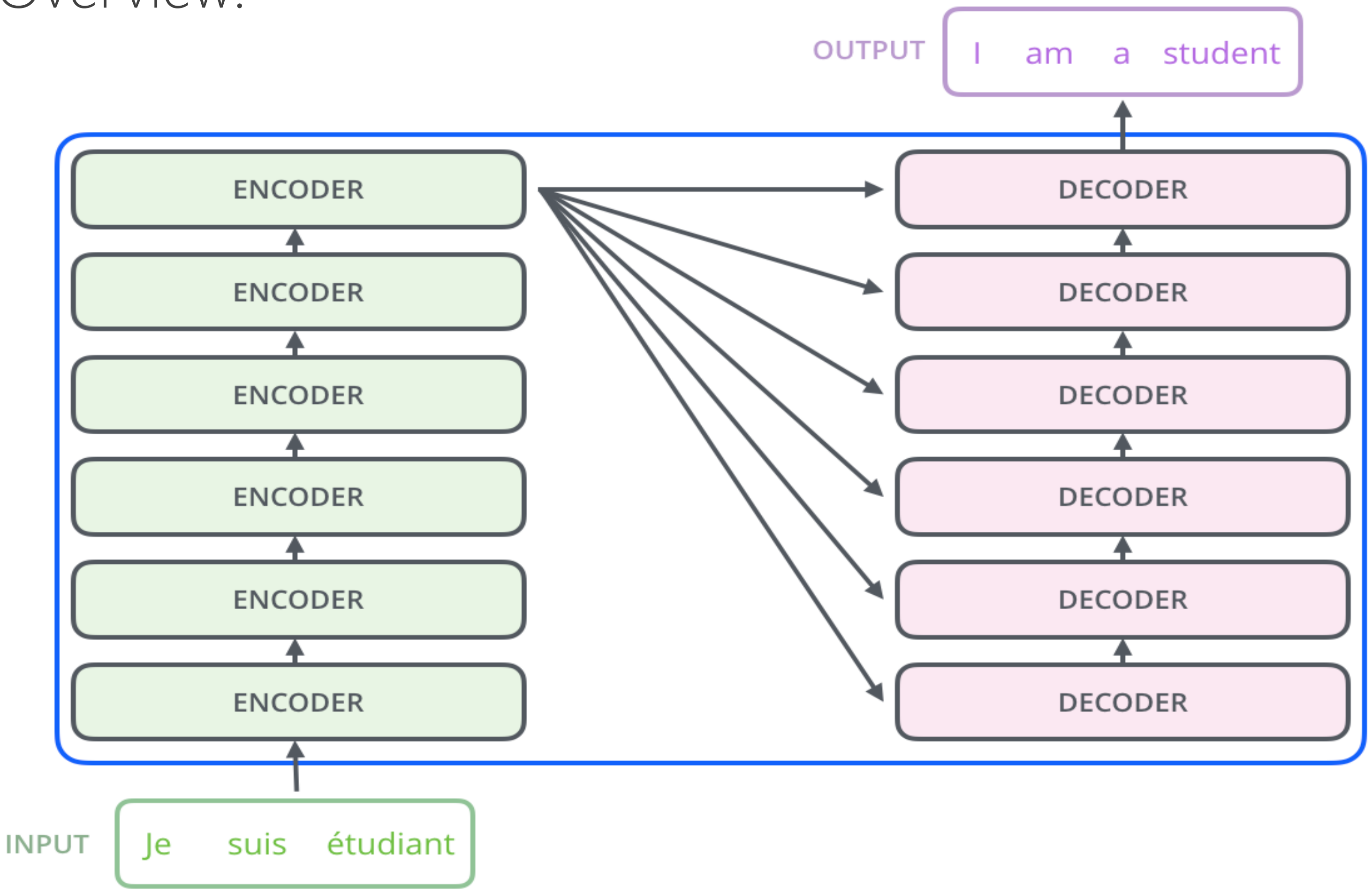
Background

Background (Transformer)

- Transformer Overview:



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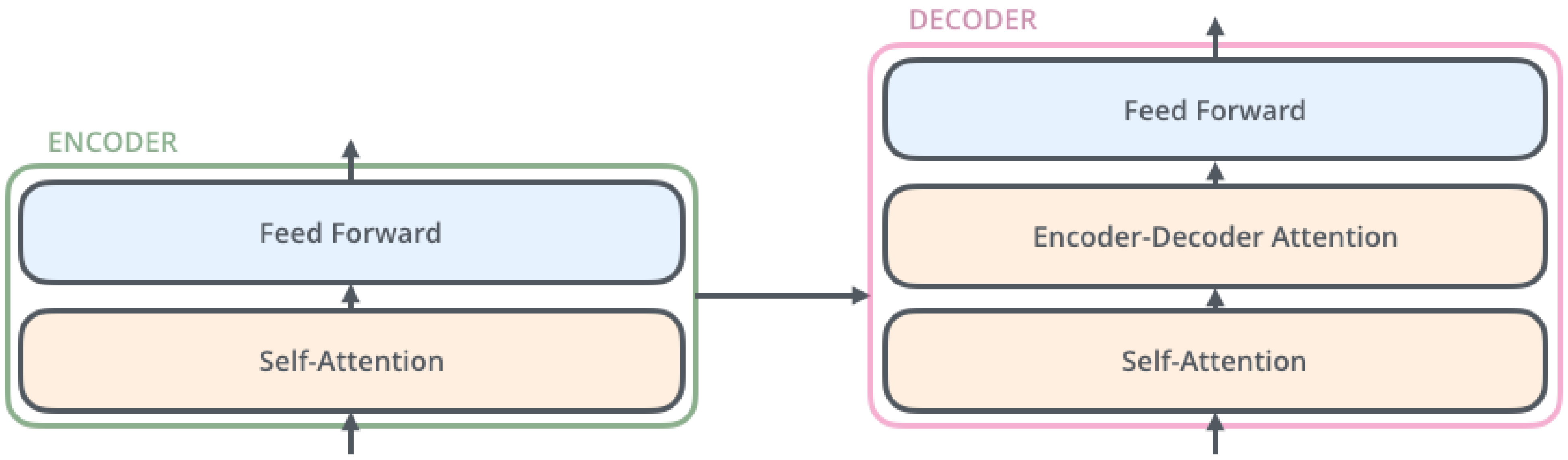
Background (Transformer)

- Transformer Overview:
  - A deep learning architecture with self-attention mechanisms.
  - Enables focus on key elements in complex data.



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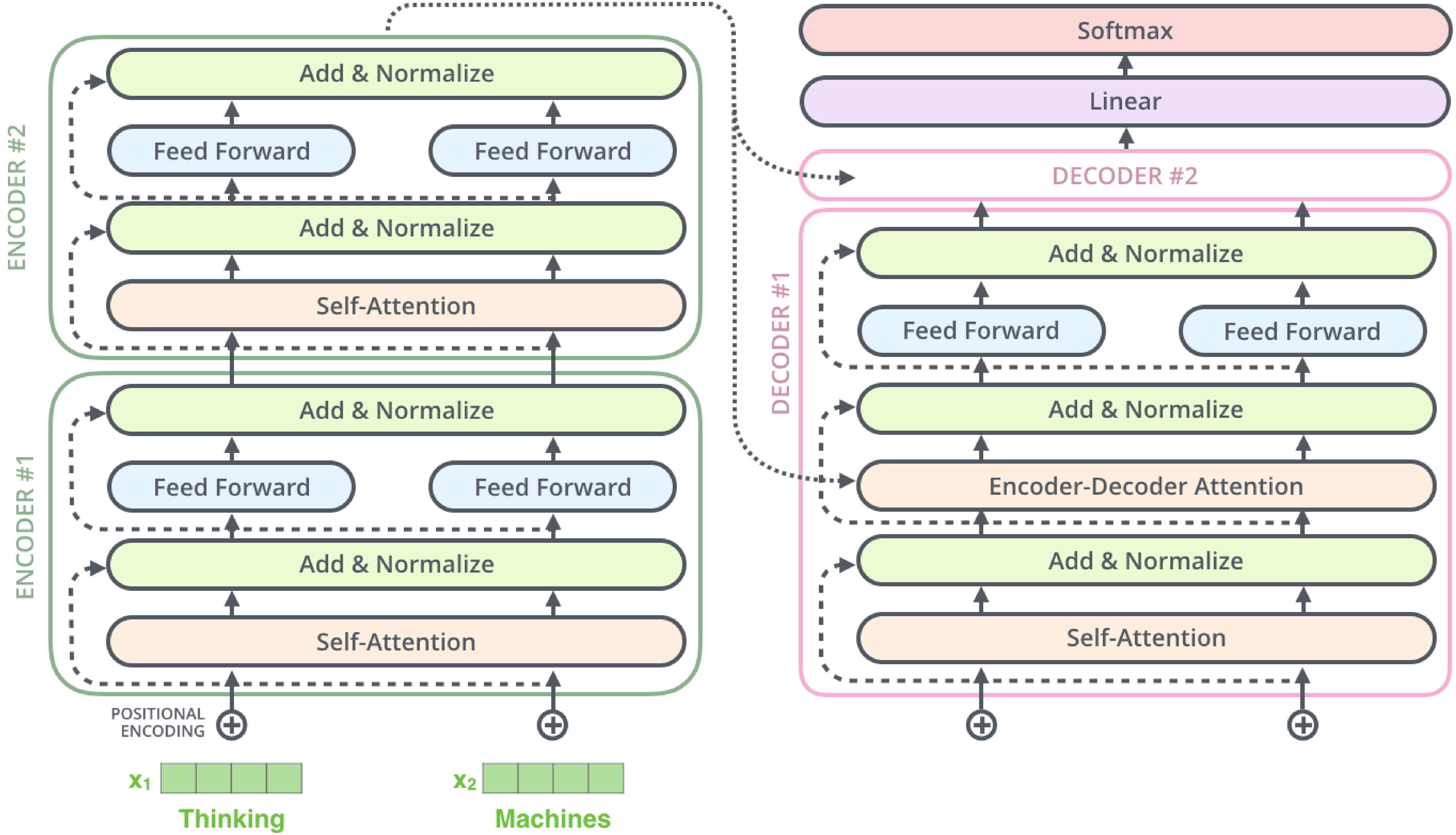
Softmax
Linear
DECODER #2
DECODER #1
Add & Normalize
Feed Forward
Feed Forward
Add & Normalize
Encoder-Decoder Attention
Add & Normalize
Self-Attention
ENCODER #2
Add & Normalize
Feed Forward
Feed Forward
Add & Normalize
Self-Attention
ENCODER #1
Add & Normalize
Feed Forward
Feed Forward
Add & Normalize
Self-Attention
POSITIONAL ENCODING
x1
x2
Thinking
Machines

Background (Transformer)

- Key Features:
  - Multi-head attention
  - Positional encodings
  - Encoder-decoder structure
- Application for the paper:
  - Image patches encoded and compressed based on semantic content.

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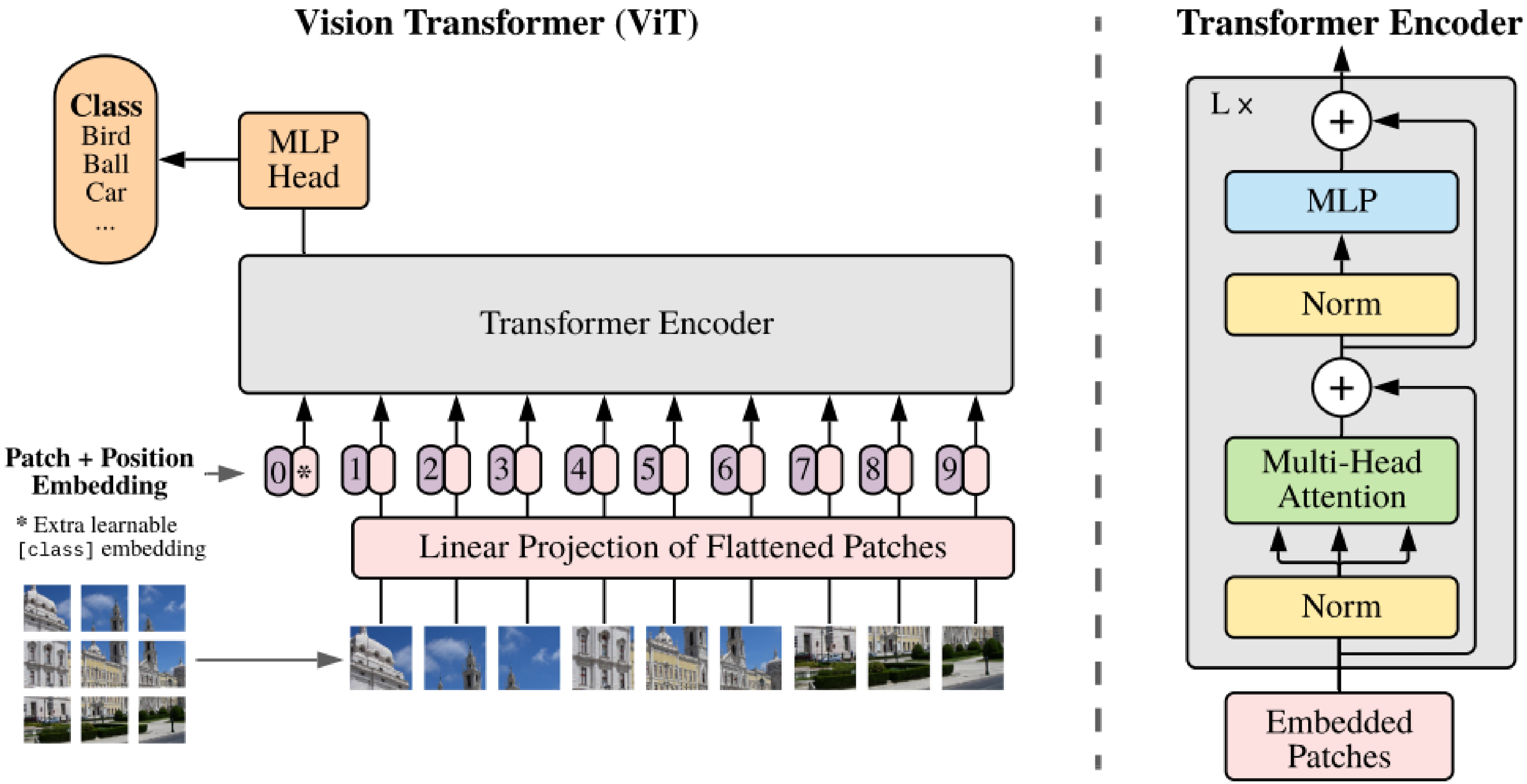
Background (Vision Transformer)

- Vision Transformer (ViT)



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Background (Vision Transformer)

- Vision Transformer (ViT):
  - Image Patching: The input image is divided into fixed-size patches, typically 16x16 pixels.
  - Patch Embedding: Each patch is flattened and linearly embedded into a lower-dimensional vector.
  - Positional Encoding: Positional embeddings are added to retain spatial information.
  - Transformer Encoder: The sequence of patch embeddings is processed by a standard Transformer encoder.
  - Classification: A special "classification token" is added to the sequence for final prediction

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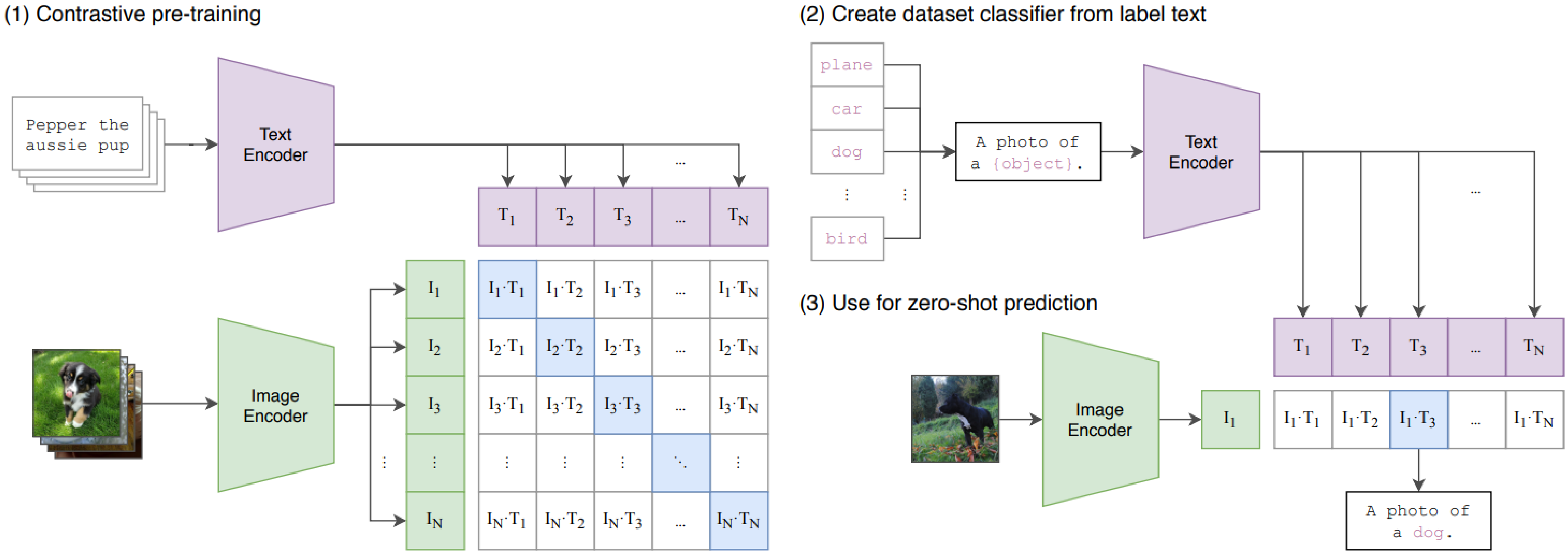
Background (CLIP)

- Contrastive Language–Image Pretraining (CLIP)
  - A model that predicts image-text similarity



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System Model

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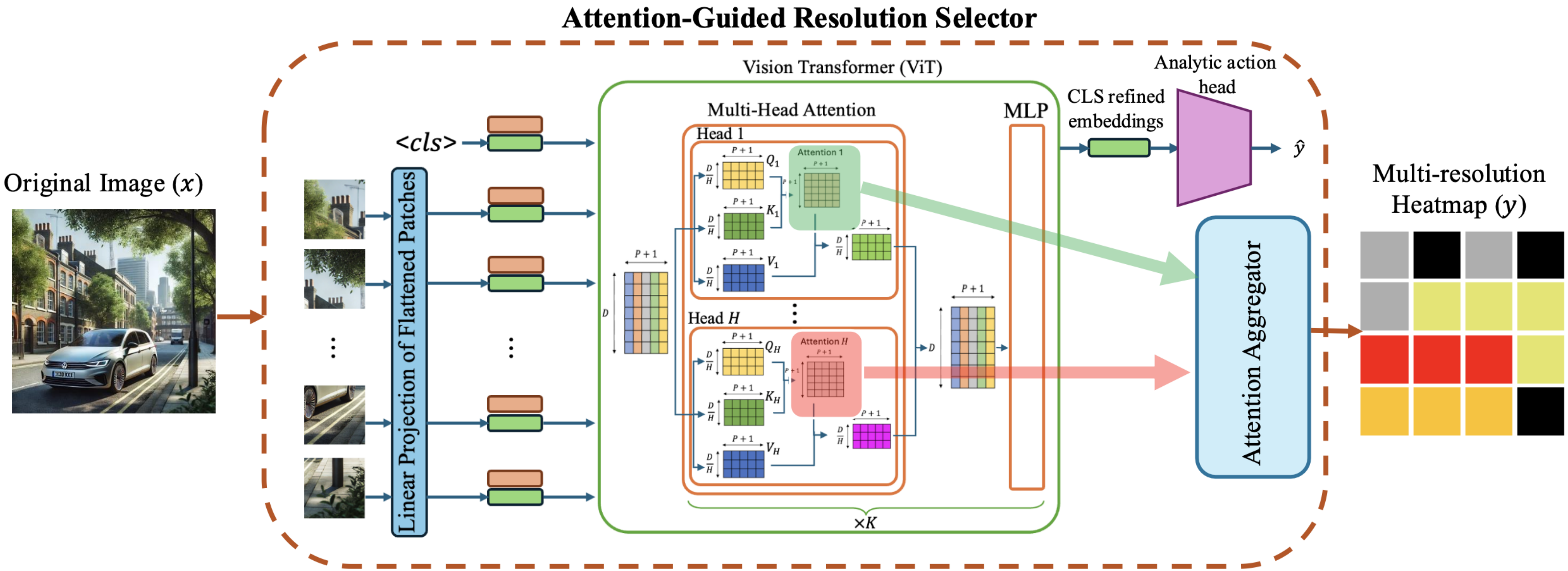
System Model

- Attention-Guided Resolution Selector determines the encoding resolution for each patch based on its semantic importance and available channel rate.



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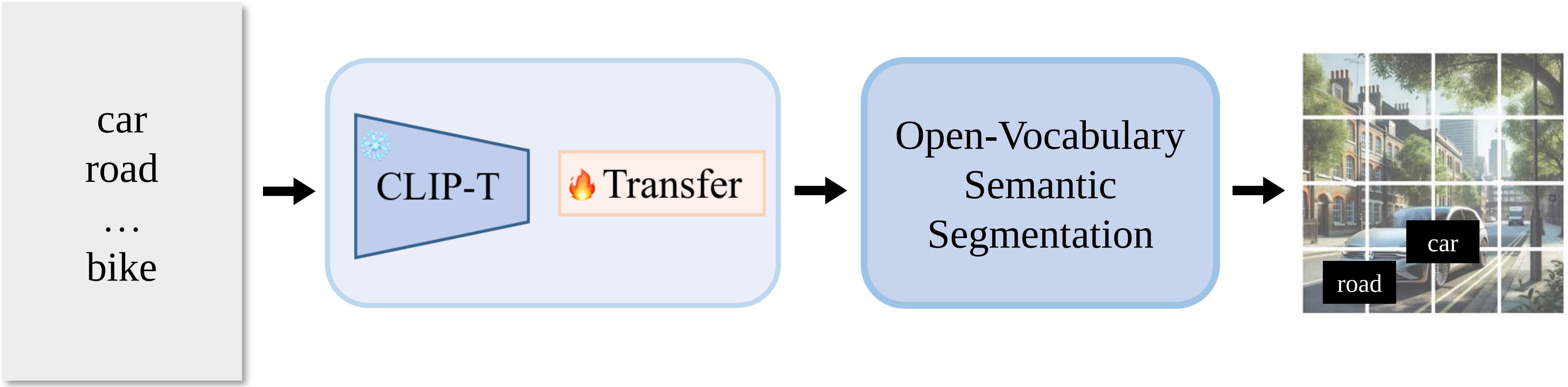
System Model

- Open-vocabulary segmentation framework find an attention score of images based on the text input



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System Model

- Key contributions:
  - Multi-resolution encoding for preserving semantic fidelity.
  - Dynamic adaptation to varying channel conditions.
- Results:
  - Optimized bandwidth utilization.
  - Maintained high task accuracy and data quality.

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Results

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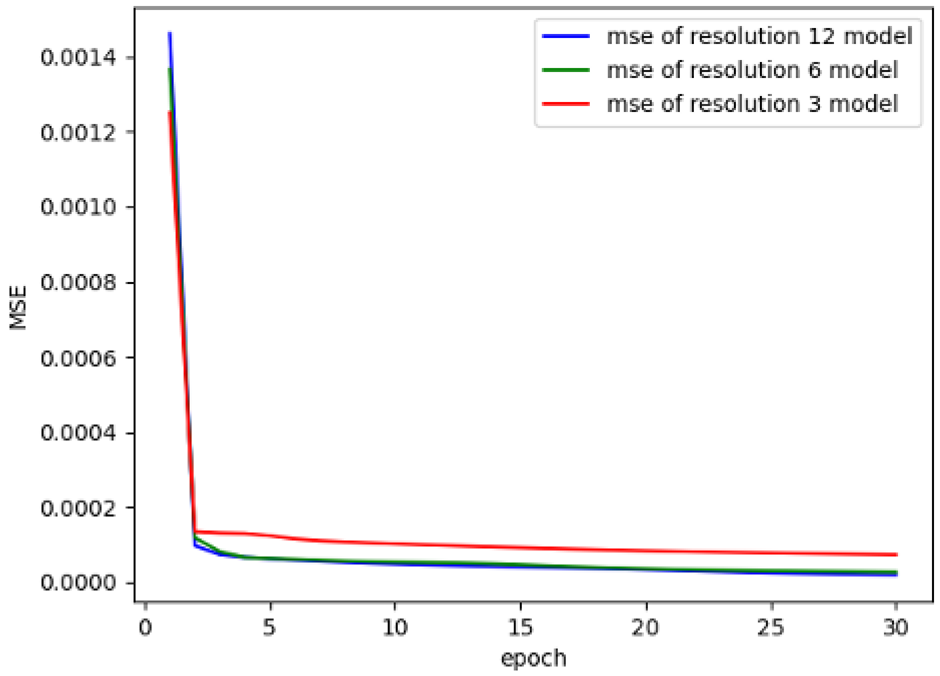
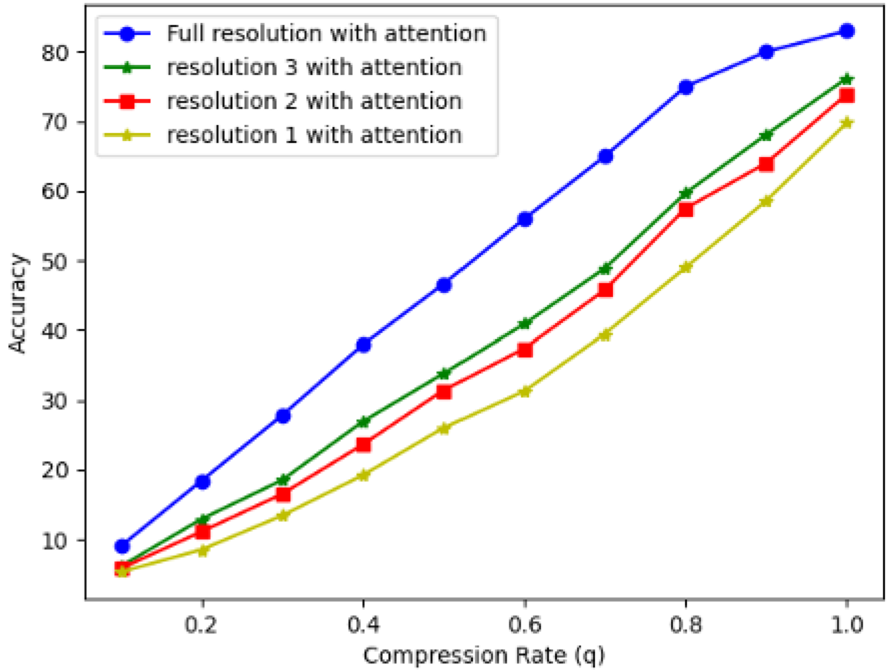
Results



<Reconstruction result for three medium resolutions.>



<Accuracy result for three medium resolutions.>

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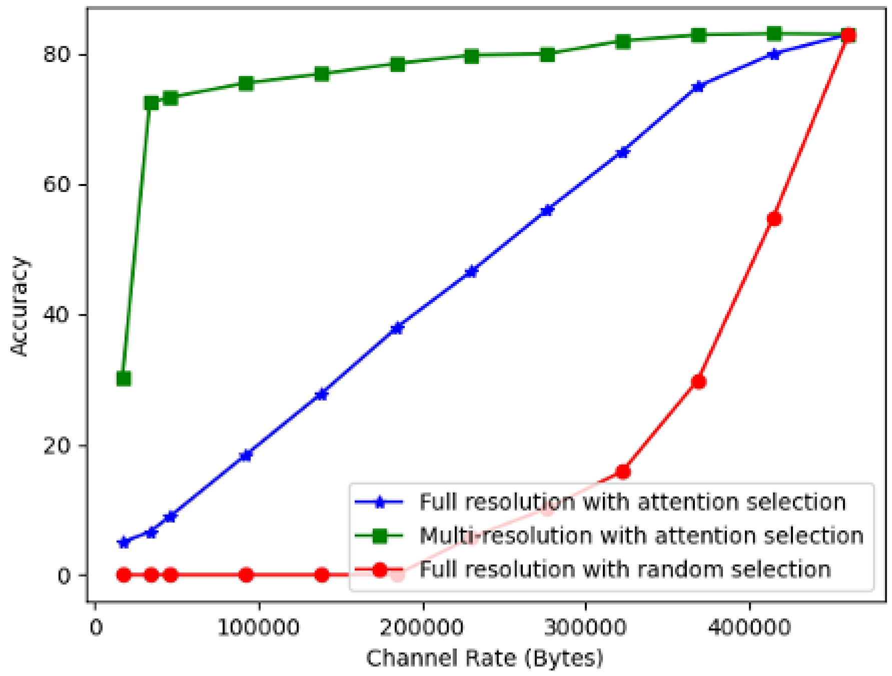
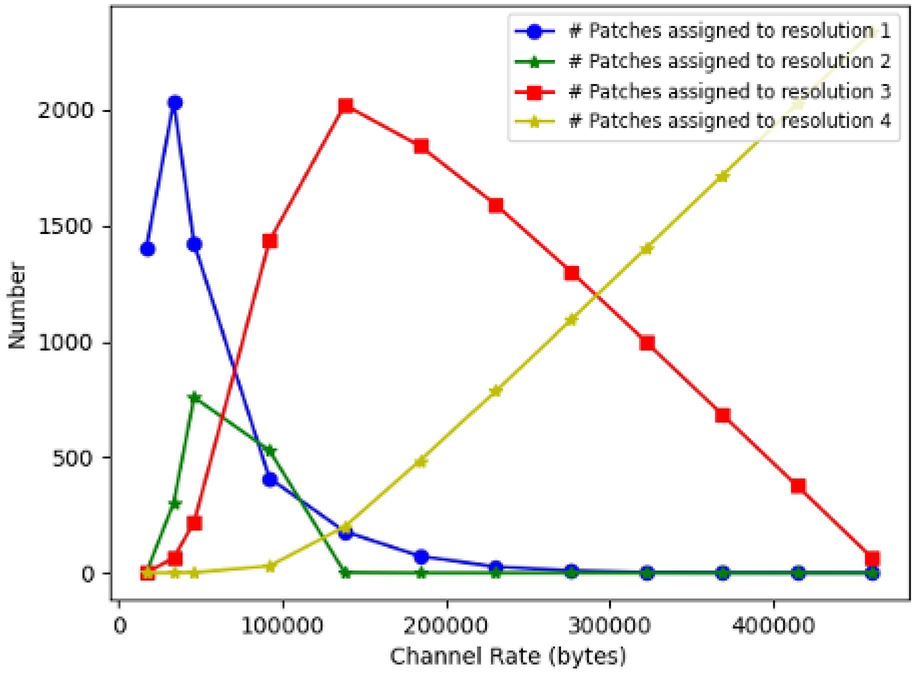
Results



<Accuracy result for adaptive multi-resolution semantic communication framework in various channel rates.>



<Resolution assignment to patches in different channel rate.>

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Discussion and Conclusion

Discussion

- Potential Directions:
  - Extend to multimodal data (e.g., text and images together).
  - Extend to video data with recent techniques in computer vision fields
  - Develop task-specific optimization techniques for diverse domains (e.g., image anomaly detection).
- Key Challenges:
  - Efficient training of adaptive encoders.
  - Addressing latency in dynamic channel conditions.

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Conclusion

- This work proposes a novel semantic communication framework that fuses open-vocabulary vision–language segmentation with transformer-based compression.
- We build on recent advances in open-vocabulary segmentation, which leverage large pre-trained vision–language models to break away from fixed label sets and segment arbitrary categories described by text prompts.

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