# Hybrid Concept Bottleneck Models

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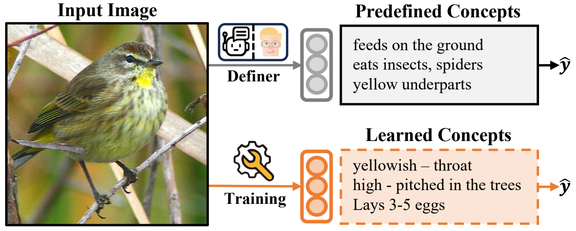
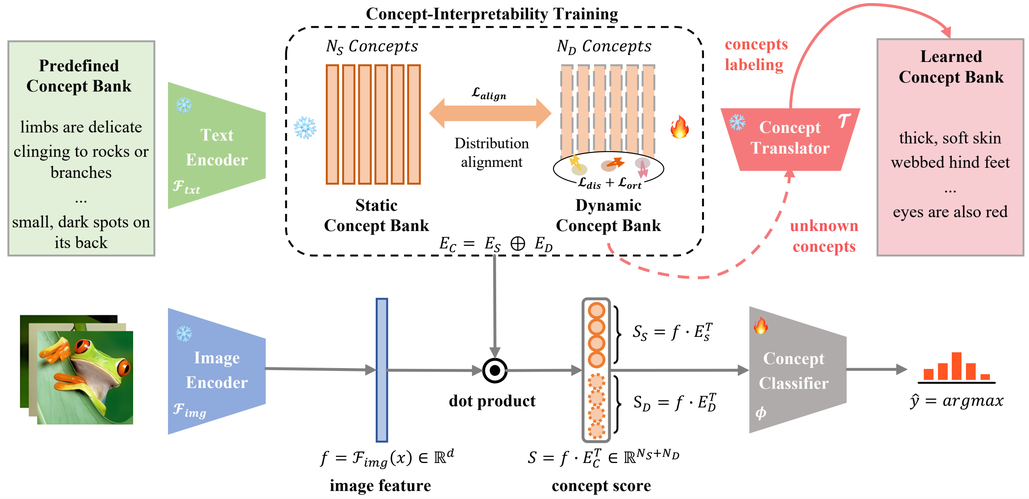
CVPR Nashville JUNE 11-15, 2025

## Motivation



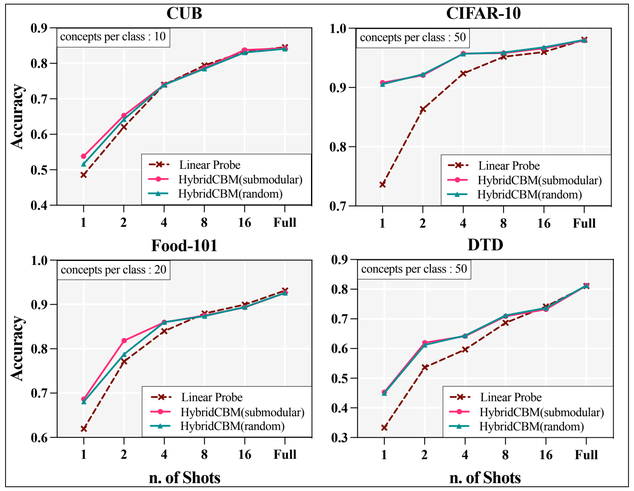

- The quality and completeness of the predefined concepts significantly affect the performance of CBMs.
- **Innovative Hybrid Concept Bank**: introduces a hybrid concept bank bank that combines static and dynamic concepts, allowing it to adapt and refine its interpretative capabilities dynamically.
- **Integration of LLM Technologies:**
  1) Using LLM for defining static concepts, translating new concepts
  2) Using VLM for evaluating the interpretability of concepts.

## Methodology




## Quantitative Analysis

**Comparison of test accuracy between HybridCBM with submodular and random selection methods, and Linear Probe across 4 datasets.**




**Evaluate the interpretability of HybridCBM's static and dynamic concepts through various metrics on two levels: Feature & Concept**

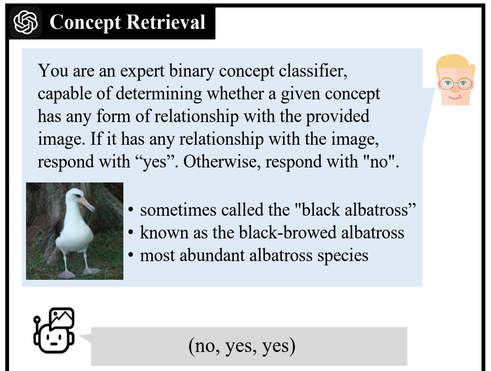
| Loss | Concept Bank | Purity (%) | Separation (%) | Semantics (%) | Precision@t (%) |
|---|---|---|---|---|---|
| | | Feature Level | | Concept Level | |
| $\mathcal{L}_{cls}$ | Static (submodular) | 19.3 | 86.2 | **38.3** | 48.5 |
| | Static (random) | 19.2 | 82.4 | 30.9 | 47.3 |
| | Dynamic | 0.1 | 100.0 | 0.01 | 0.05 |
| $\mathcal{L}_{cls+dis}$ | Dynamic | 71.9 | 76.9 | 30.0 | 34.8 |
| $\mathcal{L}_{cls+dis+ort}$ | Dynamic | 72.0 | 77.1 | 28.9 | 34.1 |
| $\mathcal{L}_{cls+dis+ort+align}$ | Dynamic | 39.8 | 80.0 | **32.8** | **46.2** |

## Qualitative Analysis

| | Class Name | Sample | Case interpretability | |
|---|---|---|---|---|
| | | | static concepts | dynamic concepts |
| CUB | Laysan Albatross |  | 1.lays 4-6 white eggs<br>2.black and white striped body | 1.black and white albatross<br>2.largest albatross species |
| Food-101 | Baklava |  | 1.flaky, phyllo dough texture<br>2.filled with nuts and sweetened with syrup | 1.light brown center<br>2.a food is arranged on a large platter |
| Flower | Clematis |  | 1.popular choice for making garlands and wreaths<br>2.borne on a climbing vine | 1.large , a seed plant<br>2.violet |

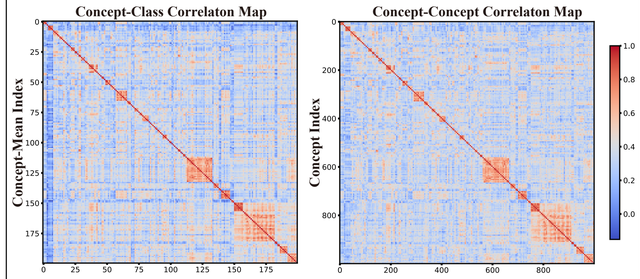
**The top-2 static and dynamic concepts for randomly selected classes across three datasets are presented, focusing on case interpretability.**

### Concept Retrieval




**The concept retrieval process with vision-language model GPT-4o is illustrated on the right.**

## Concept Correlation Structures




Comparison of dynamic concept correlation structures on the CUB dataset.

- **Concept-Class concepts**: our dynamic concepts align closely with their corresponding classes while effectively capturing diversity across classes.
- **Concept-Concept concepts:** highlights the diversity among concept with different classes.