1. General Baseline Method (`baseline_lv1`)

Core Pipeline

The baseline agent implements the reference **Embodied AI Challenge** navigation architecture:

1. **Feature Extraction** – Compute **SIFT** descriptors for all exploration images.
2. **Codebook Generation** – Train a **K-Means (128 clusters)** model to form a visual vocabulary.
3. **VLAD Encoding** – Aggregate local SIFT residuals against their cluster centroids, producing compact per-image vectors.
4. **Database & Graph Construction** – Store all VLAD vectors and connect each image to its 10 nearest neighbors (Euclidean distance) to form a **K-NN weighted graph**.
5. **Navigation Phase** –
    - Compute the VLAD descriptor of the current first-person view (FPV).
    - Find the nearest pre-exploration image using a **BallTree** search.
    - Use **A*** on the KNN graph to plan the shortest path from current → goal image.
    - Display the *next best view* for manual control and goal alignment.

Key Characteristics

- Relies entirely on **geometric visual features** (no learning or policy).
- Requires **precomputed graphs and descriptors** before runtime.
- Driven by **manual keyboard input** — the agent reacts to user commands (`WASD` , `Q` , `SPACE`).
- Uses `cv2.SIFT_create()` , `sklearn.KMeans` , and `networkx` for navigation graph logic.

Summary

`baseline_lv1` serves as a reproducible foundation using **classical place-recognition**: SIFT → KMeans → VLAD → BallTree → A* Pathfinding.

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2. Enhanced Method (`full_auto`)

Extended Architecture

The `full_auto` variant (or *Baseline++*) refines and automates the original pipeline across three dimensions: **feature fusion**, **adaptive graph weighting**, and **autonomous goal handling**.

(a) Hybrid Feature Extraction

- Replaces SIFT with **ORB + color histograms** (RGB 4×4×4 bins).
- Combines local binary texture (ORB) and global color information into ~96-D hybrid descriptors.
- Improves robustness under lighting and viewpoint changes.

(b) Incremental Codebook Learning

- Adopts **MiniBatchKMeans** for scalable online clustering on large datasets (~18k+ frames).
- Performs dimensional consistency checks to automatically retrain mismatched models.

(c) VLAD + Color Database

- Stores both **VLAD embeddings** (structural similarity) and **color histograms** (appearance).
- Introduces blended edge weights:
  $$w_{ij} = \alpha \cdot d_{\text{VLAD}}(i,j) + (1 - \alpha) \cdot d_{\text{color}}(i,j)$$
  with $\alpha = 0.8$.
- Produces a **multi-modal navigation graph** that preserves both geometric and semantic continuity.

(d) Adaptive Graph & Navigation

- Builds an “adaptive” KNN graph (`knn_graph_plus.pkl`) using hybrid weights.
- Uses a **heuristic A*** (partial Euclidean heuristic to goal).
- Maintains a **recent-neighbor buffer** (majority voting across last 5 frames) to stabilize motion and suppress noise.

(e) Autonomous Goal Handling

- Automatically detects the nearest neighbor of target images.
- Supports **semi- or fully autonomous navigation** without manual query triggers.

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3. Comparison Summary

Aspect	Baseline Lv1	Full_Auto (Baseline++)	Effect / Implication
Feature Type	SIFT (128-D float)	ORB + Color Histogram (~96-D hybrid)	Faster, more illumination-invariant
Clustering	Standard KMeans	MiniBatchKMeans	Scalable & memory-efficient
Descriptor Fusion	Single VLAD vector	VLAD + Color	Integrates texture & color cues
Graph Edge Weight	Euclidean (VLAD distance)	Weighted (VLAD + Color)	Improves semantic path locality
Path Planning	A*	Heuristic A* + neighbor voting	Fewer backtracks, smoother motion
Human Input	Manual key queries	Semi/auto navigation	Closer to full autonomy
Robustness	Sensitive to lighting, texture	Hybrid and noise-tolerant	More stable performance
Computation Cost	High (SIFT)	Lower (ORB + MiniBatch)	Enables near real-time execution
Graph File	`knn_graph.pkl`	`knn_graph_plus.pkl`	Adaptive edge weighting

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4. Methodological Distinctions

- **Baseline Lv1**
  → Deterministic visual place-recognition with manual control.
  → Simple geometric matching (SIFT + VLAD).
- **Full_Auto**
  → Autonomous navigation combining local binary descriptors, color histograms, and adaptive graph search.
  → Employs hybrid features and dynamic graph heuristics for robustness.

In essence:

> `baseline_lv1` = manual, SIFT-based visual navigation
> `full_auto` = autonomous, hybrid multi-modal navigation

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5. Performance Insights

Empirically:

- **Baseline Lv1** reaches goals but often oscillates or fails under repetitive textures.
- **Full_Auto** demonstrates **shorter navigation times**, smoother transitions, and fewer dead-ends due to its hybrid descriptors and adaptive path planning.

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6. Summary Table of Improvements

Improvement Area	Technique	Impact
Feature Representation	ORB + Color	Better robustness to illumination, faster processing
Clustering	MiniBatchKMeans	Handles large exploration datasets efficiently
Navigation Graph	VLAD + Color weights	Captures richer scene similarity
Planning Heuristic	A* with distance heuristic	Reduces unnecessary detours
Stability	Neighbor majority filter	Suppresses transient mis-matches
Autonomy	Auto-goal + auto-next-view	Enables fully automated runs

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7. References

- Embodied AI Challenge baseline documentation (NYU, 2024)
- Source implementations:
  - `baseline_lv1.py` – Classical SIFT + VLAD baseline
  - `baseline-full-auto.py` – Hybrid ORB + Color, adaptive graph, autonomous navigation

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