retrieval_dataset_v3

September 20, 2025

1 Retrieval metrics with different embeddings, before keypoints

- “Flag face landmarks”
- “Position face landmarks”
- “Positions norm face landmarks”
- “Flags + positions unnorm”
- “Flags + positions norm”
- “All features face landmarks”

Load the dataset

[12]:

```
from matplotlib.lines import lineStyles
%load_ext autoreload
%autoreload 2

from libraries.embeddings_utils import *
import ipynbname
from libraries.classifier_utils import *
from libraries.retrieval_utils import *
from libraries.file_manager_utils import *

project_dir = f"{os.getcwd().
 ↪split('SIDS_revelation_project')[0]}SIDS_revelation_project/"
image_dataset_path = f"{project_dir}datasets/onback_onstomach_v3"
model_path_fd = f"{project_dir}/models/4.fd_weights/best.pt"
```

```
The autoreload extension is already loaded. To reload it, use:
  %reload_ext autoreload
```

[13]:

```
emb_builder = EmbeddingBuilder(model_path, image_dataset_path, "load")
```

```
Extracting dataset info from .coco.json
file:---------------------------------------------
Dataset contains 4158 valid samples, and labels are {'baby_on_back': 1,
'baby_on_stomach': 2}
--------------------------------------------------------------------------------
----------
```

```
Loading features from
.csv----------------------------------------------------------------
Features loaded succesfully, in particular there are 4158 files in the dataset
--------------------------------------------------------------------------------
----------

Embedding builder initialized
successfully------------------------------------------------
Face detection model: 4 (YOLOv8)
Dataset: /home/terra/Desktop/unimore/AI_engineering/SIDS_revelation_project/data
sets/onback_onstomach_v3
Dataset dimension: 4158
Dataset labels: {'baby_safe': 0, 'baby_unsafe': 1}
--------------------------------------------------------------------------------
----------
```

[14]:

```python
print(f"Dataset contains {emb_builder.dim_dataset} elements.\nIn particular {emb_builder.dim_dataset-emb_builder.y.sum()} {'baby_safe' if emb_builder.classes_bs['baby_safe'] == 0 else 'baby_unsafe'} and {emb_builder.y.sum()} {'baby_safe' if emb_builder.classes_bs['baby_safe'] == 1 else 'baby_unsafe'}")
```

```
Dataset contains 4158 elements.
In particular 2146 baby_safe and 2012 baby_unsafe
```

Create embeddings

[15]:

```python
e_flags = emb_builder.create_embedding(flags = True)
e_positions = emb_builder.create_embedding(flags = True, positions=True)
e_positions_norm = emb_builder.create_embedding(flags = True, positions_normalized=True)
e_all_unnorm = emb_builder.create_embedding(flags = True, positions=True, geometric_info=True)
e_all_norm = emb_builder.create_embedding(flags = True, positions_normalized = True, geometric_info=True)
e_all = emb_builder.create_embedding(flags = True, positions = True, positions_normalized=True, geometric_info=True)
```

```
Embedding
creation------------------------------------------------------------------------
Features: ['flag_eye1', 'flag_eye2', 'flag_nose', 'flag_mouth']
FINISHED: 4158 embedding created
--------------------------------------------------------------------------------
----------

Embedding
creation------------------------------------------------------------------------
```

```
Features: ['flag_eye1', 'flag_eye2', 'flag_nose', 'flag_mouth', 'x_eye1',
'y_eye1', 'x_eye2', 'y_eye2', 'x_nose', 'y_nose', 'x_mouth', 'y_mouth']
FINISHED: 4158 embedding created
--------------------------------------------------------------------------------
----------

Embedding
creation------------------------------------------------------------------------
Features: ['flag_eye1', 'flag_eye2', 'flag_nose', 'flag_mouth', 'x_eye1_norm',
'y_eye1_norm', 'x_eye2_norm', 'y_eye2_norm', 'x_nose_norm', 'y_nose_norm',
'x_mouth_norm', 'y_mouth_norm']
FINISHED: 4158 embedding created
--------------------------------------------------------------------------------
----------

Embedding
creation------------------------------------------------------------------------
Features: ['flag_eye1', 'flag_eye2', 'flag_nose', 'flag_mouth', 'x_eye1',
'y_eye1', 'x_eye2', 'y_eye2', 'x_nose', 'y_nose', 'x_mouth', 'y_mouth',
'eye_distance', 'eye_distance_norm', 'face_vertical_length',
'face_vertical_length_norm', 'face_angle_vertical', 'face_angle_horizontal',
'symmetry_diff', 'head_ration']
FINISHED: 4158 embedding created
--------------------------------------------------------------------------------
----------

Embedding
creation------------------------------------------------------------------------
Features: ['flag_eye1', 'flag_eye2', 'flag_nose', 'flag_mouth', 'x_eye1_norm',
'y_eye1_norm', 'x_eye2_norm', 'y_eye2_norm', 'x_nose_norm', 'y_nose_norm',
'x_mouth_norm', 'y_mouth_norm', 'eye_distance', 'eye_distance_norm',
'face_vertical_length', 'face_vertical_length_norm', 'face_angle_vertical',
'face_angle_horizontal', 'symmetry_diff', 'head_ration']
FINISHED: 4158 embedding created
--------------------------------------------------------------------------------
----------

Embedding
creation------------------------------------------------------------------------
Features: ['flag_eye1', 'flag_eye2', 'flag_nose', 'flag_mouth', 'x_eye1',
'y_eye1', 'x_eye2', 'y_eye2', 'x_nose', 'y_nose', 'x_mouth', 'y_mouth',
'x_eye1_norm', 'y_eye1_norm', 'x_eye2_norm', 'y_eye2_norm', 'x_nose_norm',
'y_nose_norm', 'x_mouth_norm', 'y_mouth_norm', 'eye_distance',
'eye_distance_norm', 'face_vertical_length', 'face_vertical_length_norm',
'face_angle_vertical', 'face_angle_horizontal', 'symmetry_diff', 'head_ration']
FINISHED: 4158 embedding created
--------------------------------------------------------------------------------
----------
```

Initialize retrieval objects

[16]:
```
embeddings = [e_flags, e_positions, e_positions_norm, e_all_unnorm, e_all_norm,␣
 ↪e_all]
embeddings_names = ["Flag face landmarks", "Position face landmarks",␣
 ↪"Positions norm face landmarks", "Flags + positions unnorm", "Flags +␣
 ↪positions norm", "All features face landmarks"]

retrieval_euclidean = { name: ImageRetrieval(emb, emb_builder.y, emb_builder.
 ↪image_paths, image_dataset_path, emb_builder.classes_bs)
                        for name, emb  in zip(embeddings_names, embeddings)}
retrieval_cosine = { name: ImageRetrieval(emb, emb_builder.y, emb_builder.
 ↪image_paths, image_dataset_path, emb_builder.classes_bs)
                        for name, emb  in zip(embeddings_names, embeddings)}
retrieval_mahalanobis = { name: ImageRetrieval(emb, emb_builder.y, emb_builder.
 ↪image_paths, image_dataset_path, emb_builder.classes_bs)
                        for name, emb  in zip(embeddings_names, embeddings)}
```

[17]:
```
for name, retrieval in retrieval_euclidean.items():
    retrieval.build_index(metric="euclidean")

for name, retrieval in retrieval_cosine.items():
    retrieval.build_index(metric="cosine")

for name, retrieval in retrieval_mahalanobis.items():
    retrieval.build_mahalanobis_index()
```

Evaluate precison, recall@R and silhouette scores

[18]:
```
k_values = [5, 10, 20, 50]
precision_scores_euclidean = {name: retrieval.
 ↪plot_precision_at_k(k_values=k_values, verbose=False)
                              for name, retrieval in retrieval_euclidean.
 ↪items()}
print("Processed n' 1")

precision_scores_cosine = {name: retrieval.
 ↪plot_precision_at_k(k_values=k_values, verbose=False)
                              for name, retrieval in retrieval_cosine.items()}
print("Processed n' 2")

precision_scores_mahalanobis = {name: retrieval.
 ↪plot_precision_at_k(k_values=k_values, verbose=False)
                              for name, retrieval in retrieval_mahalanobis.
 ↪items()}
print("Processed n' 3")
print("Precision scores evaluated successfully!")
```

```
Processed n' 1
Processed n' 2
Processed n' 3
Precision scores evaluated successfully!
```

[19]:

```
recall_scores_euclidean = {name: retrieval.recall_at_R()
                              for name, retrieval in retrieval_euclidean.
 ↪items()}
print("Processed n' 1")

recall_scores_cosine = {name: retrieval.recall_at_R()
                              for name, retrieval in retrieval_cosine.items()}
print("Processed n' 2")

recall_scores_mahalanobis = {name: retrieval.recall_at_R()
                              for name, retrieval in retrieval_mahalanobis.
 ↪items()}
print("Processed n' 3")
print("Recall@R scores evaluated successfully!")
```

```
Processed n' 1
Processed n' 2
Processed n' 3
Recall@R scores evaluated successfully!
```

[20]:

```
silhouette_scores_euclidean = {name: retrieval.plot_silhouette_per_class()
                              for name, retrieval in retrieval_euclidean.
 ↪items()}
print("Processed n' 1")

silhouette_scores_cosine = {name: retrieval.plot_silhouette_per_class()
                              for name, retrieval in retrieval_cosine.items()}
print("Processed n' 2")

silhouette_scores_mahalanobis = {name: retrieval.plot_silhouette_per_class()
                              for name, retrieval in retrieval_mahalanobis.
 ↪items()}
print("Processed n' 3")
print("Silhouette scores evaluated successfully!")
```

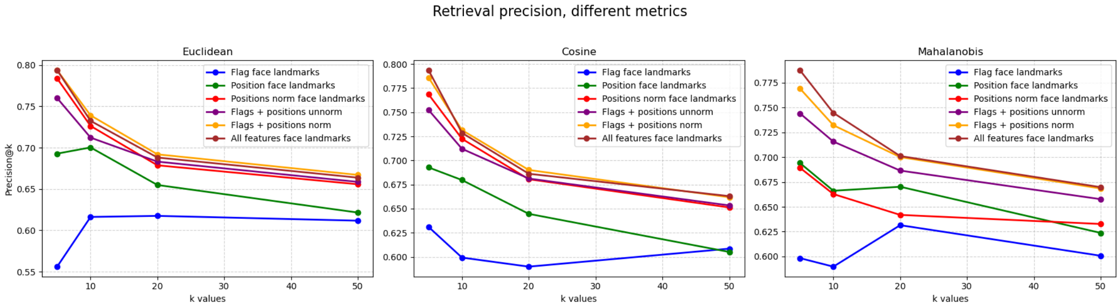
```
Processed n' 1
Processed n' 2
Processed n' 3
Silhouette scores evaluated successfully!
```

Compare embeddings according to precision, recall, silhouette scores and UMAP distriution

Precision scores

[21]:

```
import matplotlib.pyplot as plt
figsize = (18, 5)

fig, axes = plt.subplots(1, 3, figsize=figsize, sharey=False)

metrics = ["Euclidean", "Cosine", "Mahalanobis"]
all_scores = [precision_scores_euclidean, precision_scores_cosine,␣
 ↪precision_scores_mahalanobis]
colors = ["blue", "green", "red", "purple", "orange", "brown"]

for ax, metric, scores in zip(axes, metrics, all_scores):
    for score, label, color in zip(scores.values(), scores.keys(), colors):
        ax.plot(k_values, score, marker="o", color=color, linewidth=2,␣
 ↪label=label)
    ax.set_title(metric)
    ax.set_xlabel("k values")
    ax.grid(True, linestyle="--", alpha=0.6)
    if ax == axes[0]:
        ax.set_ylabel("Precision@k")
    ax.legend()

plt.suptitle("Retrieval precision, different metrics", fontsize=16)
plt.tight_layout(rect=[0, 0, 1, 0.95])
plt.show()
```

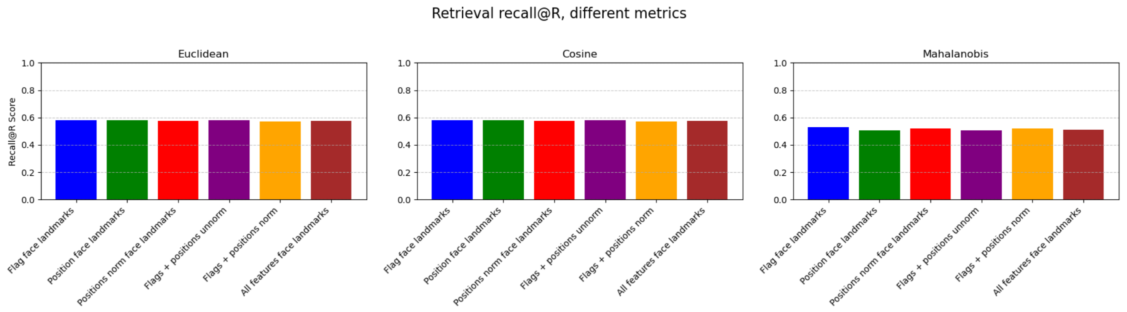


Recall@R scores

[22]:

```
figsize = (18, 5)
fig, axes = plt.subplots(1, 3, figsize=figsize, sharey=False)

metrics = ["Euclidean", "Cosine", "Mahalanobis"]
all_scores = [recall_scores_euclidean, recall_scores_cosine,␣
 ↪recall_scores_mahalanobis]
colors = ["blue", "green", "red", "purple", "orange", "brown"]

for ax, metric, scores in zip(axes, metrics, all_scores):
    ax.bar(scores.keys(), scores.values(), color=colors[:len(scores)])
    ax.set_title(metric)
    ax.set_ylabel("Recall@R Score" if ax == axes[0] else "")
    ax.set_xticklabels(scores.keys(), rotation=45, ha="right")
    ax.set_ylim(0, 1)
    ax.grid(axis='y', linestyle='--', alpha=0.7)

plt.suptitle("Retrieval recall@R, different metrics", fontsize=16)
plt.tight_layout(rect=[0, 0, 1, 0.95])
plt.show()
```

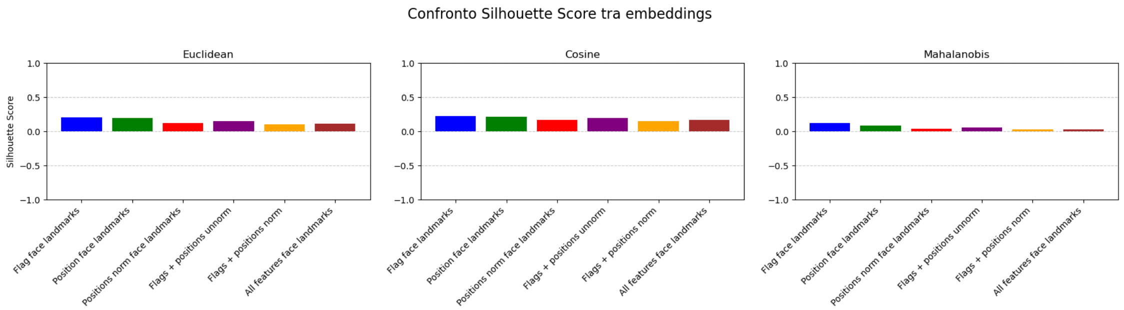
```
/tmp/ipykernel_19559/21631909.py:12: UserWarning: set_ticklabels() should only
be used with a fixed number of ticks, i.e. after set_ticks() or using a
FixedLocator.
  ax.set_xticklabels(scores.keys(), rotation=45, ha="right")
/tmp/ipykernel_19559/21631909.py:12: UserWarning: set_ticklabels() should only
be used with a fixed number of ticks, i.e. after set_ticks() or using a
FixedLocator.
  ax.set_xticklabels(scores.keys(), rotation=45, ha="right")
/tmp/ipykernel_19559/21631909.py:12: UserWarning: set_ticklabels() should only
be used with a fixed number of ticks, i.e. after set_ticks() or using a
FixedLocator.
  ax.set_xticklabels(scores.keys(), rotation=45, ha="right")
```



Silhouette scores

```
[23]: figsize = (18, 5)
fig, axes = plt.subplots(1, 3, figsize=figsize, sharey=False)

metrics = ["Euclidean", "Cosine", "Mahalanobis"]
all_scores = [silhouette_scores_euclidean, silhouette_scores_cosine,␣
  ↪silhouette_scores_mahalanobis]
colors = ["blue", "green", "red", "purple", "orange", "brown"]

for ax, metric, scores in zip(axes, metrics, all_scores):
    ax.bar(scores.keys(), scores.values(), color=colors[:len(scores)])
    ax.set_title(metric)
    ax.set_ylabel("Silhouette Score" if ax == axes[0] else "")
    ax.set_xticklabels(scores.keys(), rotation=45, ha="right")
    ax.set_ylim(-1, 1)  # Silhouette score range
    ax.grid(axis='y', linestyle='--', alpha=0.7)

plt.suptitle("Confronto Silhouette Score tra embeddings", fontsize=16)
plt.tight_layout(rect=[0, 0, 1, 0.95])
plt.show()
```

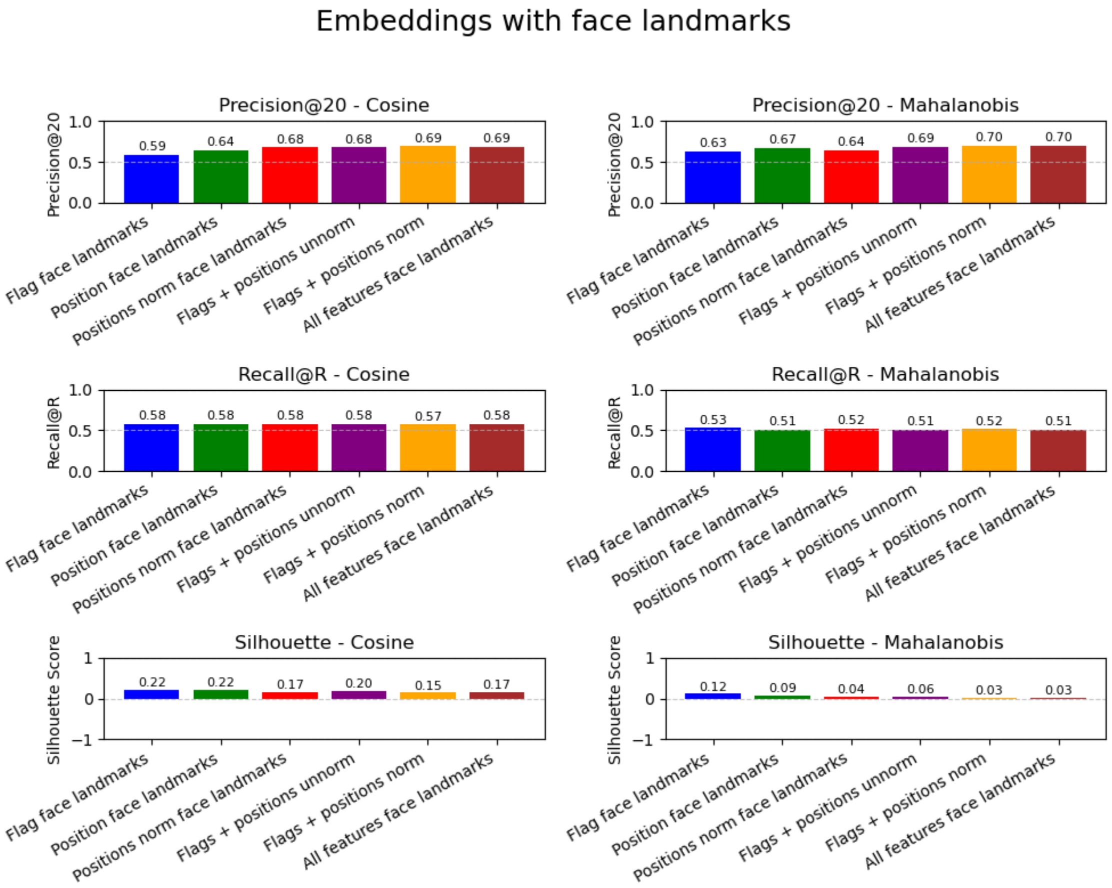
```
/tmp/ipykernel_19559/1504056166.py:12: UserWarning: set_ticklabels() should only
be used with a fixed number of ticks, i.e. after set_ticks() or using a
FixedLocator.
  ax.set_xticklabels(scores.keys(), rotation=45, ha="right")
/tmp/ipykernel_19559/1504056166.py:12: UserWarning: set_ticklabels() should only
be used with a fixed number of ticks, i.e. after set_ticks() or using a
FixedLocator.
  ax.set_xticklabels(scores.keys(), rotation=45, ha="right")
/tmp/ipykernel_19559/1504056166.py:12: UserWarning: set_ticklabels() should only
be used with a fixed number of ticks, i.e. after set_ticks() or using a
FixedLocator.
  ax.set_xticklabels(scores.keys(), rotation=45, ha="right")
```



Recap with all scores

[24]:
```
figsize = (10,8)
fig, axes = plt.subplots(3, 2, figsize=figsize, sharey=False)

colors = ["blue", "green", "red", "purple", "orange", "brown"]

# --- Prima riga: Precision@20 ---
metrics_prec = ["Cosine", "Mahalanobis"]
scores_prec = [
    [val[2] for val in precision_scores_cosine.values()],
    [val[2] for val in precision_scores_mahalanobis.values()]
]
```

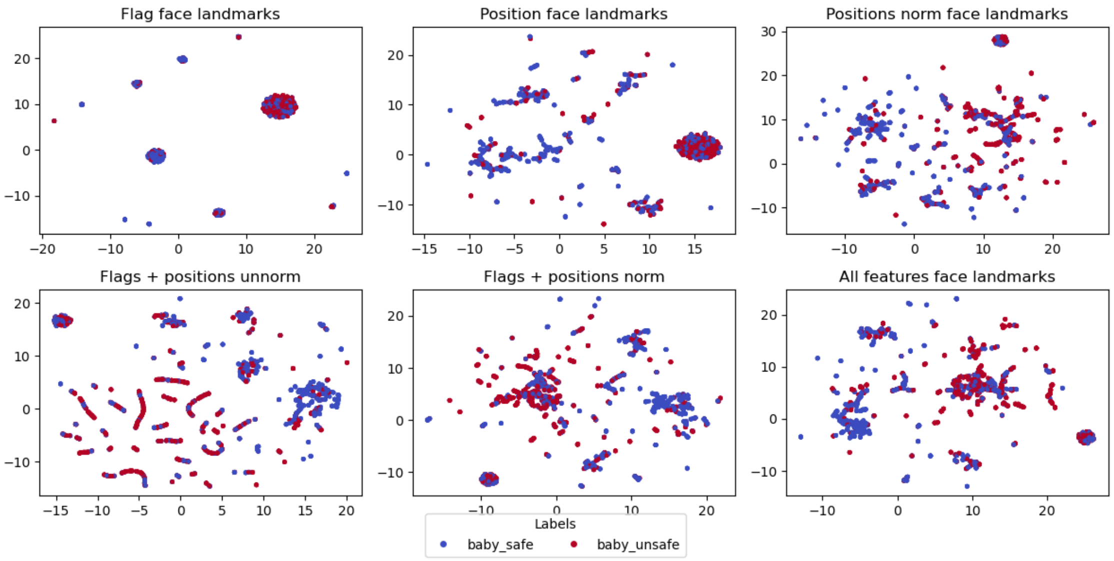
```
embeddings_labels = list(precision_scores_cosine.keys())

for ax, metric, scores in zip(axes[0, :2], metrics_prec, scores_prec):
    bars = ax.bar(embeddings_labels, scores, color=colors[:
 ↪len(embeddings_labels)])
    ax.set_title(f"Precision@20 - {metric}")
    ax.set_ylabel("Precision@20")
    ax.set_ylim(0, 1)
    ax.set_xticks(range(len(embeddings_labels)))
    ax.set_xticklabels(embeddings_labels, rotation=30, ha="right")
    ax.grid(axis='y', linestyle='--', alpha=0.7)
    # etichette sopra le barre
    for bar in bars:
        h = bar.get_height()
        ax.text(bar.get_x() + bar.get_width()/2., h + 0.02,
                f"{h:.2f}", ha='center', va='bottom', fontsize=8)

# --- Seconda riga: Recall@R ---
metrics_rec = ["Cosine", "Mahalanobis"]
scores_rec = [recall_scores_cosine, recall_scores_mahalanobis]

for ax, metric, scores in zip(axes[1, :2], metrics_rec, scores_rec):
    bars = ax.bar(scores.keys(), scores.values(), color=colors[:len(scores)])
    ax.set_title(f"Recall@R - {metric}")
    ax.set_ylabel("Recall@R")
    ax.set_ylim(0, 1)
    ax.set_xticks(range(len(scores)))
    ax.set_xticklabels(scores.keys(), rotation=30, ha="right")
    ax.grid(axis='y', linestyle='--', alpha=0.7)
    # etichette sopra le barre
    for bar in bars:
        h = bar.get_height()
        ax.text(bar.get_x() + bar.get_width()/2., h + 0.02,
                f"{h:.2f}", ha='center', va='bottom', fontsize=8)

# --- Terza riga: Silhouette ---
metrics_sil = ["Cosine", "Mahalanobis"]
scores_sil = [ silhouette_scores_cosine, silhouette_scores_mahalanobis]

# Come hai 3 metriche ma solo 2 colonne, puoi fare solo le prime due colonne o␣
 ↪cambiare a 3x2
for ax, metric, scores in zip(axes[2, :], metrics_sil[:2], scores_sil[:2]):
    bars = ax.bar(scores.keys(), scores.values(), color=colors[:len(scores)])
    ax.set_title(f"Silhouette - {metric}")
    ax.set_ylabel("Silhouette Score")
    ax.set_ylim(-1, 1)
    ax.set_xticks(range(len(scores)))
    ax.set_xticklabels(scores.keys(), rotation=30, ha="right")
    ax.grid(axis='y', linestyle='--', alpha=0.7)
    # etichette sopra le barre
    for bar in bars:
        h = bar.get_height()
        ax.text(bar.get_x() + bar.get_width()/2., h + 0.02,
                f"{h:.2f}", ha='center', va='bottom', fontsize=8)

plt.suptitle("Embeddings with face landmarks", fontsize=18)
plt.tight_layout(rect=[0, 0, 1, 0.95])
plt.show()
```



UMAP embeddings distribution

[25]:
```
import matplotlib.pyplot as plt
import umap
from matplotlib.lines import Line2D
import math
```

```
retrieval_items = list(retrieval_cosine.items())
n = len(retrieval_items)
cols = 3  # massimo 3 grafici per riga
rows = math.ceil(n / cols)

fig, axes = plt.subplots(rows, cols, figsize=(4*cols, 3*rows), sharey=False)
axes = axes.reshape(rows, cols) if n > 1 else [[axes]]

# Creo la legenda una sola volta (dal primo embedding)
cmap = plt.colormaps["coolwarm"].resampled(2)
first_ret = retrieval_items[0][1]
legend_elements = [
    Line2D([0], [0], marker='o', color='w', markerfacecolor=cmap(idx),
           markersize=6, label=lbl)
    for lbl, idx in first_ret.classes_bs.items()
]

for i, (name, ret) in enumerate(retrieval_items):
    r = i // cols
    c = i % cols
    ax = axes[r, c]

    # UMAP projection
    reducer = umap.UMAP(n_components=2, random_state=42)
    proj = reducer.fit_transform(ret.embeddings_norm)

    # Scatter sul subplot
    ax.scatter(proj[:, 0], proj[:, 1], c=ret.labels, s=6, cmap=cmap)
    ax.set_title(name)

for j in range(n, rows*cols):
    r = j // cols
    c = j % cols
    fig.delaxes(axes[r, c])

fig.legend(handles=legend_elements, title="Labels", loc="lower center", ncol=len(legend_elements))
plt.tight_layout(rect=[0, 0.05, 1, 1])
plt.show()
```



Compare embeddings according to visual image similarity

[26]:

```
image_paths = emb_builder.image_paths
idx_query = 98
image_to_retrieve = f"{image_dataset_path}/{image_paths[idx_query]}"
print(image_to_retrieve)
print("Image to retrieve")
img = mpimg.imread(image_to_retrieve)
plt.figure(figsize=(3, 3))
plt.imshow(img)
plt.axis('off')
plt.show()

for name, retrieval in retrieval_euclidean.items():
    print(f"{name}".ljust(100, "-"))
    distances_all, image_paths_similar_all = retrieval.retrieve_similar(idx_query=idx_query,k=5,verbose=False)
    retrieval.show_images(image_paths_similar_all)
```

```
/home/terra/Desktop/unimore/AI_engineering/SIDS_revelation_project/datasets/onback_onstomach_v3/8183A0BE-C370-4CDD-8252-6B699E31D570_JPG_jpg.rf.955e09e07223486cb7f30911544ba793.jpg
Image to retrieve
```

```
Flag face landmarks-------------------------------------------------------------
--------------------
```

```
Position face landmarks---------------------------------------------------------
--------------------
```

```
Positions norm face
landmarks-----------------------------------------------------------------------
```

```
Flags + positions unnorm--------------------------------------------------------
--------------------
```

```
Flags + positions norm----------------------------------------------------------
--------------------
```

```
All features face landmarks-----------------------------------------------------
--------------------
```

Classifier training with different embeddings

[27]:
```
embeddings_classifiers = {name : Classifier(emb, emb_builder.y, emb_builder.
 ↪classes_bs) for name, emb in zip(embeddings_names, embeddings)}
```

[28]:
```
clf = XGBClassifier(
            n_estimators=300,
            max_depth=5,
            learning_rate=0.05,
            subsample=0.8,
            colsample_bytree=0.8,
            reg_lambda=1,
            reg_alpha=0.5,
            random_state=None
        )

learning_scores = { name: classifier.plot_learning_curve(clf, verbose = False)␣
 ↪for name, classifier in embeddings_classifiers.items()}
print("Learning scores evaluated successfully!")
```

```
/home/terra/anaconda3/envs/SIDS_project/lib/python3.10/site-
packages/xgboost/core.py:377: FutureWarning: Your system has an old version of
glibc (< 2.28). We will stop supporting Linux distros with glibc older than 2.28
after **May 31, 2025**. Please upgrade to a recent Linux distro (with glibc >=
2.28) to use future versions of XGBoost.
Note: You have installed the 'manylinux2014' variant of XGBoost. Certain
features such as GPU algorithms or federated learning are not available. To use
these features, please upgrade to a recent Linux distro with glibc 2.28+, and
install the 'manylinux_2_28' variant.
  warnings.warn(
/home/terra/anaconda3/envs/SIDS_project/lib/python3.10/site-
packages/xgboost/core.py:377: FutureWarning: Your system has an old version of
glibc (< 2.28). We will stop supporting Linux distros with glibc older than 2.28
after **May 31, 2025**. Please upgrade to a recent Linux distro (with glibc >=
2.28) to use future versions of XGBoost.
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install the 'manylinux_2_28' variant.
  warnings.warn(
/home/terra/anaconda3/envs/SIDS_project/lib/python3.10/site-
packages/xgboost/core.py:377: FutureWarning: Your system has an old version of
glibc (< 2.28). We will stop supporting Linux distros with glibc older than 2.28
after **May 31, 2025**. Please upgrade to a recent Linux distro (with glibc >=
2.28) to use future versions of XGBoost.
Note: You have installed the 'manylinux2014' variant of XGBoost. Certain
```

```
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these features, please upgrade to a recent Linux distro with glibc 2.28+, and
install the 'manylinux_2_28' variant.
  warnings.warn(
/home/terra/anaconda3/envs/SIDS_project/lib/python3.10/site-
packages/xgboost/core.py:377: FutureWarning: Your system has an old version of
glibc (< 2.28). We will stop supporting Linux distros with glibc older than 2.28
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2.28) to use future versions of XGBoost.
Note: You have installed the 'manylinux2014' variant of XGBoost. Certain
features such as GPU algorithms or federated learning are not available. To use
these features, please upgrade to a recent Linux distro with glibc 2.28+, and
install the 'manylinux_2_28' variant.
  warnings.warn(
/home/terra/anaconda3/envs/SIDS_project/lib/python3.10/site-
packages/xgboost/core.py:377: FutureWarning: Your system has an old version of
glibc (< 2.28). We will stop supporting Linux distros with glibc older than 2.28
after **May 31, 2025**. Please upgrade to a recent Linux distro (with glibc >=
2.28) to use future versions of XGBoost.
Note: You have installed the 'manylinux2014' variant of XGBoost. Certain
features such as GPU algorithms or federated learning are not available. To use
these features, please upgrade to a recent Linux distro with glibc 2.28+, and
install the 'manylinux_2_28' variant.
  warnings.warn(
/home/terra/anaconda3/envs/SIDS_project/lib/python3.10/site-
packages/xgboost/core.py:377: FutureWarning: Your system has an old version of
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/home/terra/anaconda3/envs/SIDS_project/lib/python3.10/site-
packages/xgboost/core.py:377: FutureWarning: Your system has an old version of
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Note: You have installed the 'manylinux2014' variant of XGBoost. Certain
features such as GPU algorithms or federated learning are not available. To use
these features, please upgrade to a recent Linux distro with glibc 2.28+, and
install the 'manylinux_2_28' variant.
  warnings.warn(
```
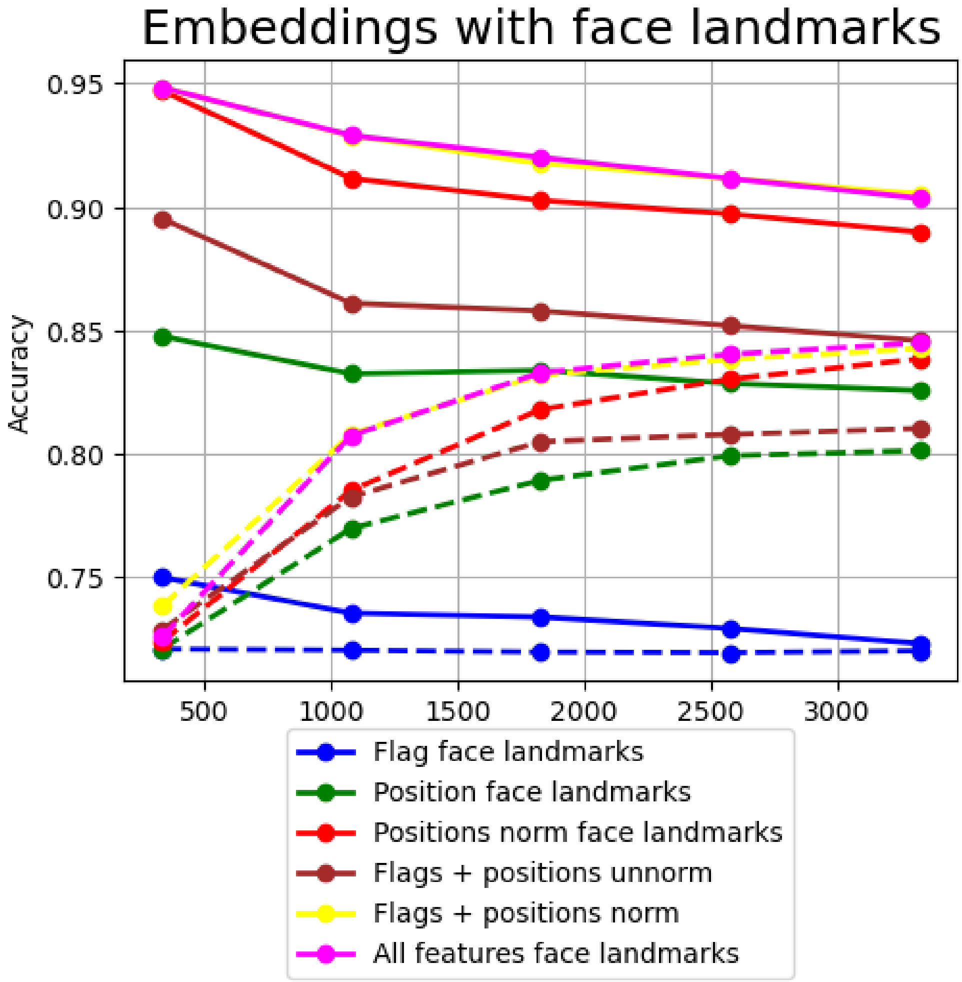

```
Learning scores evaluated successfully!
```

[37]:

```
figsize = (embeddings_classifiers["Flag face landmarks"].figsize[0],␣
 ↪embeddings_classifiers["Flag face landmarks"].figsize[1])
colors = ["blue", "green", "red", "brown", "yellow", "fuchsia"]

plt.figure(figsize=figsize)
for score, label, color in zip(learning_scores.values(), learning_scores.
 ↪keys(), colors):
    plt.plot(score[0], score[3], marker="o", color=color, linewidth=2,␣
 ↪label=label)
    plt.plot(score[0], score[4], marker="o", color=color,␣
 ↪linewidth=2,linestyle="--")
    #plt.plot(score[0][len(score[0])-1], score[4][len(score[4])-1],␣
 ↪marker="x",markersize = 10, color=color)

# Legenda
plt.legend(
    loc="lower center",          # posizione di riferimento
    bbox_to_anchor=(0.5, -0.5),    # sposta la legenda a destra del grafico
    fontsize=10
)
plt.ylabel("Accuracy")
plt.title("Embeddings with face landmarks", fontsize=18)
plt.grid(True)
plt.show()
```



2 Retrieval metrics with different embeddings, with keypoints

- "All features face + pose positions"
- "All features face + pose geometrics"
- "All features face + all features pose"

Load the dataset

[32]:
```
%load_ext autoreload
%autoreload 2

from libraries.embeddings_utils import *
import ipynbname
from libraries.classifier_utils import *
from libraries.retrieval_utils import *
from libraries.file_manager_utils import *
```

```
project_dir = f"{os.getcwd().
 ↪split('SIDS_revelation_project')[0]}SIDS_revelation_project/"
image_dataset_path = f"{project_dir}datasets/onback_onstomach_v3"
model_path_fd = f"{project_dir}/models/4.fd_weights/best.pt"
model_path_pe=f"{project_dir}/models/2.pe_weights/best.pt"
```

```
The autoreload extension is already loaded. To reload it, use:
  %reload_ext autoreload
```

[33]:
```
emb_builder = EmbeddingBuilder(model_path_fd, image_dataset_path, "load",␣
 ↪model_path_pe)
```

```
Extracting dataset info from .coco.json
file:---------------------------------------------
Dataset contains 4158 valid samples, and labels are {'baby_on_back': 1,
'baby_on_stomach': 2}
---------------------------------------------------------------------------------
----------

Loading features from
.csv-----------------------------------------------------------------
Features loaded succesfully, in particular there are 4158 files in the dataset
---------------------------------------------------------------------------------
----------

Embedding builder initialized
successfully-------------------------------------------------
Face detection model: 4 (YOLOv8)
Dataset: /home/terra/Desktop/unimore/AI_engineering/SIDS_revelation_project/data
sets/onback_onstomach_v3
Dataset dimension: 4158
Dataset labels: {'baby_safe': 0, 'baby_unsafe': 1}
---------------------------------------------------------------------------------
----------
```

Create embeddings

[34]:
```
e_all_positions =emb_builder.create_embedding(flags = True, positions =␣
 ↪True,positions_normalized=True, geometric_info=True,␣
 ↪k_positions_normalized=True)

e_all_geometric = emb_builder.create_embedding(flags = True, positions =␣
 ↪True,positions_normalized=True, geometric_info=True, k_geometric_info=True)
```

```
e_all_all = emb_builder.create_embedding(flags = True, positions =␣
 ↪True,positions_normalized=True, geometric_info=True,␣
 ↪k_positions_normalized=True, k_geometric_info=True)
```

```
Embedding
creation------------------------------------------------------------------------
Features: ['flag_eye1', 'flag_eye2', 'flag_nose', 'flag_mouth', 'x_eye1',
'y_eye1', 'x_eye2', 'y_eye2', 'x_nose', 'y_nose', 'x_mouth', 'y_mouth',
'x_eye1_norm', 'y_eye1_norm', 'x_eye2_norm', 'y_eye2_norm', 'x_nose_norm',
'y_nose_norm', 'x_mouth_norm', 'y_mouth_norm', 'eye_distance',
'eye_distance_norm', 'face_vertical_length', 'face_vertical_length_norm',
'face_angle_vertical', 'face_angle_horizontal', 'symmetry_diff', 'head_ration',
'x_nose_k', 'y_nose_k', 'x_left_eye_k', 'y_left_eye_k', 'x_right_eye_k',
'y_right_eye_k', 'x_left_ear', 'y_left_ear', 'x_right_ear', 'y_right_ear',
'x_left_shoulder', 'y_left_shoulder', 'x_right_shoulder', 'y_right_shoulder',
'x_left_elbow', 'y_left_elbow', 'x_right_elbow', 'y_right_elbow',
'x_left_wrist', 'y_left_wrist', 'x_right_wrist', 'y_right_wrist', 'x_left_hip',
'y_left_hip', 'x_right_hip', 'y_right_hip', 'x_left_knee', 'y_left_knee',
'x_right_knee', 'y_right_knee', 'x_left_ankle', 'y_left_ankle', 'x_right_ankle',
'y_right_ankle']
FINISHED: 4158 embedding created
--------------------------------------------------------------------------------
----------

Embedding
creation------------------------------------------------------------------------
Features: ['flag_eye1', 'flag_eye2', 'flag_nose', 'flag_mouth', 'x_eye1',
'y_eye1', 'x_eye2', 'y_eye2', 'x_nose', 'y_nose', 'x_mouth', 'y_mouth',
'x_eye1_norm', 'y_eye1_norm', 'x_eye2_norm', 'y_eye2_norm', 'x_nose_norm',
'y_nose_norm', 'x_mouth_norm', 'y_mouth_norm', 'eye_distance',
'eye_distance_norm', 'face_vertical_length', 'face_vertical_length_norm',
'face_angle_vertical', 'face_angle_horizontal', 'symmetry_diff', 'head_ration',
'shoulders_dist', 'shoulder_hip_right_dist', 'shoulder_hip_left_dist',
'nose_shoulder_right', 'nose_shoulder_left', 'shoulder_left_knee_right',
'shoulder_right_knee_left', 'knee_ankle_right', 'knee_ankle_left',
'nose_hip_right', 'nose_hip_left', 'elbow_shoulder_hip_right',
'elbow_shoulder_hip_left', 'shoulder_elbow_wrist_right',
'shoulder_elbow_wrist_left', 'shoulder_hip_knee_right',
'shoulder_hip_knee_left', 'hip_knee_ankle_right', 'hip_knee_ankle_left',
'shoulders_line_inclination', 'hips_line_inclination', 'torsion']
FINISHED: 4158 embedding created
--------------------------------------------------------------------------------
----------

Embedding
creation------------------------------------------------------------------------
```

```
Features: ['flag_eye1', 'flag_eye2', 'flag_nose', 'flag_mouth', 'x_eye1',
'y_eye1', 'x_eye2', 'y_eye2', 'x_nose', 'y_nose', 'x_mouth', 'y_mouth',
'x_eye1_norm', 'y_eye1_norm', 'x_eye2_norm', 'y_eye2_norm', 'x_nose_norm',
'y_nose_norm', 'x_mouth_norm', 'y_mouth_norm', 'eye_distance',
'eye_distance_norm', 'face_vertical_length', 'face_vertical_length_norm',
'face_angle_vertical', 'face_angle_horizontal', 'symmetry_diff', 'head_ration',
'x_nose_k', 'y_nose_k', 'x_left_eye_k', 'y_left_eye_k', 'x_right_eye_k',
'y_right_eye_k', 'x_left_ear', 'y_left_ear', 'x_right_ear', 'y_right_ear',
'x_left_shoulder', 'y_left_shoulder', 'x_right_shoulder', 'y_right_shoulder',
'x_left_elbow', 'y_left_elbow', 'x_right_elbow', 'y_right_elbow',
'x_left_wrist', 'y_left_wrist', 'x_right_wrist', 'y_right_wrist', 'x_left_hip',
'y_left_hip', 'x_right_hip', 'y_right_hip', 'x_left_knee', 'y_left_knee',
'x_right_knee', 'y_right_knee', 'x_left_ankle', 'y_left_ankle', 'x_right_ankle',
'y_right_ankle', 'shoulders_dist', 'shoulder_hip_right_dist',
'shoulder_hip_left_dist', 'nose_shoulder_right', 'nose_shoulder_left',
'shoulder_left_knee_right', 'shoulder_right_knee_left', 'knee_ankle_right',
'knee_ankle_left', 'nose_hip_right', 'nose_hip_left',
'elbow_shoulder_hip_right', 'elbow_shoulder_hip_left',
'shoulder_elbow_wrist_right', 'shoulder_elbow_wrist_left',
'shoulder_hip_knee_right', 'shoulder_hip_knee_left', 'hip_knee_ankle_right',
'hip_knee_ankle_left', 'shoulders_line_inclination', 'hips_line_inclination',
'torsion']
FINISHED: 4158 embedding created
--------------------------------------------------------------------------------
----------
```

Initialize retrieval objects

[38]:

```python
embeddings = [e_all_positions, e_all_geometric, e_all_all]
embeddings_names = ["All features face + pose positions",  "All features face + pose geometrics", "All features face + all features pose"]

retrieval_euclidean = { name: ImageRetrieval(emb, emb_builder.y, emb_builder.image_paths, image_dataset_path, emb_builder.classes_bs)
                        for name, emb  in zip(embeddings_names, embeddings)}
retrieval_cosine = { name: ImageRetrieval(emb, emb_builder.y, emb_builder.image_paths, image_dataset_path, emb_builder.classes_bs)
                        for name, emb  in zip(embeddings_names, embeddings)}
retrieval_mahalanobis = { name: ImageRetrieval(emb, emb_builder.y, emb_builder.image_paths, image_dataset_path, emb_builder.classes_bs)
                        for name, emb  in zip(embeddings_names, embeddings)}
```

[39]:

```python
for name, retrieval in retrieval_euclidean.items():
    retrieval.build_index(metric="euclidean")

for name, retrieval in retrieval_cosine.items():
    retrieval.build_index(metric="cosine")
```

```
for name, retrieval in retrieval_mahalanobis.items():
    retrieval.build_mahalanobis_index()
```

Evaluate precison, recall@R and silhouette scores

```
[40]: k_values = [5, 10, 20, 50]
      precision_scores_euclidean = {name: retrieval.
        ↪plot_precision_at_k(k_values=k_values, verbose=False)
                                    for name, retrieval in retrieval_euclidean.
        ↪items()}
      print("Processed n' 1")
      precision_scores_cosine = {name: retrieval.
        ↪plot_precision_at_k(k_values=k_values, verbose=False)
                                    for name, retrieval in retrieval_cosine.items()}
      print("Processed n' 2")
      precision_scores_mahalanobis = {name: retrieval.
        ↪plot_precision_at_k(k_values=k_values, verbose=False)
                                    for name, retrieval in retrieval_mahalanobis.
        ↪items()}
      print("Processed n' 3")
      print("Precision scores evaluated successfully!")
```

```
Processed n' 1
Processed n' 2
Processed n' 3
Precision scores evaluated successfully!
```

```
[41]: recall_scores_euclidean = {name: retrieval.recall_at_R()
                                    for name, retrieval in retrieval_euclidean.
        ↪items()}
      print("Processed n' 1")
      recall_scores_cosine = {name: retrieval.recall_at_R()
                                    for name, retrieval in retrieval_cosine.items()}
      print("Processed n' 2")
      recall_scores_mahalanobis = {name: retrieval.recall_at_R()
                                    for name, retrieval in retrieval_mahalanobis.
        ↪items()}
      print("Processed n' 3")
      print("Recall@R scores evaluated successfully!")
```

```
Processed n' 1
Processed n' 2
Processed n' 3
Recall@R scores evaluated successfully!
```

```
[42]: silhouette_scores_euclidean = {name: retrieval.plot_silhouette_per_class()
```

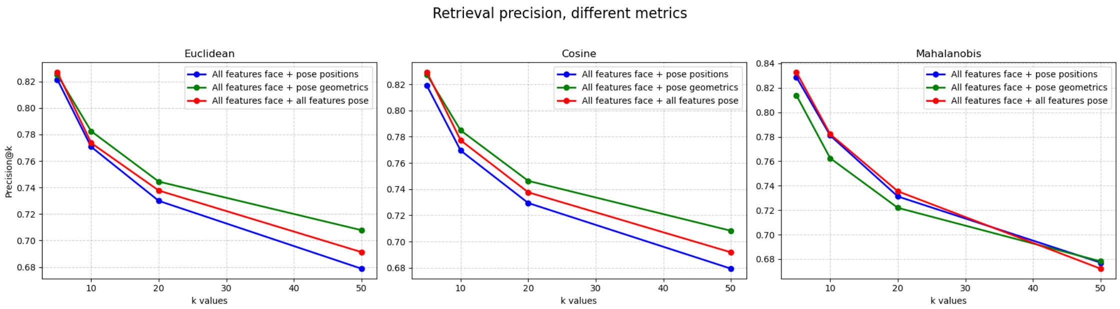
```
                              for name, retrieval in retrieval_euclidean.
 ↪items()}
print("Processed n' 1")
silhouette_scores_cosine = {name: retrieval.plot_silhouette_per_class()
                              for name, retrieval in retrieval_cosine.items()}
print("Processed n' 2")
silhouette_scores_mahalanobis = {name: retrieval.plot_silhouette_per_class()
                              for name, retrieval in retrieval_mahalanobis.
 ↪items()}
print("Processed n' 3")
print("Silhouette scores evaluated successfully!")
```

```
Processed n' 1
Processed n' 2
Processed n' 3
Silhouette scores evaluated successfully!
```

Compare embeddings according to precision, recall, silhouette scores and UMAP distribution

Precision scores

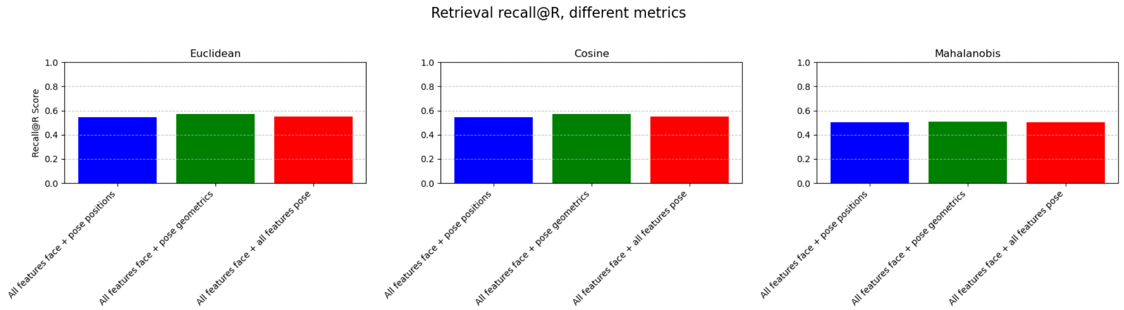
[43]:
```
import matplotlib.pyplot as plt
figsize = (18, 5)

fig, axes = plt.subplots(1, 3, figsize=figsize, sharey=False)

metrics = ["Euclidean", "Cosine", "Mahalanobis"]
all_scores = [precision_scores_euclidean, precision_scores_cosine,␣
 ↪precision_scores_mahalanobis]
colors = ["blue", "green", "red", "purple", "orange", "brown"]

for ax, metric, scores in zip(axes, metrics, all_scores):
    for score, label, color in zip(scores.values(), scores.keys(), colors):
        ax.plot(k_values, score, marker="o", color=color, linewidth=2,␣
 ↪label=label)
    ax.set_title(metric)
    ax.set_xlabel("k values")
    ax.grid(True, linestyle="--", alpha=0.6)
    if ax == axes[0]:
        ax.set_ylabel("Precision@k")
    ax.legend()

plt.suptitle("Retrieval precision, different metrics", fontsize=16)
plt.tight_layout(rect=[0, 0, 1, 0.95])
plt.show()
```



Recall@R scores

```
[44]: figsize = (18, 5)
fig, axes = plt.subplots(1, 3, figsize=figsize, sharey=False)

metrics = ["Euclidean", "Cosine", "Mahalanobis"]
all_scores = [recall_scores_euclidean, recall_scores_cosine,␣
  ↪recall_scores_mahalanobis]
colors = ["blue", "green", "red", "purple", "orange", "brown"]

for ax, metric, scores in zip(axes, metrics, all_scores):
    ax.bar(scores.keys(), scores.values(), color=colors[:len(scores)])
    ax.set_title(metric)
    ax.set_ylabel("Recall@R Score" if ax == axes[0] else "")
    ax.set_xticklabels(scores.keys(), rotation=45, ha="right")
    ax.set_ylim(0, 1)
    ax.grid(axis='y', linestyle='--', alpha=0.7)

plt.suptitle("Retrieval recall@R, different metrics", fontsize=16)
plt.tight_layout(rect=[0, 0, 1, 0.95])
plt.show()
```

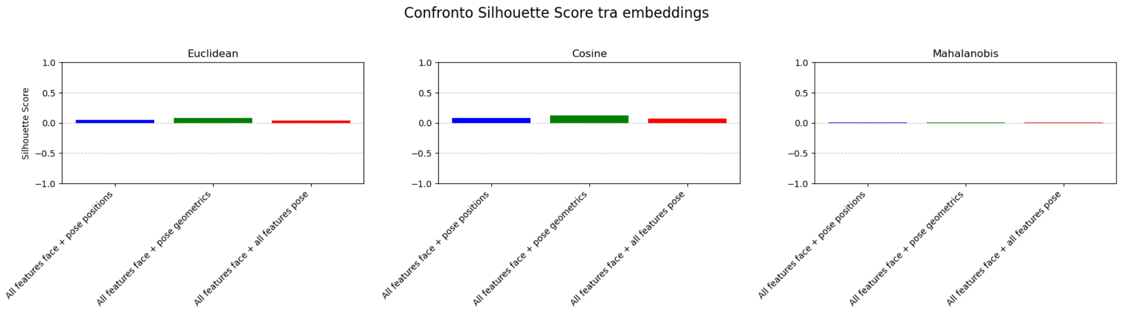
```
/tmp/ipykernel_19559/153923360.py:12: UserWarning: set_ticklabels() should only
be used with a fixed number of ticks, i.e. after set_ticks() or using a
FixedLocator.
  ax.set_xticklabels(scores.keys(), rotation=45, ha="right")
/tmp/ipykernel_19559/153923360.py:12: UserWarning: set_ticklabels() should only
be used with a fixed number of ticks, i.e. after set_ticks() or using a
FixedLocator.
  ax.set_xticklabels(scores.keys(), rotation=45, ha="right")
/tmp/ipykernel_19559/153923360.py:12: UserWarning: set_ticklabels() should only
be used with a fixed number of ticks, i.e. after set_ticks() or using a
FixedLocator.
  ax.set_xticklabels(scores.keys(), rotation=45, ha="right")
```



Silhouette scores

```
[45]: figsize = (18, 5)
fig, axes = plt.subplots(1, 3, figsize=figsize, sharey=False)

metrics = ["Euclidean", "Cosine", "Mahalanobis"]
all_scores = [silhouette_scores_euclidean, silhouette_scores_cosine,␣
 ↪silhouette_scores_mahalanobis]
colors = ["blue", "green", "red", "purple", "orange", "brown"]

for ax, metric, scores in zip(axes, metrics, all_scores):
    ax.bar(scores.keys(), scores.values(), color=colors[:len(scores)])
    ax.set_title(metric)
    ax.set_ylabel("Silhouette Score" if ax == axes[0] else "")
    ax.set_xticklabels(scores.keys(), rotation=45, ha="right")
    ax.set_ylim(-1, 1)  # Silhouette score range
    ax.grid(axis='y', linestyle='--', alpha=0.7)

plt.suptitle("Confronto Silhouette Score tra embeddings", fontsize=16)
plt.tight_layout(rect=[0, 0, 1, 0.95])
plt.show()
```

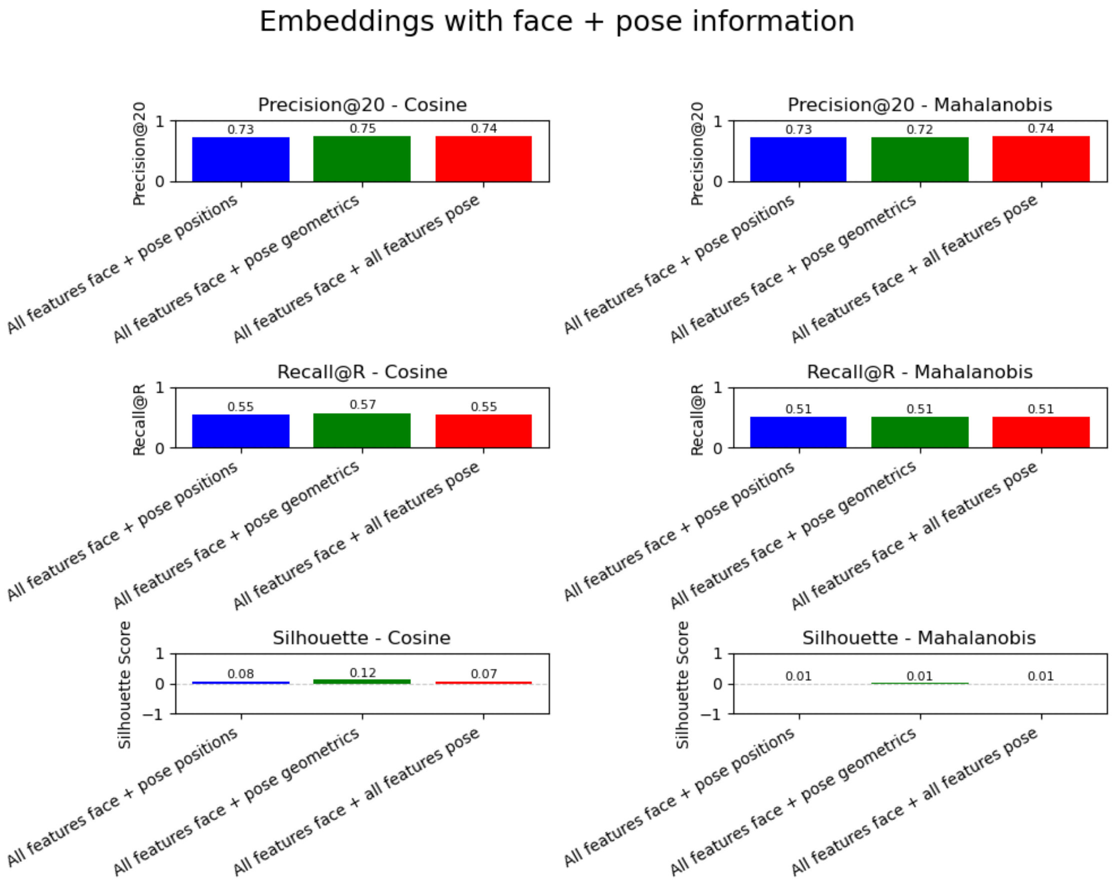
```
/tmp/ipykernel_19559/1504056166.py:12: UserWarning: set_ticklabels() should only
be used with a fixed number of ticks, i.e. after set_ticks() or using a
FixedLocator.
  ax.set_xticklabels(scores.keys(), rotation=45, ha="right")
/tmp/ipykernel_19559/1504056166.py:12: UserWarning: set_ticklabels() should only
be used with a fixed number of ticks, i.e. after set_ticks() or using a
FixedLocator.
  ax.set_xticklabels(scores.keys(), rotation=45, ha="right")
/tmp/ipykernel_19559/1504056166.py:12: UserWarning: set_ticklabels() should only
be used with a fixed number of ticks, i.e. after set_ticks() or using a
FixedLocator.
  ax.set_xticklabels(scores.keys(), rotation=45, ha="right")
```



Recap with all scores

```
[46]: import matplotlib.pyplot as plt

figsize = (10,8)
fig, axes = plt.subplots(3, 2, figsize=figsize, sharey=False)

colors = ["blue", "green", "red", "purple", "orange", "brown"]

# --- Prima riga: Precision@20 ---
metrics_prec = ["Cosine", "Mahalanobis"]
scores_prec = [
    [val[2] for val in precision_scores_cosine.values()],
    [val[2] for val in precision_scores_mahalanobis.values()]
]
embeddings_labels = list(precision_scores_cosine.keys())

for ax, metric, scores in zip(axes[0, :2], metrics_prec, scores_prec):
    bars = ax.bar(embeddings_labels, scores, color=colors[:
 ↪len(embeddings_labels)])
    ax.set_title(f"Precision@20 - {metric}")
    ax.set_ylabel("Precision@20")
    ax.set_ylim(0, 1)
    ax.set_xticks(range(len(embeddings_labels)))
    ax.set_xticklabels(embeddings_labels, rotation=30, ha="right")
    ax.grid(axis='y', linestyle='--', alpha=0.7)
    # etichette sopra le barre
    for bar in bars:
        h = bar.get_height()
        ax.text(bar.get_x() + bar.get_width()/2., h + 0.02,
                f"{h:.2f}", ha='center', va='bottom', fontsize=8)

# --- Seconda riga: Recall@R ---
metrics_rec = ["Cosine", "Mahalanobis"]
scores_rec = [recall_scores_cosine, recall_scores_mahalanobis]
```

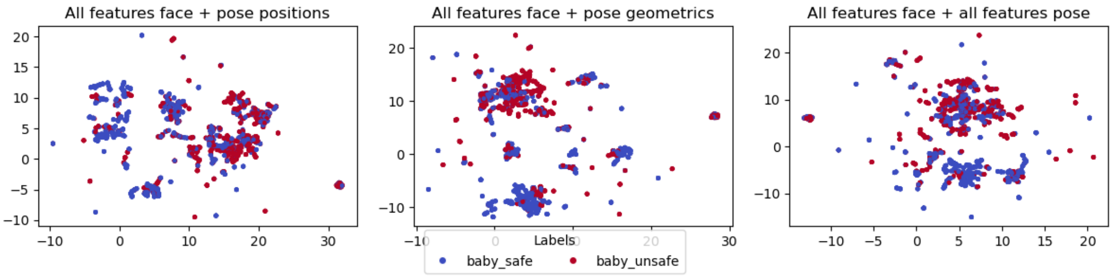
```python
for ax, metric, scores in zip(axes[1, :2], metrics_rec, scores_rec):
    bars = ax.bar(scores.keys(), scores.values(), color=colors[:len(scores)])
    ax.set_title(f"Recall@R - {metric}")
    ax.set_ylabel("Recall@R")
    ax.set_ylim(0, 1)
    ax.set_xticks(range(len(scores)))
    ax.set_xticklabels(scores.keys(), rotation=30, ha="right")
    ax.grid(axis='y', linestyle='--', alpha=0.7)
    # etichette sopra le barre
    for bar in bars:
        h = bar.get_height()
        ax.text(bar.get_x() + bar.get_width()/2., h + 0.02,
                f"{h:.2f}", ha='center', va='bottom', fontsize=8)

# --- Terza riga: Silhouette ---
metrics_sil = ["Cosine", "Mahalanobis"]
scores_sil = [ silhouette_scores_cosine, silhouette_scores_mahalanobis]

# Come hai 3 metriche ma solo 2 colonne, puoi fare solo le prime due colonne o cambiare a 3x2
for ax, metric, scores in zip(axes[2, :], metrics_sil[:2], scores_sil[:2]):
    bars = ax.bar(scores.keys(), scores.values(), color=colors[:len(scores)])
    ax.set_title(f"Silhouette - {metric}")
    ax.set_ylabel("Silhouette Score")
    ax.set_ylim(-1, 1)
    ax.set_xticks(range(len(scores)))
    ax.set_xticklabels(scores.keys(), rotation=30, ha="right")
    ax.grid(axis='y', linestyle='--', alpha=0.7)
    # etichette sopra le barre
    for bar in bars:
        h = bar.get_height()
        ax.text(bar.get_x() + bar.get_width()/2., h + 0.02,
                f"{h:.2f}", ha='center', va='bottom', fontsize=8)

plt.suptitle("Embeddings with face + pose information", fontsize=18)
plt.tight_layout(rect=[0, 0, 1, 0.95])
plt.show()
```



UMAP distribution

[47]:

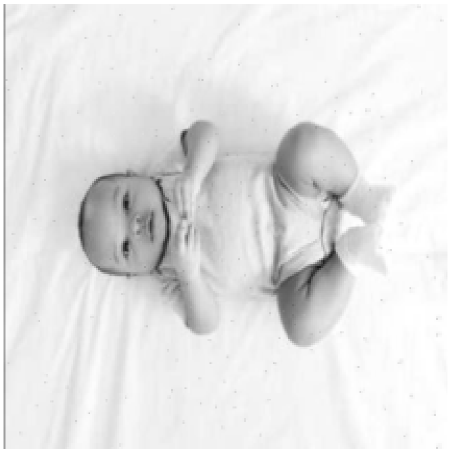
```
import matplotlib.pyplot as plt
import umap
from matplotlib.lines import Line2D
import math

retrieval_items = list(retrieval_cosine.items())
n = len(retrieval_items)
cols = 3  # massimo 3 grafici per riga
rows = math.ceil(n / cols)

fig, axes = plt.subplots(rows, cols, figsize=(4*cols, 3*rows), sharey=False)
axes = axes.reshape(rows, cols) if n > 1 else [[axes]]

# Creo la legenda una sola volta (dal primo embedding)
cmap = plt.colormaps["coolwarm"].resampled(2)
first_ret = retrieval_items[0][1]
legend_elements = [
    Line2D([0], [0], marker='o', color='w', markerfacecolor=cmap(idx),
           markersize=6, label=lbl)
    for lbl, idx in first_ret.classes_bs.items()
]

for i, (name, ret) in enumerate(retrieval_items):
    r = i // cols
    c = i % cols
    ax = axes[r, c]

    # UMAP projection
    reducer = umap.UMAP(n_components=2, random_state=42)
    proj = reducer.fit_transform(ret.embeddings_norm)

    # Scatter sul subplot
    ax.scatter(proj[:, 0], proj[:, 1], c=ret.labels, s=6, cmap=cmap)
    ax.set_title(name)

for j in range(n, rows*cols):
    r = j // cols
    c = j % cols
    fig.delaxes(axes[r, c])

fig.legend(handles=legend_elements, title="Labels", loc="lower center", ncol=len(legend_elements))
plt.tight_layout(rect=[0, 0.05, 1, 1])
plt.show()
```



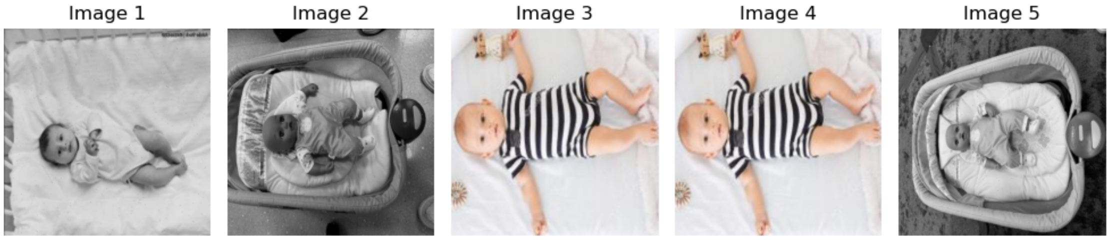
Compare embeddings according to visual image similarity

[57]:
```
image_paths = emb_builder.image_paths
idx_query = 125
image_to_retrieve = f"{image_dataset_path}/{image_paths[idx_query]}"

print("Image to retrieve")
img = mpimg.imread(image_to_retrieve)
plt.figure(figsize=(3, 3))
plt.imshow(img)
plt.axis('off')
plt.show()

for name, retrieval in retrieval_euclidean.items():
    print(f"{name}".ljust(100, "-"))
    distances_all, image_paths_similar_all = retrieval.
 ↪retrieve_similar(idx_query=idx_query,k=5,verbose=False)
    retrieval.show_images(image_paths_similar_all)
```

```
Image to retrieve
```



```
All features face + pose
positions------------------------------------------------------------------
```



```
All features face + pose
geometrics-----------------------------------------------------------------
```

Image 1

Image 2

Image 3

Image 4

Image 5

```
All features face + all features
pose---------------------------------------------------------------
```

Image 1

Image 2

Image 3

Image 4

Image 5

Classifier training with different embeddings

```
[62]: embeddings_classifiers = {name : Classifier(emb, emb_builder.y, emb_builder.classes_bs) for name, emb in zip(embeddings_names, embeddings)}
```

```
[ ]: emb
```

```
[ ]: clf = XGBClassifier(
                 n_estimators=300,
                 max_depth=5,
                 learning_rate=0.05,
                 subsample=0.8,
                 colsample_bytree=0.8,
                 reg_lambda=1,
                 reg_alpha=0.5,
                 random_state=None
             )

     learning_scores = { name: classifier.plot_learning_curve(clf, verbose = False) for name, classifier in embeddings_classifiers.items()}
     print("Learning scores evaluated successfully!")
```

```
[61]:
```

```
figsize = (embeddings_classifiers["All features face + pose positions"].
 ↪figsize[0]*1.5, embeddings_classifiers["All features face + pose positions"].
 ↪figsize[1]*1.5)
colors = ["blue", "green", "red", "brown", "yellow", "fuchsia"]


plt.figure(figsize=figsize)
for score, label, color in zip(learning_scores.values(), learning_scores.
 ↪keys(), colors):
    plt.plot(score[0], score[3], marker="o", color=color, linewidth=2,␣
 ↪label=label)
    plt.plot(score[0], score[4], marker="o", color=color,␣
 ↪linewidth=2,linestyle="--")
    #plt.plot(score[0][len(score[0])-1], score[4][len(score[4])-1],␣
 ↪marker="x",markersize = 10, color=color)

# Legenda
plt.legend(
    loc="lower center",          # posizione di riferimento
    bbox_to_anchor=(0.5, -0.3),    # sposta la legenda a destra del grafico
    fontsize=10
)
plt.ylabel("Accuracy")
plt.title("Embeddings with face + pose information", fontsize=18)
plt.grid(True)
plt.show()
```

```
---------------------------------------------------------------------------
KeyError                                  Traceback (most recent call last)
Cell In[61], line 1
----> 1 figsize = (embeddings_classifiers["All features face + pose positions"]
 ↪figsize[0]*1.5, embeddings_classifiers["All features face + pose positions"].
 ↪figsize[1]*1.5)
      2 colors = ["blue", "green", "red", "brown", "yellow", "fuchsia"]
      5 plt.figure(figsize=figsize)

KeyError: 'All features face + pose positions'
```

[ ]:
```
save_as_pdf(ipynbname.path())
```