

# breast\_cancer\_spatial

May 8, 2025

## 1 Spatial Analysis of Breast Cancer Microenvironment

In this exercise, you will analyze spatial transcriptomics data from breast cancer tissue to identify tumor microenvironment components, visualize tumor heterogeneity, and detect interaction patterns between tumor and immune cells.

```
[138]: import matplotlib.pyplot as plt
import seaborn as sns
import numpy as np
import scanpy as sc
import squidpy as sq
import tensorflow as tf
from sklearn.model_selection import train_test_split
from tensorflow.keras.layers import Dense, Dropout
from tensorflow.keras.models import Sequential
from tensorflow.keras.optimizers import Adam
from tensorflow.keras.utils import to_categorical
```

```
# Load the breast cancer dataset
adata_bc = sq.datasets.visium_fluo_adata()
```

```
[ ]: # Basic data exploration
print(f"Dataset shape: {adata_bc.shape}")
print(f"Available annotations: {list(adata_bc.obs.columns)}")

# Preprocess data
sc.pp.normalize_total(adata_bc, target_sum=1e4)
sc.pp.log1p(adata_bc)
sc.pp.highly_variable_genes(adata_bc, n_top_genes=2000)
adata_bc_hvg = adata_bc[:, adata_bc.var.highly_variable]
sc.pp.scale(adata_bc_hvg)

# View tissue structure
plt.figure(figsize=(12, 10))
sc.pl.spatial(adata_bc, img_key="hires", size=1.5)
```

Dataset shape: (2800, 16562)  
Available annotations: ['in\_tissue', 'array\_row', 'array\_col',

```

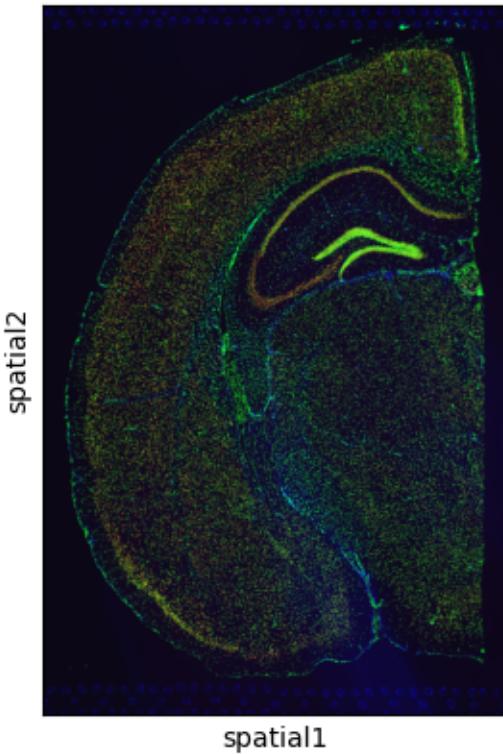
'n_genes_by_counts', 'log1p_n_genes_by_counts', 'total_counts',
'log1p_total_counts', 'pct_counts_in_top_50_genes',
'pct_counts_in_top_100_genes', 'pct_counts_in_top_200_genes',
'pct_counts_in_top_500_genes', 'total_counts_MT', 'log1p_total_counts_MT',
'pct_counts_MT', 'n_counts', 'leiden', 'cluster']
WARNING: adata.X seems to be already log-transformed.

/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/scanpy/preprocessing/_scale.py:317: UserWarning: Received a view of an
AnnData. Making a copy.

    view_to_actual(adata)
/var/folders/8j/_nnvcqj93gvgk18wygygd9tw0000gn/T/ipykernel_26778/3748696719.py:1
4: FutureWarning: Use `squidpy.pl.spatial_scatter` instead.
    sc.pl.spatial(adata_bc, img_key="hires", size=1.5)

<Figure size 1200x1000 with 0 Axes>

```



```

[ ]: # Prepare data for neural network
X_bc = adata_bc_hvg.X.copy()

# For simplicity, we'll use unsupervised approach with autoencoder
# Define a simple autoencoder
input_dim = X_bc.shape[1]

```

```

encoding_dim = 64

# Encoder
input_layer = tf.keras.layers.Input(shape=(input_dim,))
encoder = tf.keras.layers.Dense(256, activation="relu")(input_layer)
encoder = tf.keras.layers.Dropout(0.2)(encoder)
encoder = tf.keras.layers.Dense(encoding_dim, activation="relu")(encoder)

# Decoder
decoder = tf.keras.layers.Dense(256, activation="relu")(encoder)
decoder = tf.keras.layers.Dropout(0.2)(decoder)
output_layer = tf.keras.layers.Dense(input_dim, activation="sigmoid")(decoder)

# Autoencoder model
autoencoder = tf.keras.models.Model(inputs=input_layer, outputs=output_layer)
autoencoder.compile(optimizer="adam", loss="mse")

# Train autoencoder
autoencoder.fit(
    X_bc, X_bc, epochs=20, batch_size=64, shuffle=True, validation_split=0.2
)

# Create a model to extract the encoded features
encoder_model = tf.keras.models.Model(inputs=input_layer, outputs=encoder)
encoded_features = encoder_model.predict(X_bc)

```

Epoch 1/20  
 35/35 0s 6ms/step - loss:  
 1.1134 - val\_loss: 0.9834  
 Epoch 2/20  
 35/35 0s 4ms/step - loss:  
 0.9880 - val\_loss: 0.9780  
 Epoch 3/20  
 35/35 0s 4ms/step - loss:  
 0.9931 - val\_loss: 0.9732  
 Epoch 4/20  
 35/35 0s 4ms/step - loss:  
 1.0061 - val\_loss: 0.9710  
 Epoch 5/20  
 35/35 0s 5ms/step - loss:  
 0.9722 - val\_loss: 0.9689  
 Epoch 6/20  
 35/35 0s 4ms/step - loss:  
 0.9774 - val\_loss: 0.9682  
 Epoch 7/20  
 35/35 0s 5ms/step - loss:  
 0.9716 - val\_loss: 0.9672  
 Epoch 8/20

```

35/35          0s 5ms/step - loss:
0.9777 - val_loss: 0.9658
Epoch 9/20
35/35          0s 4ms/step - loss:
0.9665 - val_loss: 0.9646
Epoch 10/20
35/35          0s 4ms/step - loss:
0.9700 - val_loss: 0.9639
Epoch 11/20
35/35          0s 5ms/step - loss:
0.9551 - val_loss: 0.9632
Epoch 12/20
35/35          0s 5ms/step - loss:
0.9557 - val_loss: 0.9624
Epoch 13/20
35/35          0s 5ms/step - loss:
0.9517 - val_loss: 0.9614
Epoch 14/20
35/35          0s 5ms/step - loss:
0.9491 - val_loss: 0.9609
Epoch 15/20
35/35          0s 5ms/step - loss:
0.9507 - val_loss: 0.9618
Epoch 16/20
35/35          0s 5ms/step - loss:
0.9455 - val_loss: 0.9608
Epoch 17/20
35/35          0s 5ms/step - loss:
0.9409 - val_loss: 0.9607
Epoch 18/20
35/35          0s 5ms/step - loss:
0.9358 - val_loss: 0.9598
Epoch 19/20
35/35          0s 5ms/step - loss:
0.9389 - val_loss: 0.9604
Epoch 20/20
35/35          0s 5ms/step - loss:
0.9259 - val_loss: 0.9604
88/88          0s 535us/step
88/88          0s 502us/step

```

```

[ ]: # Get the first and second hidden layers outputs as well
intermediate_layer_model = tf.keras.models.Model(
    inputs=input_layer,
    outputs=[autoencoder.layers[1].output, autoencoder.layers[3].output],
)
first_layer_output, second_layer_output = intermediate_layer_model.predict(X_bc)

```

88/88 0s 471us/step

```
[ ]: from sklearn.decomposition import PCA
from sklearn.manifold import TSNE
from umap import UMAP
from trimap import TRIMAP

raw_tsne = TSNE(n_components=2, random_state=42)
raw_tsne_embedding = raw_tsne.fit_transform(adata_bc_hvg.X.copy())
raw_umap = UMAP(n_components=2, random_state=42)
raw_umap_embedding = raw_umap.fit_transform(adata_bc_hvg.X.copy())
raw_trimap = TRIMAP(n_dims=2)
raw_trimap_embedding = raw_trimap.fit_transform(adata_bc_hvg.X.copy())
```

```
[ ]: methods = {"t-SNE": TSNE, "UMAP": UMAP, "TRIMAP": TRIMAP}
data = {
    "raw_data": adata_bc_hvg.X.copy(),
    "First Layer Output": first_layer_output,
    "Second Layer Output": second_layer_output,
}
results = {}

for method in methods:
    results[method] = []
    for dataset in data:
        if method != "TRIMAP":
            results[method].append(
                methods[method](n_components=2, random_state=42).fit_transform(
                    data[dataset]
                )
            )
        else:
            results[method].append(
                methods[method](n_dims=2).fit_transform(data[dataset])
            )
```

```
/Users/nicolas/studia/I_sem/wdxd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:337: RuntimeWarning: divide by zero
encountered in matmul
    Q, _ = normalizer(A @ Q)
/Users/nicolas/studia/I_sem/wdxd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:337: RuntimeWarning: overflow encountered in
matmul
    Q, _ = normalizer(A @ Q)
/Users/nicolas/studia/I_sem/wdxd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:337: RuntimeWarning: invalid value encountered
in matmul
    Q, _ = normalizer(A @ Q)
```

```

/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:338: RuntimeWarning: divide by zero
encountered in matmul
    Q, _ = normalizer(A.T @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:338: RuntimeWarning: overflow encountered in
matmul
    Q, _ = normalizer(A.T @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:338: RuntimeWarning: invalid value encountered
in matmul
    Q, _ = normalizer(A.T @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:342: RuntimeWarning: divide by zero
encountered in matmul
    Q, _ = qr_normalizer(A @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:342: RuntimeWarning: overflow encountered in
matmul
    Q, _ = qr_normalizer(A @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:342: RuntimeWarning: invalid value encountered
in matmul
    Q, _ = qr_normalizer(A @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:529: RuntimeWarning: divide by zero
encountered in matmul
    B = Q.T @ M
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:529: RuntimeWarning: overflow encountered in
matmul
    B = Q.T @ M
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:529: RuntimeWarning: invalid value encountered
in matmul
    B = Q.T @ M
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:543: RuntimeWarning: divide by zero
encountered in matmul
    U = Q @ Uhat
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:543: RuntimeWarning: overflow encountered in
matmul
    U = Q @ Uhat
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:543: RuntimeWarning: invalid value encountered
in matmul
    U = Q @ Uhat

```

```

/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:337: RuntimeWarning: divide by zero
encountered in matmul
    Q, _ = normalizer(A @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:337: RuntimeWarning: overflow encountered in
matmul
    Q, _ = normalizer(A @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:337: RuntimeWarning: invalid value encountered
in matmul
    Q, _ = normalizer(A @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:338: RuntimeWarning: divide by zero
encountered in matmul
    Q, _ = normalizer(A.T @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:338: RuntimeWarning: overflow encountered in
matmul
    Q, _ = normalizer(A.T @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:338: RuntimeWarning: invalid value encountered
in matmul
    Q, _ = normalizer(A.T @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:342: RuntimeWarning: divide by zero
encountered in matmul
    Q, _ = qr_normalizer(A @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:342: RuntimeWarning: overflow encountered in
matmul
    Q, _ = qr_normalizer(A @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:342: RuntimeWarning: invalid value encountered
in matmul
    Q, _ = qr_normalizer(A @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:529: RuntimeWarning: divide by zero
encountered in matmul
    B = Q.T @ M
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:529: RuntimeWarning: overflow encountered in
matmul
    B = Q.T @ M
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:529: RuntimeWarning: invalid value encountered
in matmul
    B = Q.T @ M

```

```

/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:543: RuntimeWarning: divide by zero
encountered in matmul
    U = Q @ Uhat
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:543: RuntimeWarning: overflow encountered in
matmul
    U = Q @ Uhat
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:543: RuntimeWarning: invalid value encountered
in matmul
    U = Q @ Uhat
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:337: RuntimeWarning: divide by zero
encountered in matmul
    Q, _ = normalizer(A @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:337: RuntimeWarning: overflow encountered in
matmul
    Q, _ = normalizer(A @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:337: RuntimeWarning: invalid value encountered
in matmul
    Q, _ = normalizer(A @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:338: RuntimeWarning: divide by zero
encountered in matmul
    Q, _ = normalizer(A.T @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:338: RuntimeWarning: overflow encountered in
matmul
    Q, _ = normalizer(A.T @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:338: RuntimeWarning: invalid value encountered
in matmul
    Q, _ = normalizer(A.T @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:342: RuntimeWarning: divide by zero
encountered in matmul
    Q, _ = qr_normalizer(A @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:342: RuntimeWarning: overflow encountered in
matmul
    Q, _ = qr_normalizer(A @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:342: RuntimeWarning: invalid value encountered
in matmul
    Q, _ = qr_normalizer(A @ Q)

```

```

/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:529: RuntimeWarning: divide by zero
encountered in matmul
    B = Q.T @ M
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:529: RuntimeWarning: overflow encountered in
matmul
    B = Q.T @ M
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:529: RuntimeWarning: invalid value encountered
in matmul
    B = Q.T @ M
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:543: RuntimeWarning: divide by zero
encountered in matmul
    U = Q @ Uhat
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:543: RuntimeWarning: overflow encountered in
matmul
    U = Q @ Uhat
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:543: RuntimeWarning: invalid value encountered
in matmul
    U = Q @ Uhat
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/umap/umap_.py:1952: UserWarning: n_jobs value 1 overridden to 1 by
setting random_state. Use no seed for parallelism.
    warn(
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/umap/umap_.py:1952: UserWarning: n_jobs value 1 overridden to 1 by
setting random_state. Use no seed for parallelism.
    warn(
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/umap/umap_.py:1952: UserWarning: n_jobs value 1 overridden to 1 by
setting random_state. Use no seed for parallelism.
    warn(
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:337: RuntimeWarning: divide by zero
encountered in matmul
    Q, _ = normalizer(A @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:337: RuntimeWarning: overflow encountered in
matmul
    Q, _ = normalizer(A @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:337: RuntimeWarning: invalid value encountered
in matmul
    Q, _ = normalizer(A @ Q)

```

```

/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:338: RuntimeWarning: divide by zero
encountered in matmul
    Q, _ = normalizer(A.T @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:338: RuntimeWarning: overflow encountered in
matmul
    Q, _ = normalizer(A.T @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:338: RuntimeWarning: invalid value encountered
in matmul
    Q, _ = normalizer(A.T @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:342: RuntimeWarning: divide by zero
encountered in matmul
    Q, _ = qr_normalizer(A @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:342: RuntimeWarning: overflow encountered in
matmul
    Q, _ = qr_normalizer(A @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:342: RuntimeWarning: invalid value encountered
in matmul
    Q, _ = qr_normalizer(A @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:529: RuntimeWarning: divide by zero
encountered in matmul
    B = Q.T @ M
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:529: RuntimeWarning: overflow encountered in
matmul
    B = Q.T @ M
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:529: RuntimeWarning: invalid value encountered
in matmul
    B = Q.T @ M
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:543: RuntimeWarning: divide by zero
encountered in matmul
    U = Q @ Uhat
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:543: RuntimeWarning: overflow encountered in
matmul
    U = Q @ Uhat
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:543: RuntimeWarning: invalid value encountered
in matmul
    U = Q @ Uhat

```

```

/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:205: RuntimeWarning: divide by zero
encountered in matmul
    ret = a @ b
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:205: RuntimeWarning: overflow encountered in
matmul
    ret = a @ b
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:205: RuntimeWarning: invalid value encountered
in matmul
    ret = a @ b
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:337: RuntimeWarning: divide by zero
encountered in matmul
    Q, _ = normalizer(A @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:337: RuntimeWarning: overflow encountered in
matmul
    Q, _ = normalizer(A @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:337: RuntimeWarning: invalid value encountered
in matmul
    Q, _ = normalizer(A @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:338: RuntimeWarning: divide by zero
encountered in matmul
    Q, _ = normalizer(A.T @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:338: RuntimeWarning: overflow encountered in
matmul
    Q, _ = normalizer(A.T @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:338: RuntimeWarning: invalid value encountered
in matmul
    Q, _ = normalizer(A.T @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:342: RuntimeWarning: divide by zero
encountered in matmul
    Q, _ = qr_normalizer(A @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:342: RuntimeWarning: overflow encountered in
matmul
    Q, _ = qr_normalizer(A @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:342: RuntimeWarning: invalid value encountered
in matmul
    Q, _ = qr_normalizer(A @ Q)

```

```

/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:529: RuntimeWarning: divide by zero
encountered in matmul
    B = Q.T @ M
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:529: RuntimeWarning: overflow encountered in
matmul
    B = Q.T @ M
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:529: RuntimeWarning: invalid value encountered
in matmul
    B = Q.T @ M
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:543: RuntimeWarning: divide by zero
encountered in matmul
    U = Q @ Uhat
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:543: RuntimeWarning: overflow encountered in
matmul
    U = Q @ Uhat
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:543: RuntimeWarning: invalid value encountered
in matmul
    U = Q @ Uhat
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:205: RuntimeWarning: divide by zero
encountered in matmul
    ret = a @ b
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:205: RuntimeWarning: overflow encountered in
matmul
    ret = a @ b
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:205: RuntimeWarning: invalid value encountered
in matmul
    ret = a @ b
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/decomposition/_pca.py:611: RuntimeWarning: divide by zero
encountered in matmul
    C = X.T @ X
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/decomposition/_pca.py:611: RuntimeWarning: overflow encountered
in matmul
    C = X.T @ X
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/decomposition/_pca.py:611: RuntimeWarning: invalid value
encountered in matmul
    C = X.T @ X

```

```

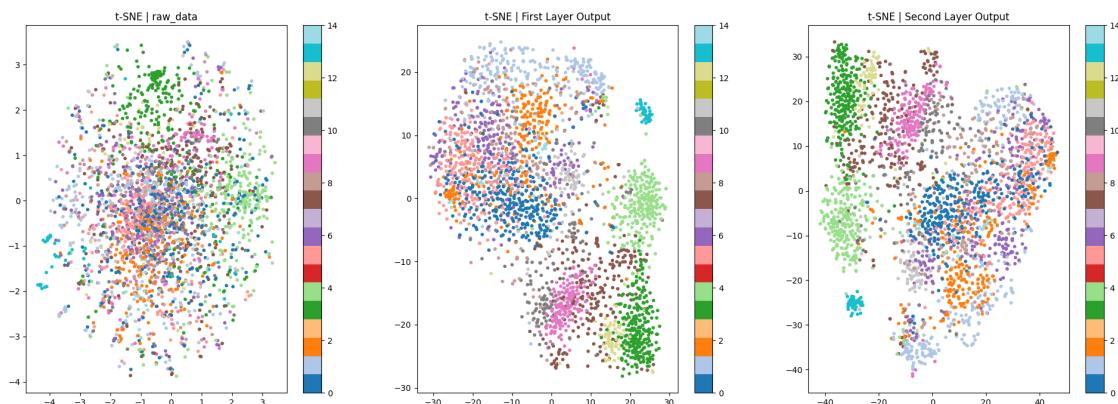
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/decomposition/_base.py:149: RuntimeWarning: divide by zero
encountered in matmul
    X_transformed = X @ self.components_.T
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/decomposition/_base.py:149: RuntimeWarning: overflow
encountered in matmul
    X_transformed = X @ self.components_.T
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/decomposition/_base.py:149: RuntimeWarning: invalid value
encountered in matmul
    X_transformed = X @ self.components_.T

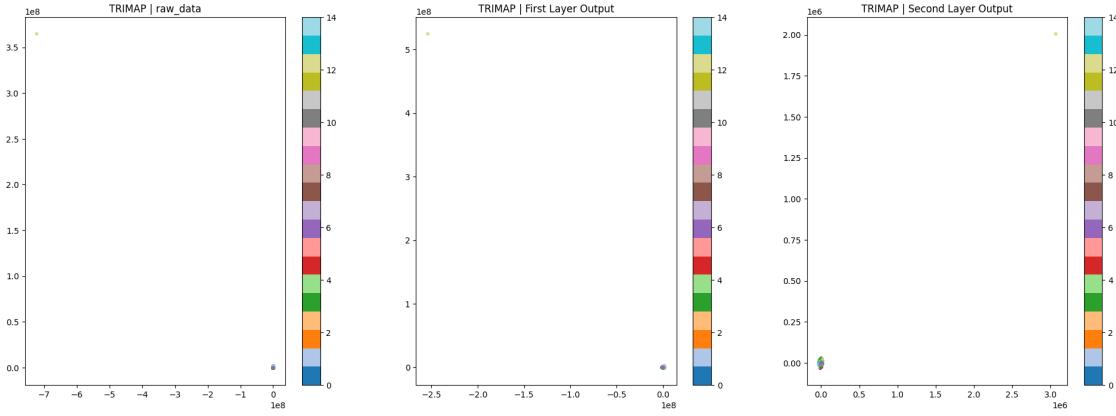
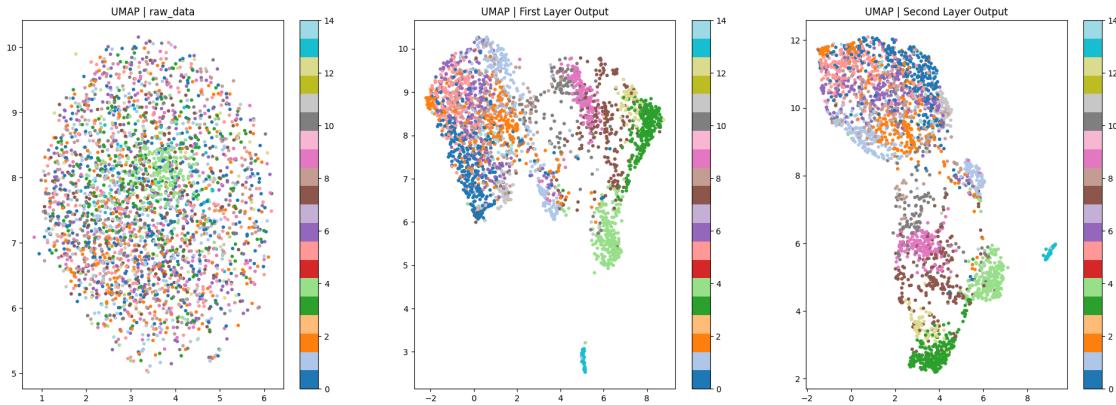
```

```

[ ]: for method in methods.keys():
    plt.figure(figsize=(24, 8))
    for idx, result in enumerate(results[method]):
        plt.subplot(1, 3, idx + 1)
        plt.scatter(
            result[:, 0],
            result[:, 1],
            c=adata_bc_hvg.obs["leiden"].astype(int),
            cmap="tab20",
            s=10,
        )
        plt.colorbar()
    plt.title(f"{method} | {list(data.keys())[idx]}")
plt.show()

```



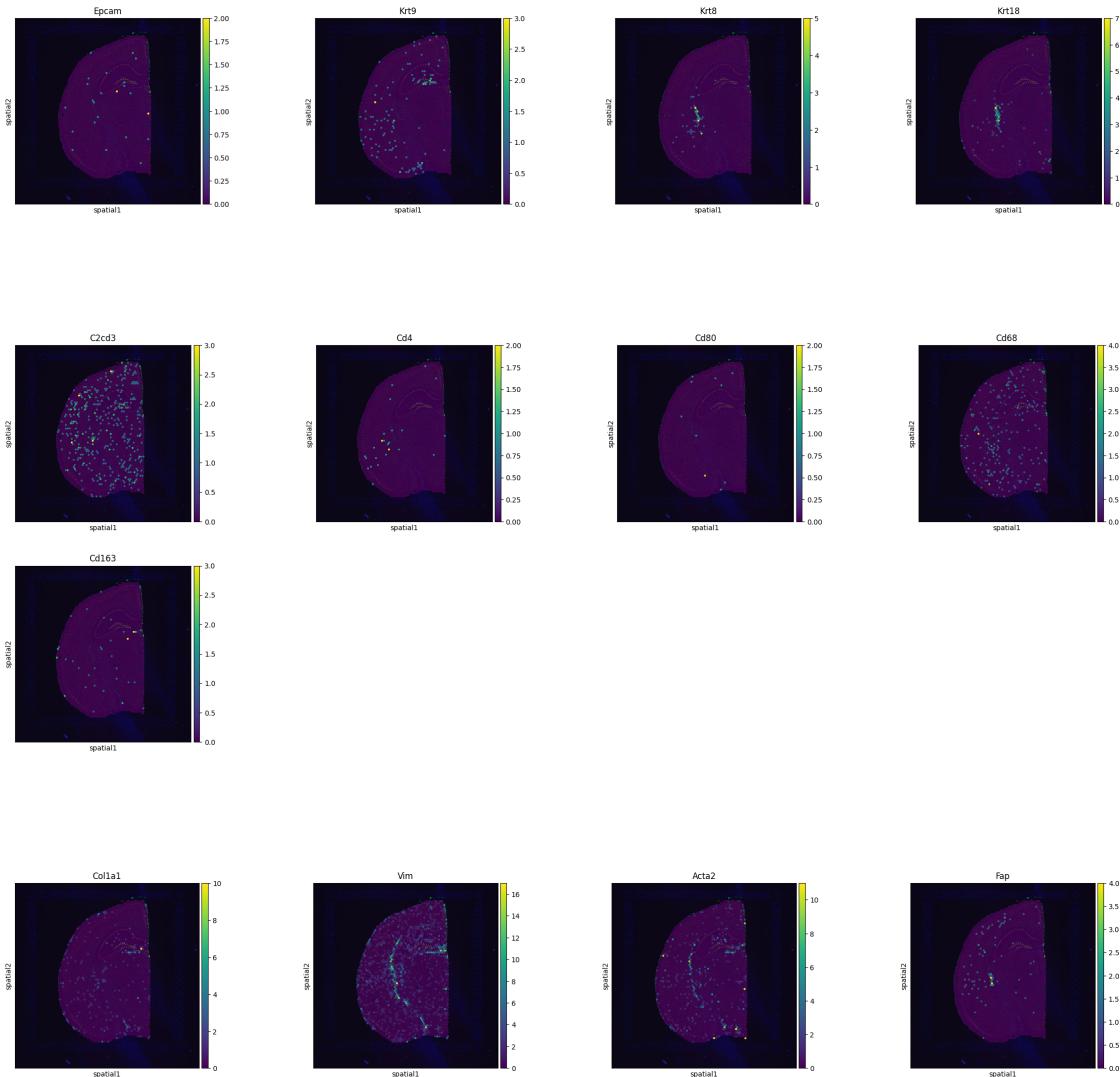


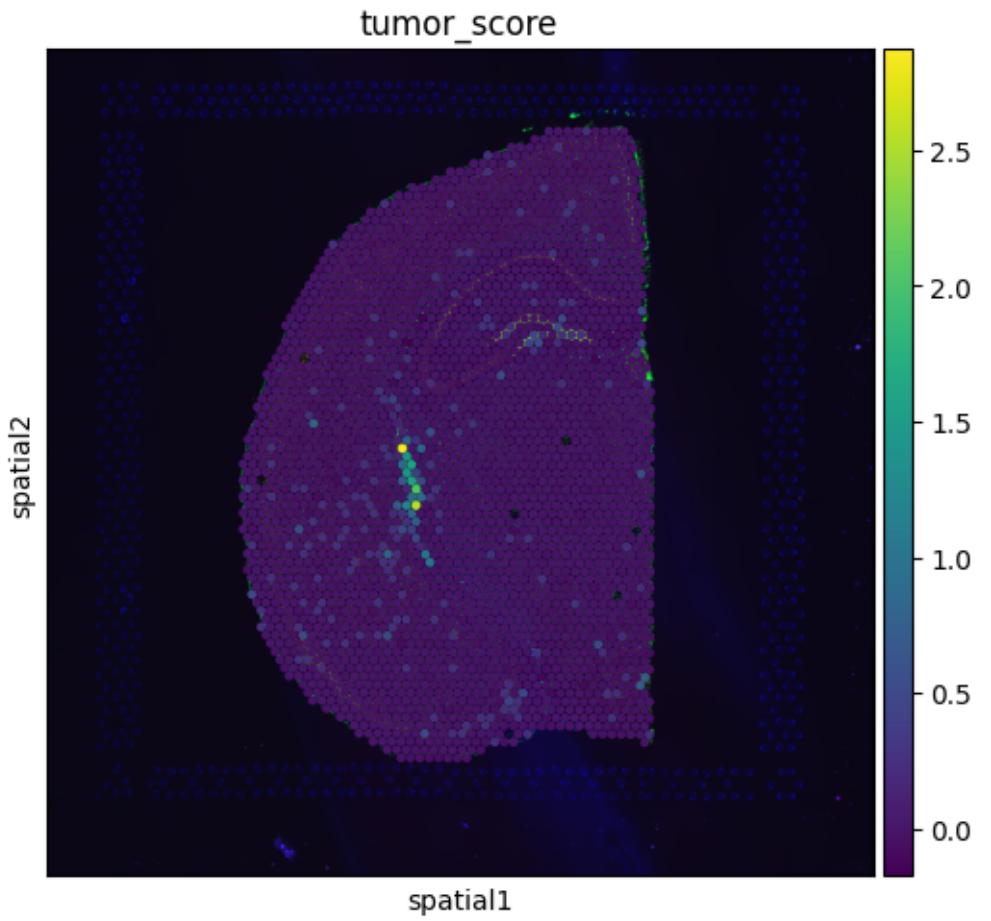
```
[ ]: # Define marker genes for different cell types
tumor_markers = ["Epcam", "Krt9", "Krt8", "Krt18"]
immune_markers = ["C2cd3", "Cd4", "Cd80", "Cd68", "Cd163"]
stromal_markers = ["Col1a1", "Vim", "Acta2", "Fap"]

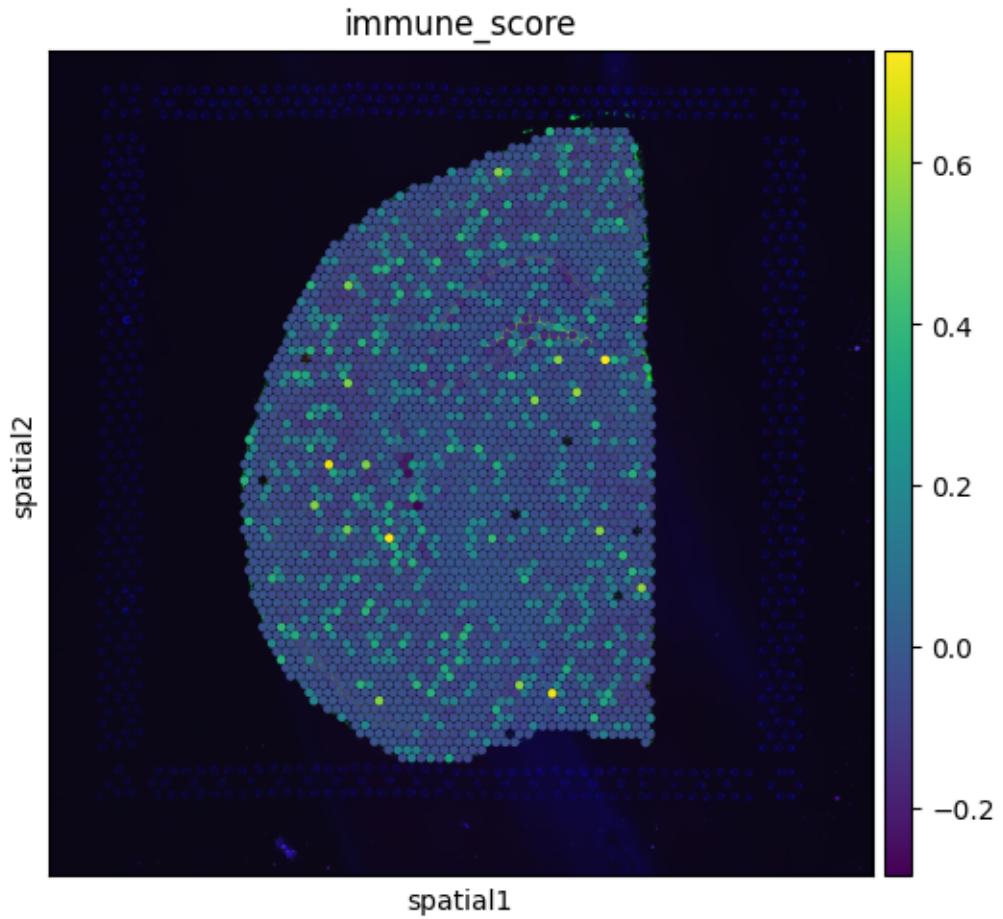
# Calculate scores for each cell type
sc.tl.score_genes(adata_bc, tumor_markers, score_name="tumor_score")
sc.tl.score_genes(adata_bc, immune_markers, score_name="immune_score")
sc.tl.score_genes(adata_bc, stromal_markers, score_name="stromal_score")

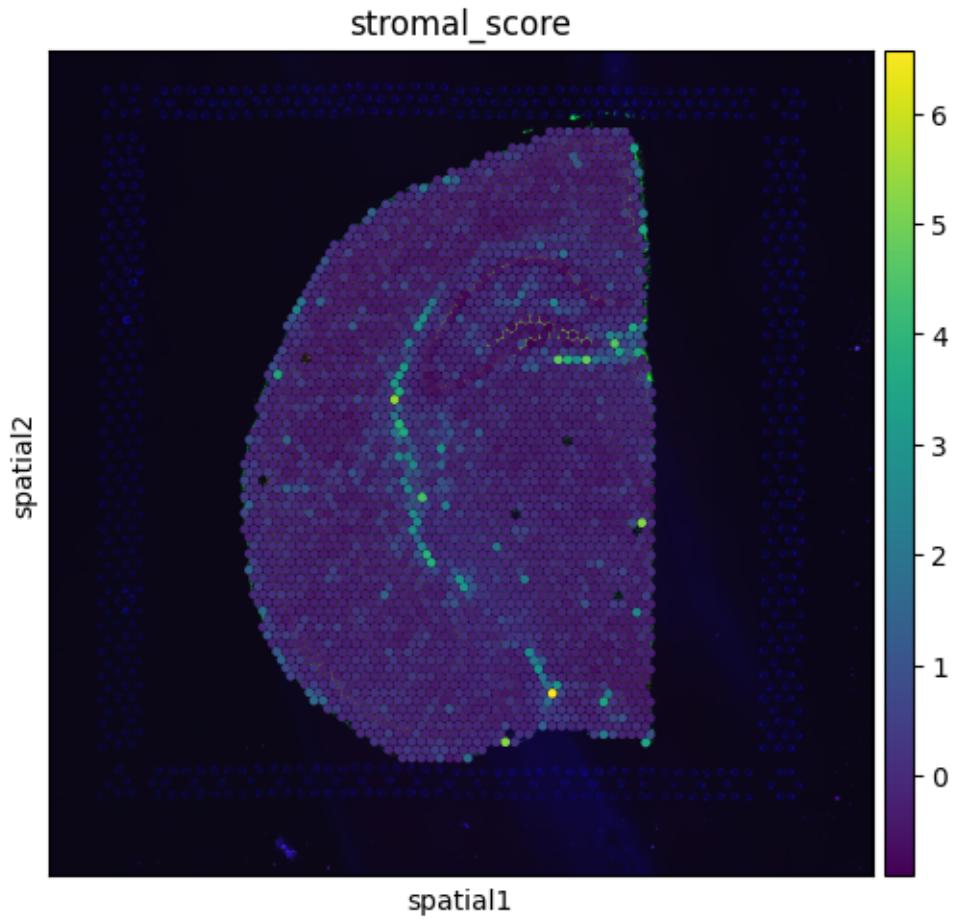
# Visualize marker gene expression and scores
for idx, marker in enumerate([tumor_markers, immune_markers, stromal_markers]):
    sq.pl.spatial_scatter(adata_bc, color=marker, size=1.5)

# Visualize cell type scores
sq.pl.spatial_scatter(adata_bc, color="tumor_score", size=1.5)
sq.pl.spatial_scatter(adata_bc, color="immune_score", size=1.5)
sq.pl.spatial_scatter(adata_bc, color="stromal_score", size=1.5)
```



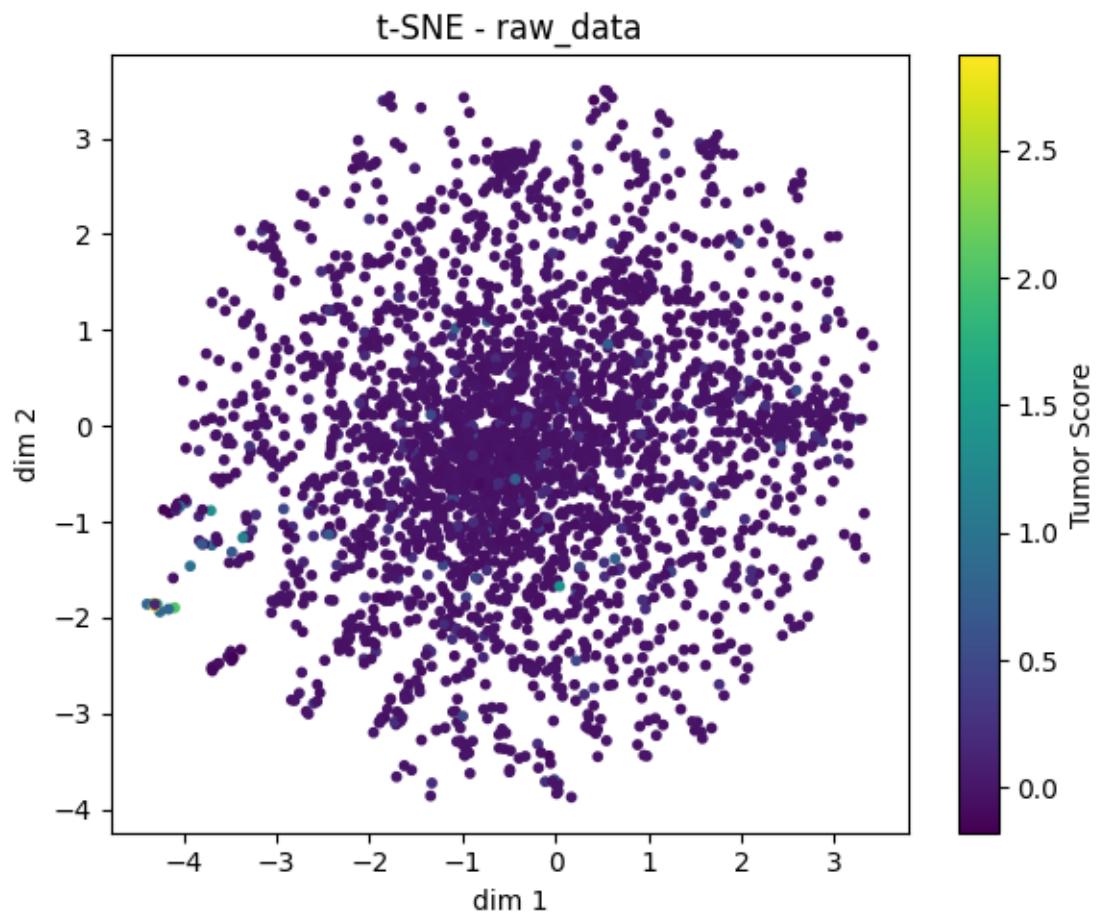


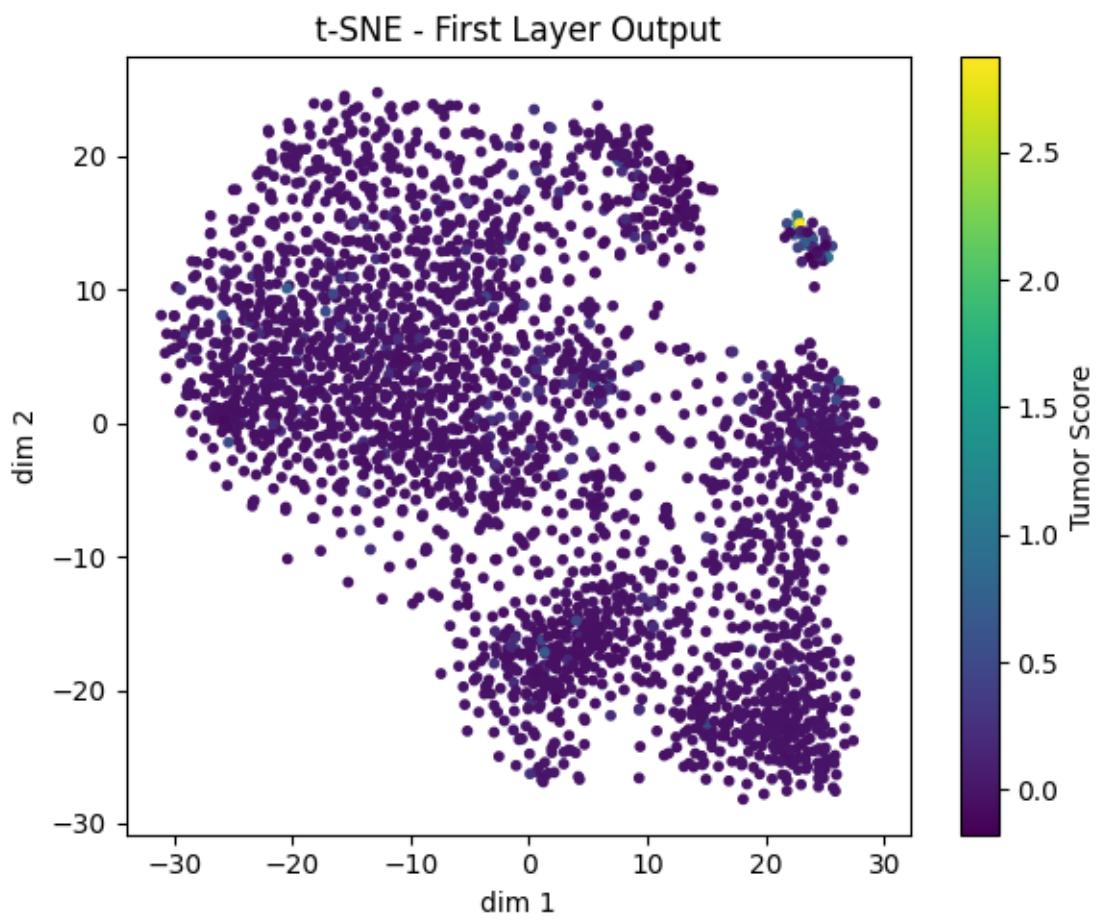


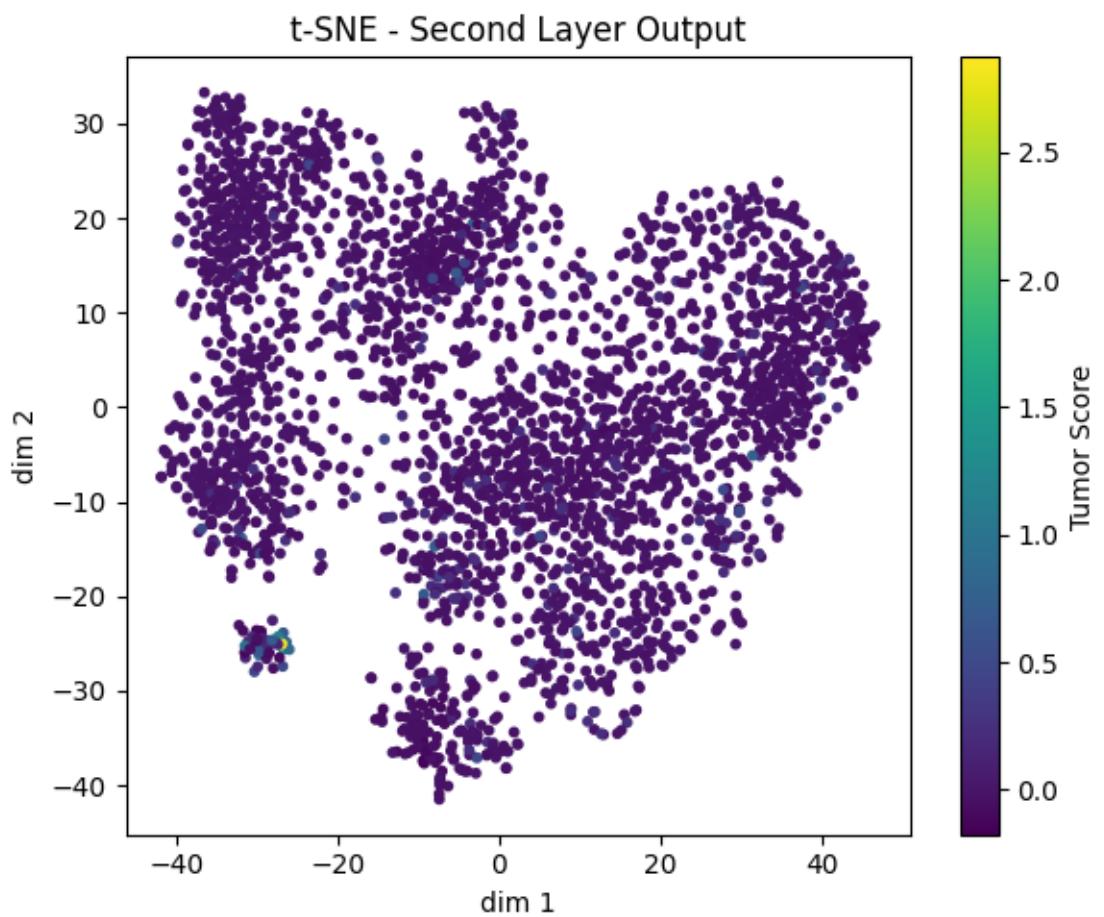


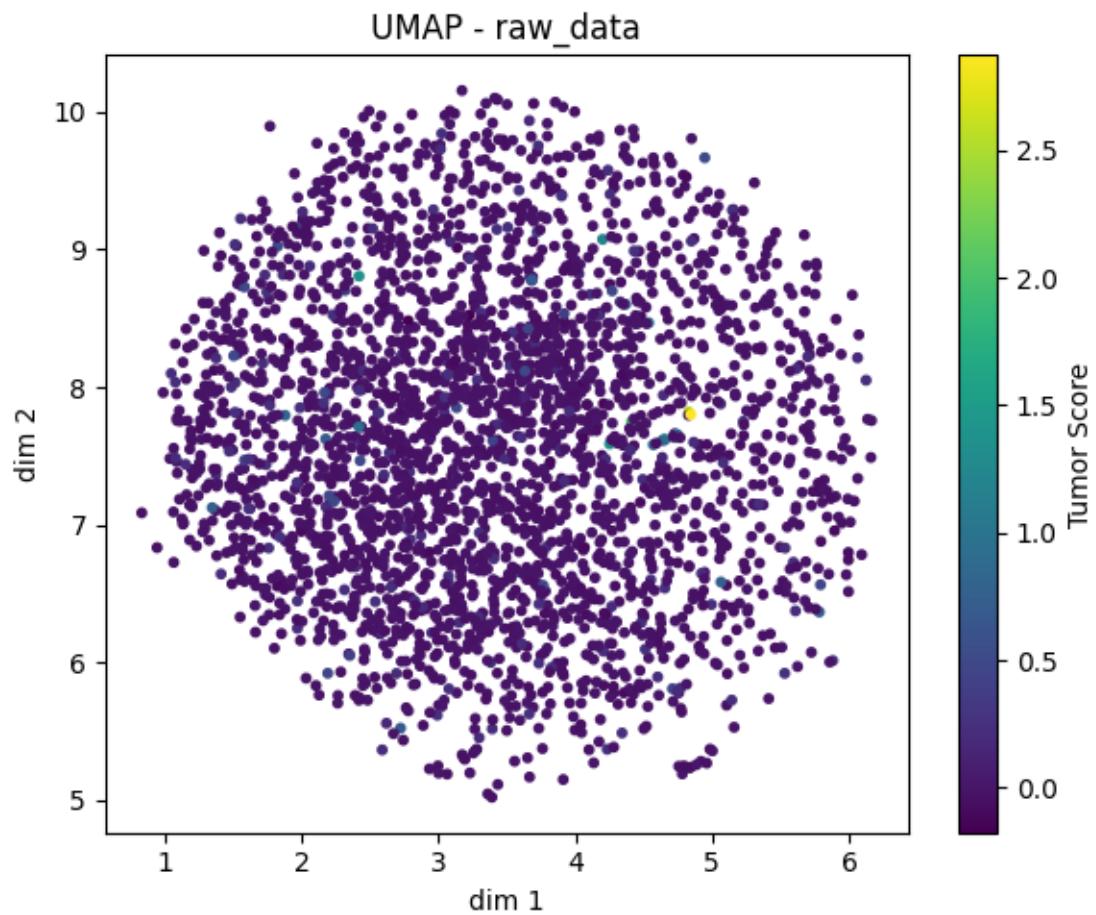
```
[ ]: labels = list(data.keys())

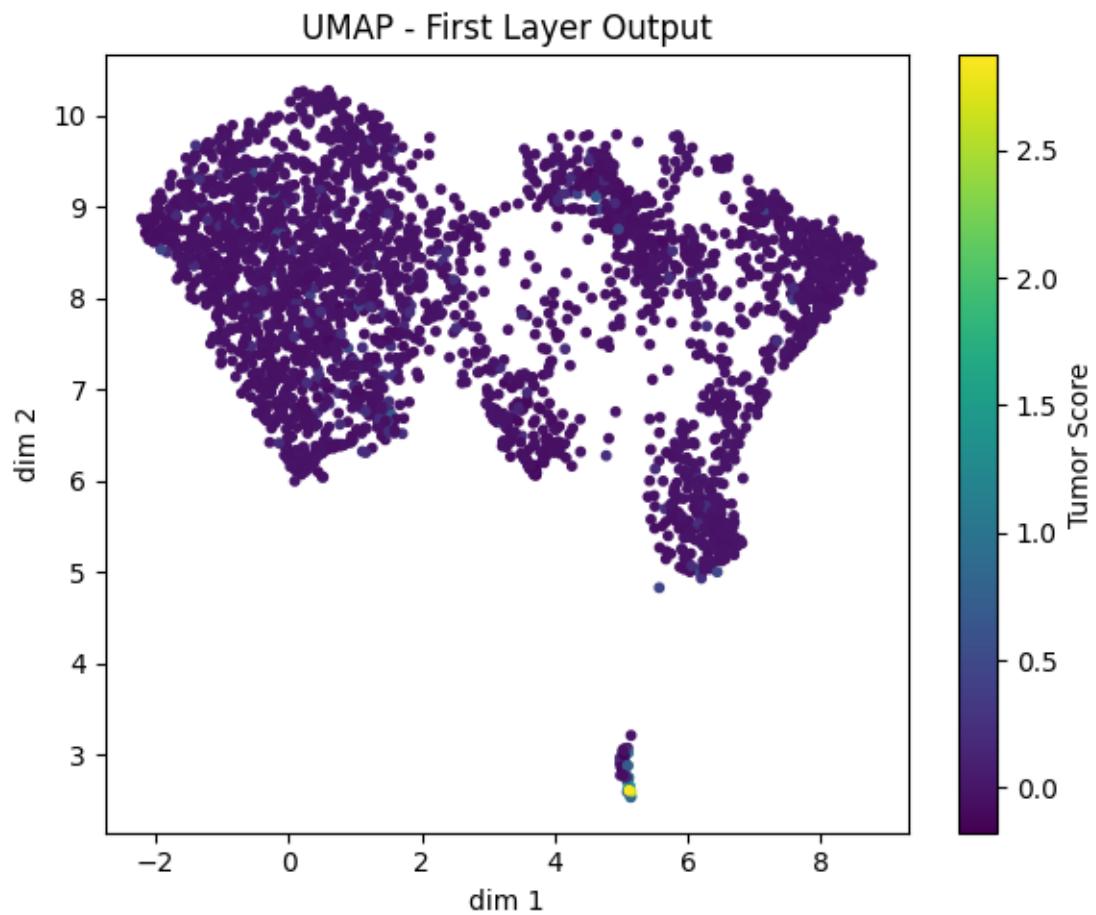
for method in results:
    for i, embedding in enumerate(results[method]):
        plt.figure(figsize=(6, 5))
        plt.scatter(
            embedding[:, 0],
            embedding[:, 1],
            c=adata_bc.obs["tumor_score"],
            cmap="viridis",
            s=10,
        )
        plt.colorbar(sc, label="Tumor Score")
        plt.title(f"{method} | {labels[i]}")
        plt.xlabel("dim 1")
        plt.ylabel("dim 2")
        plt.tight_layout()
        plt.show()
```

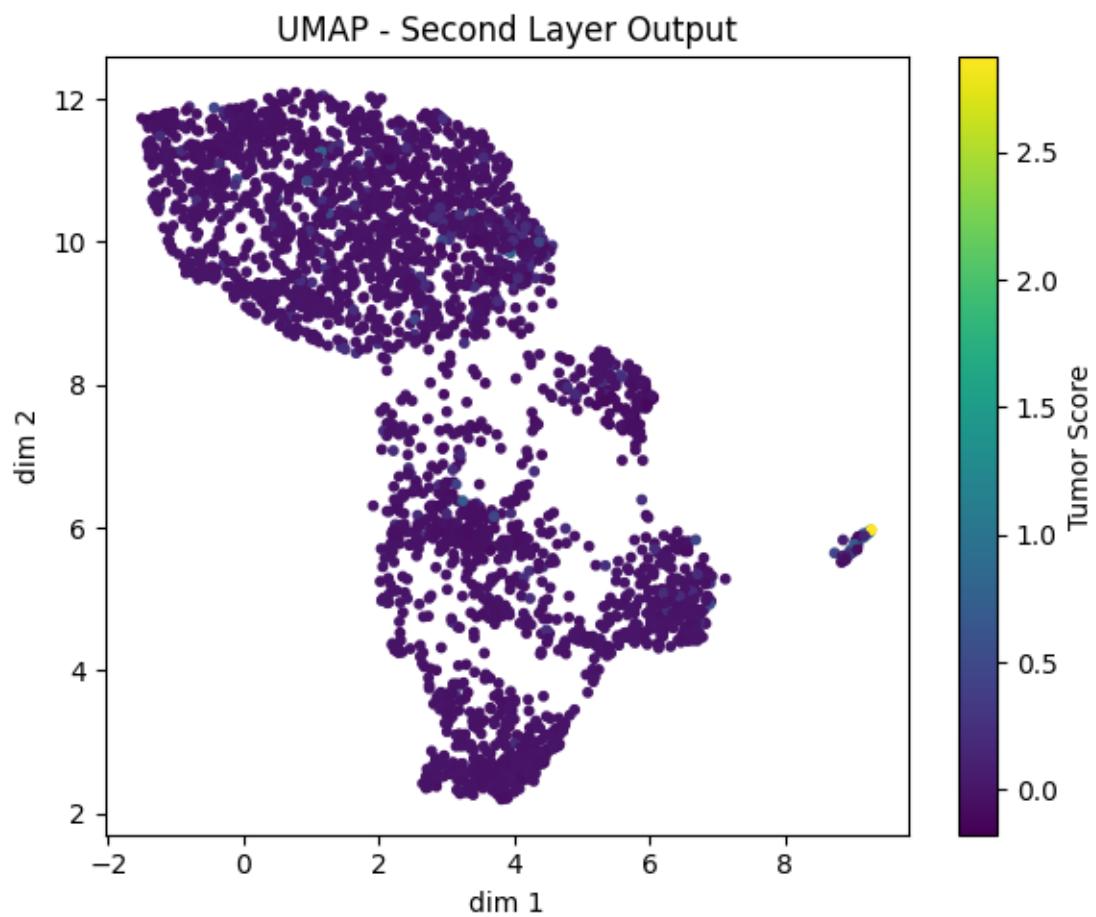


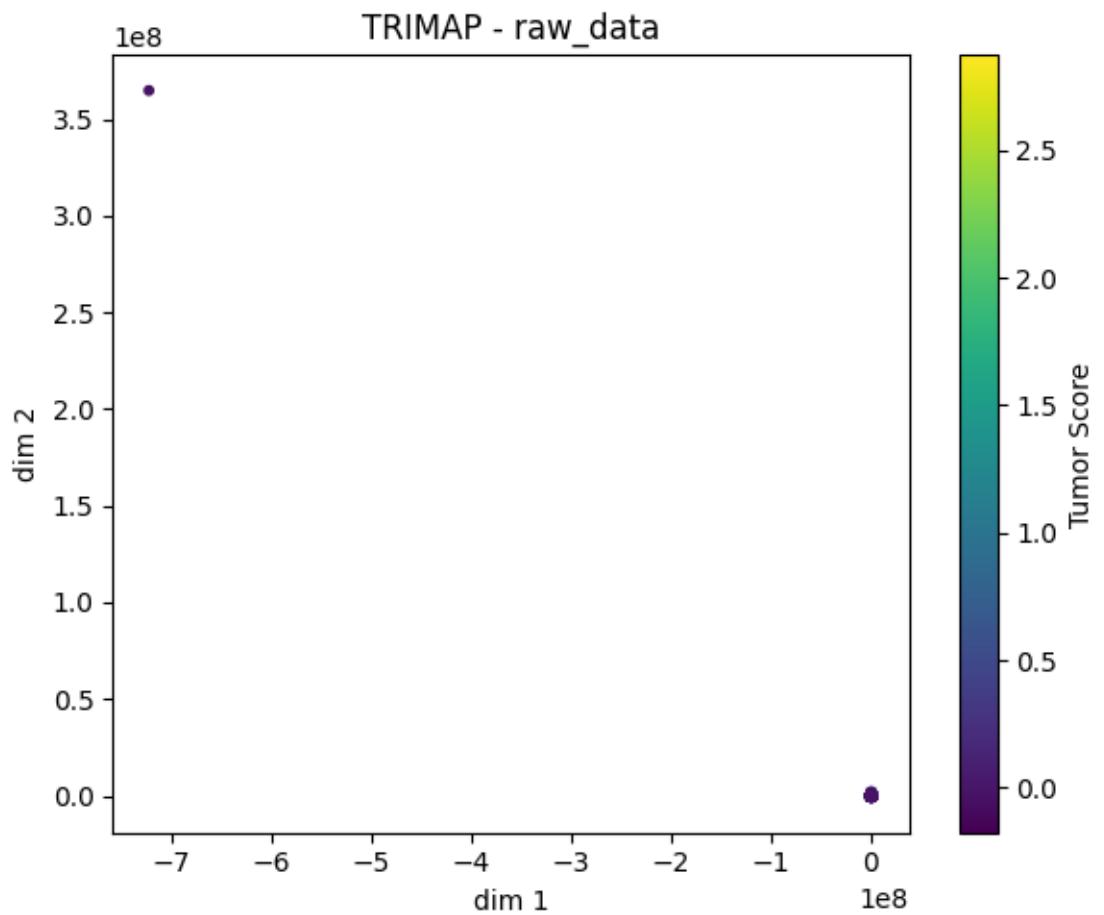


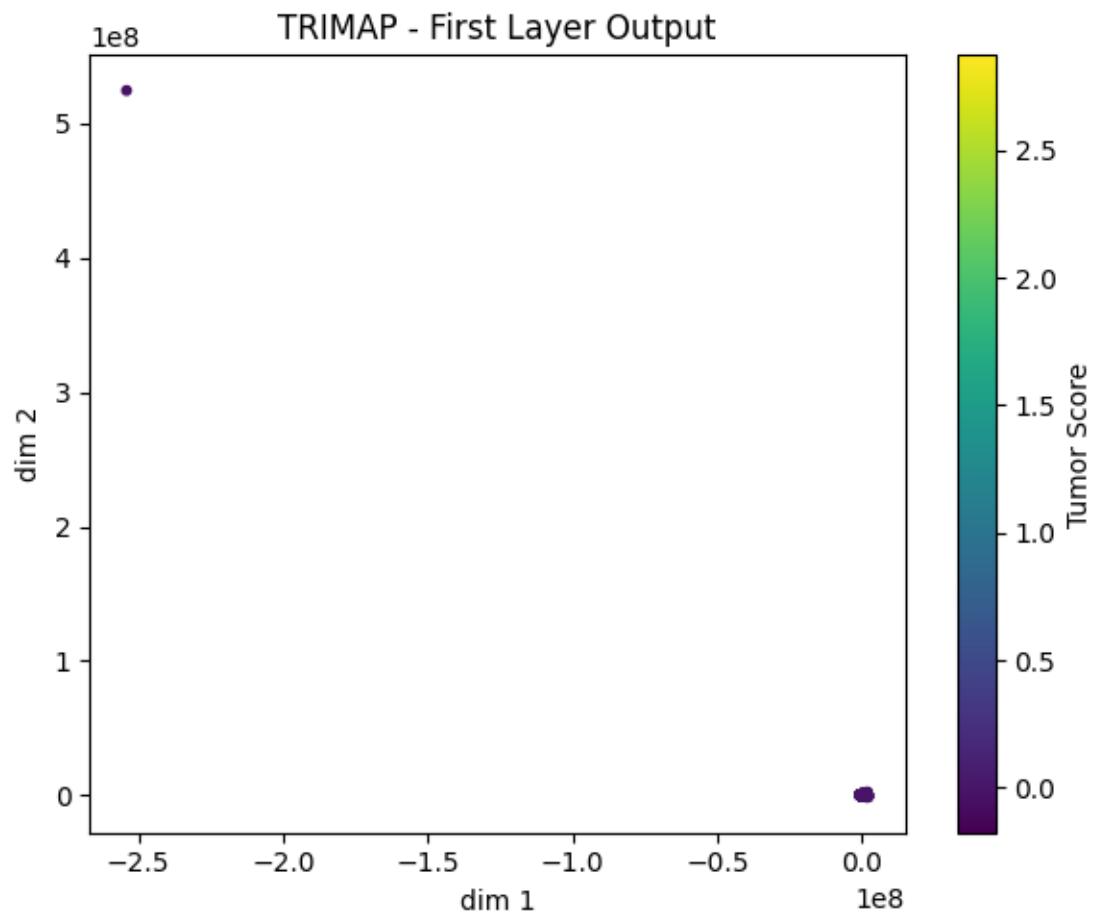


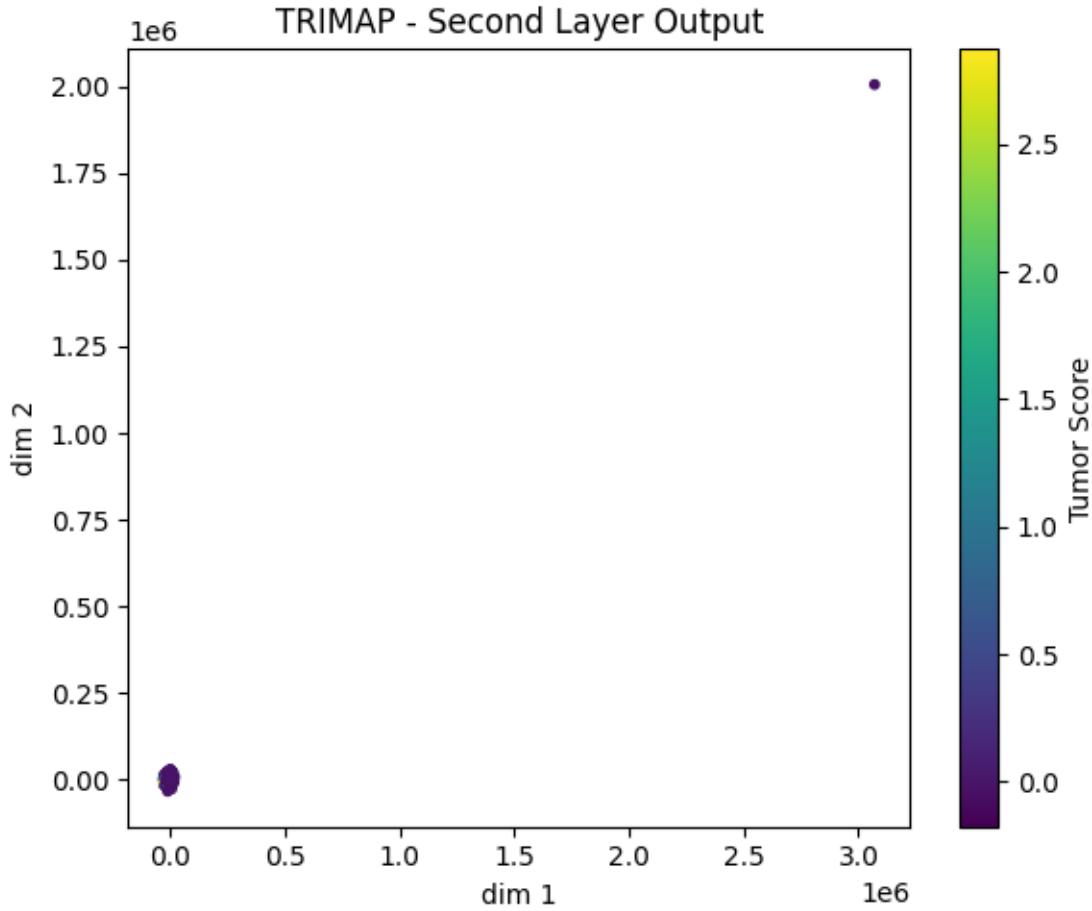












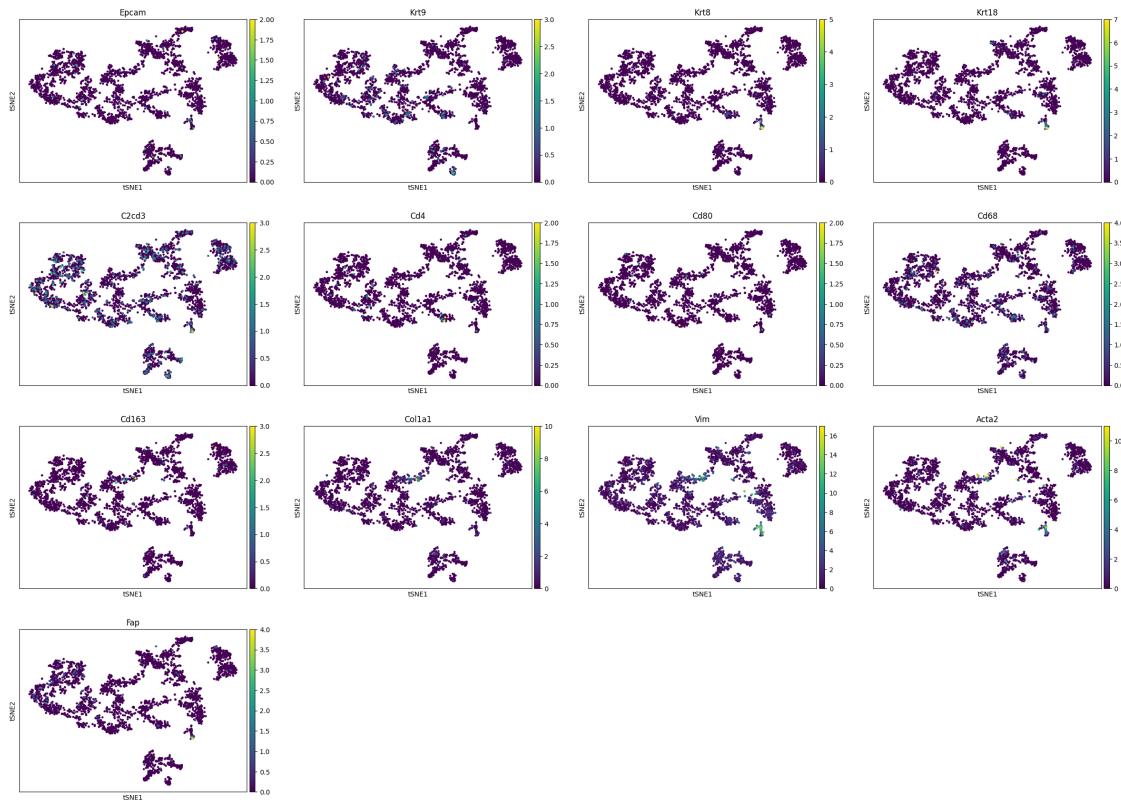
```
[ ]: sc.tl.tsne(adata_bc)
sc.pl.embedding(
    adata_bc, basis="tsne", color=tumor_markers + immune_markers +
    ↪stromal_markers
)

/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:337: RuntimeWarning: divide by zero
encountered in matmul
    Q, _ = normalizer(A @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:337: RuntimeWarning: overflow encountered in
matmul
    Q, _ = normalizer(A @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:337: RuntimeWarning: invalid value encountered
in matmul
    Q, _ = normalizer(A @ Q)
```

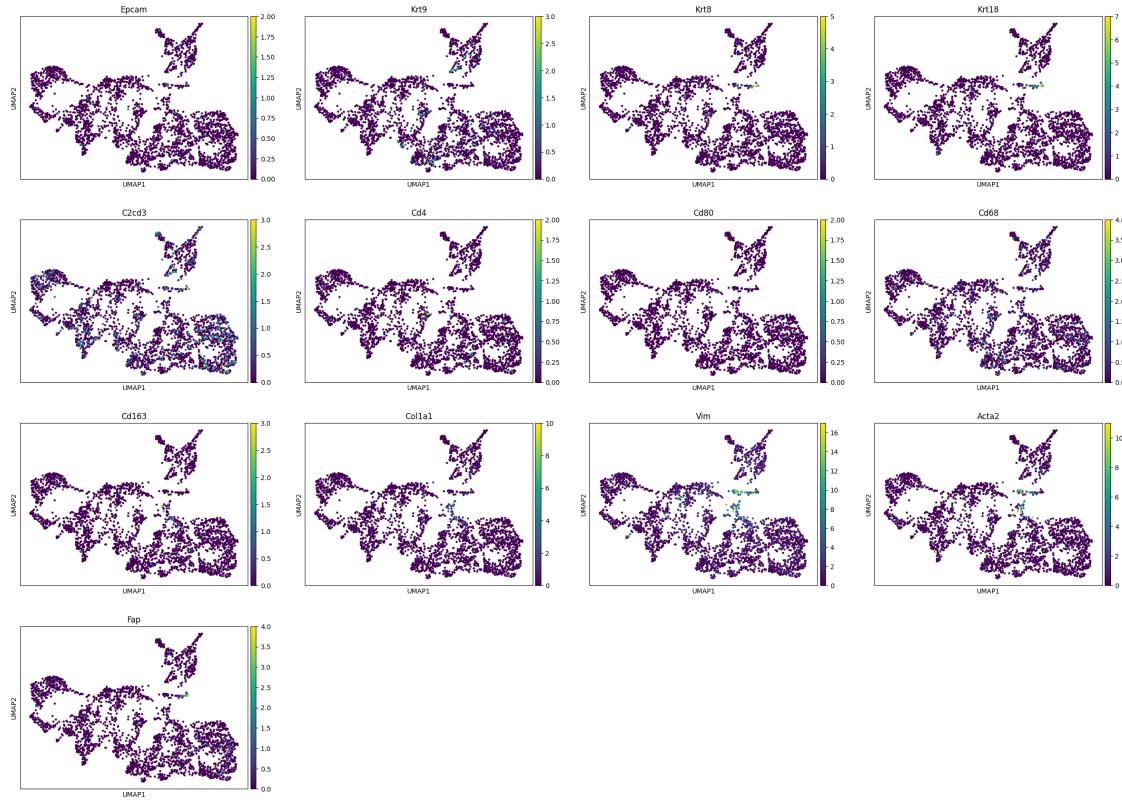
```

/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:338: RuntimeWarning: divide by zero
encountered in matmul
    Q, _ = normalizer(A.T @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:338: RuntimeWarning: overflow encountered in
matmul
    Q, _ = normalizer(A.T @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:338: RuntimeWarning: invalid value encountered
in matmul
    Q, _ = normalizer(A.T @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:342: RuntimeWarning: divide by zero
encountered in matmul
    Q, _ = qr_normalizer(A @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:342: RuntimeWarning: overflow encountered in
matmul
    Q, _ = qr_normalizer(A @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:342: RuntimeWarning: invalid value encountered
in matmul
    Q, _ = qr_normalizer(A @ Q)
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:529: RuntimeWarning: divide by zero
encountered in matmul
    B = Q.T @ M
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:529: RuntimeWarning: overflow encountered in
matmul
    B = Q.T @ M
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:529: RuntimeWarning: invalid value encountered
in matmul
    B = Q.T @ M
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:543: RuntimeWarning: divide by zero
encountered in matmul
    U = Q @ Uhat
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:543: RuntimeWarning: overflow encountered in
matmul
    U = Q @ Uhat
/Users/nicolas/studia/I_sem/wdzd/.venv/lib/python3.12/site-
packages/sklearn/utils/extmath.py:543: RuntimeWarning: invalid value encountered
in matmul
    U = Q @ Uhat

```



```
[ ]: sc.tl.umap(adata_bc)
sc.pl.embedding(
    adata_bc, basis="umap", color=tumor_markers + immune_markers +
    ↪stromal_markers
)
```



```
[ ]: # Compute neighborhood graph to analyze cell-cell interactions
sc.pp.neighbors(adata_bc, use_rep="X_pca")

# Find clusters/regions
sc.tl.leiden(adata_bc, resolution=0.8)

# Visualize clusters in spatial context
plt.figure(figsize=(10, 8))
sq.pl.spatial_scatter(adata_bc, color="leiden", size=1.5, legend_loc="on data")

# Compute interaction scores between regions
def compute_interactions(adata, cluster_key="leiden"):
    # Count neighbors of different clusters for each spot
    clusters = adata.obs[cluster_key].cat.categories
    n_clusters = len(clusters)

    # Get the indices of nearest neighbors from the connectivities matrix
    connectivity = adata.obsp["connectivities"]

    # Initialize interaction matrix
    interaction_matrix = np.zeros((n_clusters, n_clusters))
```

```

# For each spot, count interactions with spots of different clusters
for i in range(adata.n_obs):
    # Get the cluster of the current spot
    current_cluster = adata.obs[cluster_key].iloc[i]
    current_idx = np.where(clusters == current_cluster)[0][0]
    # Get indices of neighbors
    neighbors = connectivity[i].nonzero()[1]

    # Count neighbors by cluster
    for neighbor in neighbors:
        neighbor_cluster = adata.obs[cluster_key].iloc[neighbor]
        neighbor_idx = np.where(clusters == neighbor_cluster)[0][0]
        interaction_matrix[current_idx, neighbor_idx] += 1

return interaction_matrix, clusters

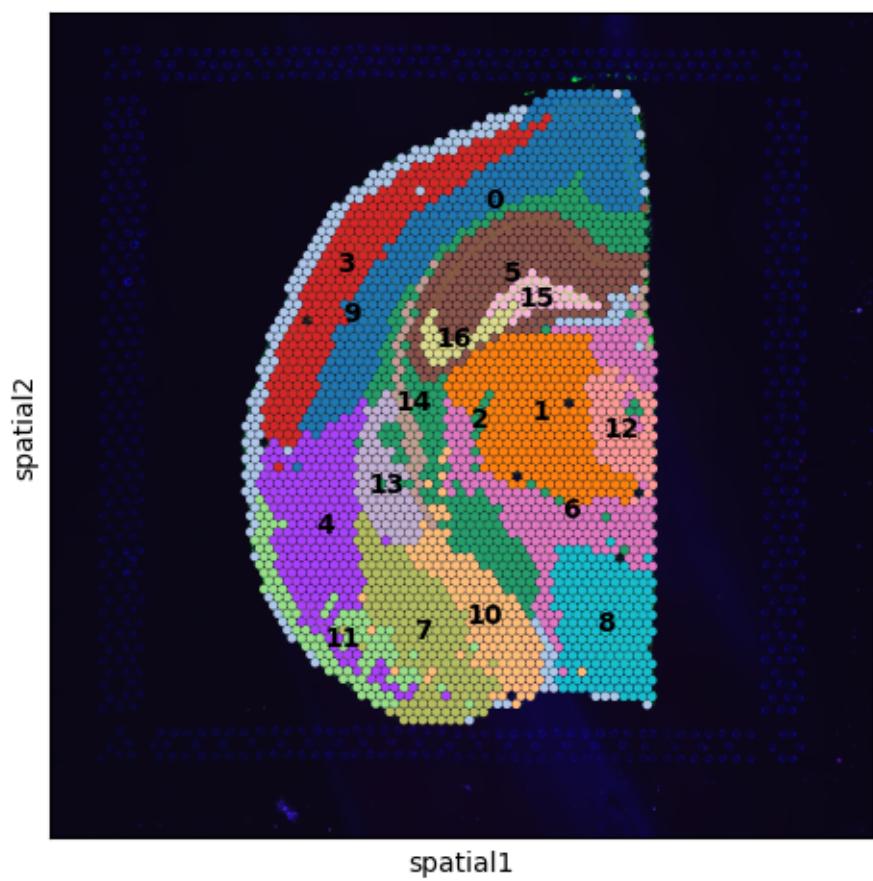
# Compute and visualize interactions
interaction_matrix, cluster_names = compute_interactions(adata_bc)

# Visualize interaction matrix
plt.figure(figsize=(10, 8))
sns.heatmap(
    interaction_matrix,
    annot=True,
    fmt=".0f",
    xticklabels=cluster_names,
    yticklabels=cluster_names,
)
plt.title("Spatial Interactions Between Clusters")
plt.xlabel("Target Cluster")
plt.ylabel("Source Cluster")
plt.show()

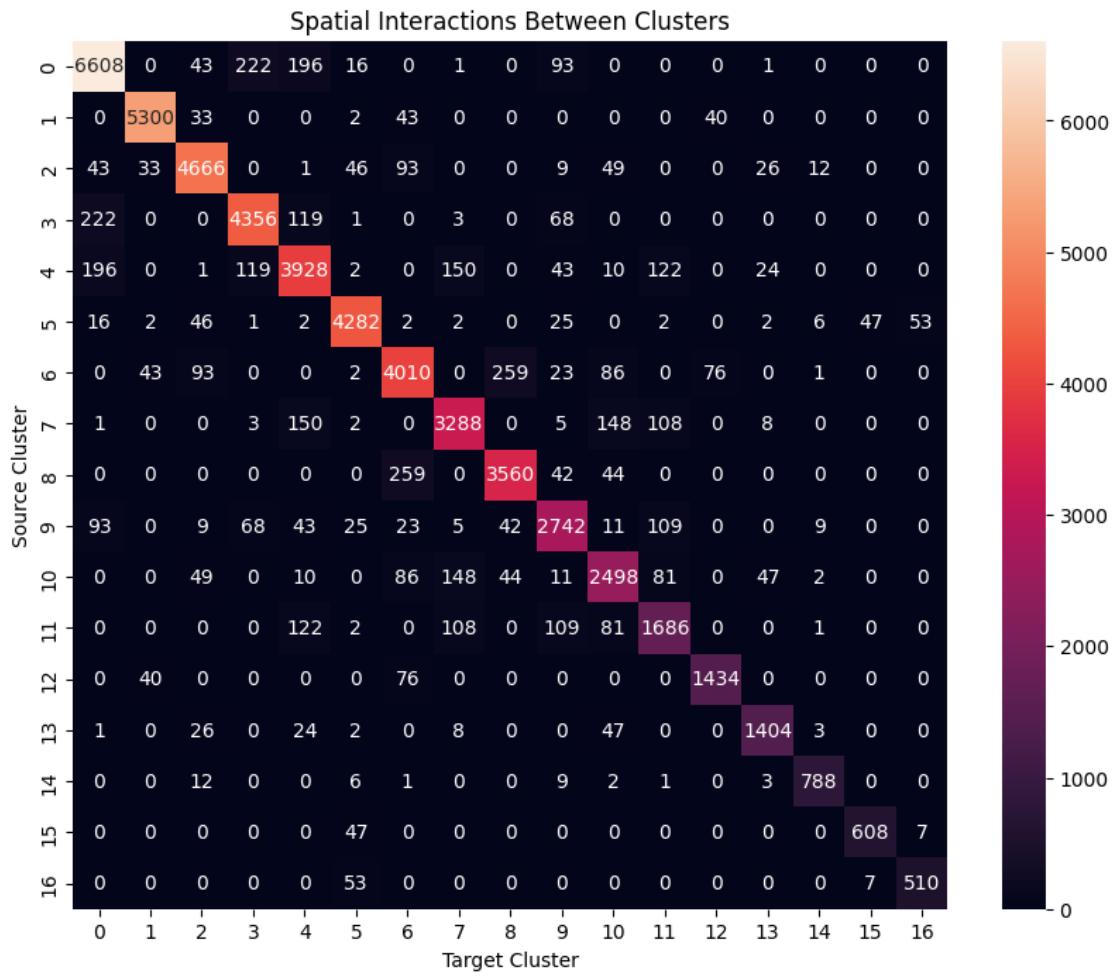
```

<Figure size 1000x800 with 0 Axes>

leiden



spatial1



[ ]: