results

March 20, 2020

1 Visualize results of experiments

1.0.1 Final figures will be saved in the 'figures' folder

[1]:
```
import numpy as np
import matplotlib.pyplot as plt
from sklearn.manifold import MDS,TSNE
from sklearn.decomposition import PCA
import matplotlib.pyplot as plt
from matplotlib.colors import ListedColormap
```

[2]:
```
import torch
from models.VAE import VAE
from environments.FourRooms import FourRooms
```

Creating an environment with 9 cells in each room. Each cell is representing a random number from mnist dataset

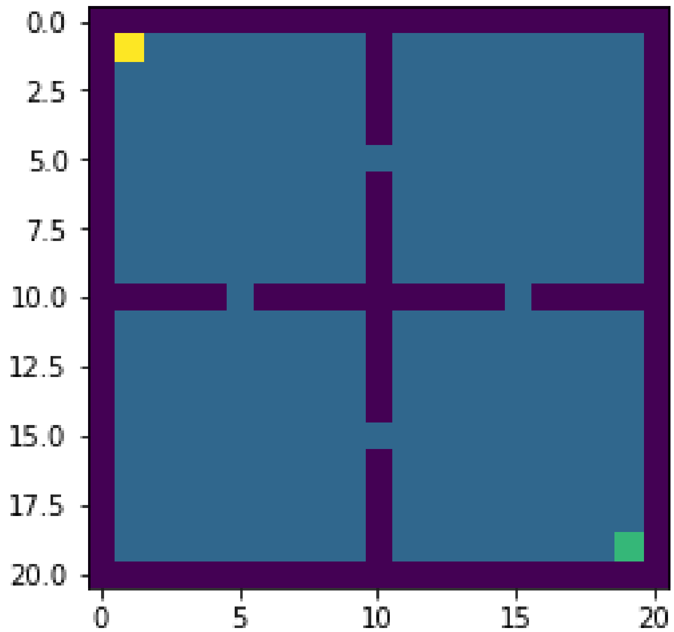
[3]:
```
room_size = 9
env = FourRooms(room_size,'mnist')
```

[4]:
```
gamma = 0.99
```

1.1 State Representation

1.1.1 Figure 2. (left)

[5]:
```
env.render()
plt.show()
```



1.2 Find SR with dynamic programming

[6]:
```
# Use this to ensure same order every time
idx_to_state = {i:state for i,state in enumerate(env.state_dict.keys())}
state_to_idx = {v:k for k,v in idx_to_state.items()}
```

Build a transition matrix

[7]:
```
T = np.zeros([env.n_states,env.n_states])
for i,s in idx_to_state.items():
    for a in range(4):
        env.state = s
        _,_,_,_ = env.step(a)
        s_tp1 = env.state
        T[state_to_idx[s],state_to_idx[s_tp1]] += 0.25
```

[8]:
```
def visualize_fourrooms_matrix(env,T,s):
    im_side = 2*env.room_size + 3
    T_image = np.zeros([im_side,im_side])
    s_x,s_y = s
    s_idx = state_to_idx[(s_x,s_y)]
    for x in range(im_side):
        for y in range(im_side):
            if (x,y) not in env.state_dict:
```

```
                T_image[x,y] = 0
            else:
                idx = state_to_idx[(x,y)]
                T_image[x,y] = T[s_idx,idx]
    return T_image
```

Build SR (DP) matrix

[111]:
```
theta = 1e-10
true_SR = np.zeros([env.n_states,env.n_states])
done = False
while not done:
    new_SR = np.matmul(T,np.eye(env.n_states)+gamma*true_SR)
    diff = np.max(np.abs(true_SR - new_SR))
    done =  diff < theta
    true_SR = new_SR
```

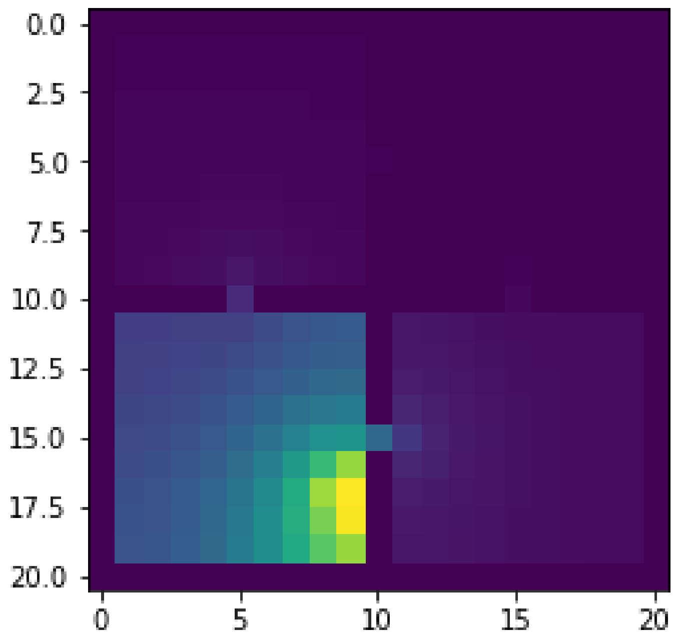
1.3 Visualize the SR (DP) representation

1.3.1 Figure 2. (right)

[112]:
```
from sklearn.neighbors.kd_tree import KDTree
```

[113]:
```
state = (17,9)
k = 80
```

[114]:
```
SR_image = visualize_fourrooms_matrix(env,true_SR,state)
plt.imshow(SR_image)
plt.show()
```



1.4 Loading saved data and visualize results

The running time for our project is ~1 day. Therefore for the sake of visualization we have uploaded the saved weights and data

VAE * Input: mnist image with size 28 X 28 * Output: embedding representation with size 32 X 1 * Upload the trained VAE

[115]:
```
in_channels = 1
embedding_size = 32
in_height = 28
in_width = 28
vae = VAE(in_channels,embedding_size,in_height,in_width)
vae.load_state_dict(torch.load('../weights/VAE/VAE_rooms_mnist.pt'))
```

[115]:
```
<All keys matched successfully>
```

Calulate the state embedding representation using the trained VAE encoder

[116]:
```
n_states = env.n_states
VAE_reps = np.zeros([n_states,embedding_size])
VAE_labels = []
for i,(state,obs) in enumerate(env.state_dict.items()):
    obs = torch.tensor(obs).permute(2,0,1) #(H,W,C)->(C,H,W)
    obs = obs.unsqueeze(0)
```

```
    with torch.no_grad():
        mu, logvar = vae.encoder(obs)
        state_embedding = torch.cat([mu, logvar],1)
        state_embedding = state_embedding.squeeze()
        state_embedding = state_embedding.cpu().numpy()
    VAE_reps[i,:] = state_embedding
    # different label for each room
    if state[0] < room_size + 1 and state[1] < room_size + 1:
        label = 0
    elif state[0] > room_size + 1 and state[1] < room_size + 1:
        label = 1
    elif state[0] < room_size + 1 and state[1] > room_size + 1:
        label = 2
    elif state[0] > room_size + 1 and state[1] > room_size + 1:
        label = 3
    else:
        label = 4
    VAE_labels.append(label)
```

1.5 Visualize training results

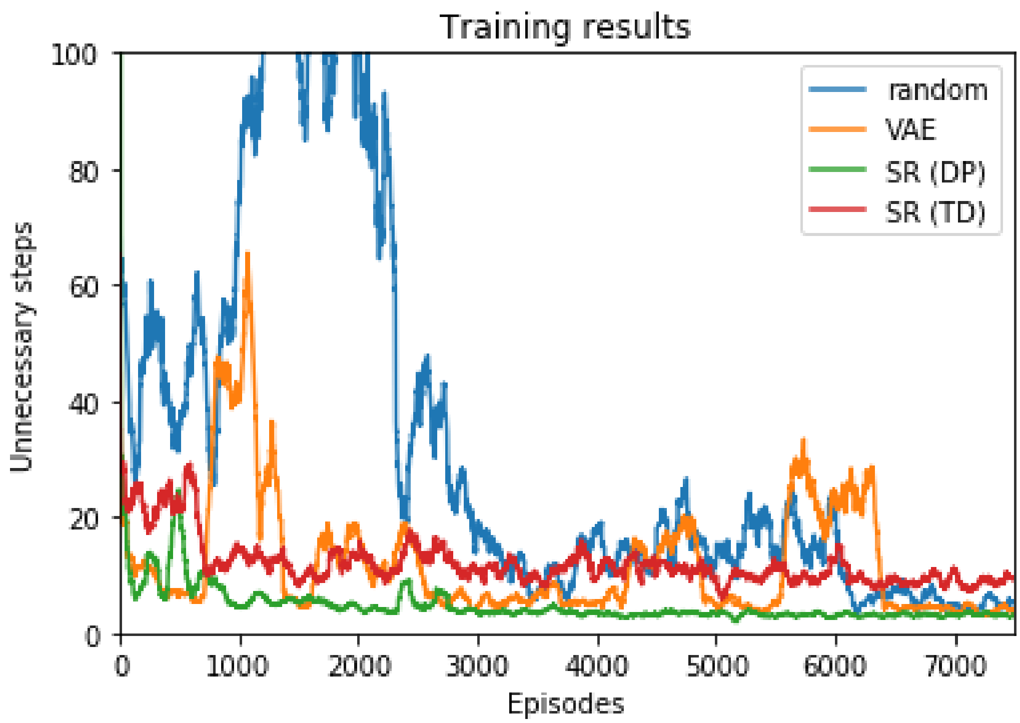
1.5.1 Figure 3

[117]:
```
rand_3knn = np.load('../results/MFEC/MFEC_rand_rooms_mnist_3knn.npy')
VAE_3knn = np.load('../results/MFEC/MFEC_VAE_rooms_mnist_3knn.npy')
SR_DP_3knn = np.load('../results/MFEC_SR/MFEC_SR_rand_DP_rooms_mnist_3knn.npy')
SR_TD_3knn = np.load('../results/MFEC_SR/
 ↪MFEC_SR_rand_TD_rooms_mnist_200epochs_3knn.npy')
```

[118]:
```
window = 100
smoothed_rand_3knn = np.convolve(rand_3knn[:,2], np.ones((window,))/window,␣
 ↪mode='valid')
smoothed_VAE_3knn = np.convolve(VAE_3knn[:,2], np.ones((window,))/window,␣
 ↪mode='valid')
smoothed_SR_DP_3knn = np.convolve(SR_DP_3knn[:,2], np.ones((window,))/window,␣
 ↪mode='valid')
smoothed_SR_TD_3knn = np.convolve(SR_TD_3knn[:,2], np.ones((window,))/window,␣
 ↪mode='valid')
```

[119]:
```
plt.plot(smoothed_rand_3knn)
plt.plot(smoothed_VAE_3knn)
plt.plot(smoothed_SR_DP_3knn)
plt.plot(smoothed_SR_TD_3knn)
plt.title("Training results")
plt.xlabel("Episodes")
```

```
plt.ylabel("Unnecessary steps")
plt.xlim([0,7500]) # The model was trained for 20000 but here we only plotted␣
↪the first part for simplicity
plt.ylim([0,100])
plt.legend(["random","VAE","SR (DP)", "SR (TD)"])
plt.savefig("figures/train_curves.png",bbox_inches = 'tight',pad_inches =␣
↪0,dpi=100)
plt.show()
```



Average number of extra steps throughout training:

[120]:
```
print("Random:", np.mean(rand_3knn[:7500,2]))
print("VAE:", np.mean(VAE_3knn[:7500,2]))
print("SR (DP):", np.mean(SR_DP_3knn[:7500,2]))
print("SR (TD):", np.mean(SR_TD_3knn[:7500,2]))
```

```
Random: 35.217866666666666
VAE: 12.92
SR (DP): 8.163733333333333
SR (TD): 12.6072
```

Average number of extra steps in the last 100 episodes

[121]:
```
print("Random:", np.mean(rand_3knn[7400:7500,2]))
print("VAE:", np.mean(VAE_3knn[7400:7500,2]))
print("SR (DP):", np.mean(SR_DP_3knn[7400:7500,2]))
print("SR (TD):", np.mean(SR_TD_3knn[7400:7500,2]))
```

```
Random: 4.3
VAE: 4.46
SR (DP): 3.24
SR (TD): 9.21
```

1.6 Multidimensional scaling plots to visualize representations of each type of embedding

[122]:
```
colors = ['green','blue','red','purple','orange']
```

Loading the saved representational results and their corresponding labels

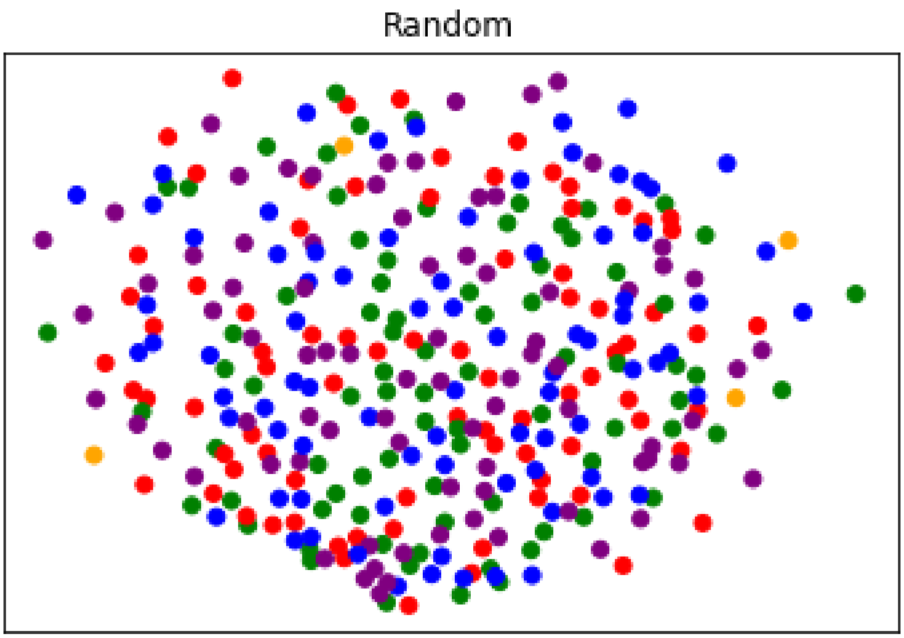
[123]:
```
emb_reps = np.load('../results/MFEC_SR/random_TD_mnist_200epochs_3knn_emb_reps.
↪npy')
SR_reps = np.load('../results/MFEC_SR/random_TD_mnist_200epochs_3knn_SR_reps.
↪npy')
labels = np.load('../results/MFEC_SR/random_TD_mnist_200epochs_3knn_labels.npy')
```

1.7 Visualize Random Representations

1.7.1 Figure 4. (top-left)

[124]:
```
mds_emb = MDS(n_components=2)
mds_emb_2d = mds_emb.fit_transform(emb_reps)
```

[125]:
```
plt.scatter(mds_emb_2d[:,0],mds_emb_2d[:
↪,1],c=labels,cmap=ListedColormap(colors))
plt.title("Random")
plt.tick_params(
    axis='both',
    which='both',
    bottom=False,
    top=False,
    left=False,
    labelbottom=False,
    labelleft=False)
plt.ticklabel_format(style='plain',useOffset=False)
plt.savefig("figures/mds_rand.png",bbox_inches = 'tight',pad_inches = 0.
↪1,dpi=100)
plt.show()
```



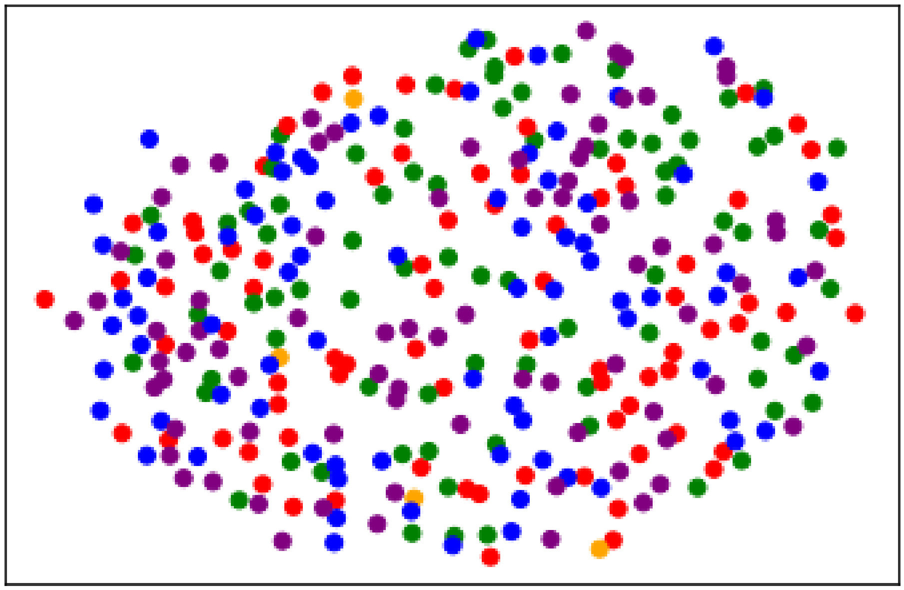
1.8 Visualize VAE Representation

1.8.1 Figure 4. (top-right)

We have represented multidimensional scaling of VAE, random and SR representation

[126]:
```
mds_vae = MDS(n_components=2)
mds_vae_2d = mds_vae.fit_transform(VAE_reps)
```

[127]:
```
plt.scatter(mds_vae_2d[:,0],mds_vae_2d[:
 ↪,1],c=labels,cmap=ListedColormap(colors))
plt.title("VAE")
plt.tick_params(
    axis='both',
    which='both',
    bottom=False,
    top=False,
    left=False,
    labelbottom=False,
    labelleft=False)
plt.ticklabel_format(style='plain',useOffset=False)
plt.savefig("figures/mds_VAE.png",bbox_inches = 'tight',pad_inches = 0.
 ↪1,dpi=100)
plt.show()
```



1.9 Visualize SR Representation

1.9.1 Figure 4. (bottom-left)

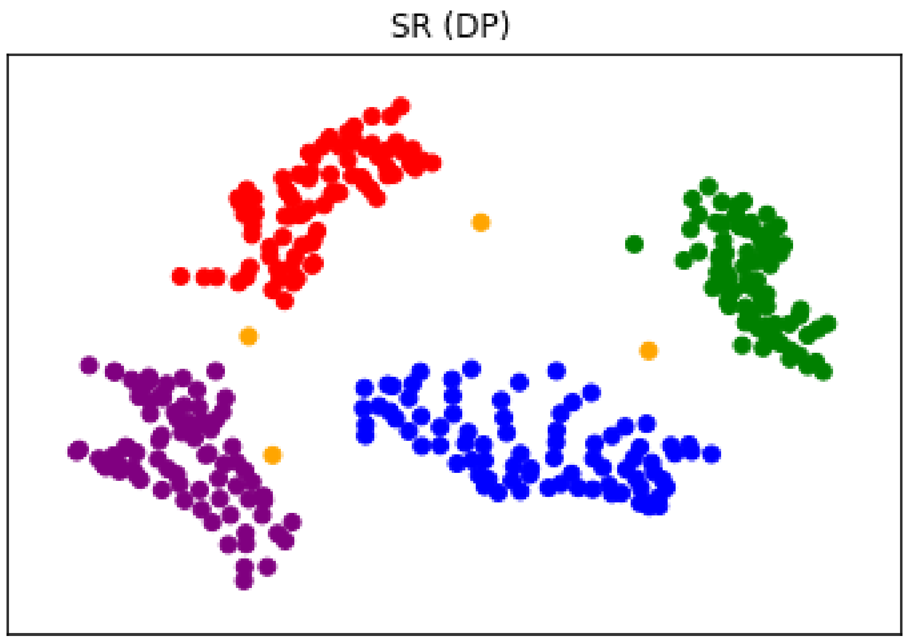
[128]:
```
# Get true SR of embeddings by matrix-multiplying SR by embedding matrix
true_SR_reps = np.matmul(true_SR,emb_reps)
```

[129]:
```
true_SR_reps = true_SR_reps/np.linalg.norm(true_SR_reps,axis=1,keepdims=True)
emb_reps = emb_reps/np.linalg.norm(emb_reps,axis=1,keepdims=True)
```

[130]:
```
mds_sr = MDS(n_components=2)
mds_sr_2d = mds_sr.fit_transform(true_SR_reps)
```

[131]:
```
plt.scatter(mds_sr_2d[:,0],mds_sr_2d[:,1],c=labels,cmap=ListedColormap(colors))
plt.title("SR (DP)")
plt.tick_params(
    axis='both',
    which='both',
    bottom=False,
    top=False,
    left=False,
    labelbottom=False,
    labelleft=False)
plt.ticklabel_format(style='plain',useOffset=False)
```

```
plt.savefig("figures/mds_SR_DP.png",bbox_inches = 'tight',pad_inches = 0.
 ↪1,dpi=100)
plt.show()
```



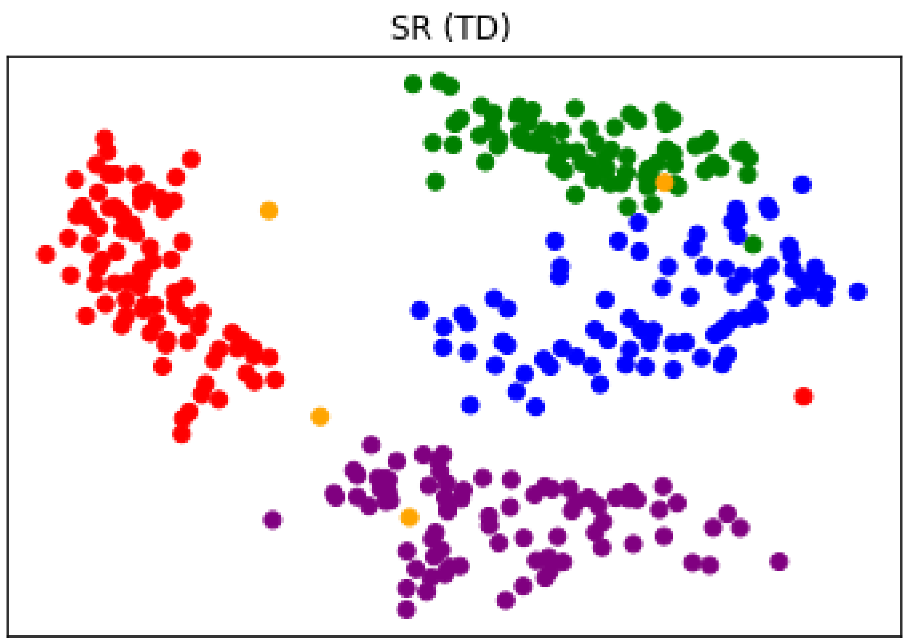
1.10 Visualize SR Representation

1.10.1 Figure 4. (bottom-right)

[132]:
```
mds_sr = MDS(n_components=2)
mds_sr_2d = mds_sr.fit_transform(SR_reps)
```

[133]:
```
plt.scatter(mds_sr_2d[:,0],mds_sr_2d[:,1],c=labels,cmap=ListedColormap(colors))
plt.title("SR (TD)")
plt.tick_params(
    axis='both',
    which='both',
    bottom=False,
    top=False,
    left=False,
    labelbottom=False,
    labelleft=False)
plt.ticklabel_format(style='plain',useOffset=False)
plt.savefig("figures/mds_SR_TD.png",bbox_inches = 'tight',pad_inches = 0.
 ↪1,dpi=100)
```

```
plt.show()
```



1.11 Visualization of the weights assigned to each of the k-nearest neighbors by an episodic control agent

1.11.1 Figure 5

[134]:
```
sr_kdtree = KDTree(true_SR_reps)
emb_kdtree = KDTree(emb_reps)
```

[60]:
```
state = (17,9)
k = 80
```

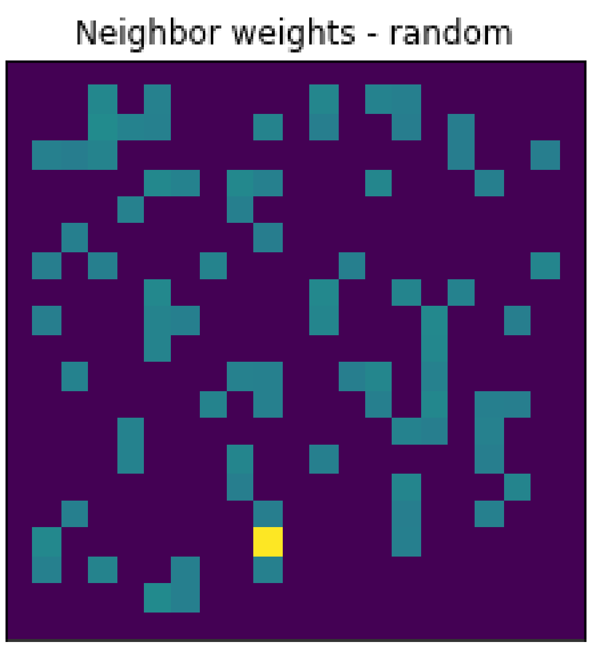
[61]:
```
def weights(distances):
    delta = 0.01
    distances = distances/(np.sum(distances)+1e-8)
    similarities = 1 / (distances+delta)
    return similarities/np.sum(similarities)
```

[62]:
```
state_idx = state_to_idx[state]
state_sr = true_SR_reps[state_idx,:]
sr_distances,sr_indices = sr_kdtree.query([state_sr],k=k,return_distance=True)
sr_weights = weights(sr_distances)
sr_w_matrix = np.zeros([env.n_states,env.n_states])
```

```
for sr_weight,idx in zip(sr_weights,sr_indices):
    sr_w_matrix[state_idx,idx] = sr_weight

state_emb = emb_reps[state_idx,:]
emb_distances,emb_indices = emb_kdtree.
 ↪query([state_emb],k=k,return_distance=True)
emb_weights = weights(emb_distances)
emb_w_matrix = np.zeros([env.n_states,env.n_states])
for emb_weight,idx in zip(emb_weights,emb_indices):
    emb_w_matrix[state_idx,idx] = emb_weight
```

[63]:
```
emb_sim_im = visualize_fourrooms_matrix(env,emb_w_matrix,state)
plt.imshow(emb_sim_im)
plt.title("Neighbor weights - random")
plt.tick_params(
    axis='both',
    which='both',
    bottom=False,
    top=False,
    left=False,
    labelbottom=False,
    labelleft=False)
plt.ticklabel_format(style='plain',useOffset=False)
plt.savefig("figures/random_neighbors.png",bbox_inches = 'tight',pad_inches = 0.
 ↪1,dpi=100)
plt.show()
```



[64]:

```
sr_sim_im = visualize_fourrooms_matrix(env,sr_w_matrix,state)
plt.imshow(sr_sim_im)
plt.title("Neighbor weights - SR (DP)")
plt.tick_params(
    axis='both',
    which='both',
    bottom=False,
    top=False,
    left=False,
    labelbottom=False,
    labelleft=False)
plt.ticklabel_format(style='plain',useOffset=False)
plt.savefig("figures/SR_DP_neighbors.png",bbox_inches = 'tight',pad_inches = 0.
 ↪1,dpi=100)
plt.show()
```