Demo of bandit algorithms

This is a simple demo of a simulated bandit environment and some baseline algorithms. In this environment, the agent can one of the actions and will receive a binary reward signal whose probability is drawn from a Beta distribution. The probabilities of these beta distributions are not known to the agent. Thus, the agents must estimate these probabilities while also trying to maximize their reward.

In [1]:

```python
import torch
import matplotlib.pyplot as plt

class BernoulliBanditEnvironment():
  def __init__(self, n_actions):
    probs = torch.distributions.Beta(1,2).sample((n_actions,))
    self.reward_dists = [
      torch.distributions.Bernoulli(probs=p)
      for p in probs
    ]

  def get_reward(self, action_index):
    return self.reward_dists[action_index].sample((1,))[0]

  def simulate_step(self, agent):
    action_index = agent.select_action()
    reward = self.get_reward(action_index)
    agent.update(action_index, reward)
    return action_index, reward

  def simulate(self, agent, n_steps, verbosity=1):
    cum_reward = 0
    for i in range(n_steps):
      action_index, reward = self.simulate_step(agent)
      cum_reward += reward
      if verbosity >= 1:
        print(
          f'Step = {i+1:02d}, '
          f'Action = {action_index.item():d}, '
          f'Reward = {reward.item():.0f}, '
          f'Cum reward = {cum_reward:.0f}, '
          f'Avg reward = {cum_reward/(i+1):.2f}, '
        )
    return cum_reward

torch.manual_seed(0)
env = BernoulliBanditEnvironment(3)
print('Reward distributions')
print(env.reward_dists)
print('\nRandom rewards for first distribution')
print([env.get_reward(0) for i in range(20)])
```

```
Reward distributions
[Bernoulli(probs: 0.6865779757499695), Bernoulli(probs: 0.2097484767436
9812), Bernoulli(probs: 0.16393446922302246)]

Random rewards for first distribution
[tensor(1.), tensor(1.), tensor(0.), tensor(1.), tensor(1.), tensor
(1.), tensor(1.), tensor(0.), tensor(1.), tensor(1.), tensor(1.), tenso
r(1.), tensor(1.), tensor(0.), tensor(0.), tensor(0.), tensor(1.), tens
or(1.), tensor(1.), tensor(1.)]
```

Interactive agent

For this agent, just uncomment the line below to interactively provide the actions yourself and see if how well you can do.

In [2]:
```
class InteractiveAgent:
  def __init__(self, n_actions):
    self.n_actions = n_actions

  def select_action(self):
    action_index = -1
    while action_index < 0:
      print(f'Enter action index from 0-{self.n_actions-1}')
      try:
        action_index = int(input())
      except Exception:
        action_index = -1
      if action_index >= 0 and action_index < self.n_actions:
        break
      else:
        print('Incorrect input, try again.')
        action_index = -1
    return torch.tensor(action_index)

  def update(self, action_index, reward):
    return self

torch.manual_seed(2)
env = BernoulliBanditEnvironment(2)
interactive_agent = InteractiveAgent(len(env.reward_dists))
# Uncomment to be interactive
#env.simulate(interactive_agent, n_steps=2)
```

Oracle agent

This is like a cheating agent that actually already knows the probabilities for each action and thus can choose the optimal action every time.

In [3]:
```python
class OracleAgent:
  def __init__(self, env):
    self.optimal_action = torch.argmax(torch.tensor([
      dist.probs for dist in env.reward_dists
    ]))

  def select_action(self):
    return self.optimal_action

  def update(self, action_index, reward):
    return self

  def __str__(self):
    return 'Oracle'

torch.manual_seed(2) # 2 and 5
env = BernoulliBanditEnvironment(2)
oracle = OracleAgent(env)
env.simulate(oracle, n_steps=20)
```

```
Step = 01, Action = 1, Reward = 0, Cum reward = 0, Avg reward = 0.00,
Step = 02, Action = 1, Reward = 1, Cum reward = 1, Avg reward = 0.50,
Step = 03, Action = 1, Reward = 1, Cum reward = 2, Avg reward = 0.67,
Step = 04, Action = 1, Reward = 0, Cum reward = 2, Avg reward = 0.50,
Step = 05, Action = 1, Reward = 1, Cum reward = 3, Avg reward = 0.60,
Step = 06, Action = 1, Reward = 1, Cum reward = 4, Avg reward = 0.67,
Step = 07, Action = 1, Reward = 1, Cum reward = 5, Avg reward = 0.71,
Step = 08, Action = 1, Reward = 0, Cum reward = 5, Avg reward = 0.62,
Step = 09, Action = 1, Reward = 1, Cum reward = 6, Avg reward = 0.67,
Step = 10, Action = 1, Reward = 1, Cum reward = 7, Avg reward = 0.70,
Step = 11, Action = 1, Reward = 1, Cum reward = 8, Avg reward = 0.73,
Step = 12, Action = 1, Reward = 1, Cum reward = 9, Avg reward = 0.75,
Step = 13, Action = 1, Reward = 1, Cum reward = 10, Avg reward = 0.77,
Step = 14, Action = 1, Reward = 1, Cum reward = 11, Avg reward = 0.79,
Step = 15, Action = 1, Reward = 1, Cum reward = 12, Avg reward = 0.80,
Step = 16, Action = 1, Reward = 1, Cum reward = 13, Avg reward = 0.81,
Step = 17, Action = 1, Reward = 1, Cum reward = 14, Avg reward = 0.82,
Step = 18, Action = 1, Reward = 0, Cum reward = 14, Avg reward = 0.78,
Step = 19, Action = 1, Reward = 1, Cum reward = 15, Avg reward = 0.79,
Step = 20, Action = 1, Reward = 1, Cum reward = 16, Avg reward = 0.80,
```

Out[3]:
```
tensor(16.)
```

Try to see how close you can get to the oracle agent

In [4]:
```
env = BernoulliBanditEnvironment(2)
n_steps = 10

interactive_agent = InteractiveAgent(len(env.reward_dists))
total_reward = 0
# Uncomment to be interactive
#total_reward = env.simulate(interactive_agent, n_steps=n_steps)
oracle_reward = env.simulate(OracleAgent(env), n_steps=10000, verbosity=0
print(f'\nThe probabilities were {[dist.probs.item() for dist in env.rewa
print(f'\nYour reward was ${total_reward}, the oracle policy would have r
```

```
The probabilities were [0.3823629915714264, 0.7332632541656494]

Your reward was $0, the oracle policy would have received an award clos
e to $7.38
```

Random agent

This agent merely chooses an action at random.

In [5]:
```python
class RandomAgent:
  def __init__(self, n_actions):
    self.n_actions = n_actions

  def select_action(self):
    return torch.randint(self.n_actions, (1,))[0]

  def update(self, action_index, reward):
    return self

  def __str__(self):
    return f'Random'

torch.manual_seed(0)
env = BernoulliBanditEnvironment(3)
random_agent = RandomAgent(len(env.reward_dists))
env.simulate(random_agent, n_steps=20)
```

```
Step = 01, Action = 2, Reward = 0, Cum reward = 0, Avg reward = 0.00,
Step = 02, Action = 1, Reward = 1, Cum reward = 1, Avg reward = 0.50,
Step = 03, Action = 0, Reward = 1, Cum reward = 2, Avg reward = 0.67,
Step = 04, Action = 1, Reward = 0, Cum reward = 2, Avg reward = 0.50,
Step = 05, Action = 2, Reward = 0, Cum reward = 2, Avg reward = 0.40,
Step = 06, Action = 1, Reward = 1, Cum reward = 3, Avg reward = 0.50,
Step = 07, Action = 1, Reward = 0, Cum reward = 3, Avg reward = 0.43,
Step = 08, Action = 2, Reward = 0, Cum reward = 3, Avg reward = 0.38,
Step = 09, Action = 2, Reward = 0, Cum reward = 3, Avg reward = 0.33,
Step = 10, Action = 1, Reward = 1, Cum reward = 4, Avg reward = 0.40,
Step = 11, Action = 1, Reward = 0, Cum reward = 4, Avg reward = 0.36,
Step = 12, Action = 1, Reward = 0, Cum reward = 4, Avg reward = 0.33,
Step = 13, Action = 2, Reward = 0, Cum reward = 4, Avg reward = 0.31,
Step = 14, Action = 1, Reward = 0, Cum reward = 4, Avg reward = 0.29,
Step = 15, Action = 2, Reward = 0, Cum reward = 4, Avg reward = 0.27,
Step = 16, Action = 2, Reward = 0, Cum reward = 4, Avg reward = 0.25,
Step = 17, Action = 2, Reward = 1, Cum reward = 5, Avg reward = 0.29,
Step = 18, Action = 2, Reward = 0, Cum reward = 5, Avg reward = 0.28,
Step = 19, Action = 1, Reward = 0, Cum reward = 5, Avg reward = 0.26,
Step = 20, Action = 0, Reward = 1, Cum reward = 6, Avg reward = 0.30,
```

Out[5]:
```
tensor(6.)
```

Greedy agent

This chooses the best action given it's current estimate of the action value function. Note the initialization value can matter significantly as higher values will encourage it to explore more.

In [6]:
```python
class GreedyAgent:
  def __init__(self, n_actions, init_value=0):
    self.init_value = init_value
    self.action_counts = torch.zeros(n_actions) #n_t
    self.action_value_func = init_value * torch.ones(n_actions)  #Q_t

  def select_action(self):
    return torch.argmax(self.action_value_func)

  def update(self, action_index, reward):
    action_count = self.action_counts[action_index]
    sum_rewards = action_count * self.action_value_func[action_index]
    new_avg_reward = (sum_rewards + reward) / (action_count + 1)

    self.action_counts[action_index] += 1
    self.action_value_func[action_index] = new_avg_reward
    return self

  def __str__(self):
    return f'Greedy(init={self.init_value})'

torch.manual_seed(0)
env = BernoulliBanditEnvironment(3)
# Try init_value = 0, 1 or 100
greedy = GreedyAgent(len(env.reward_dists), init_value=1)
env.simulate(greedy, n_steps=20)
```

```
Step = 01, Action = 0, Reward = 1, Cum reward = 1, Avg reward = 1.00,
Step = 02, Action = 0, Reward = 1, Cum reward = 2, Avg reward = 1.00,
Step = 03, Action = 0, Reward = 0, Cum reward = 2, Avg reward = 0.67,
Step = 04, Action = 1, Reward = 1, Cum reward = 3, Avg reward = 0.75,
Step = 05, Action = 1, Reward = 1, Cum reward = 4, Avg reward = 0.80,
Step = 06, Action = 1, Reward = 0, Cum reward = 4, Avg reward = 0.67,
Step = 07, Action = 2, Reward = 0, Cum reward = 4, Avg reward = 0.57,
Step = 08, Action = 0, Reward = 0, Cum reward = 4, Avg reward = 0.50,
Step = 09, Action = 1, Reward = 1, Cum reward = 5, Avg reward = 0.56,
Step = 10, Action = 1, Reward = 0, Cum reward = 5, Avg reward = 0.50,
Step = 11, Action = 1, Reward = 1, Cum reward = 6, Avg reward = 0.55,
Step = 12, Action = 1, Reward = 1, Cum reward = 7, Avg reward = 0.58,
Step = 13, Action = 1, Reward = 1, Cum reward = 8, Avg reward = 0.62,
Step = 14, Action = 1, Reward = 0, Cum reward = 8, Avg reward = 0.57,
Step = 15, Action = 1, Reward = 0, Cum reward = 8, Avg reward = 0.53,
Step = 16, Action = 1, Reward = 0, Cum reward = 8, Avg reward = 0.50,
Step = 17, Action = 1, Reward = 0, Cum reward = 8, Avg reward = 0.47,
Step = 18, Action = 0, Reward = 1, Cum reward = 9, Avg reward = 0.50,
Step = 19, Action = 0, Reward = 1, Cum reward = 10, Avg reward = 0.53,
Step = 20, Action = 0, Reward = 1, Cum reward = 11, Avg reward = 0.55,
```

Out[6]:
```
tensor(11.)
```

ϵ-greedy agent

With some probability, take a random action otherwise pick greedy action.

In [7]:
```python
class EpsilonGreedyAgent(GreedyAgent):
  def __init__(self, n_actions, epsilon):
    super().__init__(n_actions, init_value=0)
    self.epsilon = epsilon

  def select_action(self):
    if torch.rand((1,))[0] < self.epsilon:
      return torch.randint(len(self.action_value_func), (1,))[0]
    else:
      return torch.argmax(self.action_value_func)

  def __str__(self):
    return f'$\epsilon$-Greedy($\epsilon={self.epsilon:.2f}$)'

# Try init_value = 0, 1 or 100
torch.manual_seed(0)
env = BernoulliBanditEnvironment(3)
epsilon_greedy = EpsilonGreedyAgent(len(env.reward_dists), epsilon=0.2)
env.simulate(epsilon_greedy, n_steps=20)
```

```
Step = 01, Action = 0, Reward = 1, Cum reward = 1, Avg reward = 1.00,
Step = 02, Action = 0, Reward = 1, Cum reward = 2, Avg reward = 1.00,
Step = 03, Action = 0, Reward = 1, Cum reward = 3, Avg reward = 1.00,
Step = 04, Action = 0, Reward = 1, Cum reward = 4, Avg reward = 1.00,
Step = 05, Action = 0, Reward = 1, Cum reward = 5, Avg reward = 1.00,
Step = 06, Action = 1, Reward = 0, Cum reward = 5, Avg reward = 0.83,
Step = 07, Action = 0, Reward = 0, Cum reward = 5, Avg reward = 0.71,
Step = 08, Action = 0, Reward = 1, Cum reward = 6, Avg reward = 0.75,
Step = 09, Action = 0, Reward = 1, Cum reward = 7, Avg reward = 0.78,
Step = 10, Action = 2, Reward = 0, Cum reward = 7, Avg reward = 0.70,
Step = 11, Action = 0, Reward = 1, Cum reward = 8, Avg reward = 0.73,
Step = 12, Action = 0, Reward = 0, Cum reward = 8, Avg reward = 0.67,
Step = 13, Action = 0, Reward = 0, Cum reward = 8, Avg reward = 0.62,
Step = 14, Action = 0, Reward = 0, Cum reward = 8, Avg reward = 0.57,
Step = 15, Action = 0, Reward = 1, Cum reward = 9, Avg reward = 0.60,
Step = 16, Action = 2, Reward = 0, Cum reward = 9, Avg reward = 0.56,
Step = 17, Action = 0, Reward = 0, Cum reward = 9, Avg reward = 0.53,
Step = 18, Action = 0, Reward = 1, Cum reward = 10, Avg reward = 0.56,
Step = 19, Action = 0, Reward = 1, Cum reward = 11, Avg reward = 0.58,
Step = 20, Action = 0, Reward = 1, Cum reward = 12, Avg reward = 0.60,
```

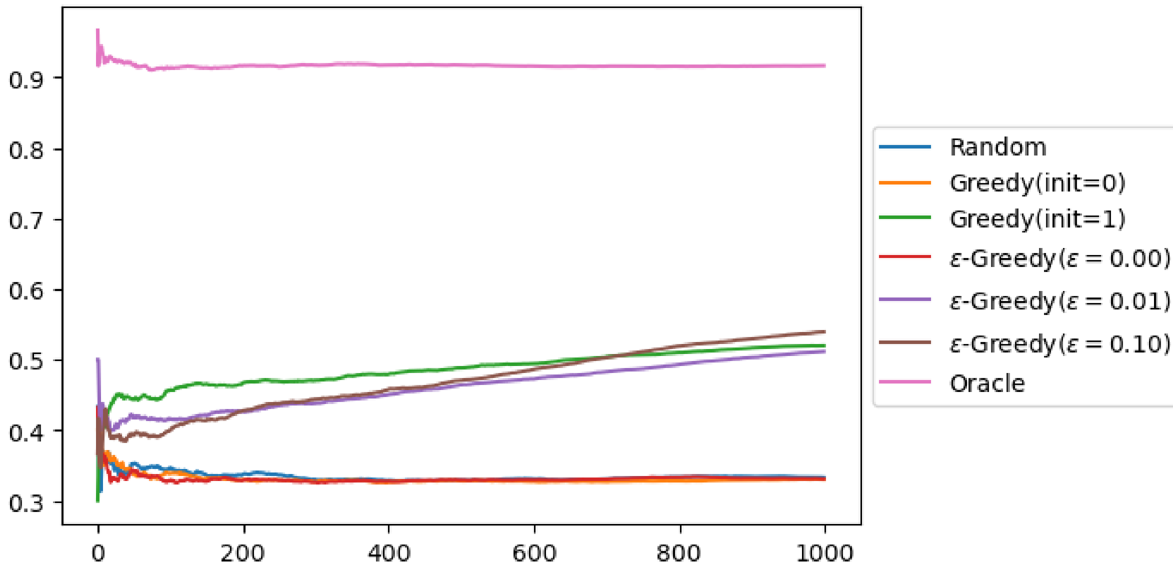
Out[7]:
```
tensor(12.)
```

Let's compare these algorithms.

In [8]:
```
# Compare algorithms
n_actions = 100
n_steps = 1000
agents = [
  RandomAgent(n_actions),
  GreedyAgent(n_actions, init_value=0),
  GreedyAgent(n_actions, init_value=1),
  EpsilonGreedyAgent(n_actions, epsilon=0.0),
  EpsilonGreedyAgent(n_actions, epsilon=0.01),
  EpsilonGreedyAgent(n_actions, epsilon=0.1),
]
label_list = []
mean_reward_tensor = []
for seed in range(30):
  mean_reward_list = []
  torch.manual_seed(seed)
  env = BernoulliBanditEnvironment(n_actions)
  #print([dist.probs.item() for dist in env.reward_dists])
  for agent in agents + [OracleAgent(env)]:
    torch.manual_seed(seed*1000)
    mean_reward = []
    cum_reward = 0
    for step in range(n_steps):
      _, reward = env.simulate_step(agent)
      cum_reward += reward
      mean_reward.append(cum_reward / (step + 1))
    mean_reward_list.append(mean_reward)
    if seed == 0:
      label_list.append(str(agent))
  mean_reward_tensor.append(mean_reward_list)

# Plot averages
average_reward_agent = torch.tensor(mean_reward_tensor).mean(dim=0)
fig = plt.figure(figsize=(6,4), dpi=100)
for x, label in zip(average_reward_agent, label_list):
  plt.plot(x, label=label)
plt.legend(loc='center left', bbox_to_anchor=(1, 0.5))
```

Out[8]: <matplotlib.legend.Legend at 0x7fa5b7ed73a0>



0.9
0.8
0.7
0.6
0.5
0.4
0.3
0
200
400
600
800
1000
Random
Greedy(init=0)
Greedy(init=1)
ε-Greedy($\varepsilon = 0.00$)
ε-Greedy($\varepsilon = 0.01$)
ε-Greedy($\varepsilon = 0.10$)
Oracle