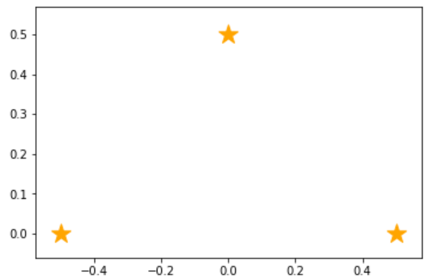
```
In [8]: %matplotlib inline
   ...: import numpy as np
   ...: from copy import copy
   ...: import math, random
   ...: import matplotlib.pyplot as plt
   ...: from matplotlib.patches import Ellipse
```

```
In [9]: class Landmark:
   ...:     def __init__(self,x,y):
   ...:         self.pos = np.array([[x],[y]])
   ...:
   ...:     def draw(self):
   ...:         plt.scatter(xs,ys,s=300,marker="*",label="landmarks",color="orange")
   ...:
   ...:     def relative_pos(self,pose):
   ...:         x,y,theta = pose
   ...:         lx,ly = self.pos[0][0],self.pos[1][0]
   ...:         distance = math.sqrt((x -lx)**2 + (y-ly)**2)
   ...:         direction = math.atan2(ly-y, lx-x) - theta
   ...:
   ...:         return (distance, direction,lx,ly)
```

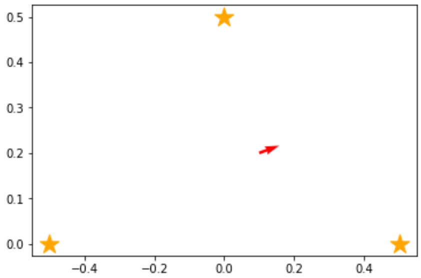
```
In [10]: class Map():
    ...:     def __init__(self):
    ...:         self.landmarks = []
    ...:
    ...:     def append_landmark(self,x,y):
    ...:         self.landmarks.append(Landmark(x,y))
    ...:
    ...:     def draw(self):
    ...:         xs = [ e.pos[0] for e in self.landmarks]
    ...:         ys = [ e.pos[1] for e in self.landmarks]
    ...:         plt.scatter(xs,ys,s=300,marker="*",label="landmarks",color="orange")
    ...:
    ...:     def relative_landmark_positions(self,pose):
    ...:         positions = []
    ...:         for i,ln in enumerate(self.landmarks):
    ...:             distance,direction,lx,ly = ln.relative_pos(pose)
    ...:             positions.append([distance,direction,lx,ly,i])
    ...:
    ...:         return positions
```

```
In [11]: m = Map()
    ...: m.append_landmark(-0.5,0.0)
    ...: m.append_landmark(0.5,0.0)
    ...: m.append_landmark(0.0,0.5)
    ...:
    ...: m.draw()
```

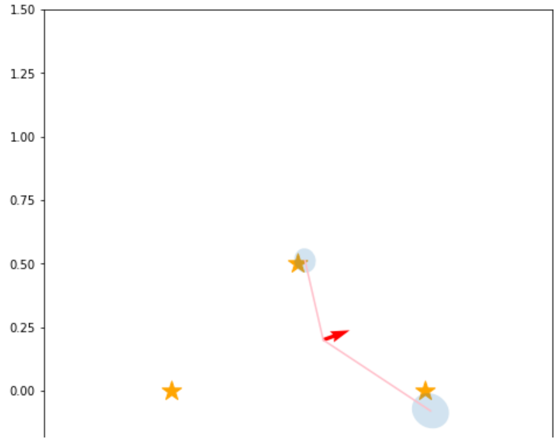



```
In [12]: class Robot:
    ...:     def __init__(self,pose):
    ...:         self.pose = pose
    ...:
    ...:     def draw(self):
    ...:         x,y,theta = self.pose
    ...:         plt.quiver([x],[y],[math.cos(theta)],[math.sin(theta)],color="red",label="actual robot motion")
    ...:
    ...:     def observation(self,m):
    ...:         measurements = m.relative_landmark_positions(self.pose)
    ...:         observations = []
    ...:
    ...:         for m in measurements:
    ...:             distance, direction,lx,ly, i = m
    ...:             if (math.cos(direction) < 0.0): continue
    ...:
    ...:             measured_distance = random.gauss(distance,distance*0.1)
    ...:             measured_direction = random.gauss(direction,5.0/180.0*math.pi)
    ...:             observations.append([measured_distance, measured_direction,lx,ly,i])
    ...:
    ...:         return observations
```

```
   ...:     def motion_model(self, pos, fw, rot):
   ...:         actual_fw = random.gauss(fw,fw/10)
   ...:         dir_error = random.gauss(0.0, math.pi / 180.0 * 3.0)
   ...:         px, py, pt = pos
   ...:
   ...:
   ...:         x = px + actual_fw * math.cos(pt + dir_error)
   ...:         y = py + actual_fw * math.sin(pt + dir_error)
   ...:
   ...:         t = pt + dir_error + random.gauss(rot,rot/10)
   ...:
   ...:         return np.array([x,y,t])

In [13]: robot = Robot(np.array([0.1,0.2,math.pi*20.0/180]) )
    ...: robot.draw()
    ...: m.draw()
```




```
In [14]: observations = robot.observation(m)
    ...: print(observations)
    ...:
    ...: fig = plt.figure(0,figsize=(8, 8))
    ...: sp = fig.add_subplot(111, aspect='equal')
    ...: sp.set_xlim(-1.0,1.0)
    ...: sp.set_ylim(-0.5,1.5)
    ...:
    ...: for observation in observations:
    ...:     x,y,theta = robot.pose
    ...:     distance, direction,lx,ly, i = observation
    ...:     lx = distance*math.cos(theta + direction) + x
    ...:     ly = distance*math.sin(theta + direction) + y
    ...:     plt.plot([robot.pose[0],  lx],[robot.pose[1],  ly],color="pink")

    ...:     c = math.cos(theta + direction)
    ...:     s = math.sin(theta + direction)
    ...:     rot = np.array([[c, -s],
    ...:                     [s,  c]])
    ...:
    ...:     err_robot = np.array([[(distance*0.1)**2,0.0],
    ...:              [0.0,(distance*math.sin(5.0/180.0*math.pi))**2]])
    ...:     err_world = (rot).dot(err_robot).dot((rot).T)
    ...:
    ...:     eig_vals,eig_vec = np.linalg.eig(err_world)
    ...:     v1 = eig_vals[0] * eig_vec[:,0]
    ...:     v2 = eig_vals[1] * eig_vec[:,1]
    ...:     v1_direction = math.atan2(v1[1],v1[0])
    ...:
    ...:     elli =
Ellipse([lx,ly],width=3*math.sqrt(np.linalg.norm(v1)),height=3*math.sqrt(np.linalg.norm(v2)),angle=v1_direction/3.14*180)
    ...:     elli.set_alpha(0.2)
    ...:     sp.add_artist(elli)
    ...:
    ...: robot.draw()
    ...: m.draw()
[[0.5055946596505443, -0.9327621060375112, 0.5, 0.0, 1], [0.32058269526034644, 1.4475772201042925, 0.0, 0.5, 2]]
```

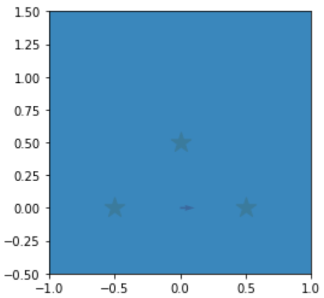


```
In [15]: class LandmarkEstimation():
    ...:     def __init__(self):
    ...:         self.pos = np.array([[0.0],[0.0]])
    ...:         self.cov = np.array([[1000000000.0**2,0.0],
    ...:                              [0.0,1000000000.0**2]])
```

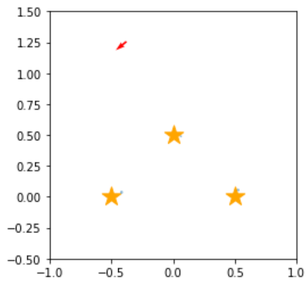
```
In [16]: class Particle():
    ...:     def __init__(self,pose,w):
    ...:         self.w = w
    ...:         self.pose = pose
    ...:         self.map = [LandmarkEstimation(),LandmarkEstimation(),LandmarkEstimation()]
    ...:
    ...:     def motion_update(self, fw, rot, robot):
    ...:         self.pose = robot.motion_model(self.pose, fw, rot)
    ...:
    ...:     def measurement_update(self, measurement):
    ...:         x,y,theta = self.pose
    ...:         distance, direction,lx,ly,i = measurement
    ...:         ln = self.map[i]
    ...:         lx = distance*math.cos(theta + direction) + x
    ...:         ly = distance*math.sin(theta + direction) + y
    ...:
    ...:         delta = np.array([[x],[y]]) - np.array([[lx],[ly]])
    ...:         coef = 2*math.pi * math.sqrt(np.linalg.det(ln.cov))
    ...:         inexp = -0.5 * (delta.T.dot(np.linalg.inv(ln.cov))).dot(delta)
    ...:         self.w *= 1.0/coef * math.exp(inexp)
    ...:
    ...:         z = np.array([[lx],[ly]])
    ...:
    ...:         c = math.cos(theta + direction)
    ...:         s = math.sin(theta + direction)
    ...:         rot = np.array([[c, -s],
    ...:                         [s,  c]])
    ...:
    ...:         err_robot = np.array([[(distance*0.1)**2,0.0],
    ...:                              [0.0,(distance*math.sin(5.0/180.0*math.pi))**2]])
    ...:         err_world = (rot).dot(err_robot).dot((rot).T)
    ...:
    ...:         ln.cov = np.linalg.inv( np.linalg.inv(ln.cov) + np.linalg.inv(err_world) )
    ...:         K = (ln.cov).dot(np.linalg.inv(err_world))
    ...:         ln.pos += K.dot( z - ln.pos )
    ...:
    ...:     def draw(self,i):
    ...:         fig = plt.figure(i,figsize=(4, 4))
    ...:         sp = fig.add_subplot(111, aspect='equal')

    ...:         sp.set_xlim(-1.0,1.0)
    ...:         sp.set_ylim(-0.5,1.5)
    ...:
    ...:         m.draw()
    ...:         x,y,theta = self.pose
    ...:         plt.quiver([x],[y],[math.cos(theta)],[math.sin(theta)],color="red",label="actual robot motion")
    ...:
    ...:         for e in self.map:
    ...:             eig_vals,eig_vec = np.linalg.eig(e.cov)
    ...:             v1 = eig_vals[0] * eig_vec[:,0]
    ...:             v2 = eig_vals[1] * eig_vec[:,1]
    ...:             v1_direction = math.atan2(v1[1],v1[0])
    ...:
    ...:
    ...:             x,y = e.pos
    ...:             elli =
Ellipse([x,y],width=3*math.sqrt(np.linalg.norm(v1)),height=3*math.sqrt(np.linalg.norm(v2)),angle=v1_direction/3.14*180)
    ...:             elli.set_alpha(0.5)
    ...:
    ...:             sp.add_artist(elli)
```

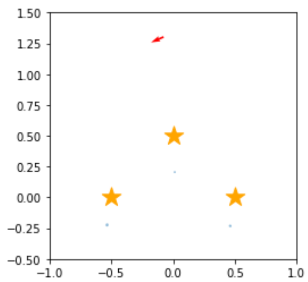
```
In [17]: import copy
    ...:
    ...: class FastSLAM():
    ...:     def __init__(self,pose):
    ...:         self.particles = [Particle(pose,1.0/100) for i in range(100)]
    ...:
    ...:     def draw(self):
    ...:         for (i,p) in enumerate(self.particles):
    ...:             p.draw(i)
    ...:             if i > 3: return
    ...:
    ...:     def motion_update(self, fw, rot, robot):
    ...:         for p in self.particles:
    ...:             p.motion_update(fw,rot, robot)
    ...:
    ...:     def measurement_update(self, measurement):
    ...:         for p in self.particles:
    ...:             p.measurement_update(measurement)
    ...:
    ...:         self.resampling()
```

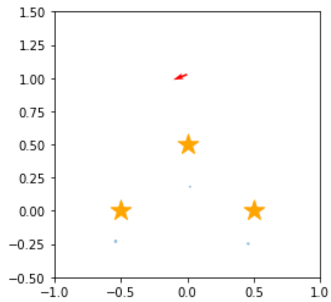
```
    ...:     def resampling(self):
    ...:         num = len(self.particles)
    ...:         ws = [e.w for e in self.particles]
    ...:
    ...:         if sum(ws) < 1e-100:
    ...:             ws = [e + 1e-100 for e in ws]
    ...:
    ...:         ps = random.choices(self.particles, weights=ws, k=num)
    ...:         self.particles = [copy.deepcopy(e) for e in ps]

In [18]: robot.pose = np.array([0.0,0.0,0.0])    #ロボットの実際の姿勢
    ...: slam = FastSLAM(robot.pose)
    ...: slam.draw()
```

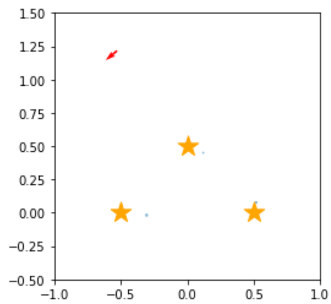


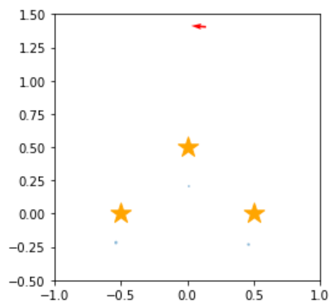
```
In [19]: def one_step(m):
    ...:     slam.motion_update(0.2, math.pi / 180.0 * 20, robot)
    ...:     robot.pose = robot.motion_model(robot.pose, 0.2, math.pi / 180.0 * 20)
    ...:     measurements = robot.observation(m)
    ...:     for m in measurements:
    ...:         slam.measurement_update(m)
    ...:
    ...: n = 100
    ...: for i in range(n):
    ...:     one_step(m)
    ...:
    ...: print(str(n) + "step後の地図")
    ...: slam.draw()
100step後の地図
```











```
In [20]:
```