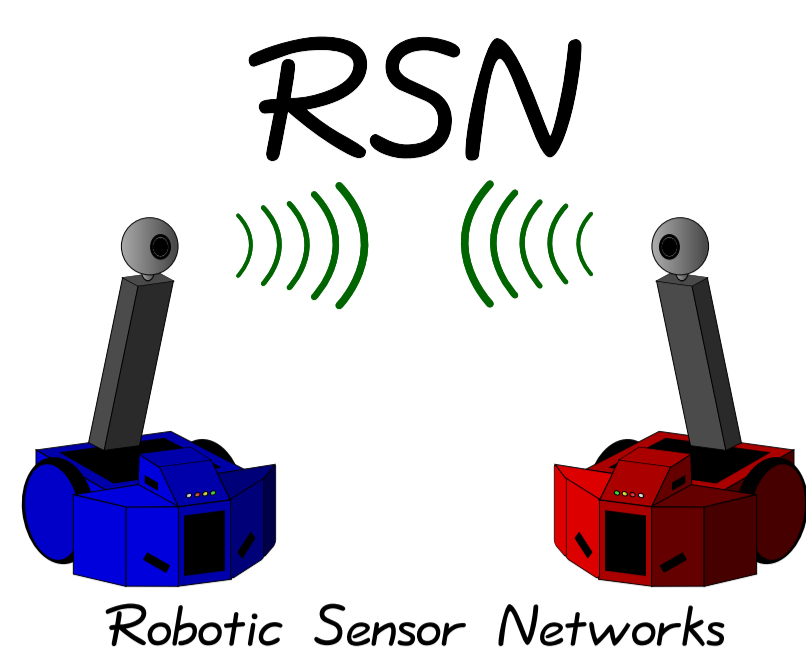


# Sensor Placement for Triangulation Based Localization

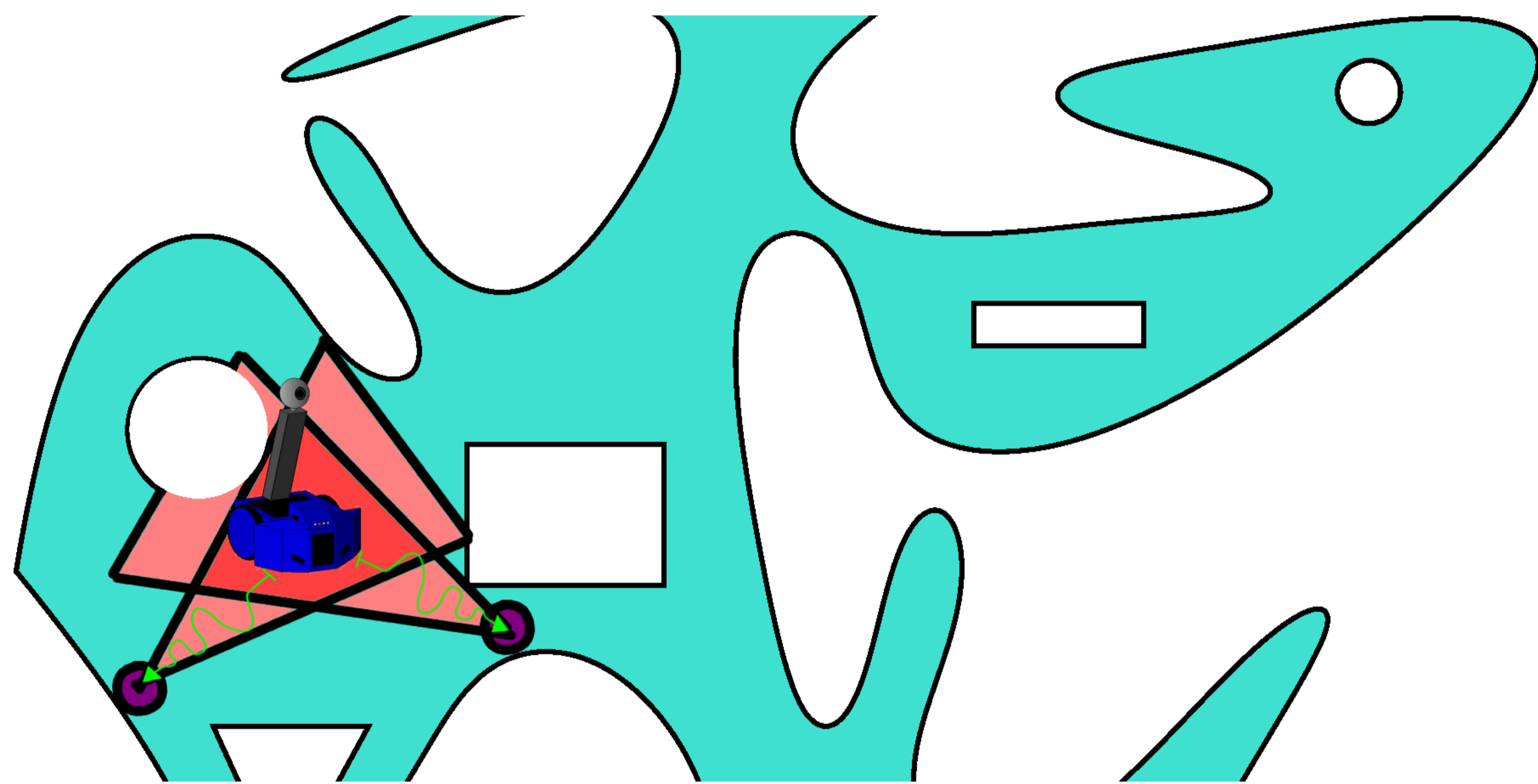


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## Motivation:

A fundamental component of a mobile-robot system is the ability to localize itself accurately in a workspace. However, due to the inaccuracy of robot hardware, mobile-robots can not localize themselves, accurately. The presence of a sensor-network (a network of small and cheap devices with sensing capabilities) can provide a robust and scalable solution to the localization problem.

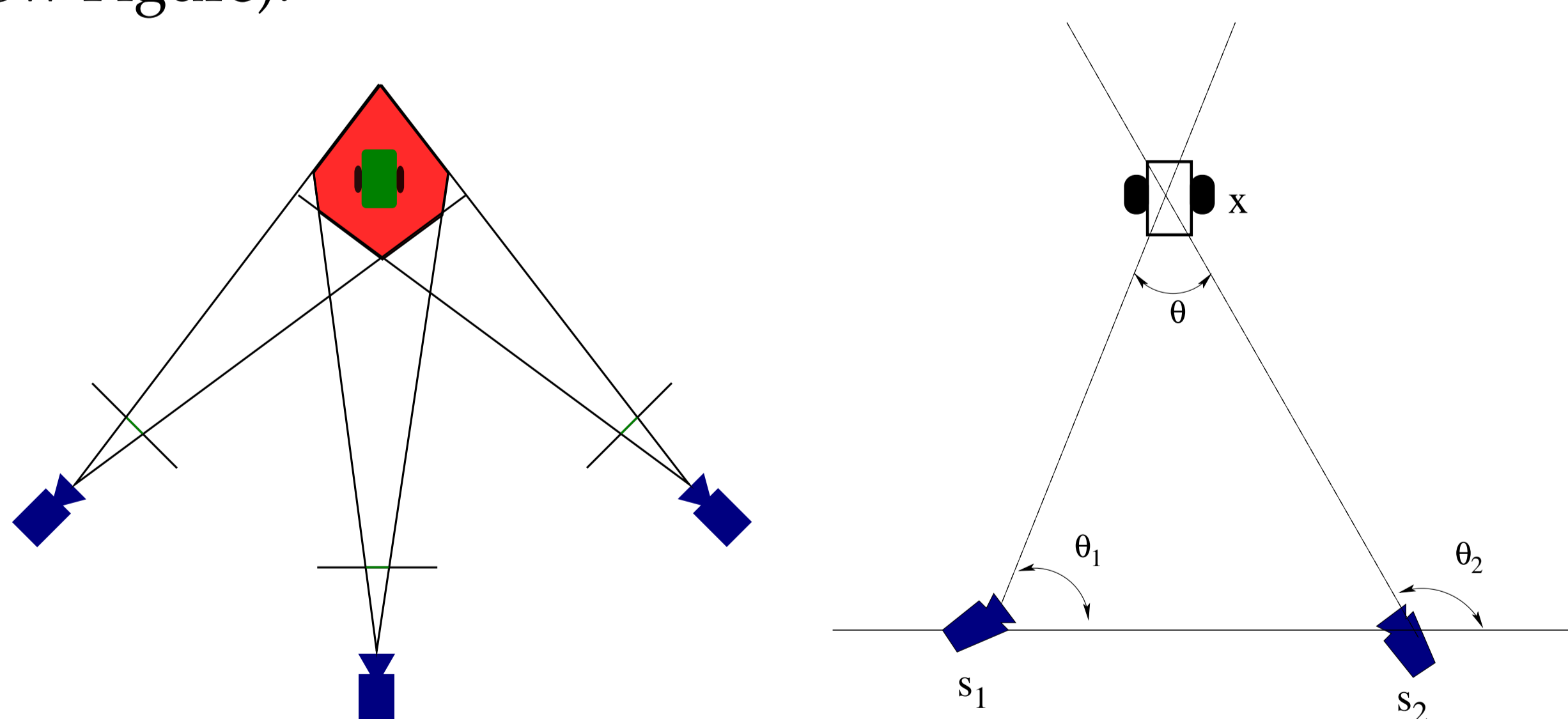


## State Estimation:

State estimation with sensor-networks is achieved by merging measurements from different sensors. Figure (Left Below) shows a geometry based state estimation with a camera-network. The conical region defined by camera location and projection of the object on the image plane, represents the state estimation of the object obtained by that camera. A robot can estimate its own location as the intersection of these measurements. Our focus is on triangulation based state estimation where only two cameras are used. In case of cameras, triangulation based uncertainty is given by:

$$U(s_1, s_2, x) = \frac{d(s_1, x) \times d(s_2, x)}{|\sin \angle s_1 x s_2|}$$

where  $d(x, y)$  denotes the Euclidean distance between  $x$  and  $y$  and  $\theta = \angle s_1 x s_2$  is the angle between the sensors and the target (Right Below Figure).



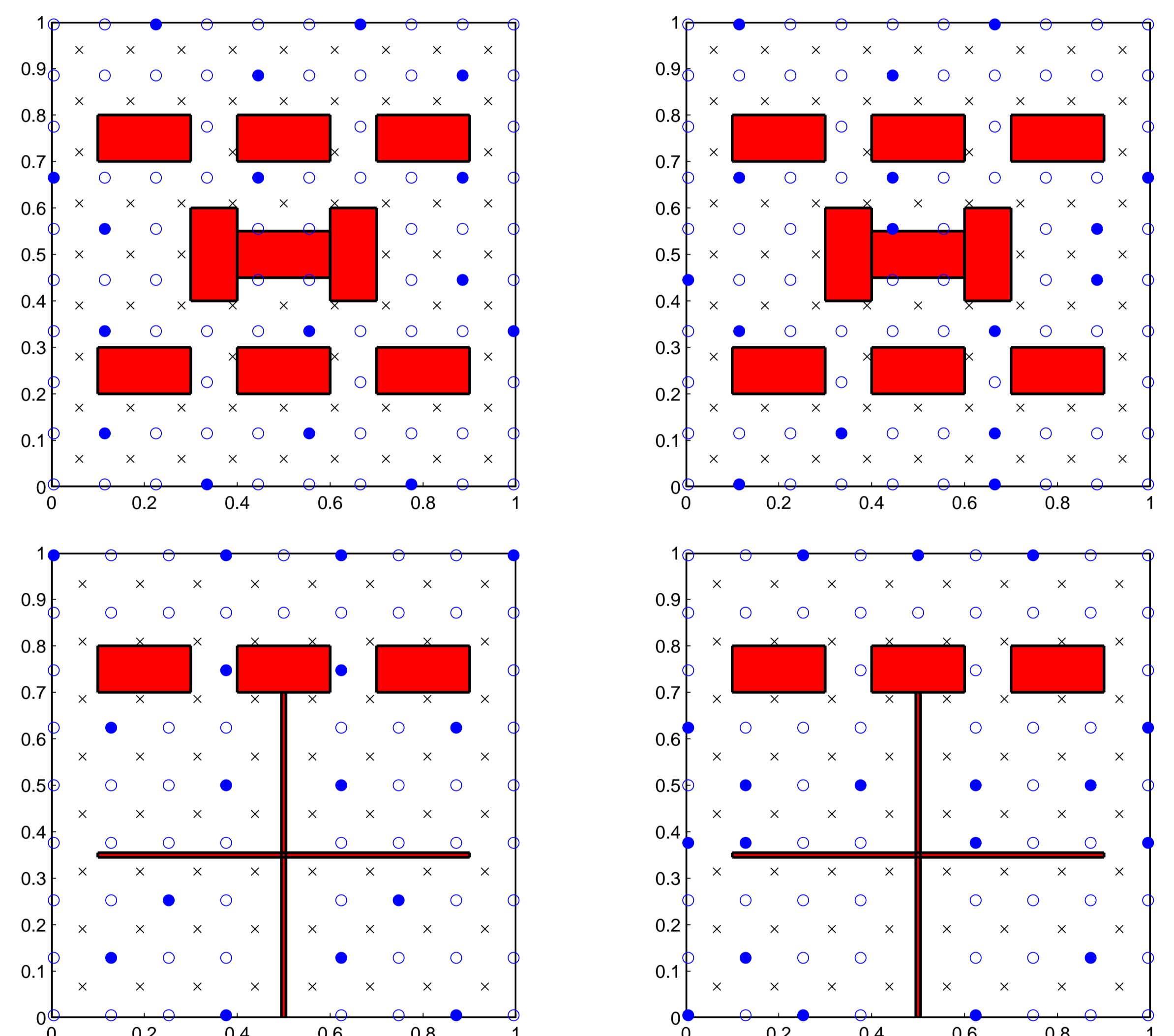
## Problem Formulation:

Let  $\mathcal{W}$  be the workspace which consists of all possible locations of the robot. For concreteness, we assume that  $\mathcal{W}$  is discretized. Similarly, let  $\mathcal{S}$  be the set of candidate sensor locations. For a given placement  $S$  and a location  $w \in \mathcal{W}$ , let  $assign(w, S)$  be the assignment function which chooses the best pair of sensors for  $w$ . Then, the uncertainty of a placement is defined as  $U(S, \mathcal{W}) = \max_{w \in \mathcal{W}} U(w, assign(w, S))$ . We can now define the *Sensor Placement Problem*: Given a workspace  $\mathcal{W}$ , candidate sensor locations  $\mathcal{S}$ , an uncertainty function  $U$  and an uncertainty threshold  $U^*$ , find a placement  $S$  with minimum cardinality such that  $U(S, \mathcal{W}) \leq U^*$ .

## Placement Algorithms:

We show that the general problem for arbitrary uncertainty models is computationally hard and we present two approximation algorithms for two different geometric instances. In the first instance, we present an approximation algorithm that deviates from the optimal solution only by a constant factor both in the number of cameras and the uncertainty in localization. However, in this instance we do not address the issue of visual-occlusions. We address visual occlusions in the second instance and present a *log-factor* approximation algorithm for a more restricted uncertainty measure (where thresholds for allowable angle and sensor-target distances are given). Finally, for the general problem, we present a solution framework based on integer linear programming and demonstrate its practical feasibility with simulations.

## Simulations:



In this simulation, we compare the ILP solution with the approximation algorithm in two different environments. Target points in the environment are represented by the symbol  $\times$ . Candidate sensor locations are represented by the symbol  $\circ$ . A filled circle indicates a sensor placed at that location. The figures on the left (resp. right) column shows the placements obtained using the ILP solution (resp. approximation algorithm for the second instance). **TOP ROW:** In this simulation, both algorithms place 16 sensors. **BOTTOM ROW:** In this simulation, the ILP solution achieved the desired uncertainty with 16 sensors whereas the approximation algorithm achieved the same uncertainty with 18 sensors.

## References

- [1] O. Tekdas and V. Isler, "Sensor Placement for Triangulation Based Localization," *Proc. IEEE Int. Conf. on Robotics and Automation*, (Rome, Italy: April 2007 (to appear)).