Spatial Considerations

A system that interacts with its environment should be “aware” of its surroundings

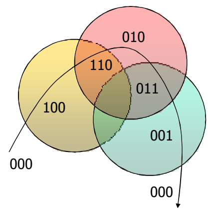
Target Tracking with Binary Proximity Sensors

- Simplest sensor model:
  - Binary

“Awareness” of the Physical World: Algorithmic Foundations

- Tracking (with perfect binary sensors)
- General tracking with imperfect sensors
- Multi-target tracking
- Hypothesis testing and data association
- Bayesian estimation
- Classification

Locating Objects in the Physical World (with Binary Sensors)



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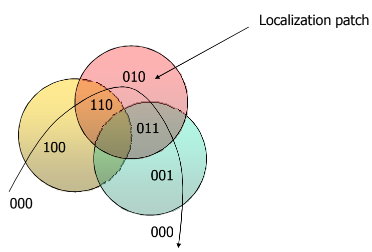

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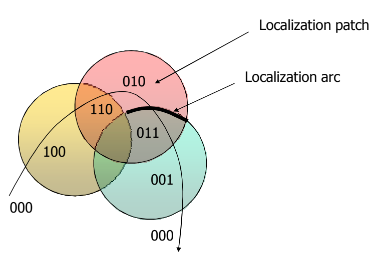

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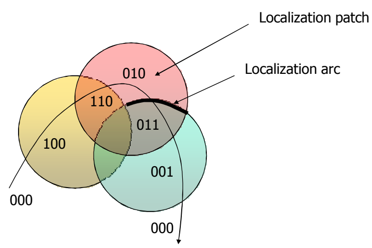
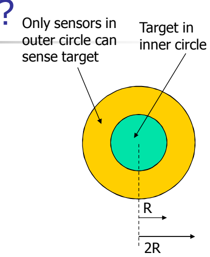


Note: Can localize only to within a patch

Patch Diameter?

- N = $\rho(4\pi R^2)$ sensors in outer circle



Patch Diameter?

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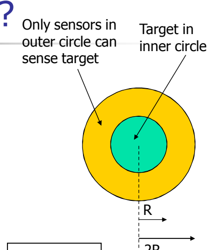
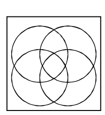
- There are at most N (N-1) + 2 patches in the inner circle





Patch Diameter?

- $N = \rho(4\pi R^2)$ sensors in outer circle
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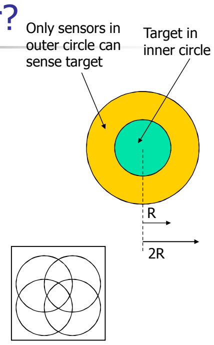
- Patch area is at least $\pi R^2/16\rho^2\pi^2R^4$



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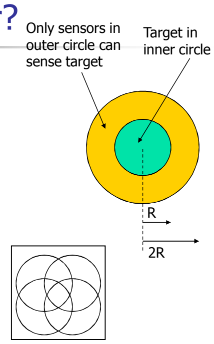

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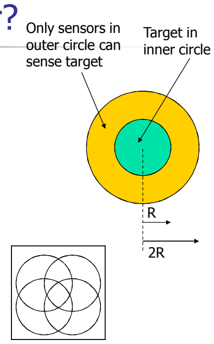
- Area = $\Omega(1/\rho^2R^2)$
- Diameter = $\Omega(1/\rho R)$



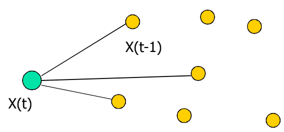
Result: Tracking Accuracy

Location error is at best
$1/\rho R$

General Target Tracking with Imperfect Sensors

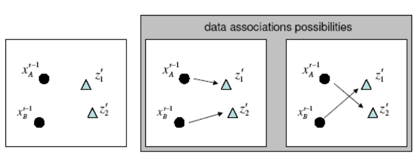
- The general single trajectory estimation problem

$$P(\text{target at } X(t)) = \int P(\text{target at } X(t) \mid \text{target was at } X(t-1)) * P(\text{target was at } X(t-1) \mid \text{observations}(t-1))\, dX(t-1)$$



Multiple Target Tracking

- The data association problem:



(a) (b) (c)

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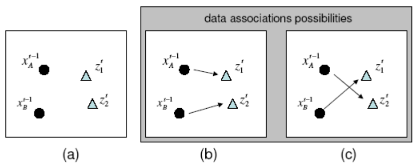

N targets → N! possible associations

Multiple Target Tracking

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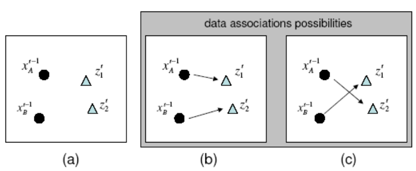
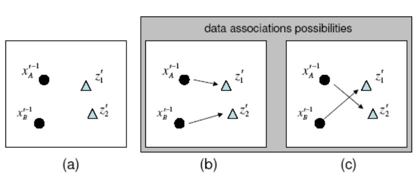


N targets → N! possible associations
T samples → $(N!)^T$ possible associations

Multiple Hypothesis Testing



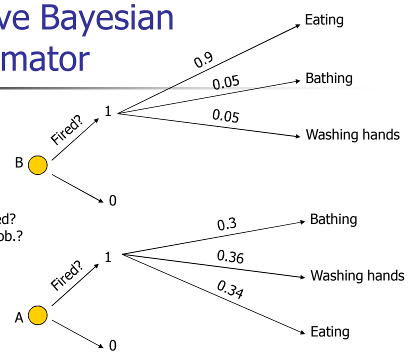
Consider $(N!)^K$ possible associations (where K is some window size → keep the top M hypotheses

Loop: Consider M(N!) possible track extensions → Keep top M

Spatial Activity Recognition

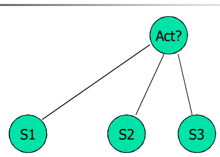
- Cameras and microphones?
  - Too intrusive
- Simple "switch" sensors
  - Perform activities
  - Collect vectors of sensor measurements for each activity
  - Find the probability that an activity is performed when a sensor is on.
  - Naive Bayesian Estimator: Multiply out the sensor probabilities.

Naive Bayesian Estimator



Both A and B Fired?
eating with prob.?

Naïve Bayesian Estimation



$$Act = \arg\max P(Act = a \mid S_1 = r_1, S_2 = r_2, \ldots, S_n = r_n)$$

$$Act = \arg\max \frac{P(Act = a)\prod P(S_i = r_i \mid Act = a)}{\prod P(S_i = r_i)}$$

Classification

- Recursively find sensor with highest information gain
  - Person vs. no person?
    - Motion sensor
      - ON: 70% person, 30% no person
      - OFF: 5% person, 95% no person
    - Magnetic sensor:
      - ON: 50% person, 50% no person
      - OFF: 55% person, 45% no person
    - Sounds sensor:
      - ON: 60% person, 40% no person
      - OFF: 50% person, 50% no person

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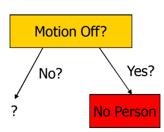

Classification

- Find sensor with highest information gain
  - Person vs. no person? Motion sensor ON and
    - Magnetic sensor:
      - ON: 65% person, 35% no person
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    - Sounds sensor:
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  - Pick magnetic sensor

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