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IDENTIFYING INSUFFICIENT DATA COVERAGE FOR ORDINAL CONTINUOUS-VALUED ATTRIBUTES

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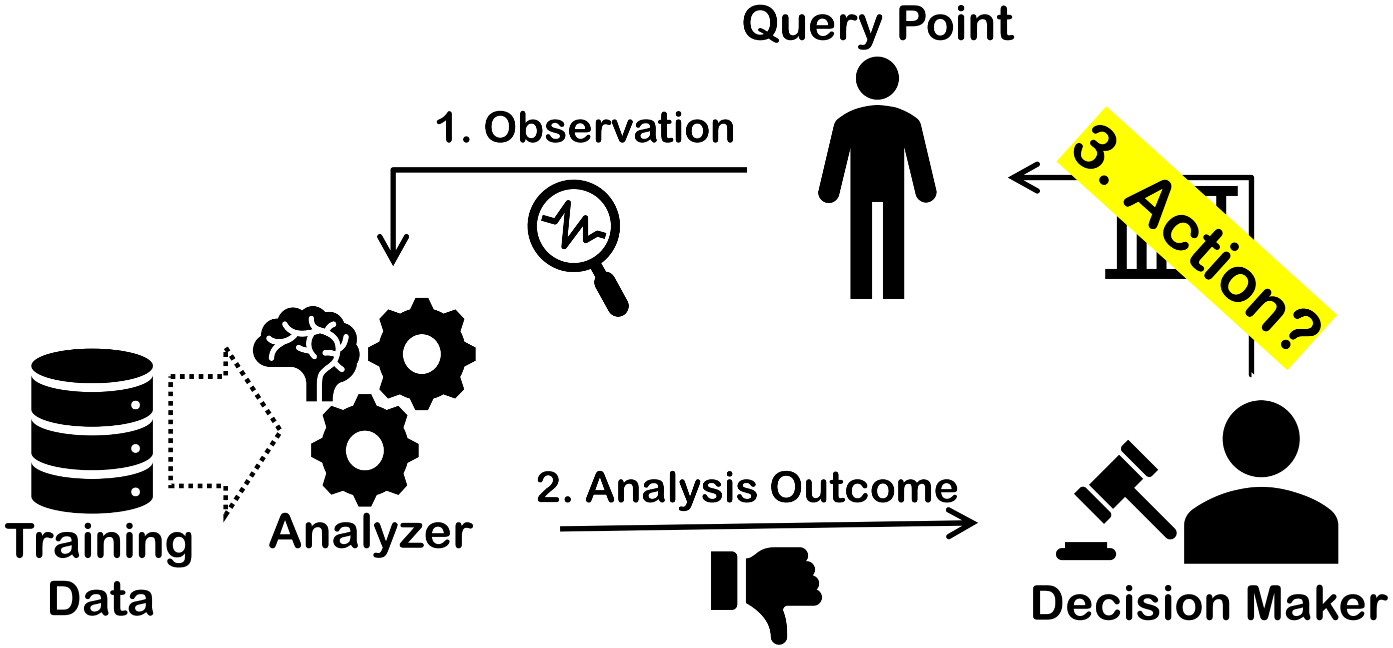
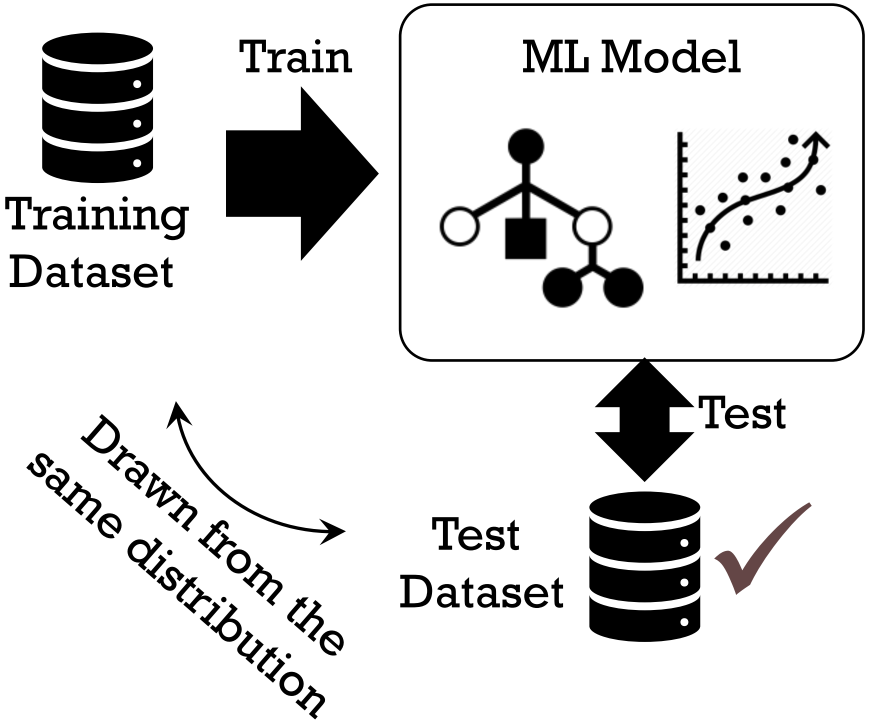
OUTLINE

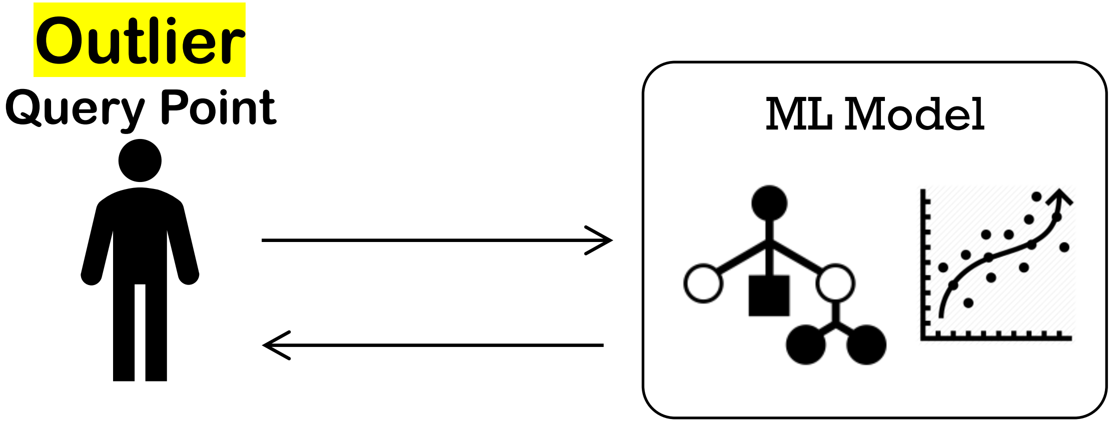
- Motivation
- Coverage
- Coverage in 2D
- Coverage in MD
- Experiments

MOTIVATION


Query Point
1. Observation
3. Action?
Training Data
Analyzer
2. Analysis Outcome
Decision Maker

MOTIVATION





(Lucky): Predictable by non-outlier points → 👍

(Unlucky): Not Predictable → 👎

COVERAGE

- We may not trust the outcome, if the query point is an outlier.

- The query point **q** is covered by training data, if
  - there are at least **k** (training) points in neighborhood

$$Cov_{\rho,k}(q, \mathcal{D}) = \begin{cases} true & if\ |\{t \in \mathcal{D} \mid \Delta(t, q) \leq \rho\}| \geq k \\ false & otherwise \end{cases}$$

- w/o loss of generality, we use ℓ_2 norm for the distance function

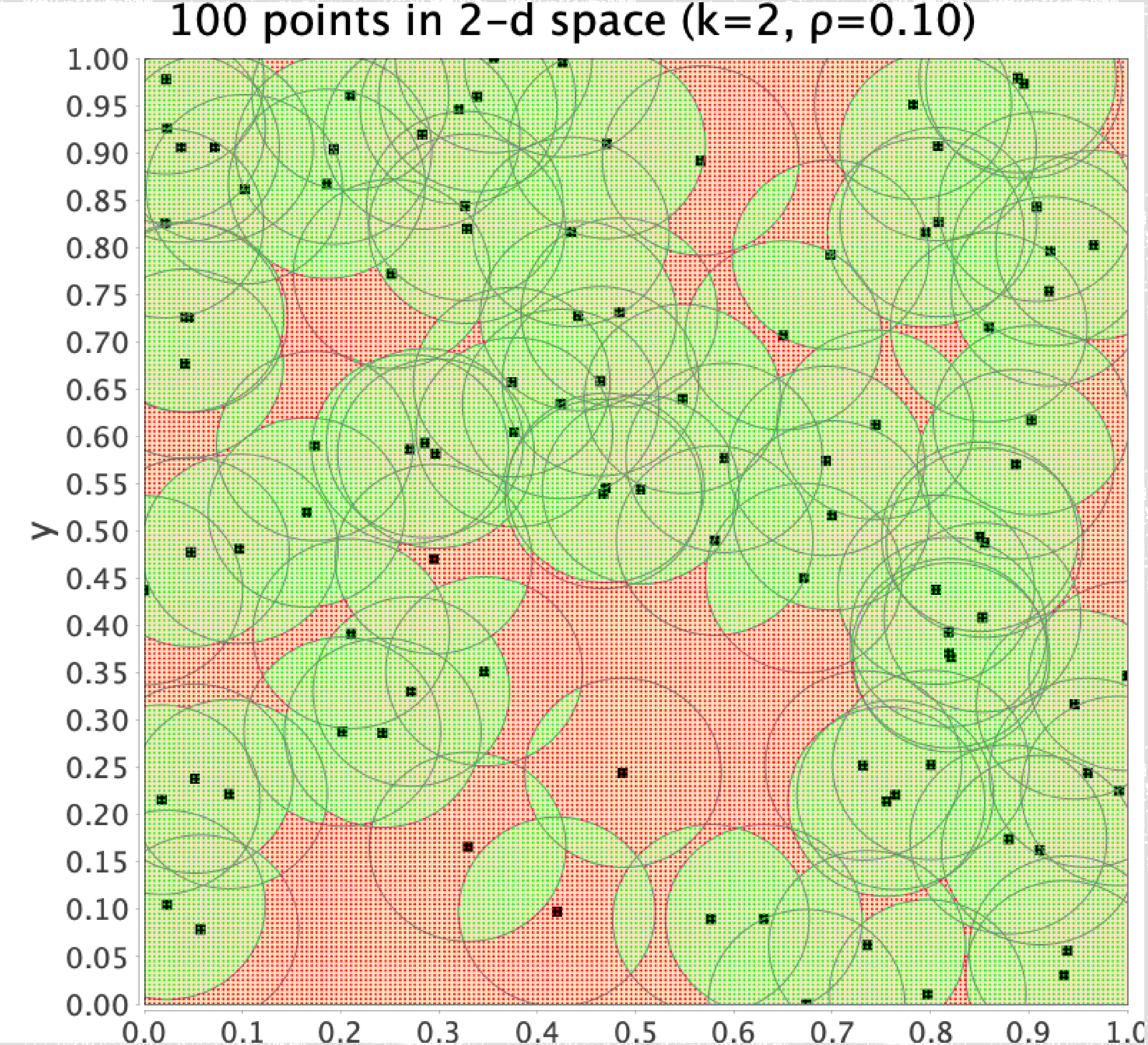
UNCOVERED REGION

- The collection of all uncovered points – any query point in this region is uncovered

- Given a dataset D with d attributes (features) $x_1 \ldots x_d$, a distance function $\Delta: R^d \times R^d \rightarrow R$, a vicinity value ρ, and a threshold value k, the uncovered region U is the set of points (value combinations) that are not covered by D. Formally:

$$U = \{q \in [0,1]^d \mid Cov(q, D) = false\}$$

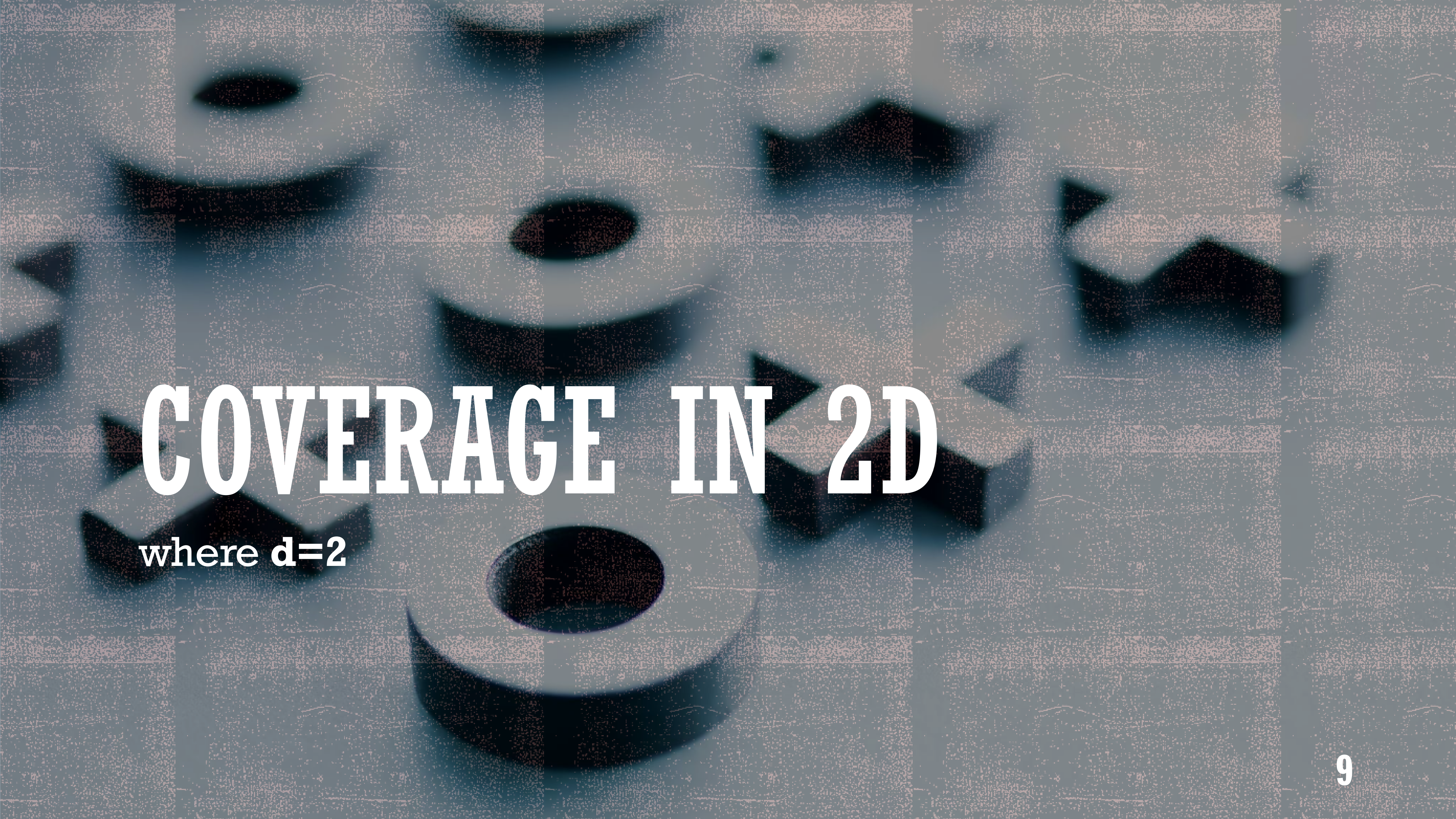
UNCOVERED REGION EXAMPLE



PROBLEM FORMULATION

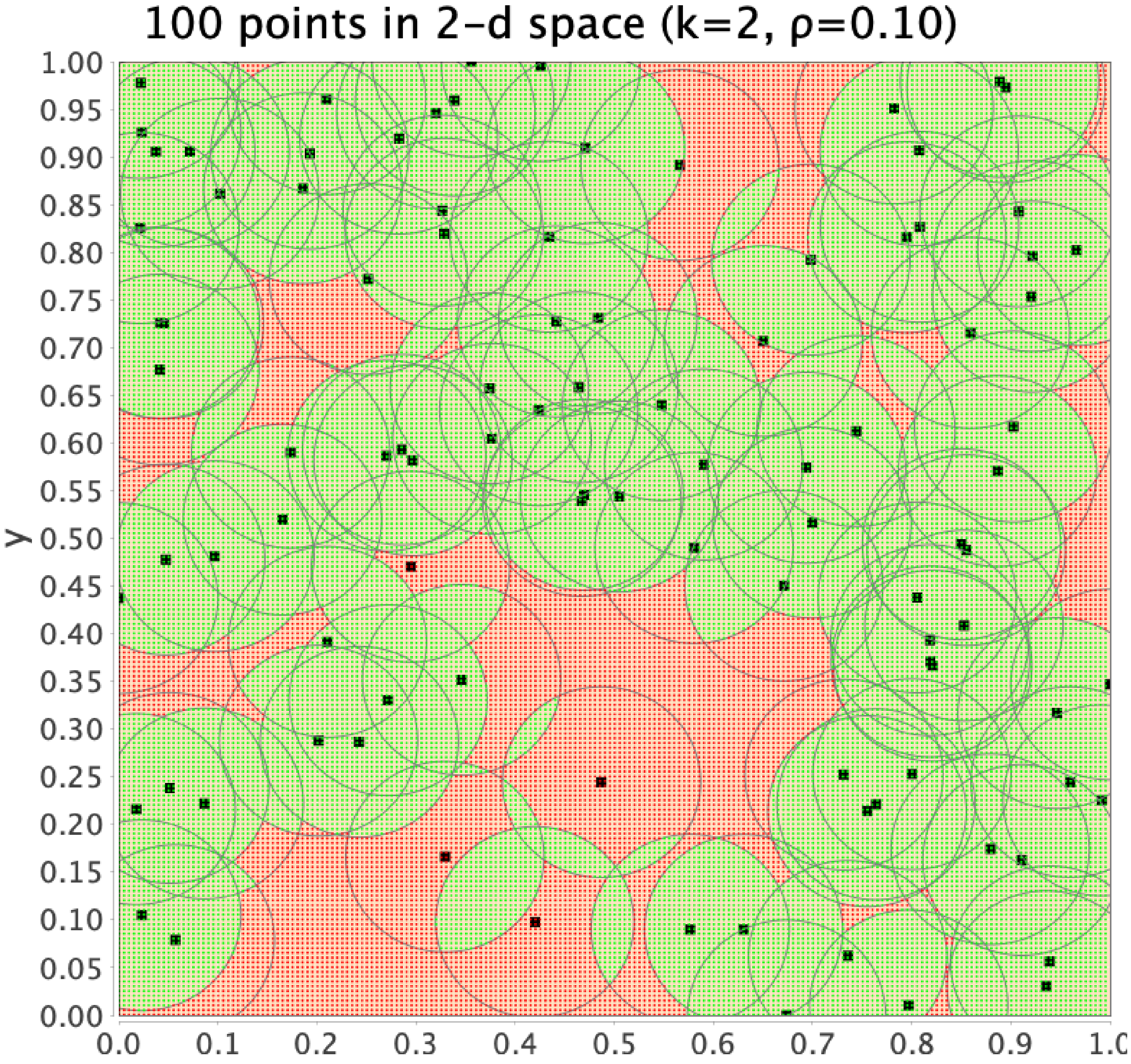
- Problem 1 (Uncovered Region Discovery): Given a dataset **D**, identify the uncovered region
  - Dataset *Annotation*: shows *potential deficiencies* in the (training) data set.

- Problem 2 (Uncovered Query Answering): Given the uncovered region, identify if a query point **q** is uncovered.



COVERAGE IN 2D

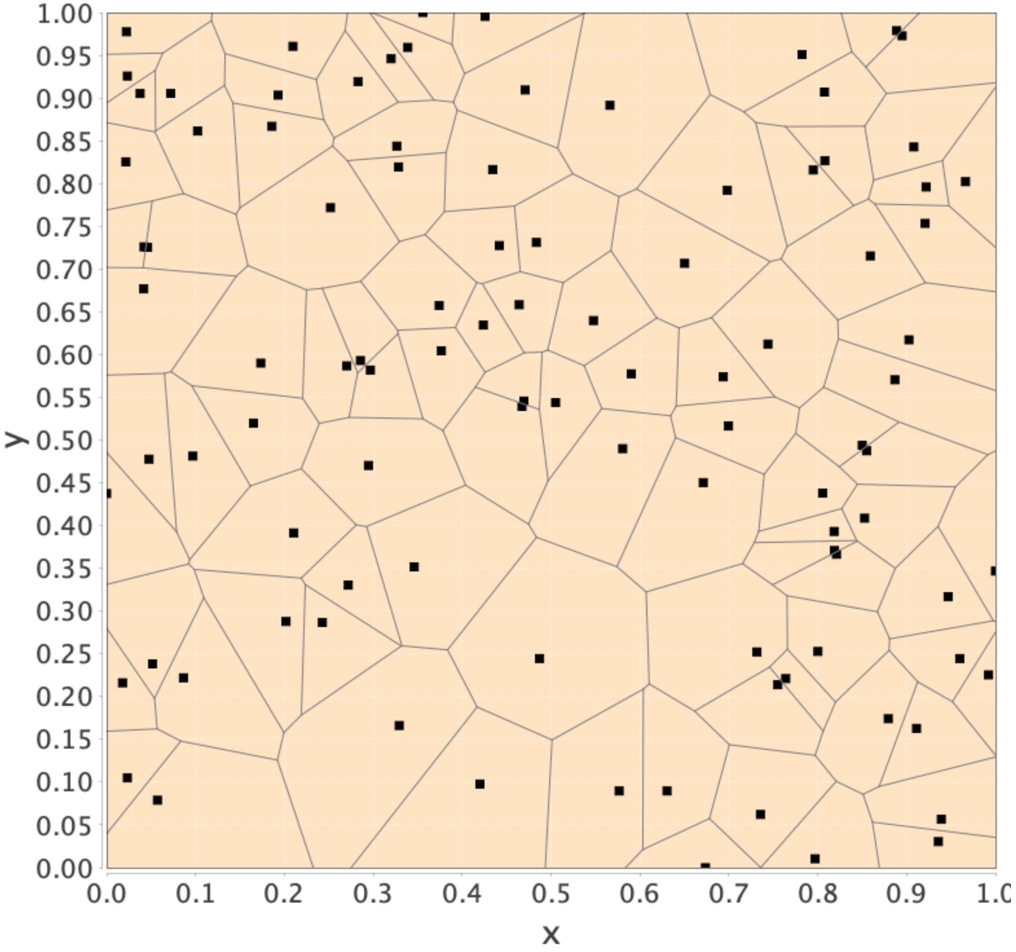
where **d=2**



UNCOVERED REGION EXAMPLE

(REVIEW): VORONOI DIAGRAMS

100 points in 2-d space (k=1, ρ=0.10)

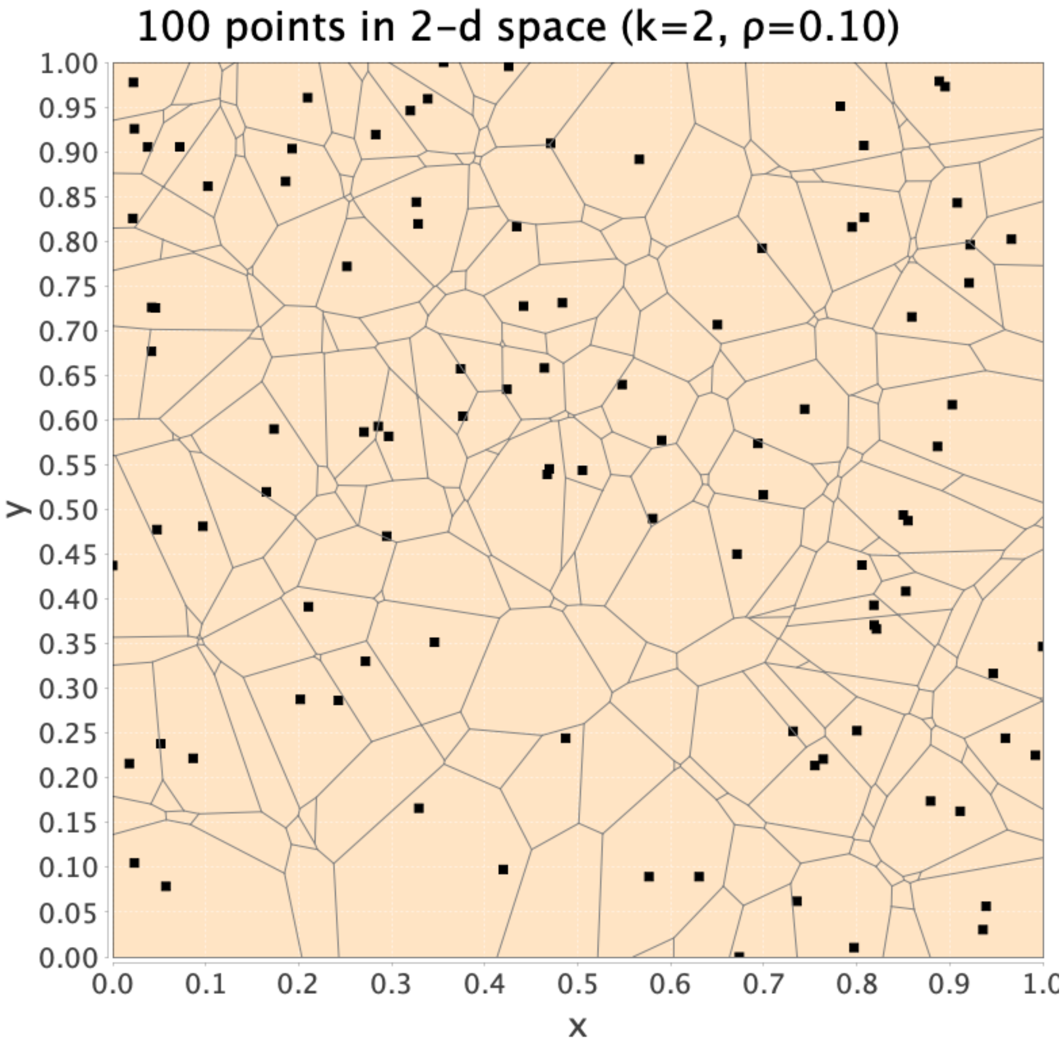


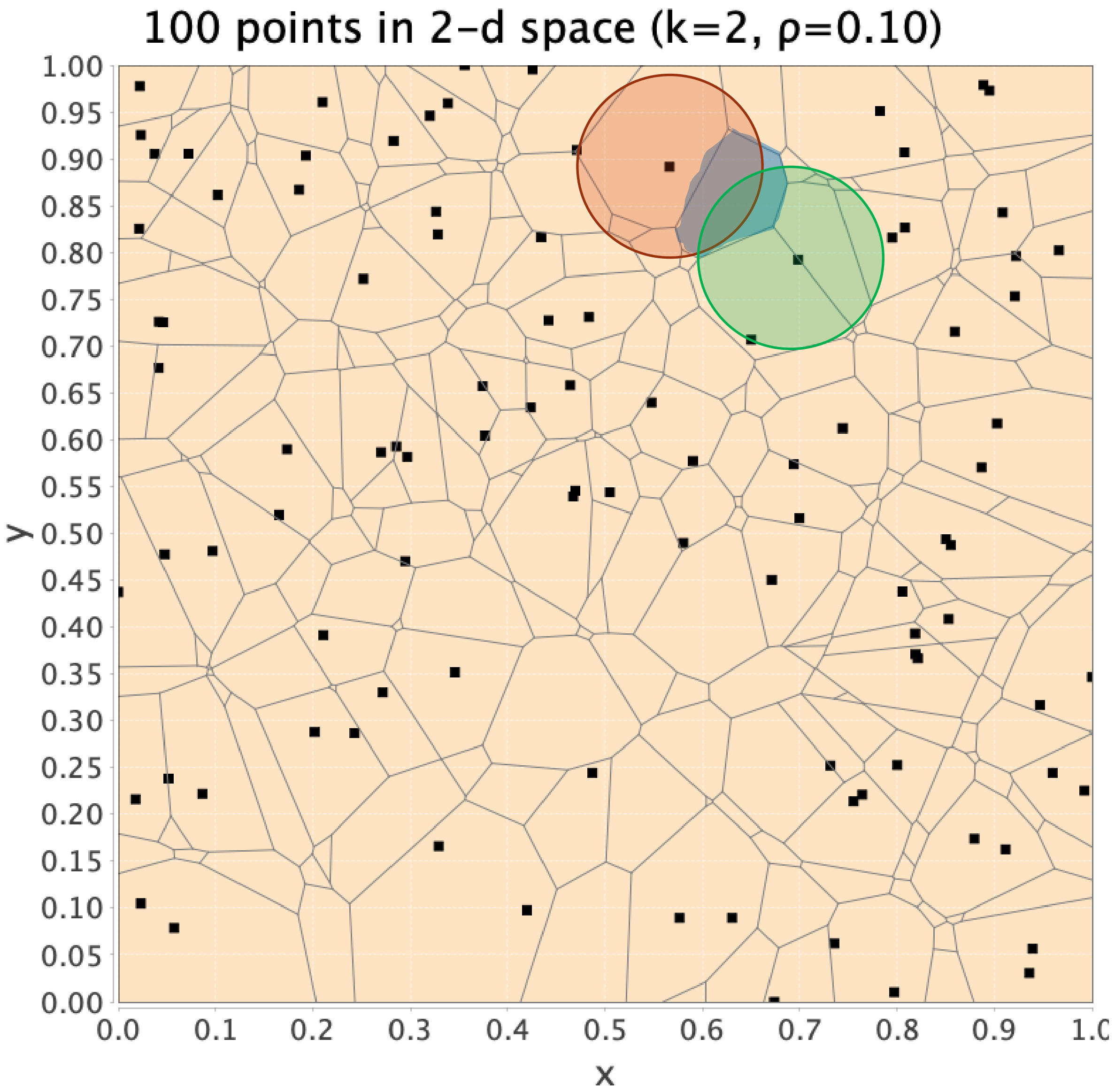
- Partition of a plane with **n** points into cells, such that all points in each cell have the same nearest point.

(REVIEW): K-VORONOI DIAGRAMS

- Extend the notion of Voronoi diagrams from nearest neighbor to k-nearest neighbor

- $O(k(n-k))$ cells
- Construction [D. T. Lee et al.]:
  - Time: $O(k^2\, n \log(n))$
  - Space: $O(k^2(n-k))$
- Query time:
  - $O(\log n)$





Connection to k-Voronoi Diagrams

- Uncovered Region Discovery :
  - Construct the k-Voronoi diagram
  - For every Voronoi cell $V(S)$:
    - Add the region outside the intersection $\cap\, O_t\ \forall\, t \in\ S$ to the uncovered region

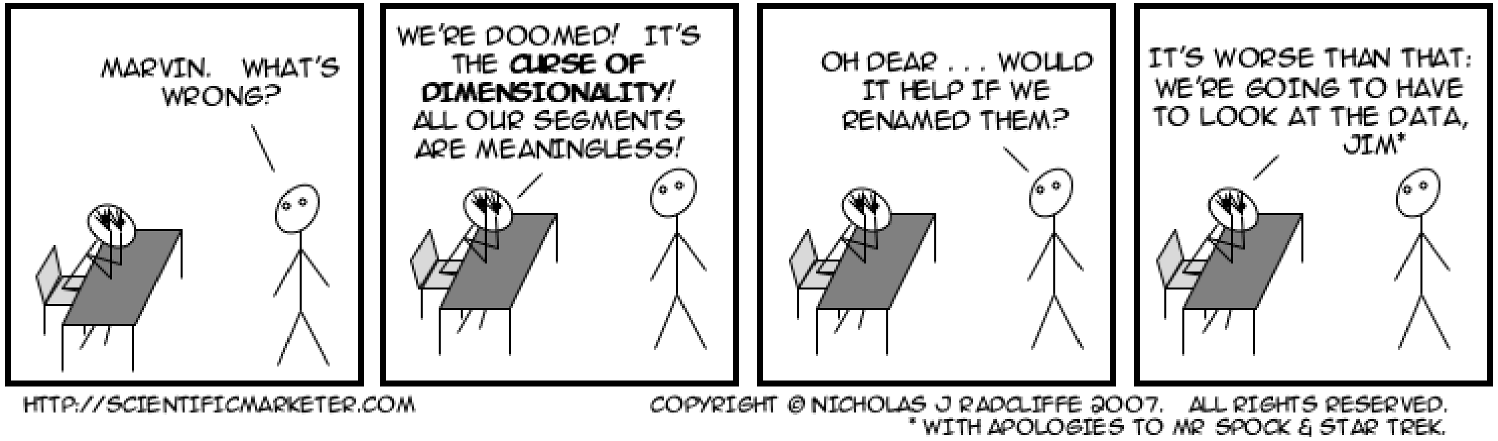
- Uncovered Query Answering:
  - Find the cell **V(S)** that **q** belongs to
  - return **uncovered** iff $\exists t \in S$ s.t. $\Delta(q,t) > \rho$

COVERAGE IN MD

where **d**≥**2**

EXTENDING 2D CASE TO MD

- **Theoretically**: Yes, but…
- **Practically**: No, due to the curse of dimensionality


MARVIN. WHAT'S WRONG?
WE'RE DOOMED! IT'S THE CURSE OF DIMENSIONALITY! ALL OUR SEGMENTS ARE MEANINGLESS!
OH DEAR . . . WOULD IT HELP IF WE RENAMED THEM?
IT'S WORSE THAN THAT: WE'RE GOING TO HAVE TO LOOK AT THE DATA, JIM*
HTTP://SCIENTIFICMARKETER.COM
COPYRIGHT © NICHOLAS J RADCLIFFE 2007. ALL RIGHTS RESERVED.
* WITH APOLOGIES TO MR SPOCK & STAR TREK.

LEARN THE UNCOVERED REGION *(APPROXIMATELY)*

- **High-level idea**:
  - Construct an $\boldsymbol{\epsilon}$**-net** by sampling "enough" query points:
    - A sample point is labeled as +1 if uncovered, -1 otherwise
  - Learn the uncovered region boundary using the $\boldsymbol{\epsilon}$**-net**

- **Negative result** (A theoretical upper-bound on the complexity of uncovered region)
  - In $\mathbf{R^d}$, the VC-dimension of the uncovered region is bounded by

$$\boldsymbol{O}(\,(\boldsymbol{d}+\mathbf{1})\,\boldsymbol{n}^{\left\lfloor \frac{\boldsymbol{d}}{2} \right\rfloor}\,\boldsymbol{k}^{\left\lceil \frac{\boldsymbol{d}}{2}+\mathbf{1} \right\rceil}\,)$$

LEARN THE UNCOVERED REGION *(APPROXIMATELY)*

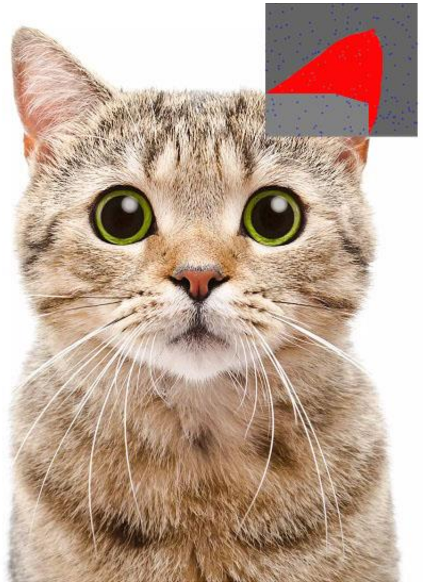
- **Practical Resolution**:
  - **Observation**: The boundary complexity depends on the number of arcs constructing it – which can be significantly less than the upper-bound
  - **High-level idea**: Apply an **exponential search** on the number of samples, until the result forms an ϵ**-net**

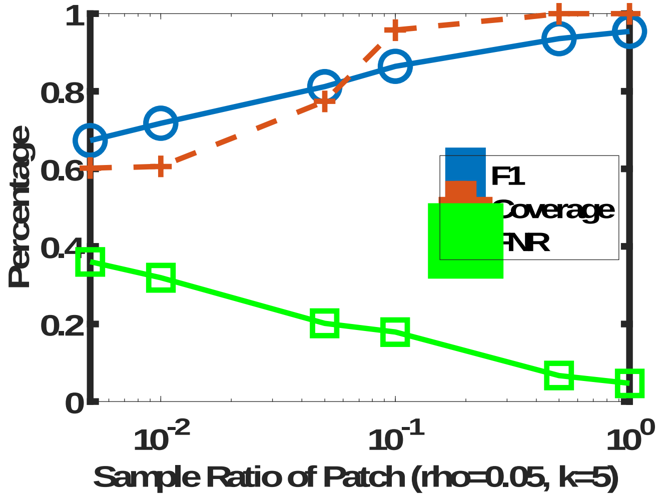
- **Uncovered Query Answering:**
  - Pass the query point **q** to the learned classifier.

EXPERIMENTS

PROOF OF CONCEPT: CLASSIFICATION

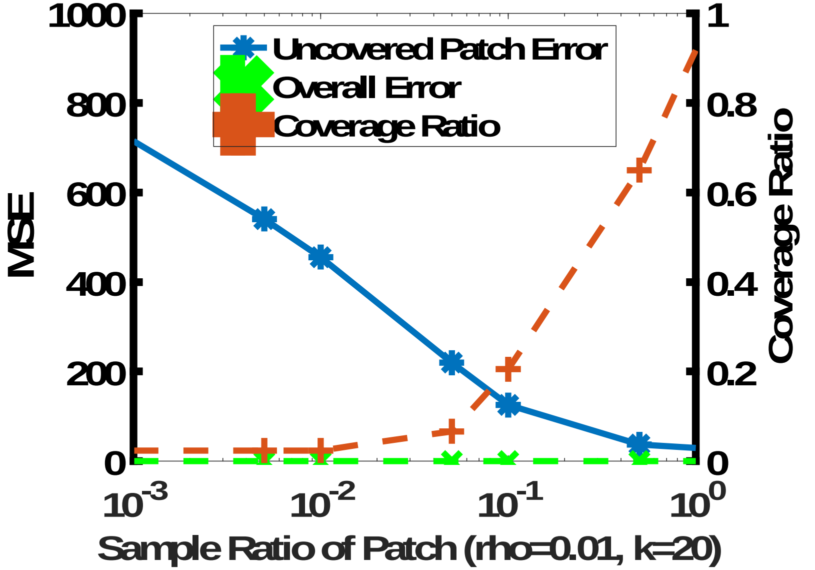
- **Goal**: Determine whether a query point belongs to the body of a cat image or background
- **Experiment**:
  - Removing the samples from the highlighted rectangle to make it uncovered
  - Overall F1 vs. Uncovered region's F1
  - False-Negatives in Red
  - Decision boundary in uncovered region
  - Effect of gradually adding points to the patch





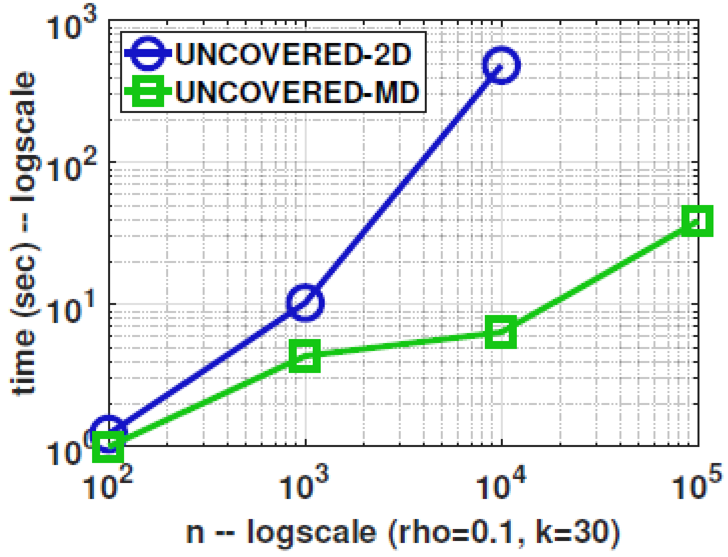
PROOF OF CONCEPT 2: REGRESSION

- **Goal:** Predict Altitude of a query point based on (Longitude, Latitude)
- **Experiment**:
  - RN dataset: (Longitude, Latitude, Altitude)
  - Removing samples from a cell in the range *10<Longitude<10.6* and *57.1<Latitude<57.6* with highly fluctuating *Altitudes* to make it uncovered
  - Overall prediction error vs. Uncovered region's prediction error
  - Effect of gradually adding points to the patch

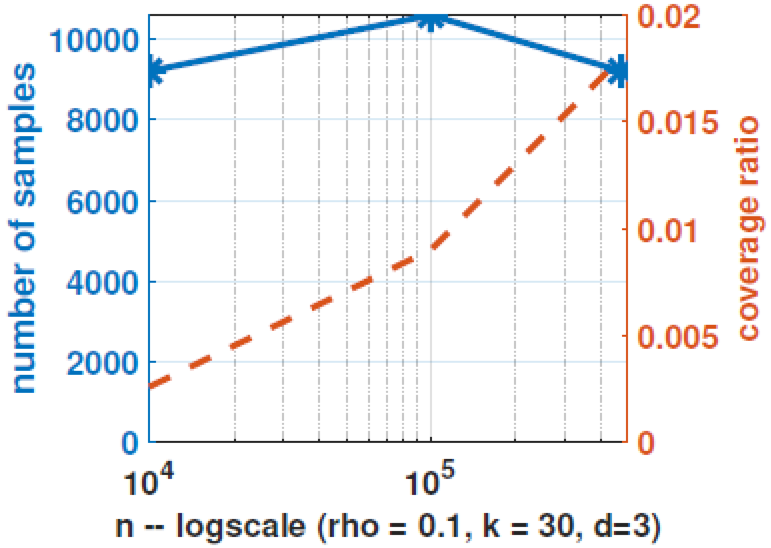


PERFORMANCE EVALUATION

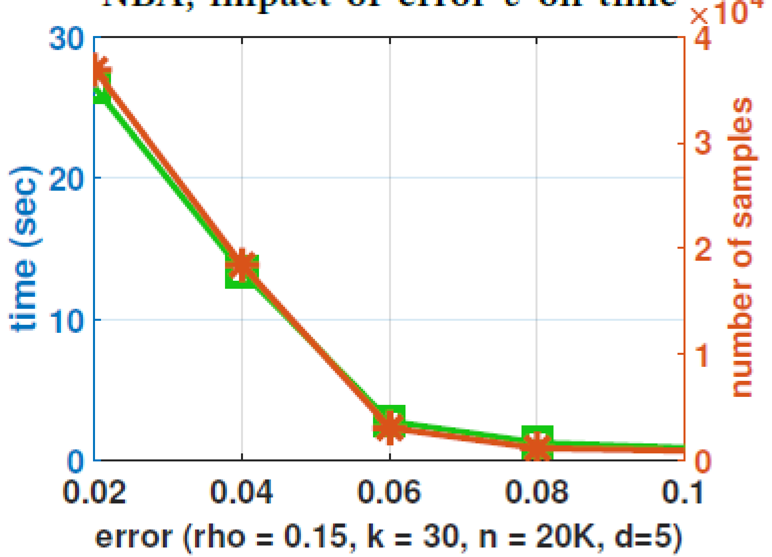
FI, impact of n on time



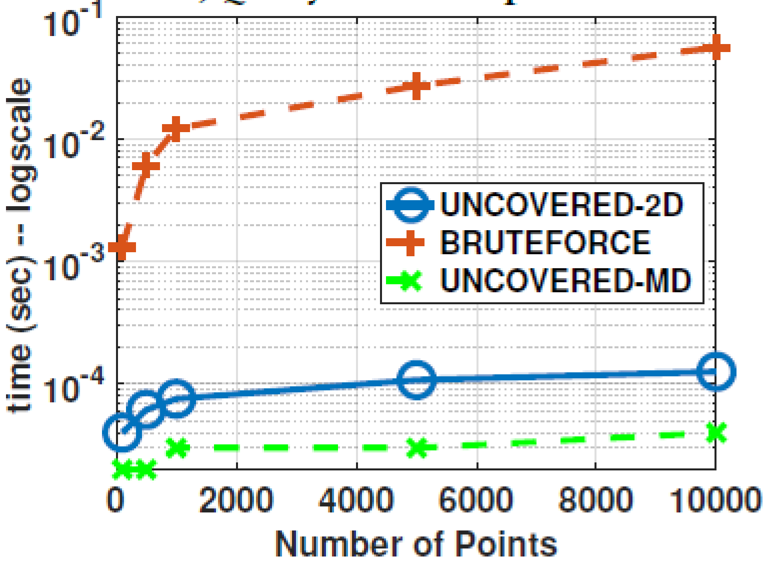
DOT, impact of n on sample size



NBA, impact of error e on time



RN, Query time comparison



THANK YOU

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