CS688: Web-Scale Image Retrieval
Inverted Index

Sung-Eui Yoon
(윤성의)

Course URL:
http://sgvr.kaist.ac.kr/~sungeui/IR

KAIST

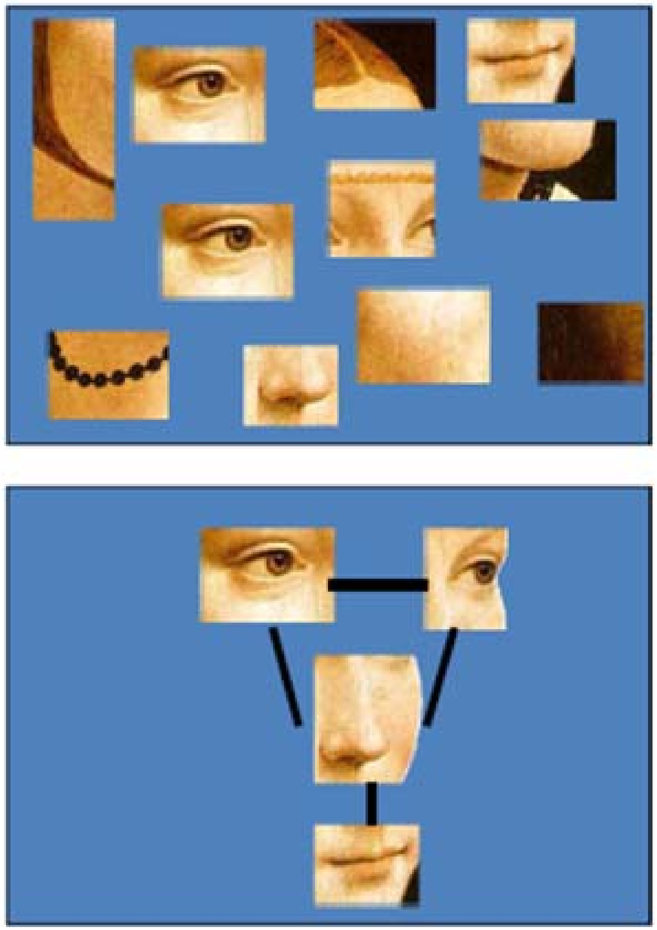
Class Objectives

- **Discuss re-ranking for achieving higher accuracy**
  - **Spatial verification**
  - **Query expansion**
- **Understand approximate nearest neighbor search**
  - **Inverted index and inverted multi-index**

- **At the last class:**
  - **Bag-of-visual-Words (BoW) models**
  - **CNN w/ triplet loss (ranking loss)**

Problems of BoW Model

- No spatial relationship between words
- How can we perform segmentation and localization?

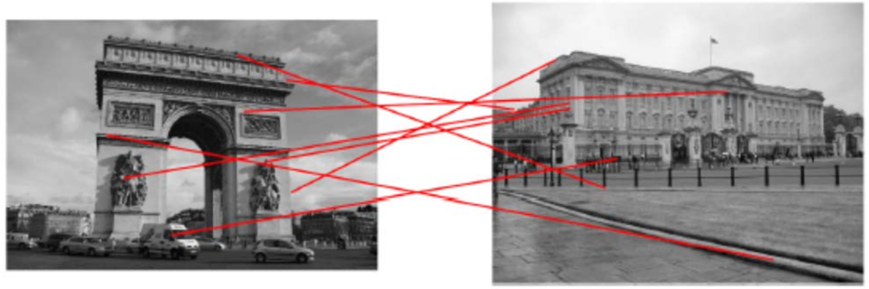


Ack.: Fei-Fei Li

Post-Processing or Reranking

Post-Processing

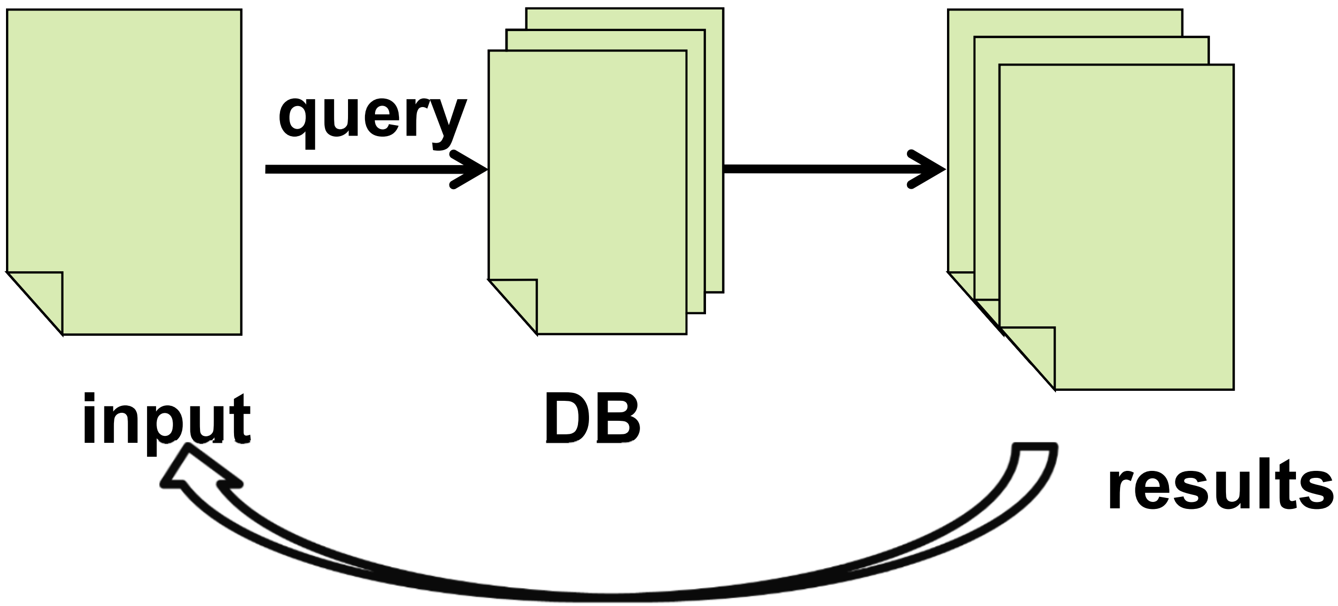
- Geometric verification
  - RANSAC



Matching w/o spatial matching

(Ack: Edward Johns et al.)

- Query expansion



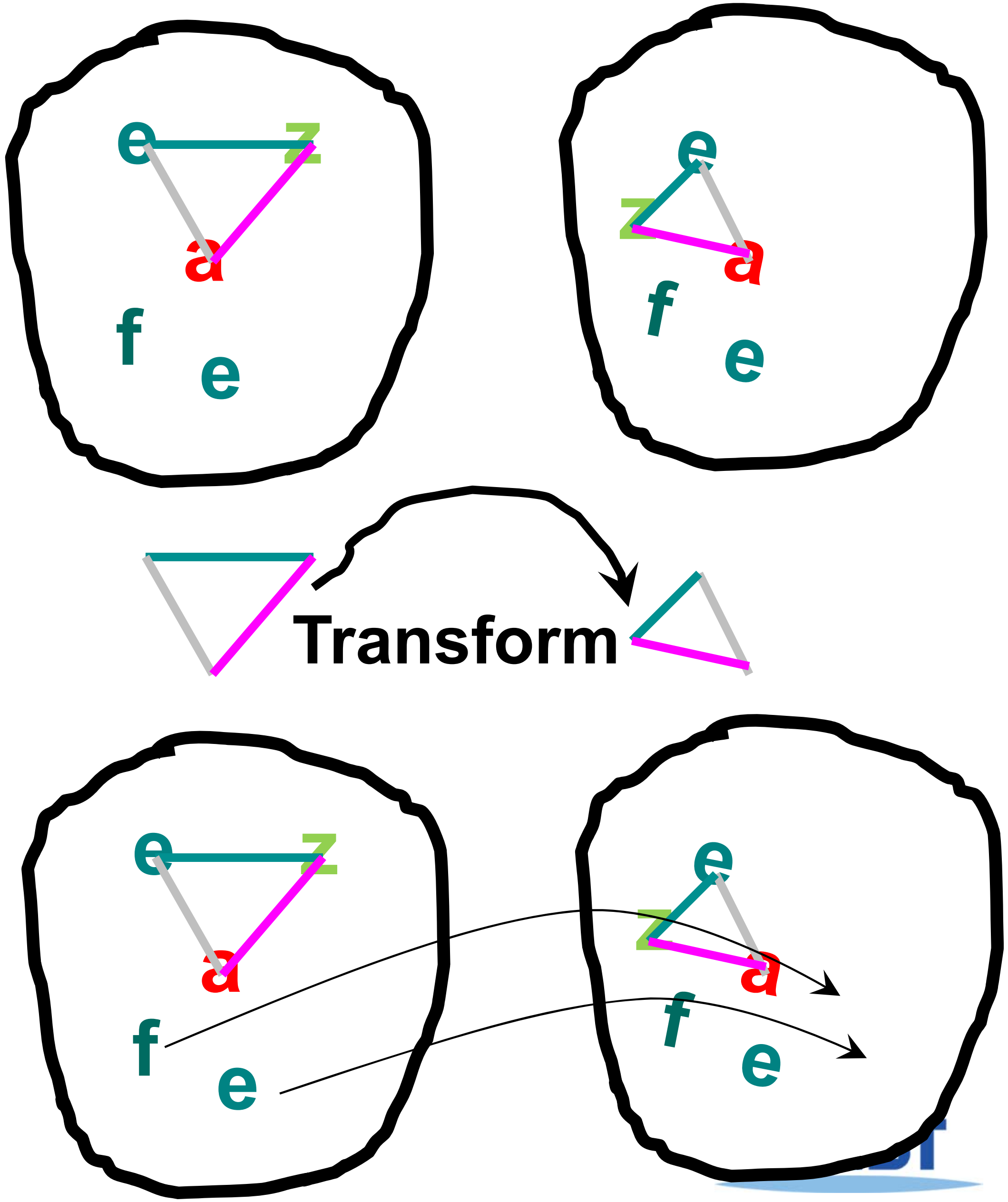
Geometric Verification using RANSAC

Repeat N times:

- Randomly choose 4 matching pairs

- Estimate transformation
  - Assume a particular transformation (Homography)

- Predict remaining points and count "inliers"

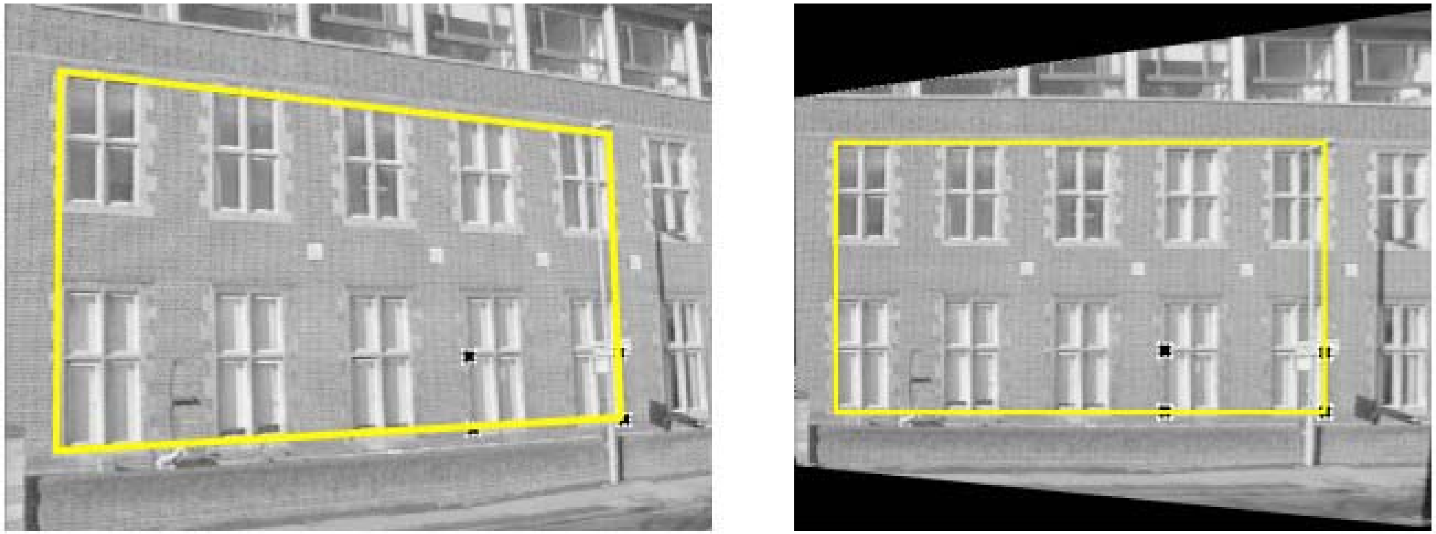


Ack.: Derek Hoiem (UIUC)

Homography

- **Transformation, H, between two planes**
  - **8 DoF due to normalization to 1**

$$s\begin{bmatrix} x' \\ y' \\ 1 \end{bmatrix} = H\begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \end{bmatrix}\begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$$

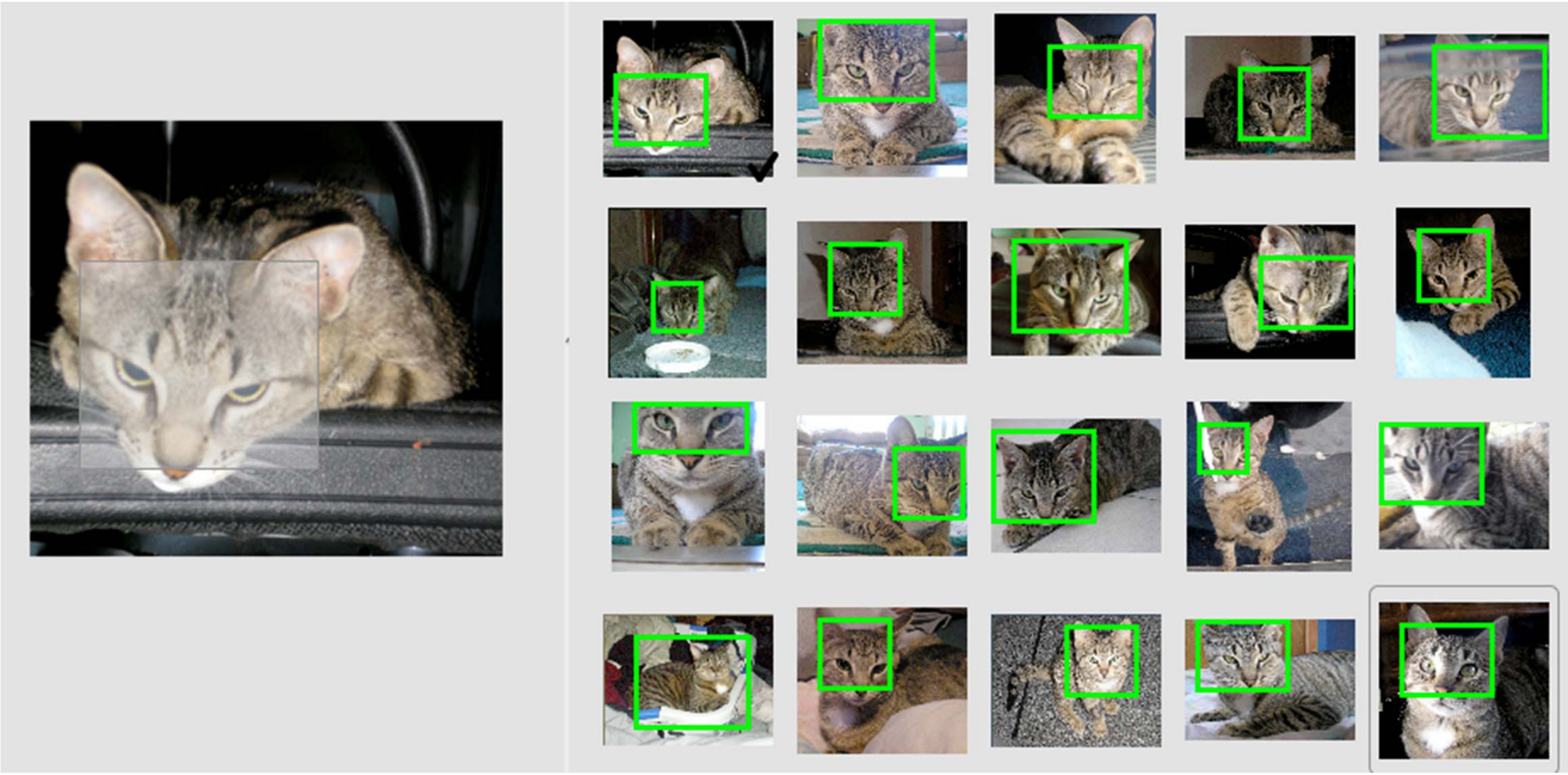


from Hartley & Zisserman

Pattern matching

- **Drones surveying city**
  - **Identify a particular car**

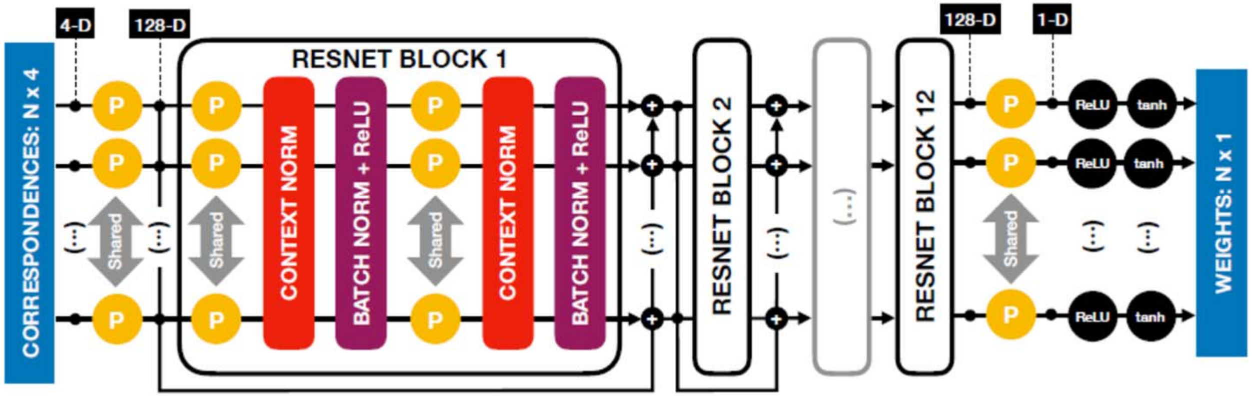
Image Retrieval with Spatially Constrained Similarity Measure

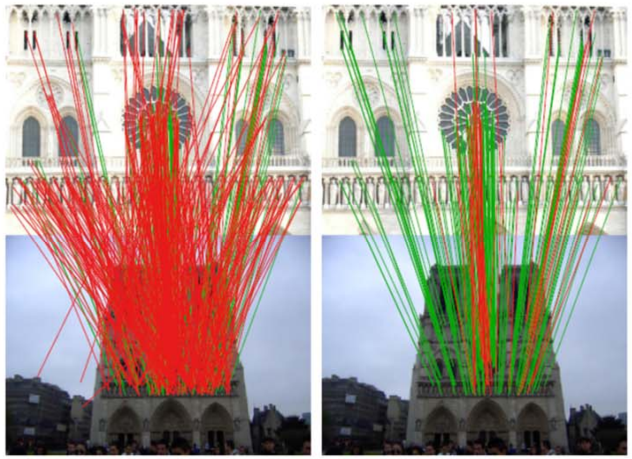


[Xiaohui Shen, Zhe Lin, Jon Brandt, Shai Avidan and Ying Wu, CVPR 2012]

Learning to Find Good Correspondences, CVPR 18

- **Given two sets of input features (e.g., SIFTs), return a prob. of being inliers for each feature**
  - **Adopt the classification approach being inlier or not**
  - **Consider the relative motion between two images for the loss function**





(a) RANSAC (b) Our approach

Query Expansion [Chum et al. 07]

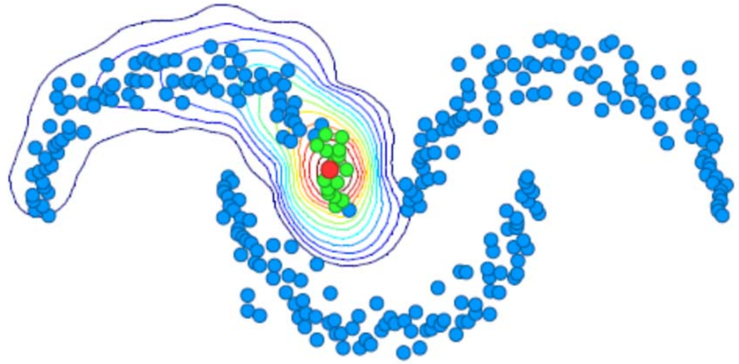
Original query

Top 4 images

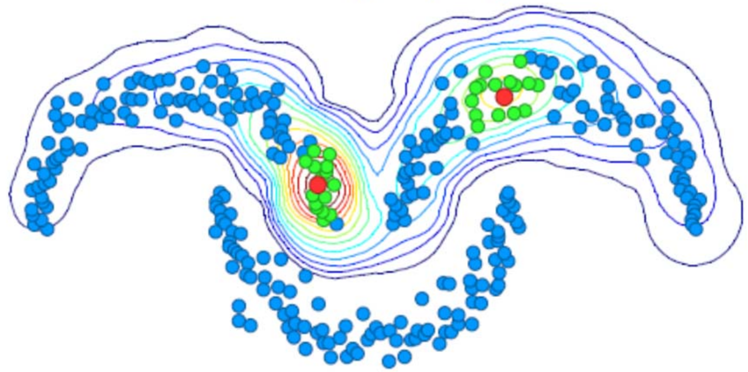
Expanded results that were not identified by the original query

Efficient Diffusion on Region Manifolds, CVPR 17 & 18

- **Identify related images by the diffusion process, i.e., random walks**
  - **Perform random walks based on the similarity between a pair of images**
- **Utilize k-Nearest Neighbor (NNs) of the query images**



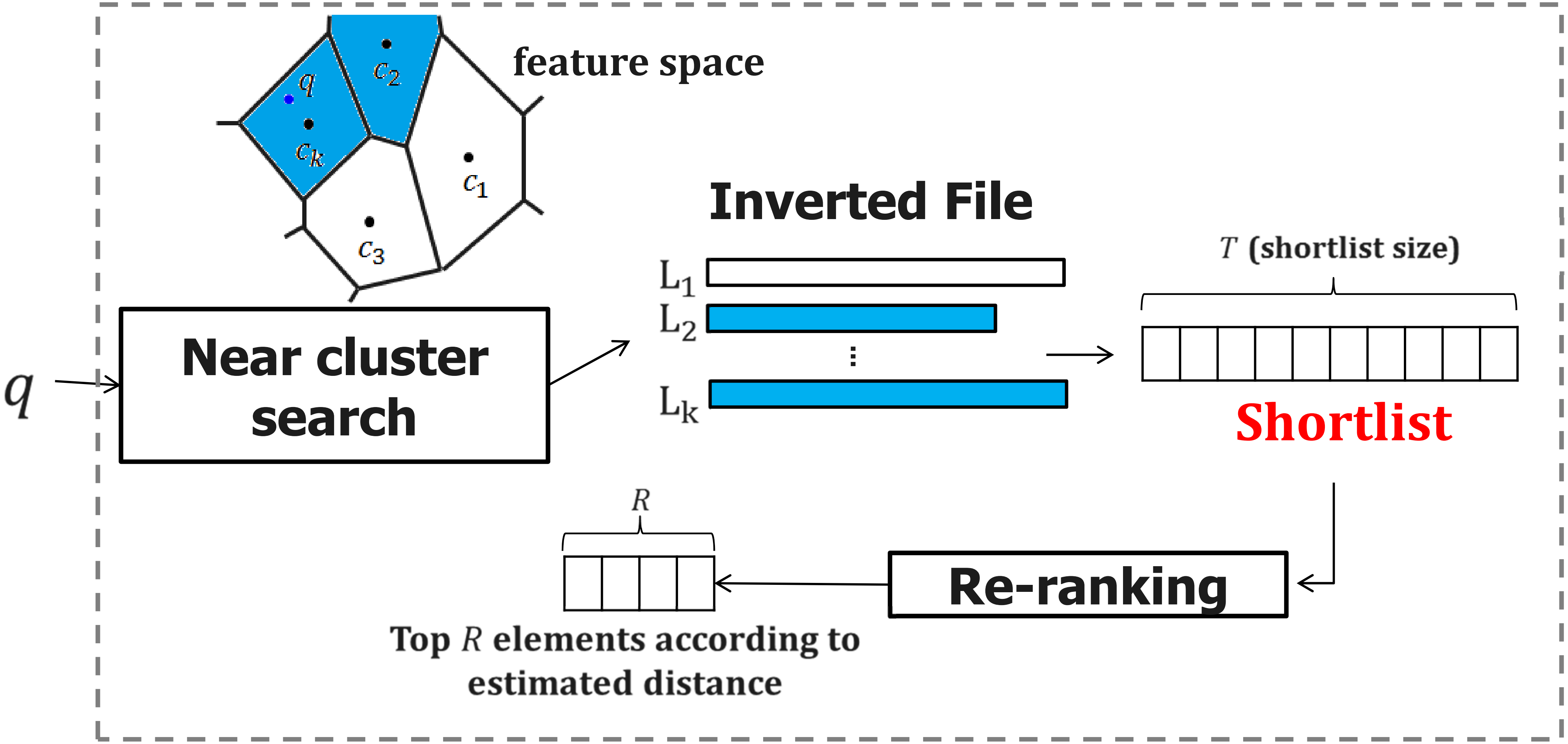
(a) single query



(b) multiple queries

Inverted File or Index for Efficient Search

- **For each word, list images containing the word**



Ack.: Dr. Heo

Inverted Index

Construction time:

- Generate a codebook by quantization
  - e.g. k-means clustering

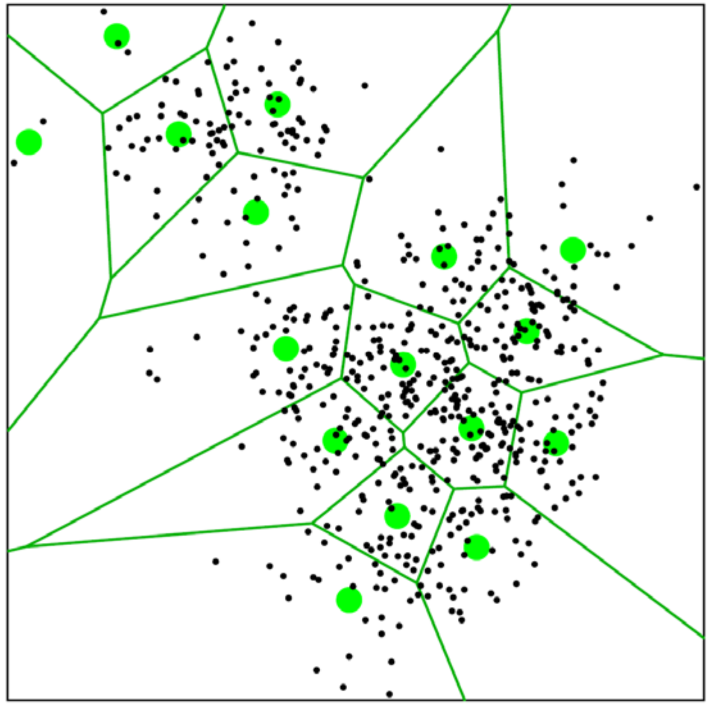
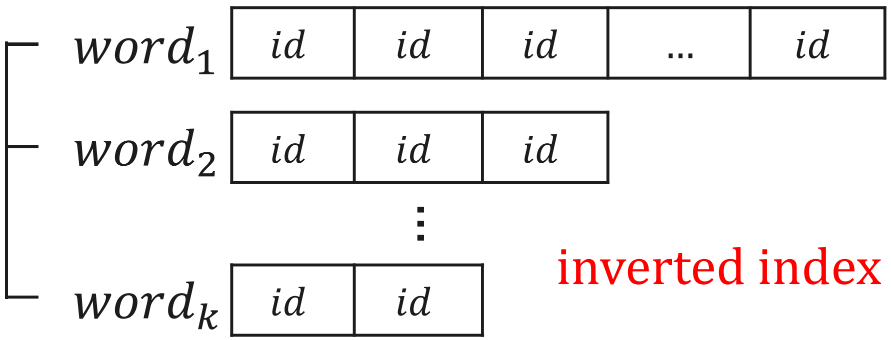


Figure from Lempitsky's slides

- Build an inverted index
  - Quantize each descriptor into the closest word
  - Organize desc. IDs in terms of words

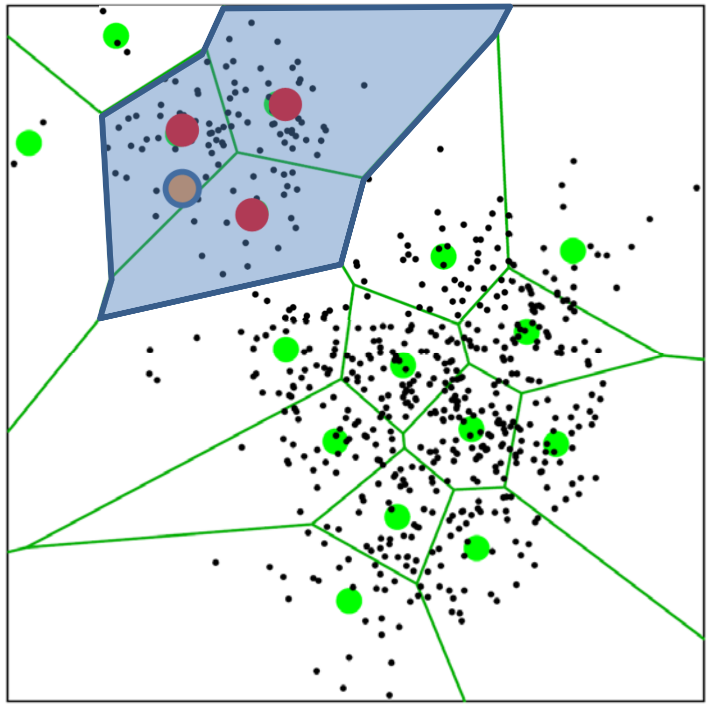


Ack.: Zhe Lin

Inverted Index

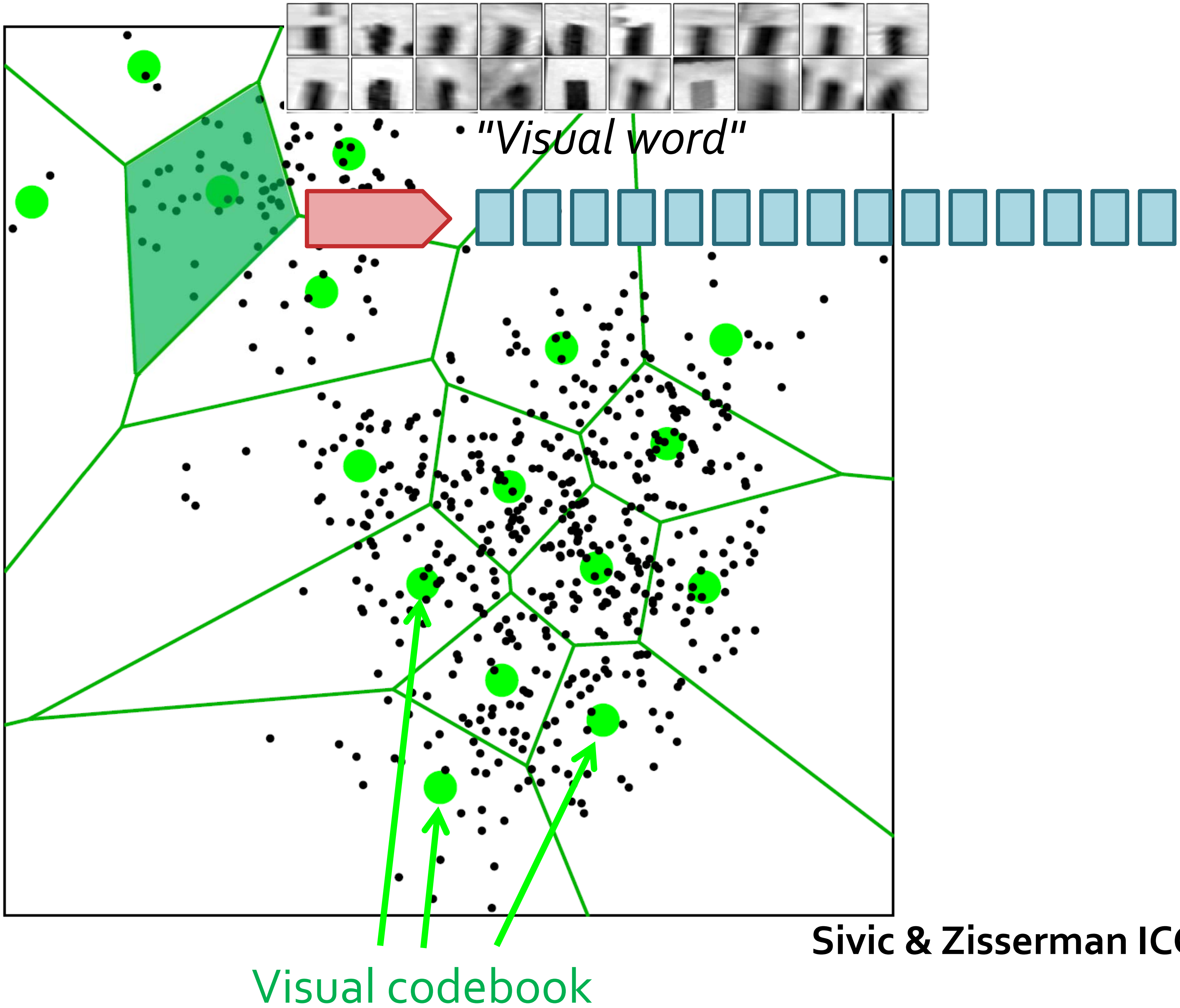
Query time:

- Given a query,
  - Find its K closest words
  - Retrieve all the data in the K lists corresponding to the words
- Large K
  - Low quantization distortion
  - Expensive to find kNN words



Ack.: Zhe Lin

The inverted index



Sivic & Zisserman ICCV 2003

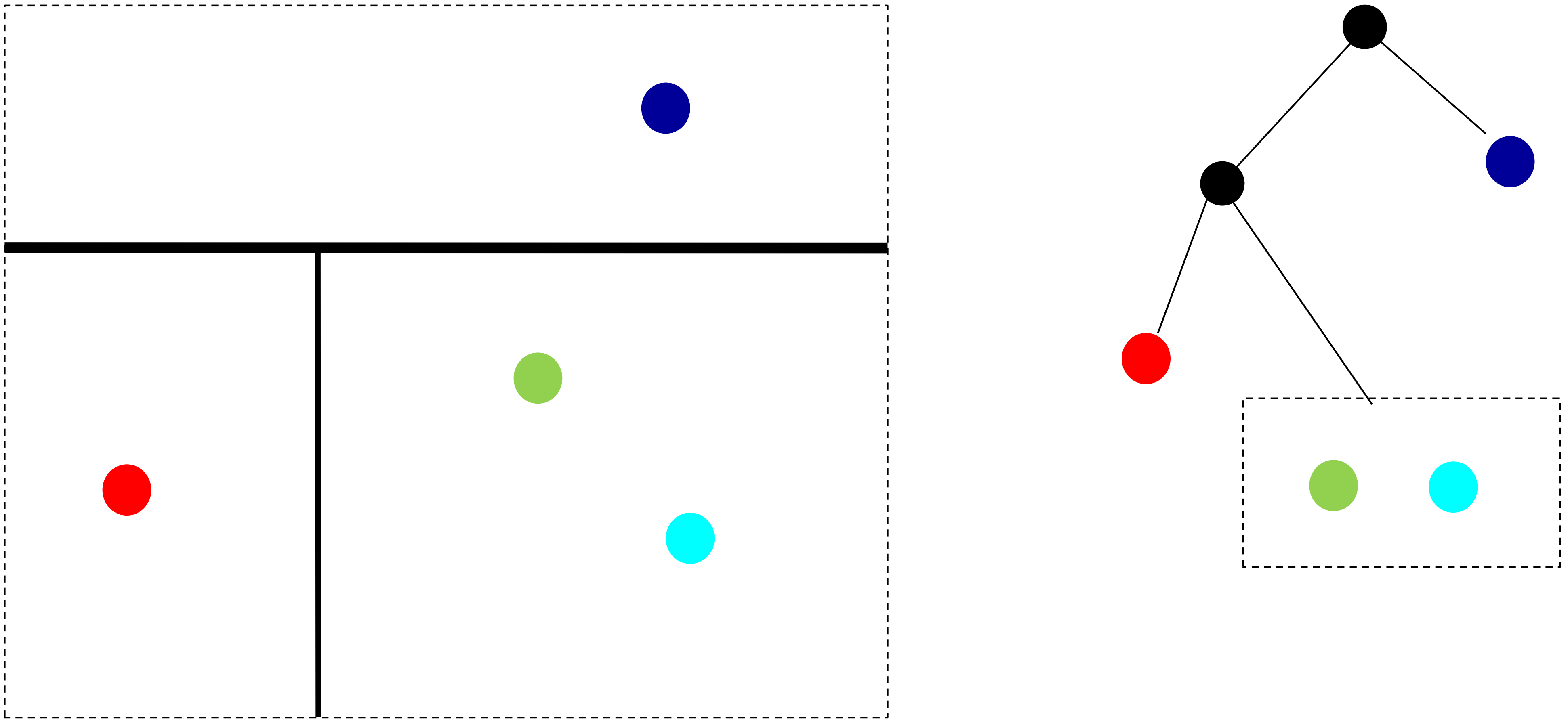
Approximate Nearest Neighbor (ANN) Search

- For large K
  - Takes time to find clusters given the query
  - Use those ANN techniques for efficiently finding near clusters

- ANN search techniques
  - kd-trees: hierarchical approaches for low-dimensional problems
  - Hashing for high dimensional problems; will be discussed later with binary code embedding
  - Quantization (k-means cluster and product quantization)

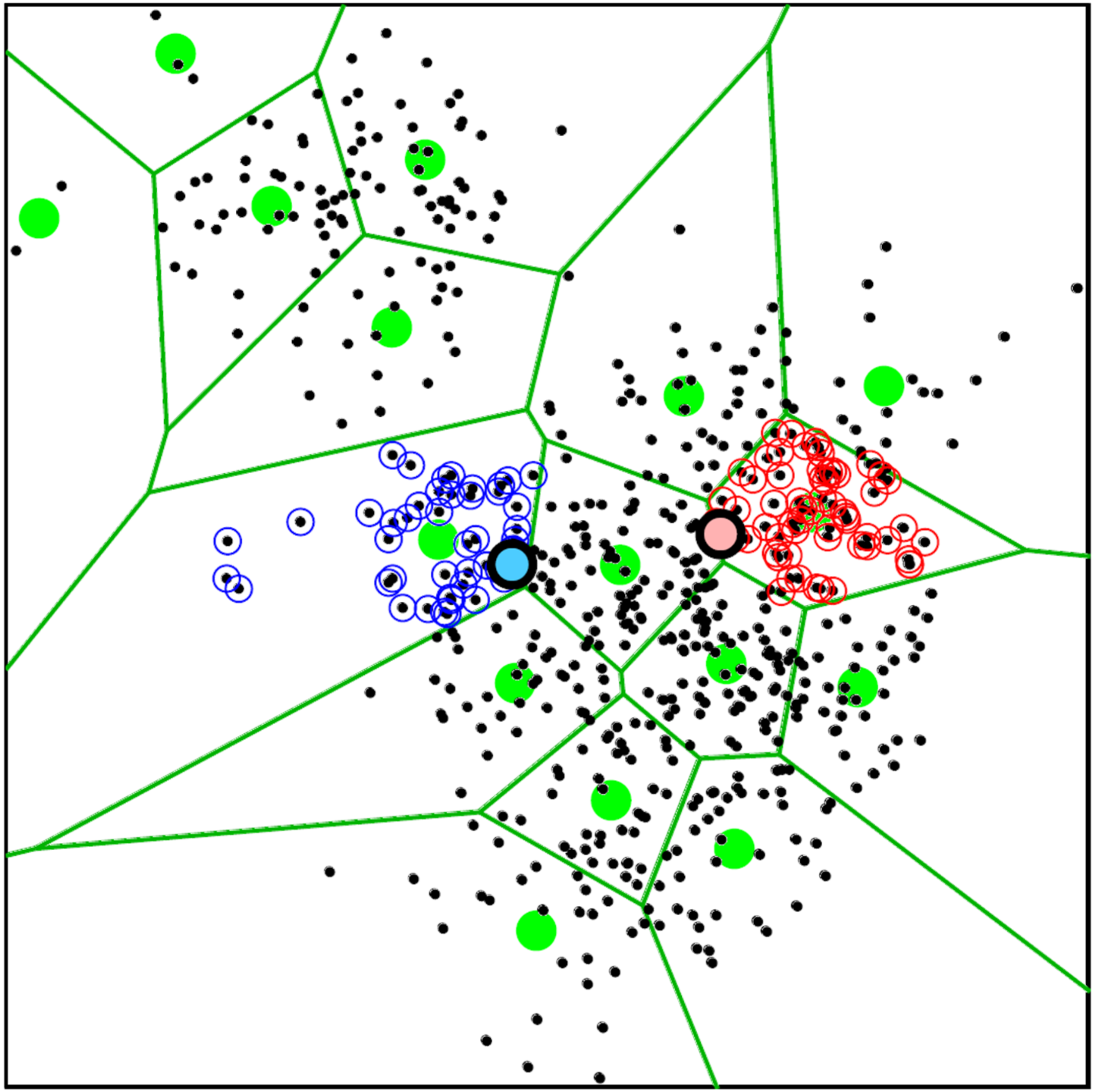
KAIST

kd-tree Example

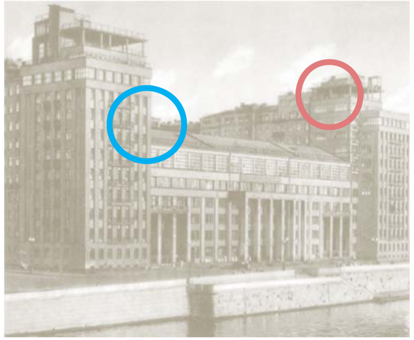


- **Many good implementations (e.g., vl-feat)**

Querying the inverted index



Query:



- Have to consider several words for best accuracy
- Want to use as big codebook as possible

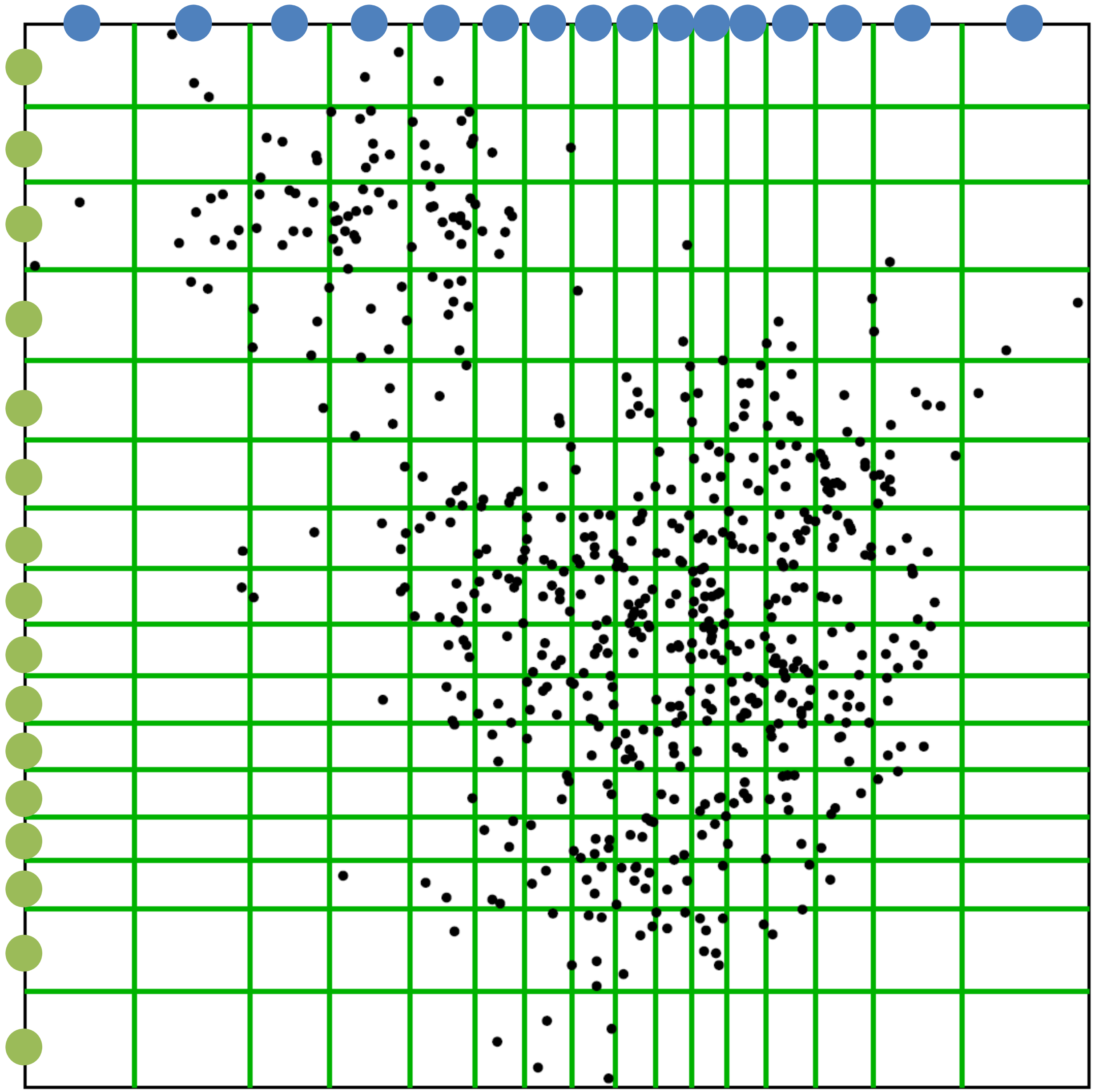
- Want to spend as little time as possible for matching to codebooks

Ack.: Lempitsky

Inverted Multi-Index [Babenko and Lempitsky, CVPR 2012]

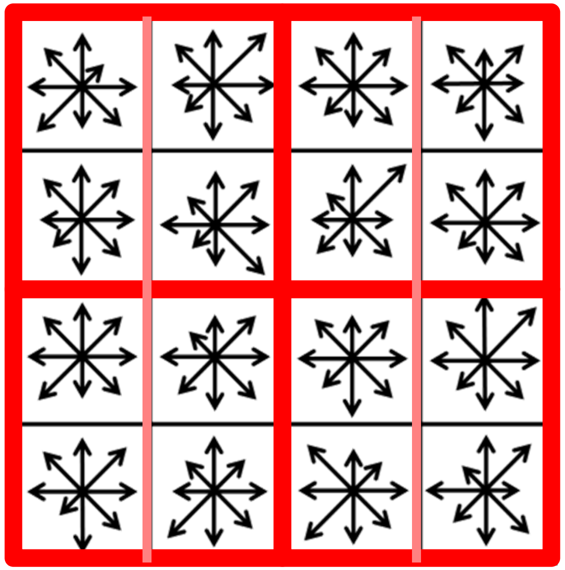
- **Product quantization for indexing**

- **Main advantage:**
  - For the same K, much finer subdivision
  - Very efficient in finding kNN codewords



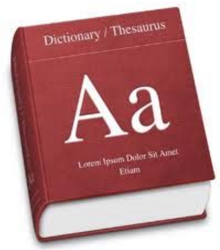
Ack.: Lempitsky

Product quantization



1. Split vector into correlated subvectors
2. use separate small codebook for each chunk

Quantization vs. Product quantization:

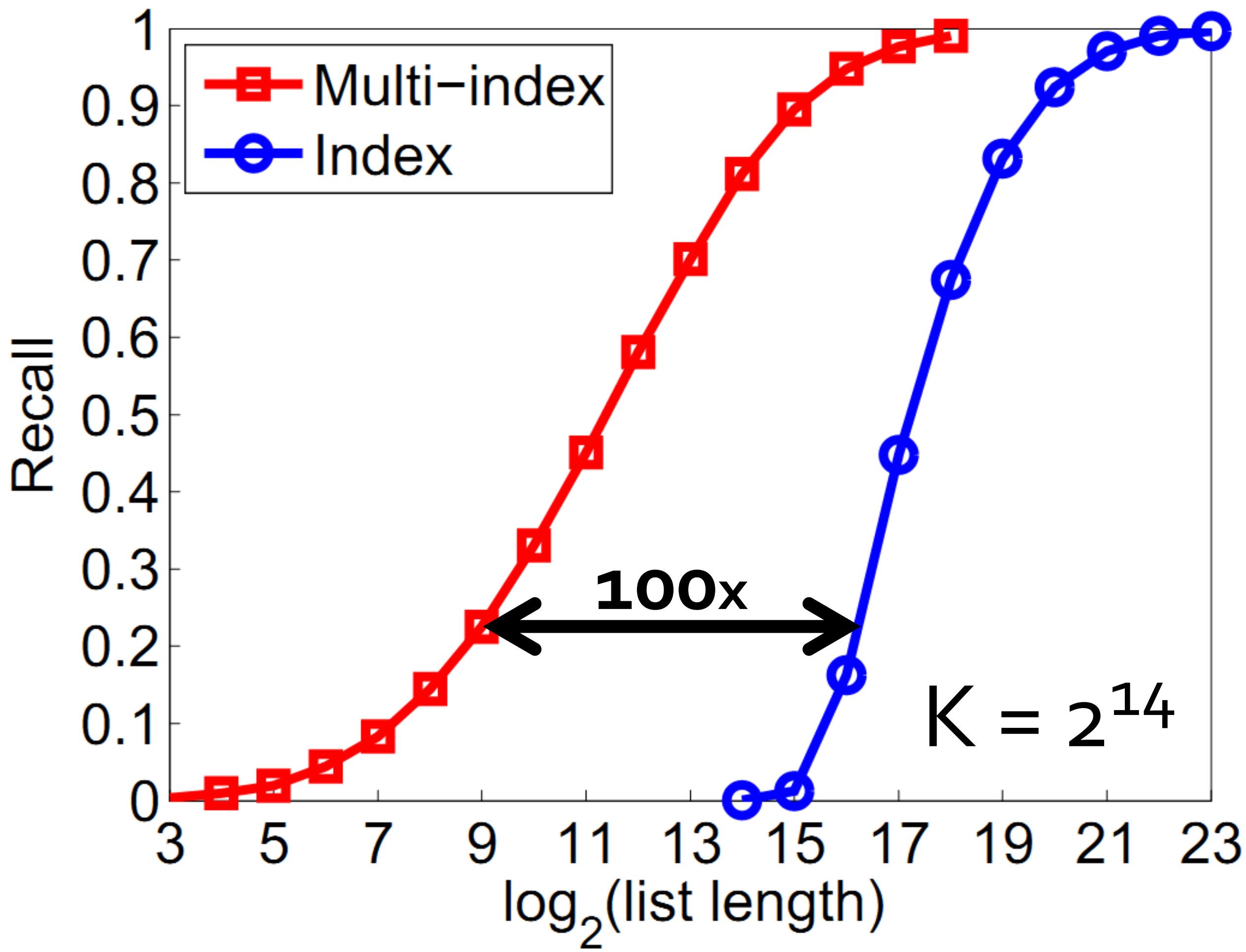


For a budget of 4 bytes per descriptor:

1. Use a single codebook with 1 billion codewords or — **many minutes** — **128GB**
2. Use 4 different codebooks with 256 codewords each — **< 1 millisecond** — **32KB**

Ack.: Lempitsky

Performance comparison on 1 B SIFT descriptors



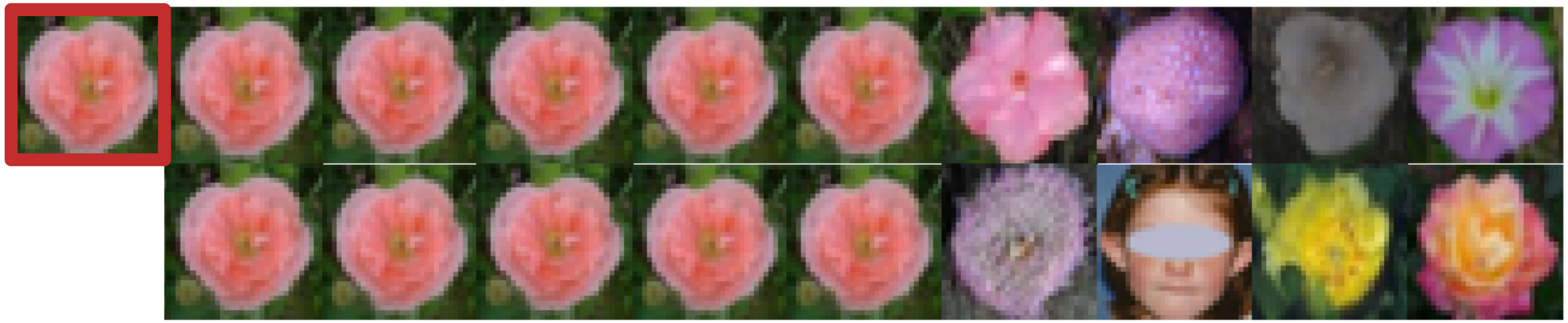
Time increase: 1.4 msec -> 2.2 msec on a single core (with BLAS instructions)

Ack.: Lempitsky

Retrieval examples

Exact NN
Uncompressed GIST

Multi-D-ADC
16 bytes



Exact NN
Uncompressed GIST

Multi-D-ADC
16 bytes

Exact NN
Uncompressed GIST

Multi-D-ADC
16 bytes

Exact NN
Uncompressed GIST

Multi-D-ADC
16 bytes

Ack.: Lempitsky

Scalability

- **Issues with billions of images?**
  - **Searching speed → inverted index**
  - **Accuracy → larger codebooks, spatial verification, expansion, features**
  - **Memory → compact representations**
  - **Easy to use?**
  - **Applications?**
  - **A new aspect?**

Class Objectives were:

- Discuss re-ranking for achieving higher accuracy
  - Spatial verification
  - Query expansion
- Understand approximate nearest neighbor search
  - Inverted index
  - Inverted multi-index

Next Time…

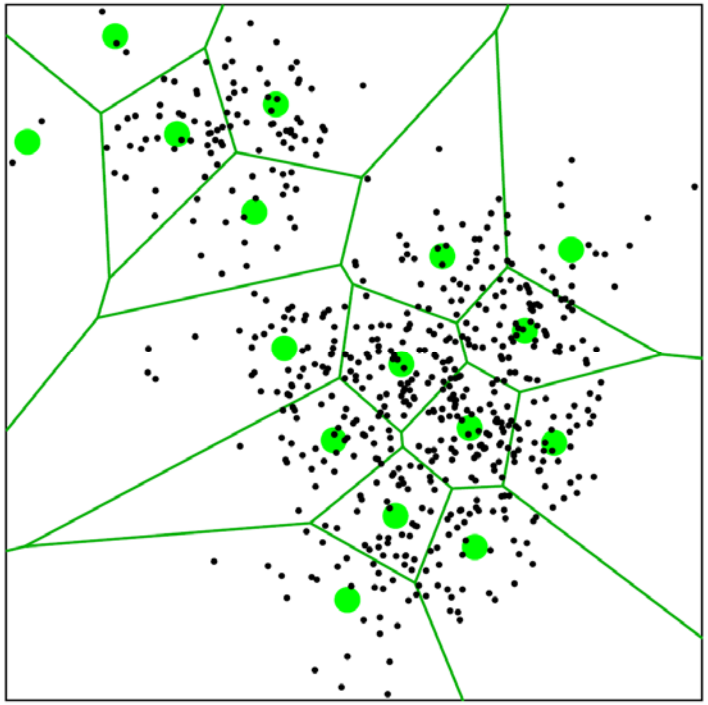
- Hashing techniques

Homework for Every Class

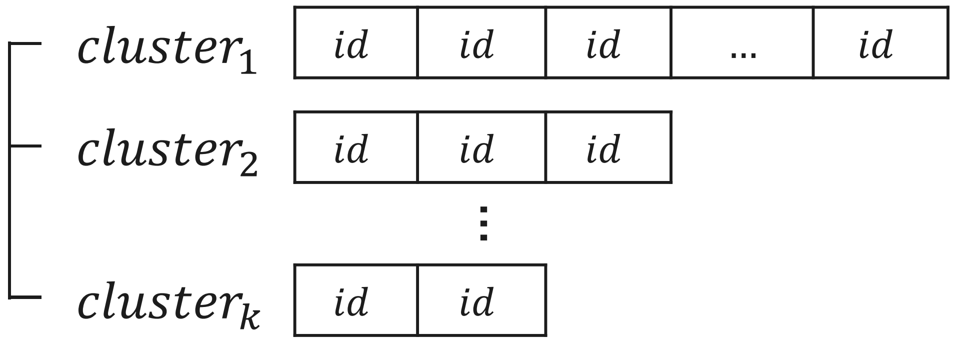
- Go over the next lecture slides
- Come up with one question on what we have discussed today
  - 1 for typical questions (that were answered in the class)
  - 2 for questions with thoughts or that surprised me
- Write questions 3 times

Figs

Inverted Index



Inverted index



Ack.: Zhe Lin