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15-826: Multimedia Databases and Data Mining

Lecture #25: Multimedia indexing

C. Faloutsos

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Must-read Material

- MM Textbook, chapters 7, 8, 9 and 10.
- Myron Flickner, et al: *Query by Image and Video Content: the QBIC System* IEEE Computer 28, 9, Sep. 1995, pp. 23-32.
- Journal of Intelligent Inf. Systems, 3, 3/4, pp. 231-262, 1994 (An earlier, more technical version of the IEEE Computer '95 paper.)
- FastMap: Textbook chapter 11; Also in: C. Faloutsos and K.I. Lin *FastMap: A Fast Algorithm for Indexing, Data-Mining and Visualization of Traditional and Multimedia Datasets* ACM SIGMOD 95, pp. 163-174.

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Outline

Goal: 'Find similar / interesting things'

- Intro to DB
- Indexing - similarity search
- Data Mining

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Indexing - Detailed outline

- primary key indexing
- secondary key / multi-key indexing
- spatial access methods
- fractals
- text
- Singular Value Decomposition (SVD)
- Multimedia
  - DSP
  - indexing
- ...

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Multimedia - Detailed outline

- Multimedia indexing
  - Motivation / problem definition
  - Main idea / time sequences
  - images
  - sub-pattern matching
  - automatic feature extraction / FastMap

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Problem

Given a large collection of (multimedia) records (eg. stocks)

Allow fast, similarity queries

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Applications

- time series: financial, marketing (click-streams!), ECGs, sound;
- images: medicine, digital libraries, education, art
- higher-d signals: scientific db (eg., astrophysics), medicine (MRI scans), entertainment (video)

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Sample queries

- find medical cases similar to Smith's
- Find pairs of stocks that move in sync
- Find pairs of documents that are similar (plagiarism?)
- find faces similar to ‘Tiger Woods’

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Detailed problem defn.:

Problem:

- given a set of multimedia objects,
- find the ones similar to a desirable query object
- for example:

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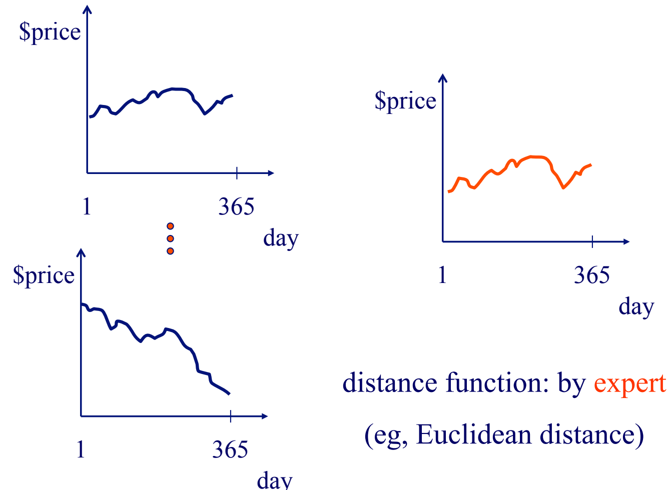

distance function: by expert

(eg, Euclidean distance)

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Types of queries

- whole match vs sub-pattern match
- range query vs nearest neighbors
- all-pairs query

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Design goals

- Fast (faster than seq. scan)
- ‘correct’ (ie., no false alarms; no false dismissals)

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Multimedia - Detailed outline

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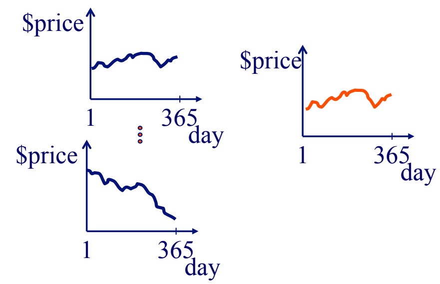
Main idea

- Eg., time sequences, 'whole matching', range queries, Euclidean distance



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Main idea

- Seq. scanning works - how to do faster?

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Idea: 'GEMINI'

(GEneric Multimedia INdexIng)

Extract a few numerical features, for a 'quick and dirty' test

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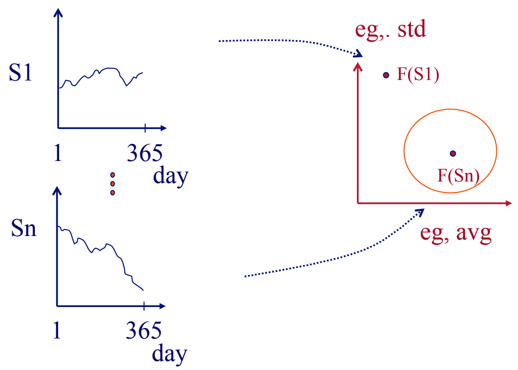
'GEMINI' - Pictorially



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GEMINI

Solution: Quick-and-dirty' filter:

- extract *n* features (numbers, eg., avg., etc.)
- map into a point in *n*-d feature space
- organize points with off-the-shelf spatial access method ('SAM')
- discard false alarms

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GEMINI

Important: Q: how to guarantee no false dismissals?

A1: preserve distances (but: difficult/ impossible)

A2: **Lower-bounding lemma**: if the mapping 'makes things look closer', then there are **no** false dismissals

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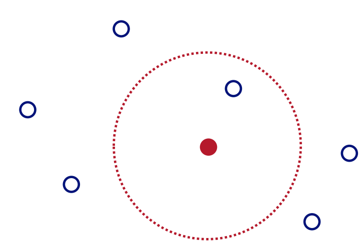
GEMINI

- 'proof' of lower-bounding lemma



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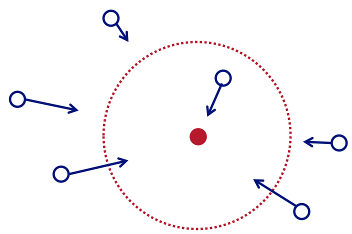
GEMINI

- 'proof' of lower-bounding lemma



Lower-bounding: Makes objects look closer to each other (& to query object)

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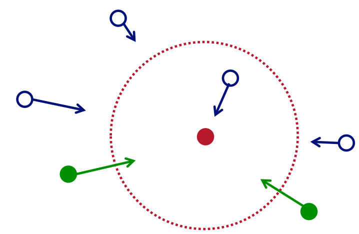
GEMINI

- 'proof' of lower-bounding lemma



Lower-bounding: Makes objects look closer to each other (& to query object)
-> ONLY **false alarms**

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GEMINI

Important:

Q: how to extract features?

A: "*if I have only one number to describe my object, what should this be?*"

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Time sequences

Q: what features?

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Time sequences

Q: what features?

A: Fourier coefficients (we' ll see them in detail soon)

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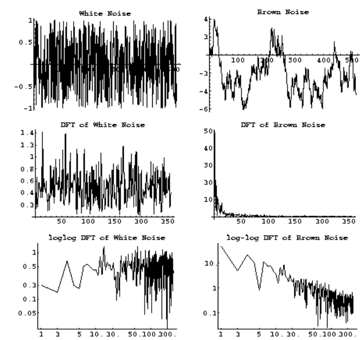
details

Time sequences

white noise brown noise

Fourier spectrum

... in log-log



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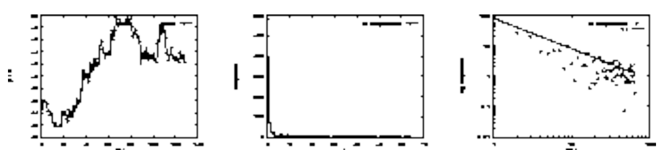
Time sequences

- Eg.:



(a) IBM stock (b) spectrum (linear scales) (c) spectrum (log scales)

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Time sequences

- conclusion: colored noises are well approximated by their first few Fourier coefficients
- colored noises appear in nature:

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Time sequences

details

- brown noise: stock prices ($1/f^2$ energy spectrum)
- pink noise: works of art (1/f spectrum)
- black noises: water reservoirs ($1/f^b$, b>2)
- (slope: related to 'Hurst exponent', for self-similar traffic, like, eg. Ethernet/web [Schroeder], [Leland+]

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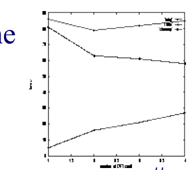
Time sequences - results

- keep the first 2-3 Fourier coefficients
- faster than seq. scan
- NO false dismissals (see book)



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Time sequences - improvements:

- improvements/variations: [Kanellakis +Goldin], [Mendelzon+Rafiei]
- could use Wavelets, or DCT
- could use segment averages [Yi+2000]

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Multimedia - Detailed outline

- multimedia
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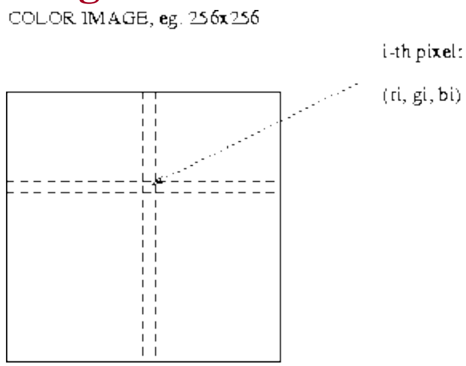
  - images (color, shapes)
  - sub-pattern matching
  - automatic feature extraction / FastMap

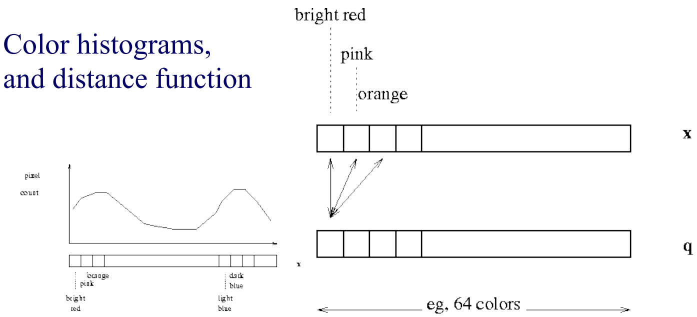
Images - color

what is an image?
A: 2-d array



Images - color

Color histograms,
and distance function

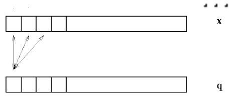


Images - color

Mathematically, the distance function is:

$$distance_{histogram}(\vec{x}, \vec{q}) = (\vec{x} - \vec{q}) \begin{bmatrix} a_{RR} & a_{RP} & \dots \\ a_{PR} & a_{PP} & \dots \\ \dots & \dots & \dots \end{bmatrix} (\vec{x} - \vec{q})^t$$

$$\dots = (\vec{x} - \vec{q}) \mathcal{A} (\vec{x} - \vec{q})^t$$



Images - color

Problem: ‘cross-talk’:

- Features are not orthogonal ->
- SAMs will not work properly

- Q: what to do?
- A: feature-extraction question

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Images - color

possible answers:

- avg red, avg green, avg blue

it turns out that this lower-bounds the histogram distance ->

- no cross-talk
- SAMs are applicable

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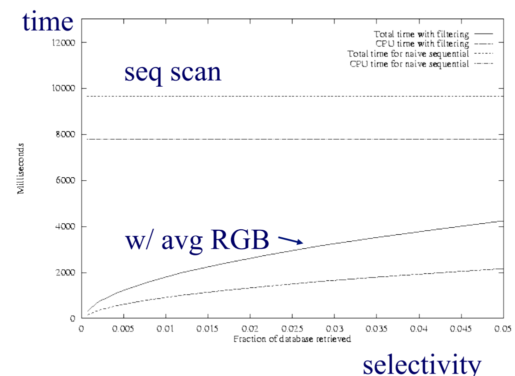
Images - color

performance:



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Multimedia - Detailed outline

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Images - shapes

- distance function: Euclidean, on the area, perimeter, and 20 ‘moments’
- (Q: how to normalize them?

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Images - shapes

- distance function: Euclidean, on the area, perimeter, and 20 ‘moments’
- (Q: how to normalize them?
- A: divide by standard deviation)

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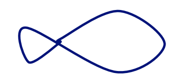
Images - shapes

- distance function: Euclidean, on the area, perimeter, and 20 ‘moments’
- (Q: other ‘features’ / distance functions?



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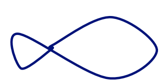
Images - shapes

- distance function: Euclidean, on the area, perimeter, and 20 ‘moments’
- (Q: other ‘features’ / distance functions?
- A1: turning angle
- A2: dilations/erosions
- A3: ...)



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Images - shapes

- distance function: Euclidean, on the area, perimeter, and 20 ‘moments’
- Q: how to do dim. reduction?

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Images - shapes

- distance function: Euclidean, on the area, perimeter, and 20 'moments'
- Q: how to do dim. reduction?
- A: Karhunen-Loeve (= centered PCA/SVD)

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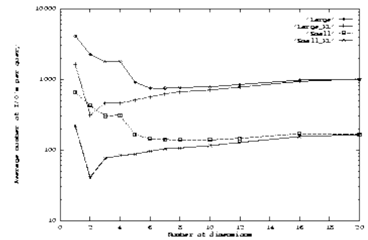
Images - shapes

- Performance: ~10x faster

log(# of I/Os)



← all kept

# of features kept

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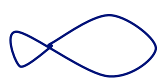
Other shape features?



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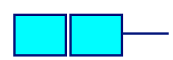
Other shape features

- Morphology (dilations, erosions, openings, closings) [Korn+, VLDB96]

shape

"structuring element"



R=1

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Other shape features

- Morphology (dilations, erosions, openings, closings) [Korn+, VLDB96]

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details

Other shape features

- Morphology (dilations, erosions, openings, closings) [Korn+, VLDB96]

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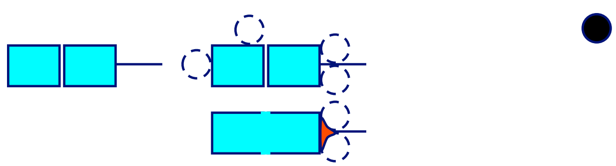
Morphology: closing

- fill in small gaps
- **very similar** to 'alpha contours'



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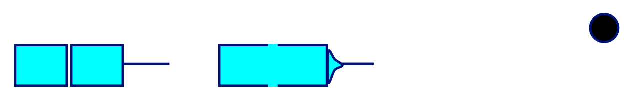
Morphology: closing

- fill in small gaps



'closing', with R=1

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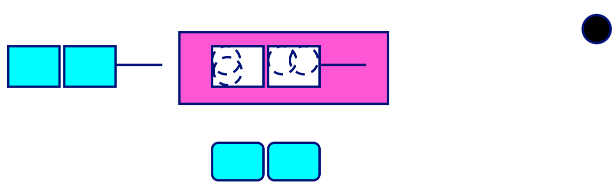
Morphology: opening

- 'closing', for the complement =
- trim small extremities



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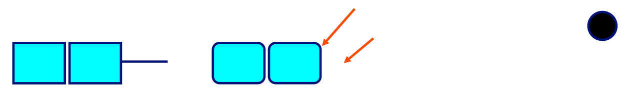
Morphology: opening

- 'closing', for the complement =
- trim small extremities



'opening'
with R=1

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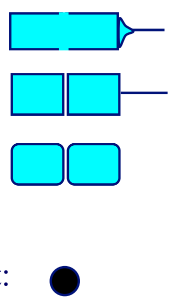
Morphology

- Closing: fills in gaps
- Opening: trims extremities
- All wrt a structuring element:



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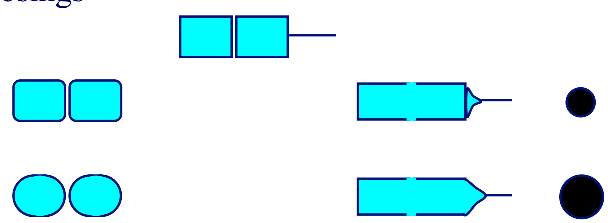
Morphology

- Features: areas of openings (R=1, 2, …) and closings



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Morphology

- Powerful method:
- 'pattern spectrum' [Maragos+]
- 'skeletonization' of images
- 'Alpha-shapes' [Edelsbrunner]
- Book: *An introduction to morphological image processing,* by Edward R. Dougherty

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Multimedia - Detailed outline

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  - sub-pattern matching
  - automatic feature extraction / FastMap

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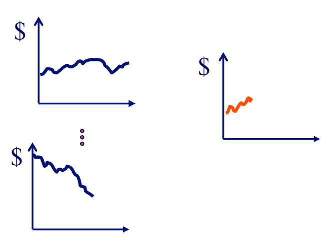
Sub-pattern matching

- Problem: find **sub**-sequences that match the given query pattern



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Sub-pattern matching

- Q: how to proceed?
- Hint: try to turn it into a 'whole-matching' problem (how?)

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Sub-pattern matching

- Assume that queries have minimum duration *w;* (eg., *w*=7 days)
- divide data sequences into windows of width *w* (overlapping, or not?)

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Sub-pattern matching

- Assume that queries have minimum duration *w;* (eg., *w*=7 days)
- divide data sequences into windows of width *w* (overlapping, or not?)
- A: sliding, overlapping windows. Thus: trails

Pictorially:

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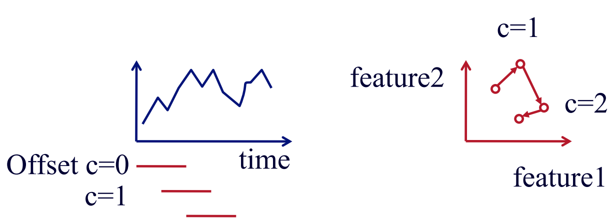
Sub-pattern matching



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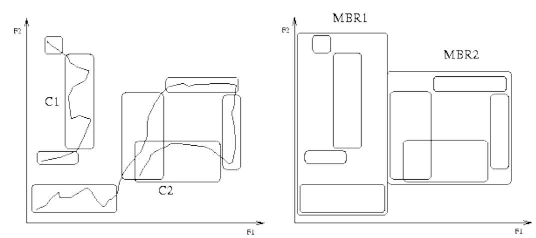
Sub-pattern matching



sequences -> trails -> MBRs in feature space

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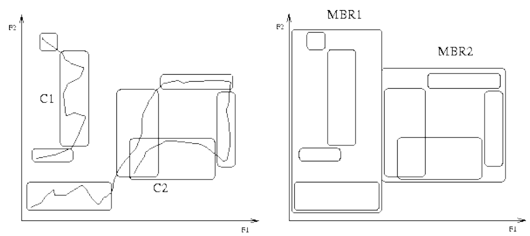
Sub-pattern matching



Q: do we store all points? why not?

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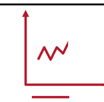
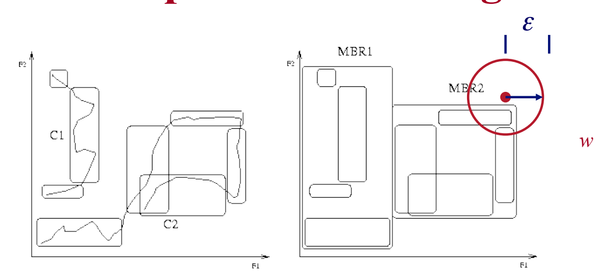


Sub-pattern matching



Q: how to do range queries of duration *w*?

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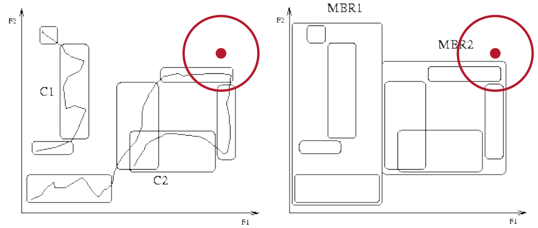
Sub-pattern matching



Q: how to do range queries of duration *w*?
A: R-tree; find qualifying stocks and intervals

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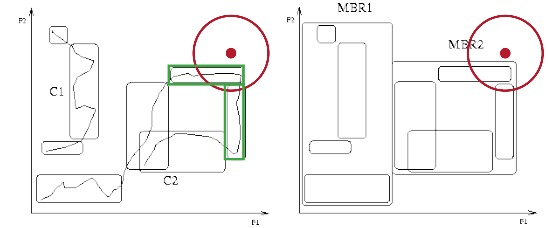
Sub-pattern matching



Q: how to do range queries of duration *w*?
A: R-tree; find qualifying stocks and intervals

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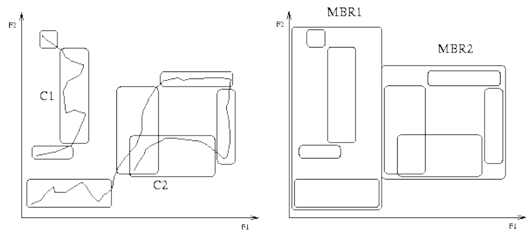
Sub-pattern matching



Q: how to do range queries of duration >*w* (say, *2*w*)?

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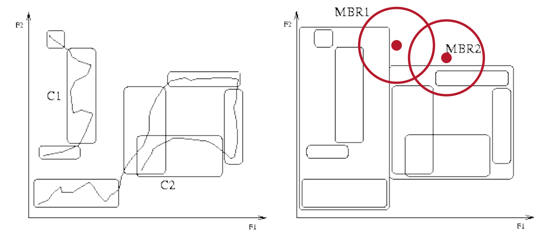
Sub-pattern matching



Q: how to do range queries of duration >*w* (say, *2*w*)?

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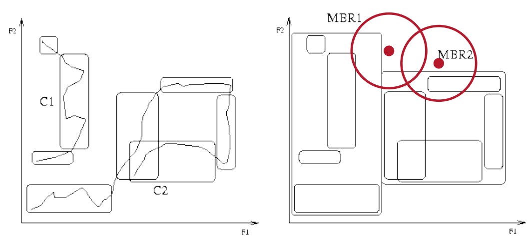
Sub-pattern matching



Q: how to do range queries of duration >*w* (say, *2*w*)?

A: Two range queries of radius epsilon and intersect
(or two queries of smaller radius and union – see paper)

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Sub-pattern matching

(improvement [Moon+2001])

- use non-overlapping windows, for data

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Conclusions

- GEMINI works for any setting (time sequences, images, etc)
- uses a 'quick and dirty' filter
- faster than seq. scan
- (but: how to extract features automatically?)

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Multimedia - Detailed outline

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  - automatic feature extraction / FastMap

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FastMap

Automatic feature extraction:

- Given a dissimilarity function of objects
- Quickly map the objects to a (k-d) `feature' space.
- (goals: indexing and/or visualization)

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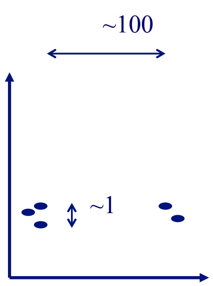
FastMap

	O1	O2	O3	O4	O5
O1	0	1	1	100	100
O2	1	0	1	100	100
O3	1	1	0	100	100
O4	100	100	100	0	1
O5	100	100	100	1	0



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FastMap

- Multi-dimensional scaling (MDS) can do that, but in O(N**2) time

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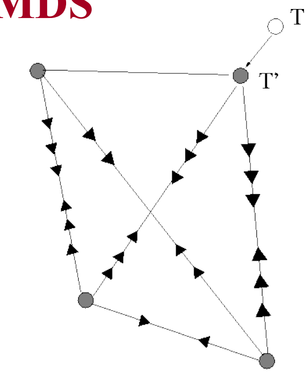
MDS

Multi Dimensional Scaling



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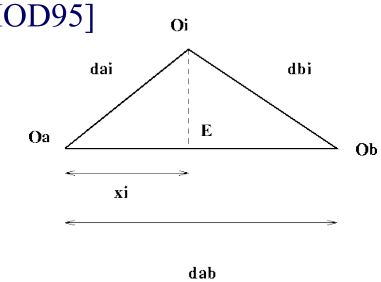
Main idea: projections

We want a linear algorithm: FastMap [SIGMOD95]



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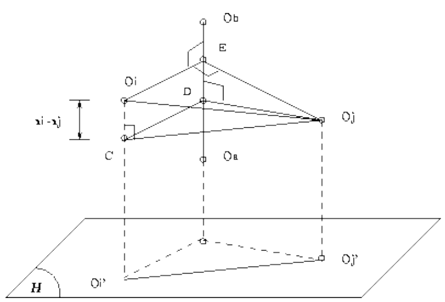
FastMap - next iteration



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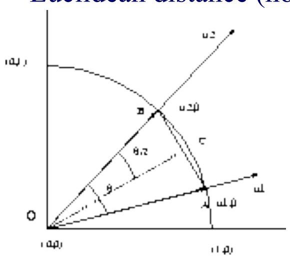
Results

Documents /cosine similarity -> Euclidean distance (how?)



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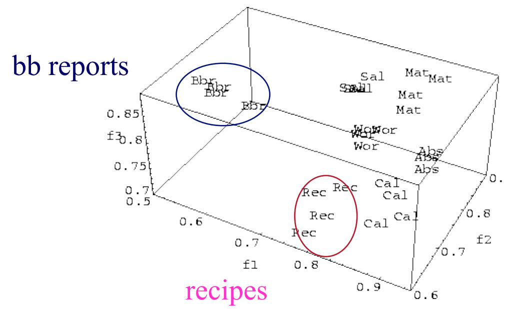
Results



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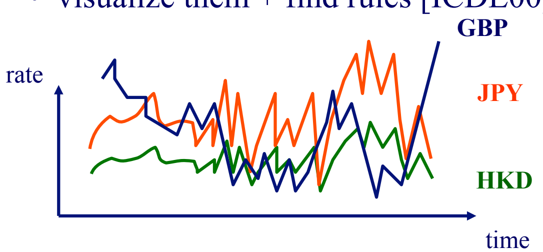
Applications: time sequences

- given *n* co-evolving time sequences
- visualize them + find rules [ICDE00]



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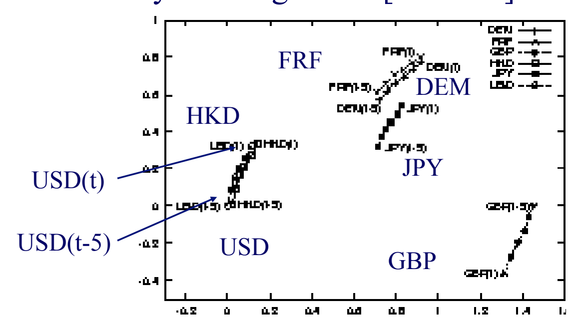
Applications - financial

- currency exchange rates [ICDE00]



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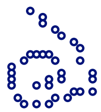
Variations

- Isomap [Tenenbaum, de Silva, Langford, 2000]
- LLE (Local Linear Embedding) [Roweis, Saul, 2000]
- MVE (Minimum Volume Embedding) [Shaw & Jebara, 2007]



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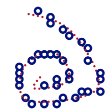

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Conclusions

- GEMINI works for multiple settings
- FastMap can extract 'features' automatically (-> indexing, visual d.m.)

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