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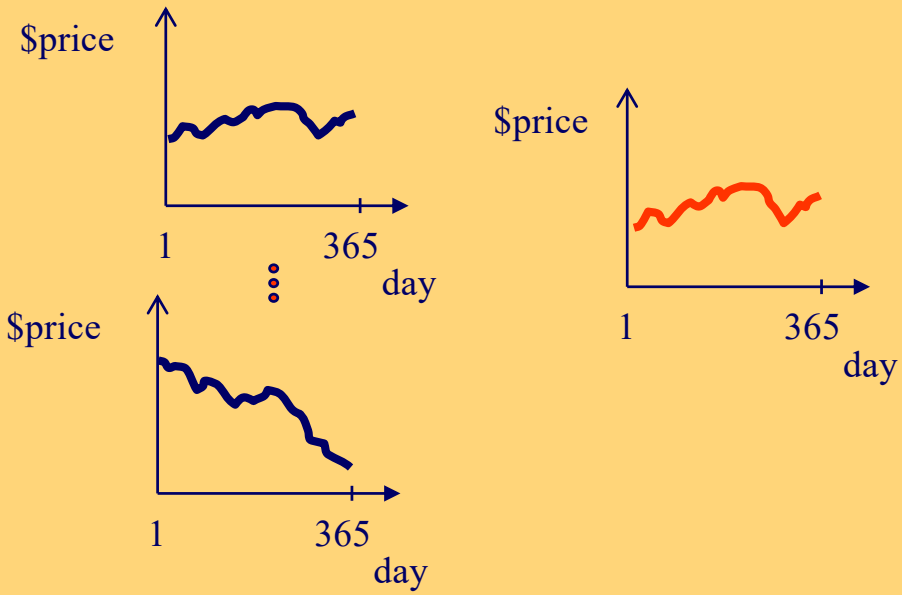
15-826: Multimedia (Databases) and Data Mining

Lecture #23: Multimedia indexing

C. Faloutsos

Problem

- Q: Find stocks similar to <MSFT>



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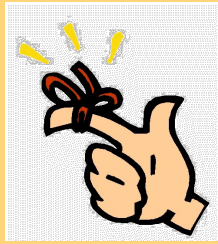
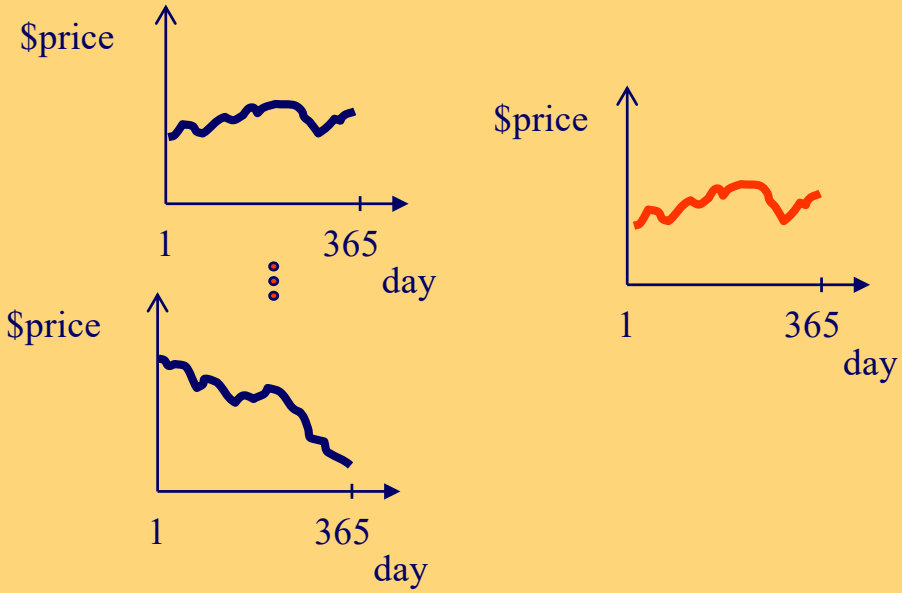


Solution

- Q: Find stocks similar to <MSFT>
- A: GEMINI: Extract features + SAM



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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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Must-read material

- ★ Laurens van der Maaten, Geoffrey Hinton, *Visualizing Data using t-SNE*, JMLR 9(86):2579−2605, 2008 (scikit-learn :

```
from sklearn.manifold import TSNE
```

- ★ Leland McInnes, John Healy, James Melville, *UMAP: Uniform Manifold Approximation and Projection for Dimension Reduction*, arxiv, 2018 (python library)

Outline

Goal: 'Find similar / interesting things'

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

Indexing - Detailed outline

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

Multimedia - Detailed outline

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

Problem

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

Allow fast, similarity queries

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)

Sample queries

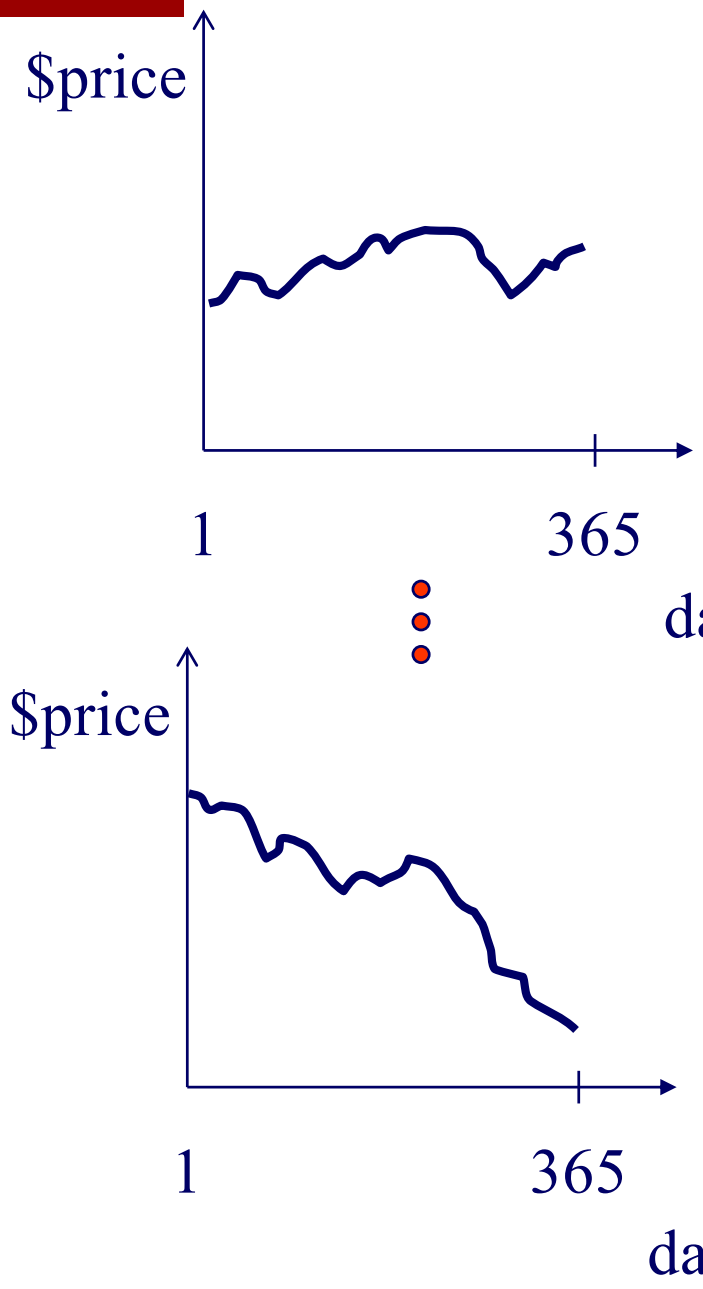
- find medical cases similar to Smith's
- Find pairs of stocks that move in sync
- Find pairs of documents that are similar (plagiarism?)
- find faces similar to 'Tiger Woods'

Detailed problem defn.:

Problem:

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

- for example:



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

Design goals

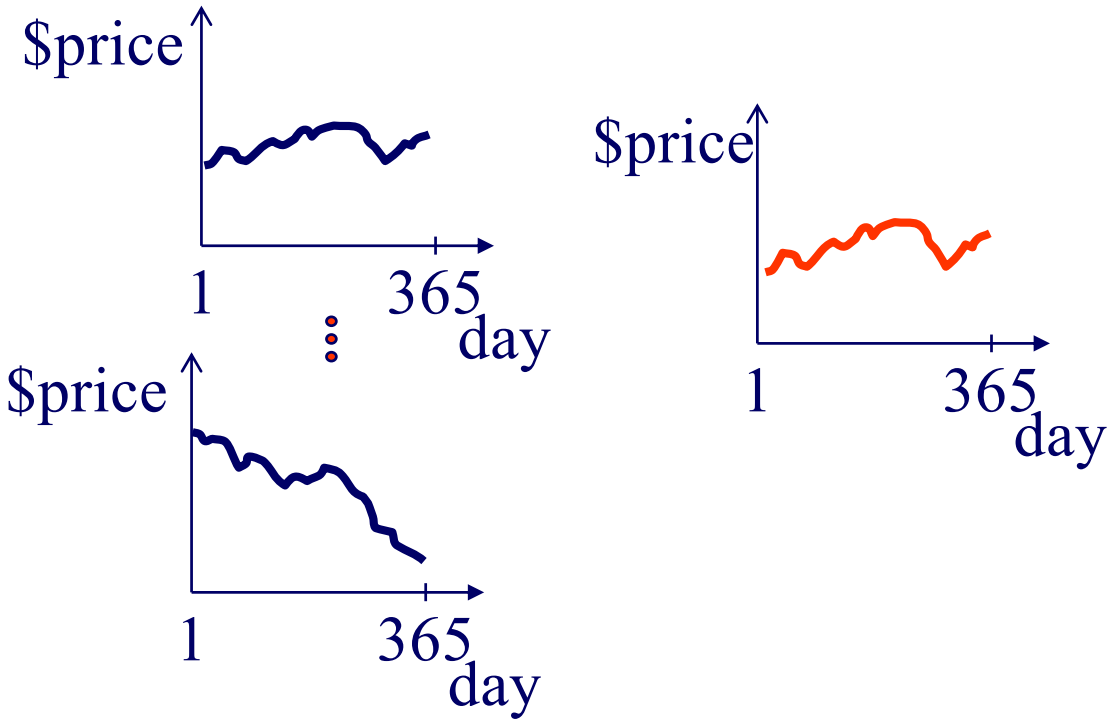
- Fast (faster than seq. scan)
- 'correct' (ie., no false alarms; no false dismissals)

Multimedia - Detailed outline

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

Main idea

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



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Main idea

- Seq. scanning works - how to do faster?

Idea: 'GEMINI'

(GEneric Multimedia INdexIng)

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

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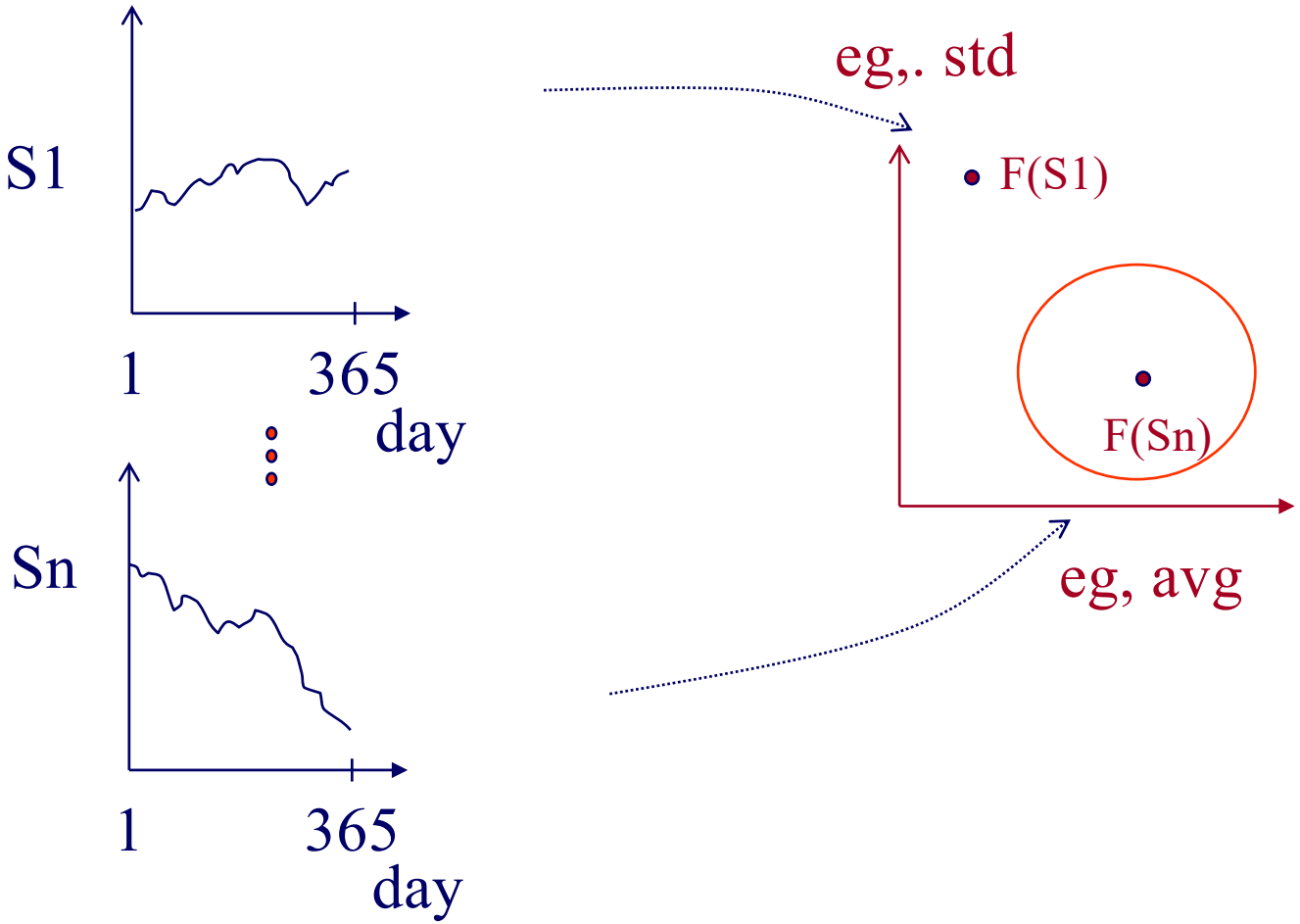
'GEMINI' - Pictorially



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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

GEMINI

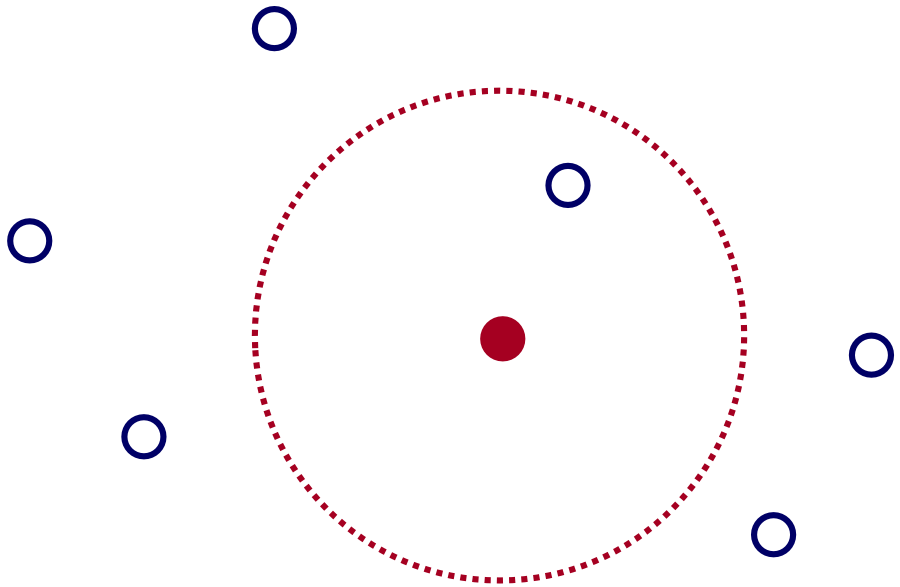
Important: Q: how to guarantee no false dismissals?

A1: preserve distances (but: difficult/impossible)

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

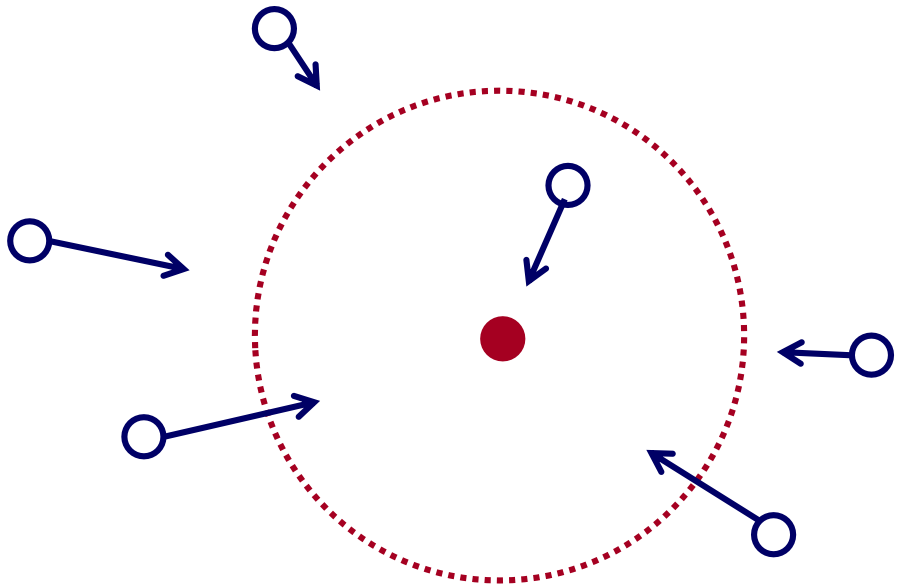
GEMINI

- 'proof' of lower-bounding lemma



GEMINI

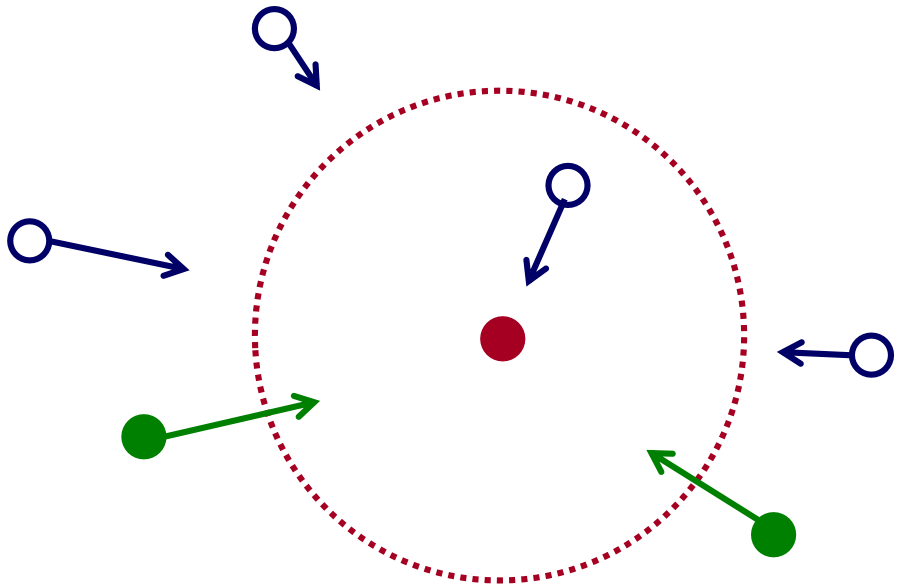
- 'proof' of lower-bounding lemma



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

GEMINI

- 'proof' of lower-bounding lemma



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

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?

Time sequences

Q: what features?

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

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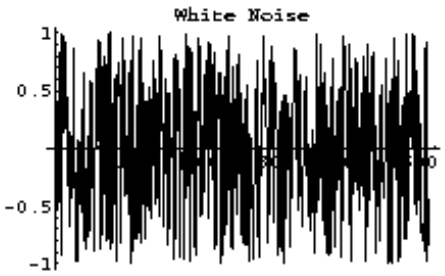
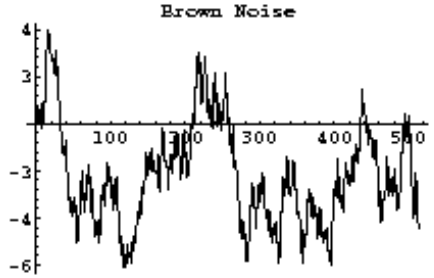
details

Time sequences

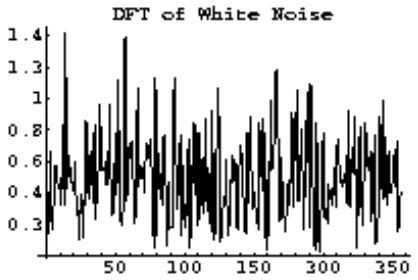
white noise

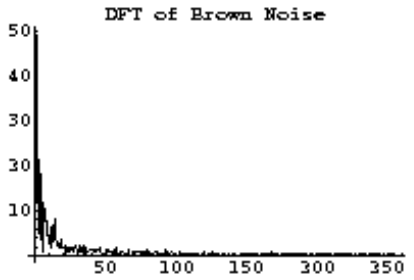
brown noise



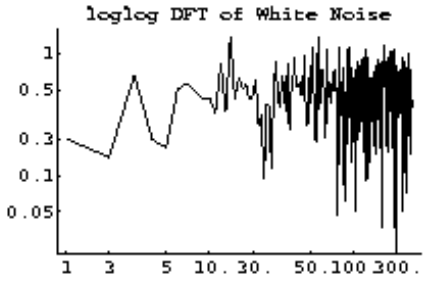


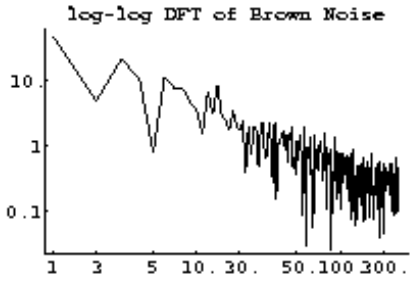
Fourier spectrum





... in log-log

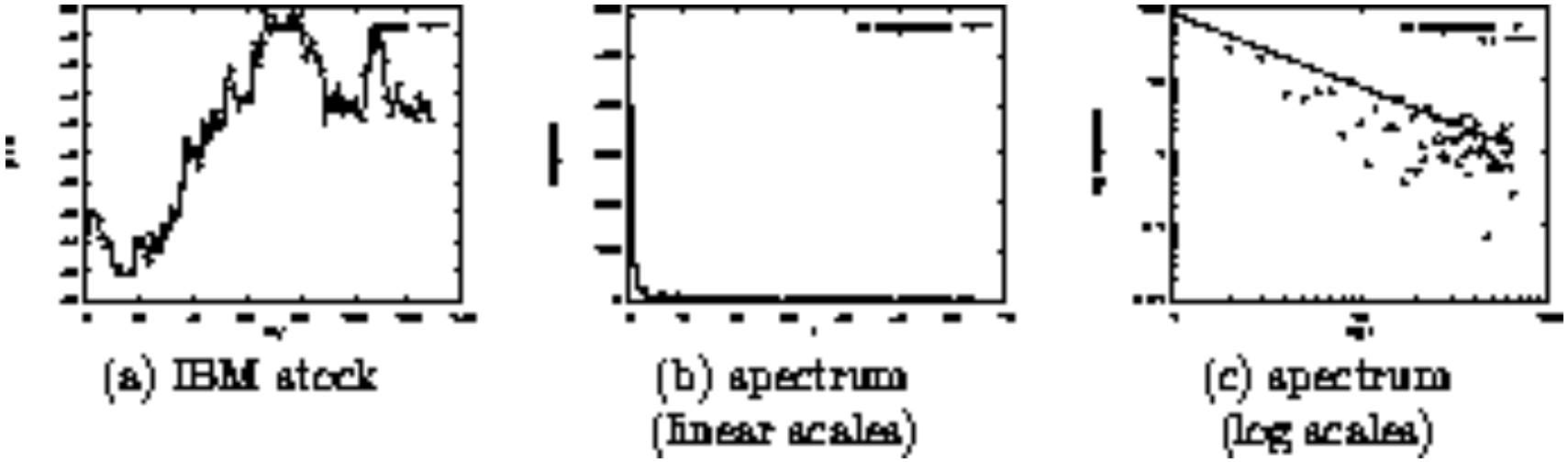




details

Time sequences

- Eg.:



Time sequences

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

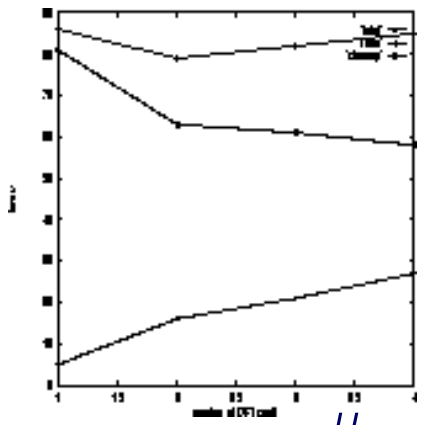
Time sequences

- 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+]

Time sequences - results

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

time



← total

← cleanup-time

← r-tree time

coeff. kept

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Time sequences - improvements:

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

SKIP

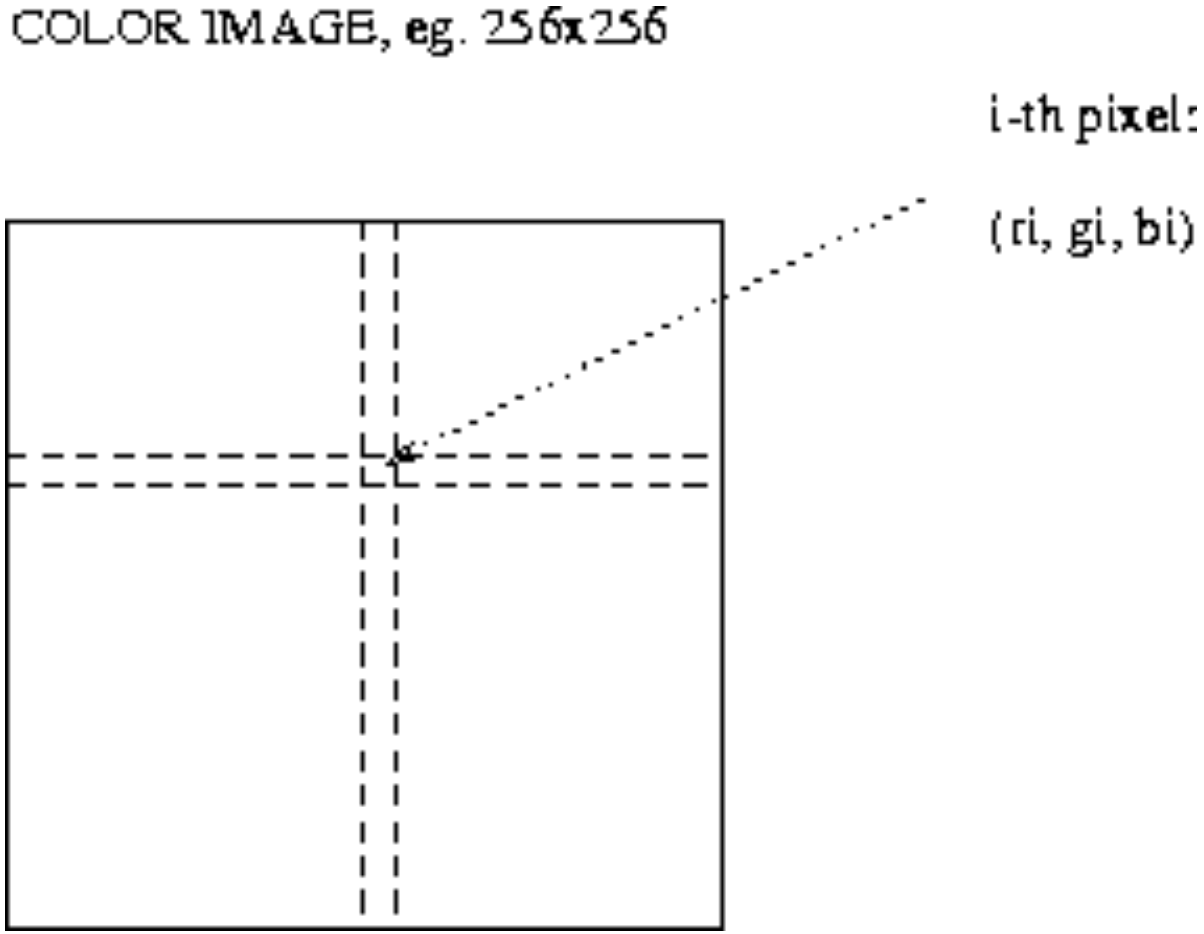
Multimedia - Detailed outline

- multimedia
  - Motivation / problem definition
  - Main idea / time sequences
  - images (color, shapes)
  - sub-pattern matching
  - automatic feature extraction / FastMap

SKIP

Images - color

what is an image?
A: 2-d array



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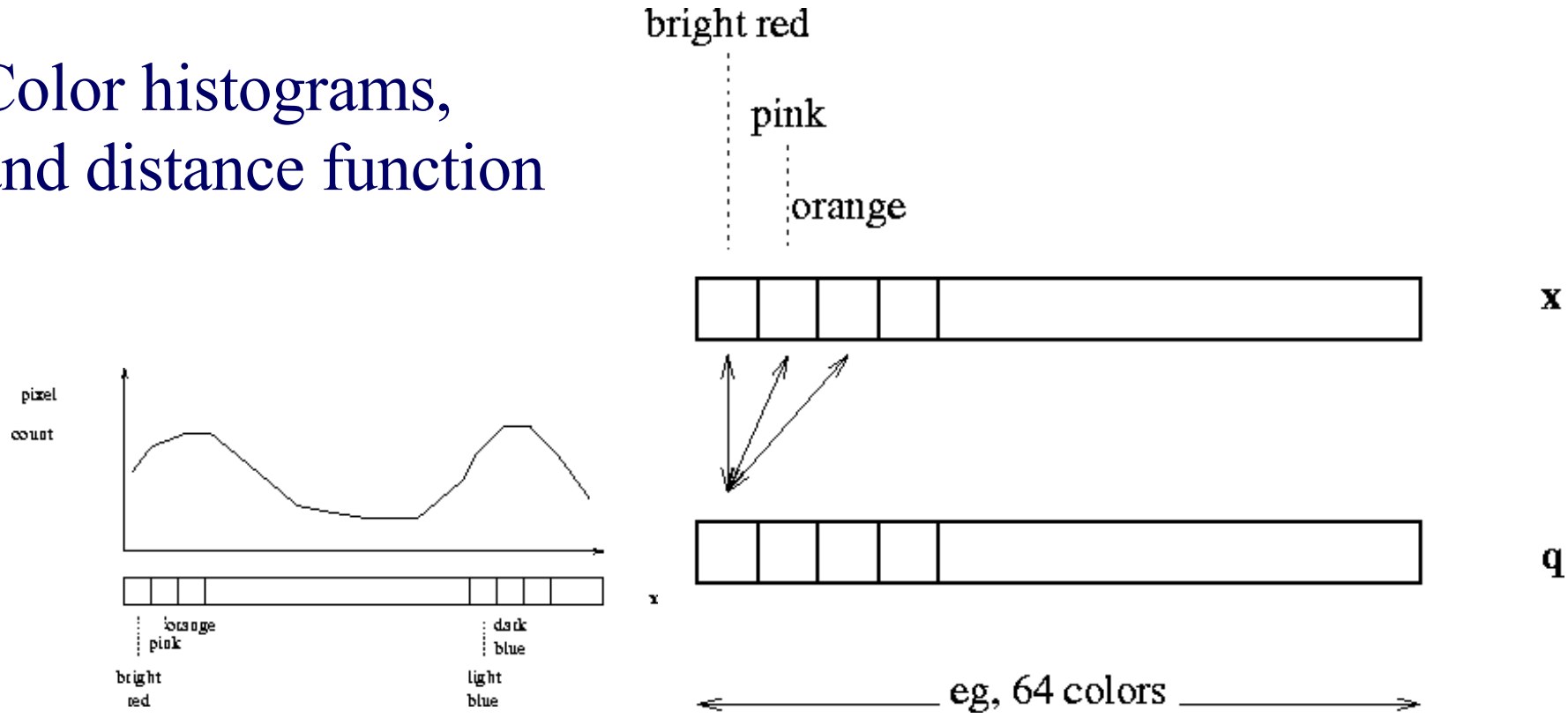
Images - color

Color histograms,
and distance function



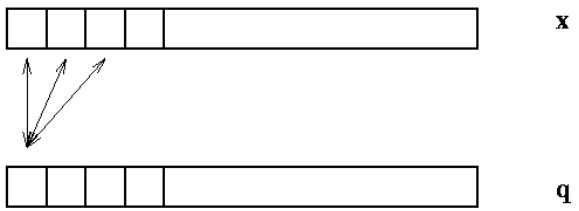
SKIP

Images - color

Mathematically, the distance function is:

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

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



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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

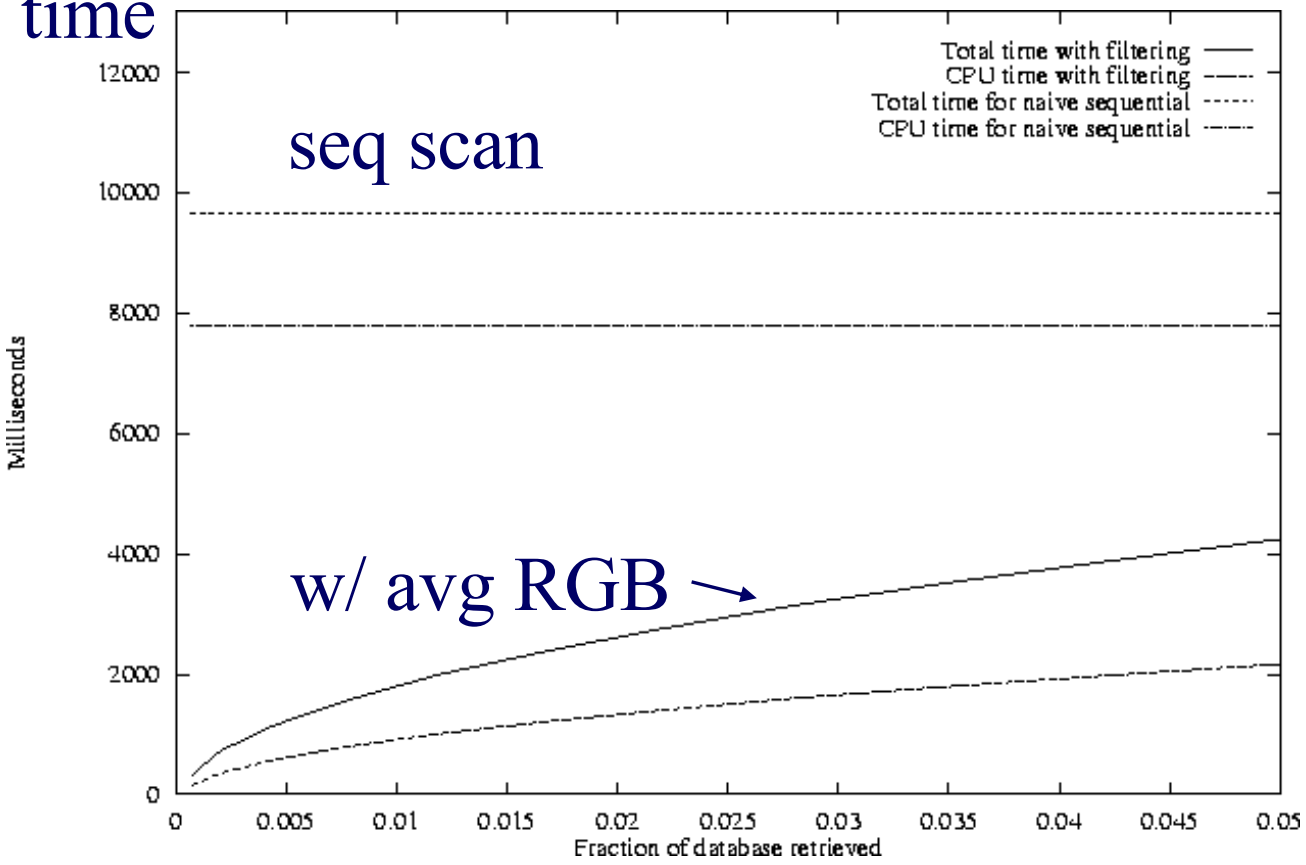
it turns out that this lower-bounds the histogram distance ->

- no cross-talk
- SAMs are applicable

SKIP

Images - color

performance: time



selectivity

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Multimedia - Detailed outline

- multimedia
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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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SKIP

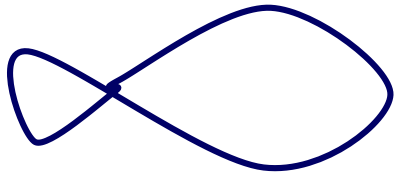
Images - shapes

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

SKIP

Images - shapes

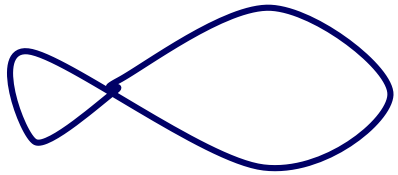
- distance function: Euclidean, on the area, perimeter, and 20 ‘moments’
- (Q: other ‘features’ / distance functions?



SKIP

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?

SKIP

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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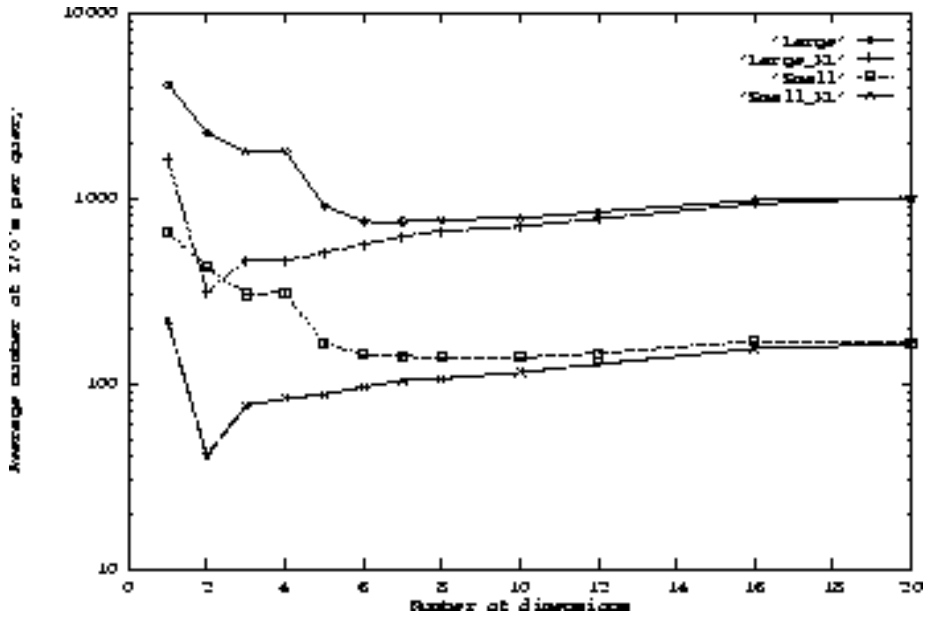
Images - shapes

- Performance: ~10x faster

log(# of I/Os)

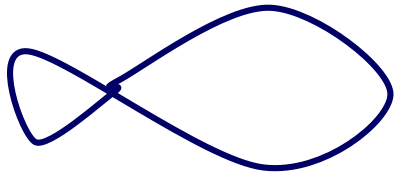


⟵ all kept

# of features kept

SKIP

Other shape features?



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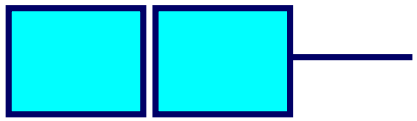
Other shape features

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

shape



"structuring element"

R=1

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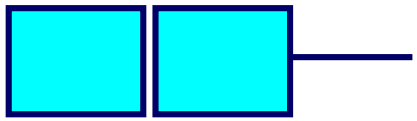
Other shape features

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

shape

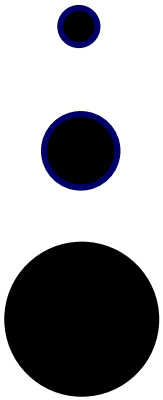


"structuring element"

R=0.5

R=1

R=2



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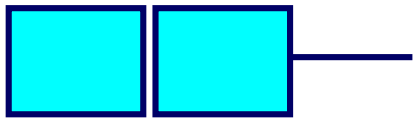
Other shape features

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

shape



"structuring element"

R=0.5

R=1

R=2

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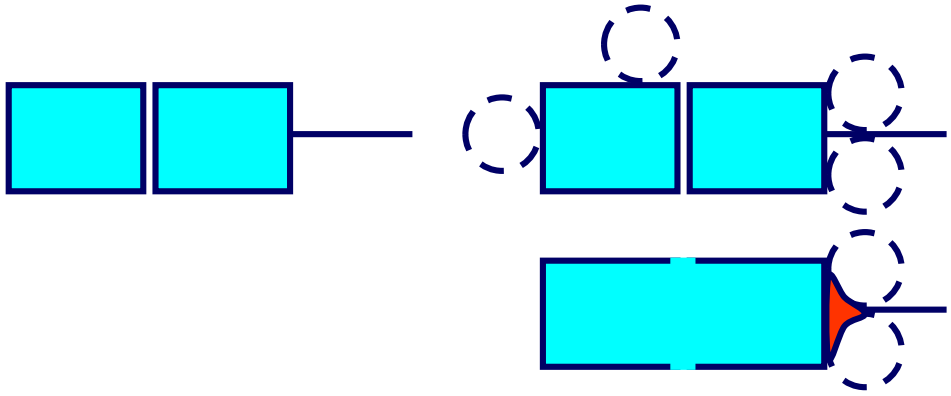
Morphology: closing

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



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Morphology: closing

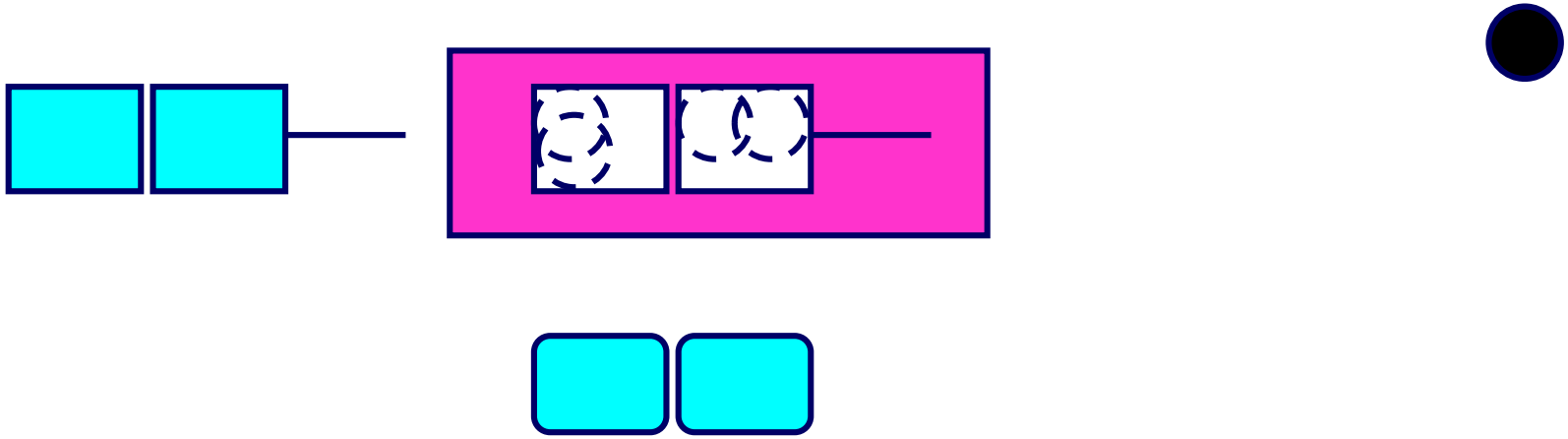
- fill in small gaps

‘closing’,
with R=1

SKIP

Morphology: opening

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



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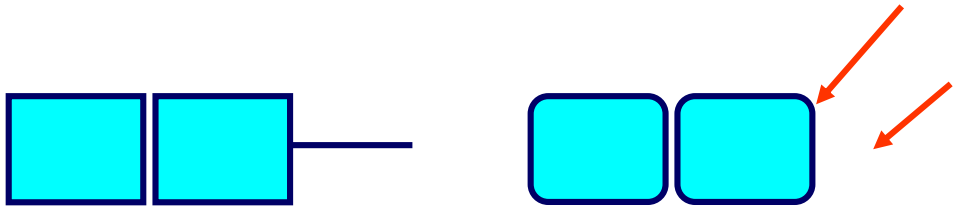
Morphology: opening

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



'opening'
with R=1

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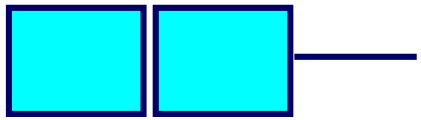
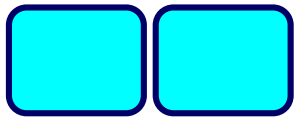
Morphology

- Closing: fills in gaps



- Opening: trims extremities



- All wrt a structuring element:

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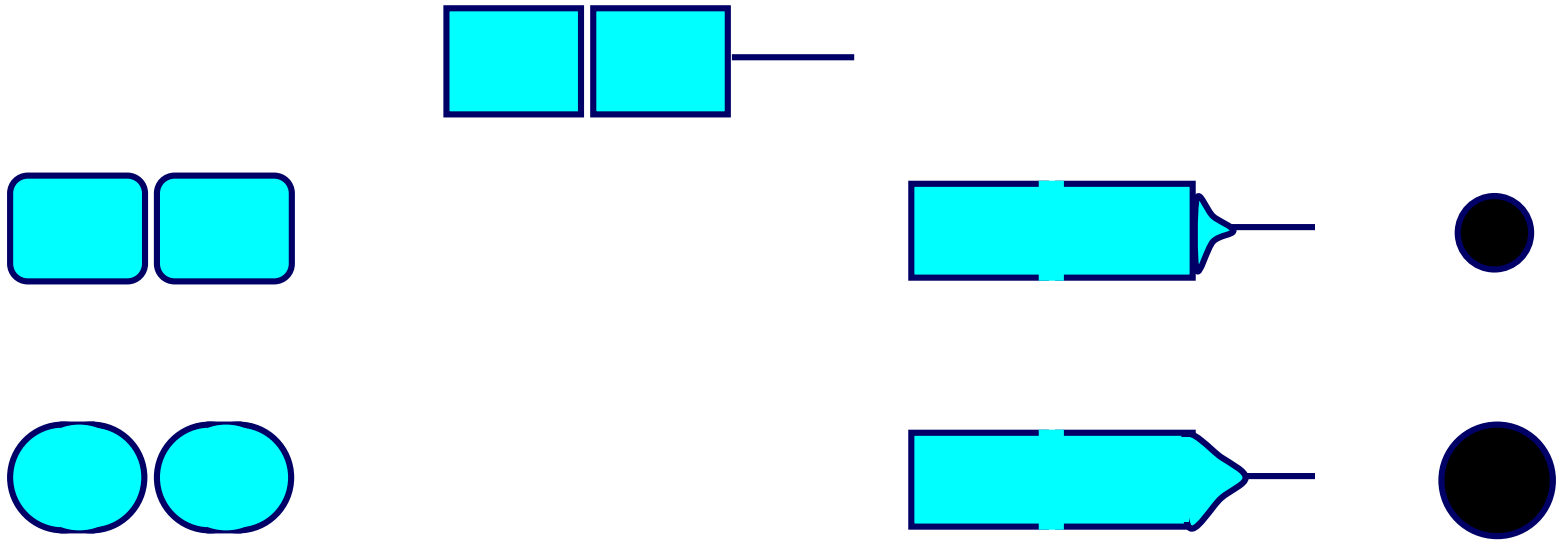
Morphology

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



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Morphology

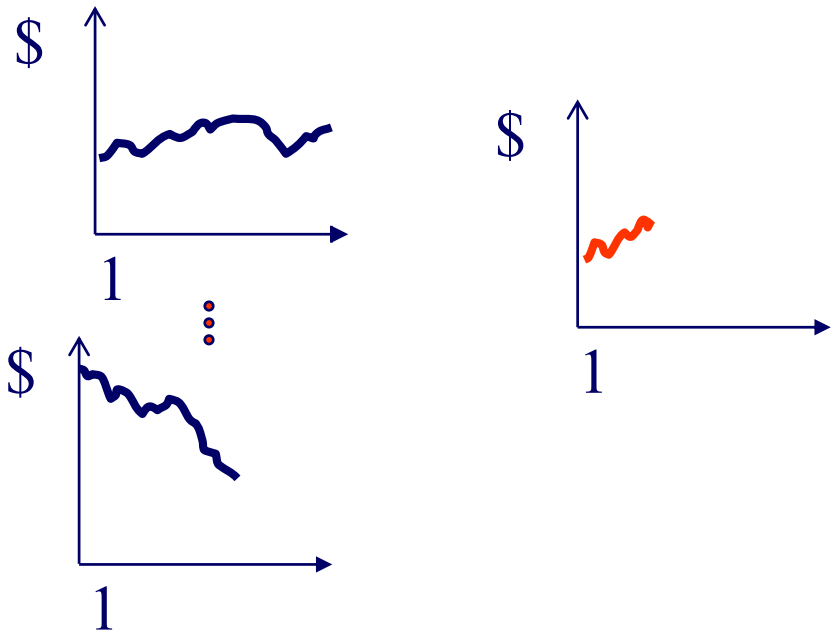
- Powerful method:
- ‘pattern spectrum’ [Maragos+]
- ‘skeletonization’ of images
- ‘Alpha-shapes’ [Edelsbrunner]
- Book: *An introduction to morphological image processing,* by Edward R. Dougherty

Multimedia - Detailed outline

- multimedia
  - Motivation / problem definition
  - Main idea / time sequences
  - images (color; shape)
  - sub-pattern matching
  - automatic feature extraction / FastMap

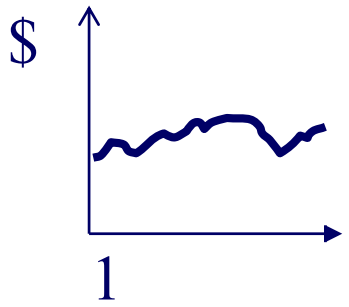
Sub-pattern matching

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



Sub-pattern matching

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



Sub-pattern matching

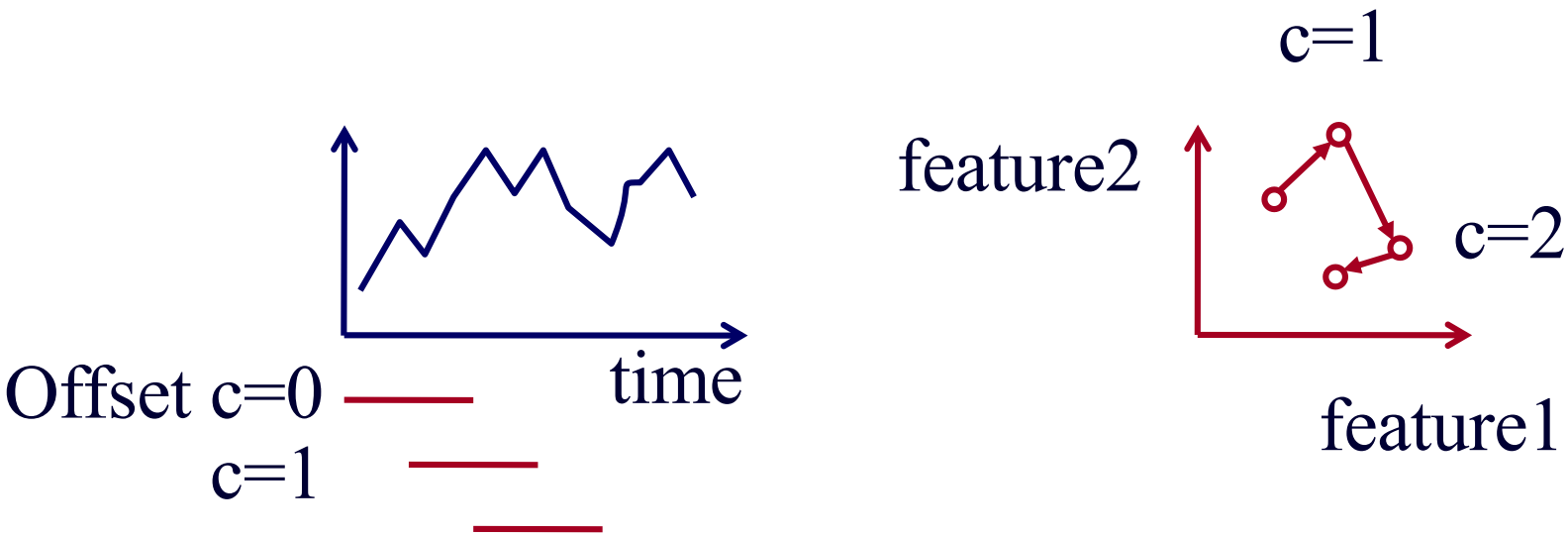
- Assume that queries have minimum duration *w;* (eg., *w*=7 days)
- divide data sequences into windows of width *w* (overlapping, or not?)

Sub-pattern matching

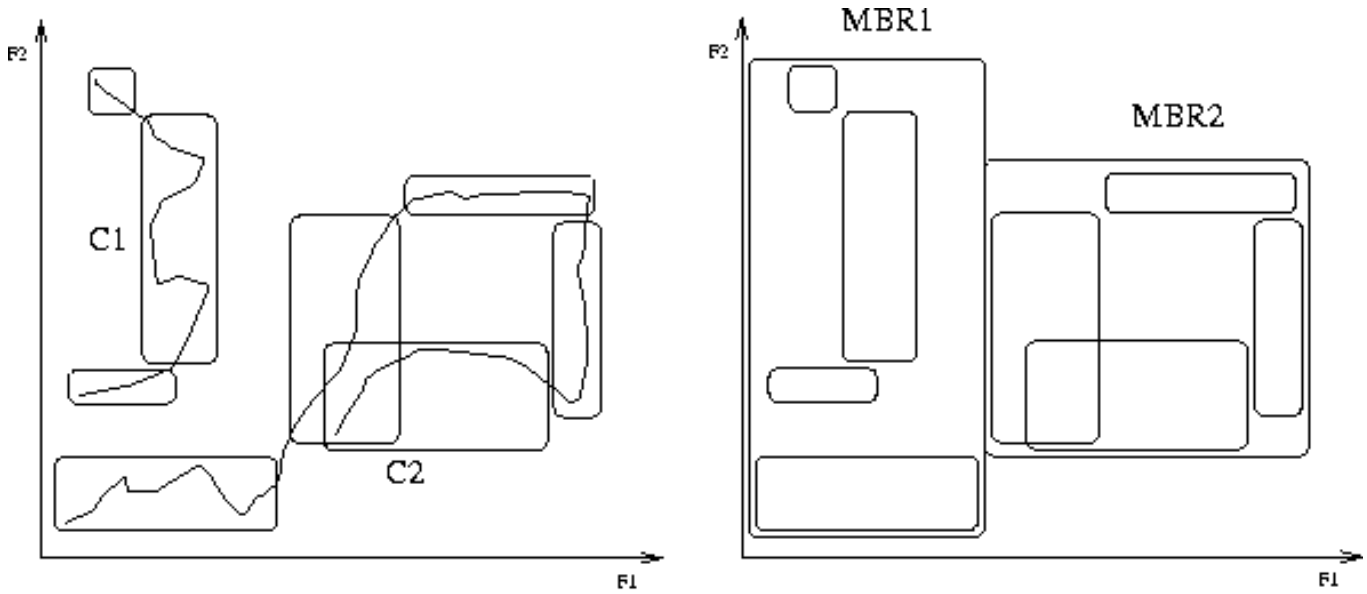
- Assume that queries have minimum duration *w;* (eg., *w*=7 days)
- divide data sequences into windows of width *w* (overlapping, or not?)
- A: sliding, overlapping windows. Thus: trails

Pictorially:

Sub-pattern matching

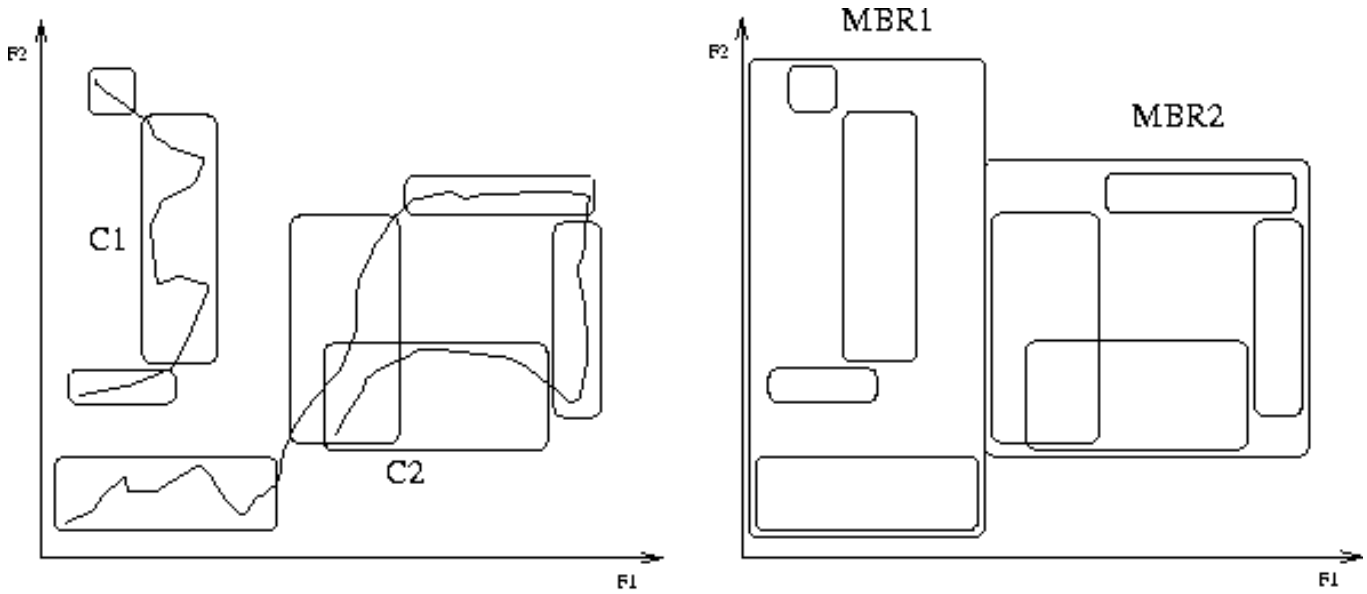


Sub-pattern matching



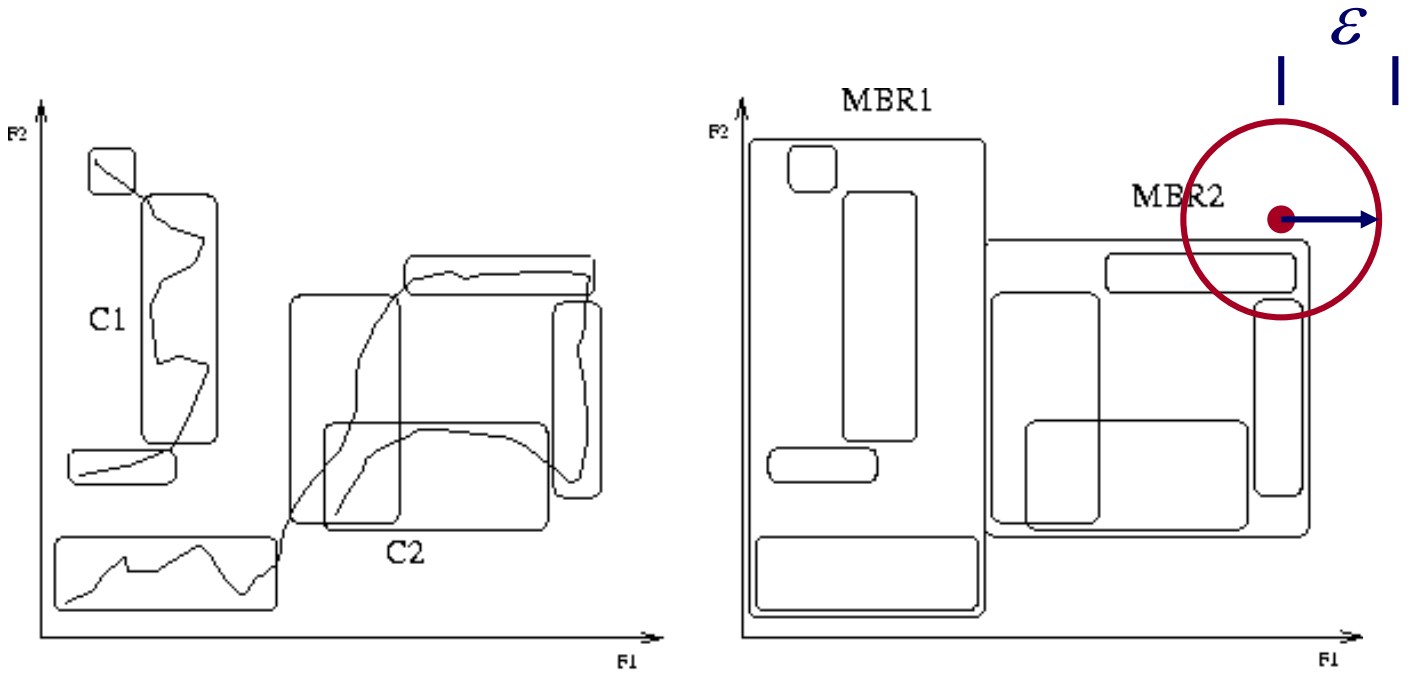
sequences -> trails -> MBRs in feature space

Sub-pattern matching



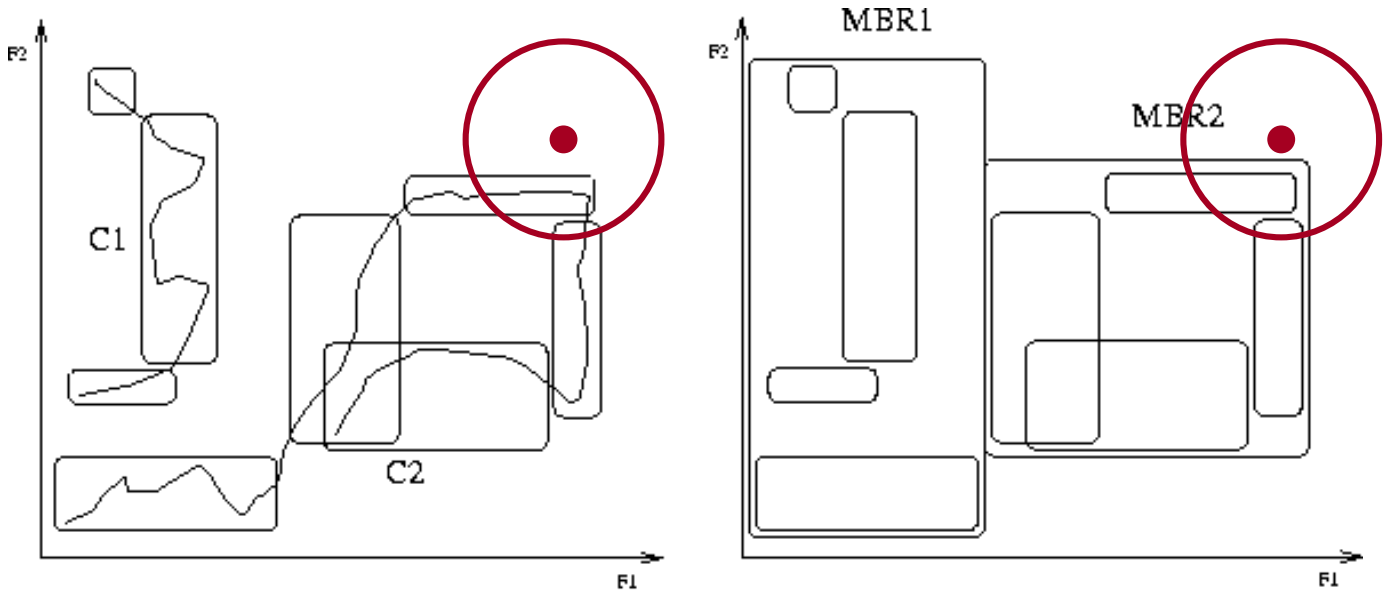
Q: do we store all points? why not?

Sub-pattern matching



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

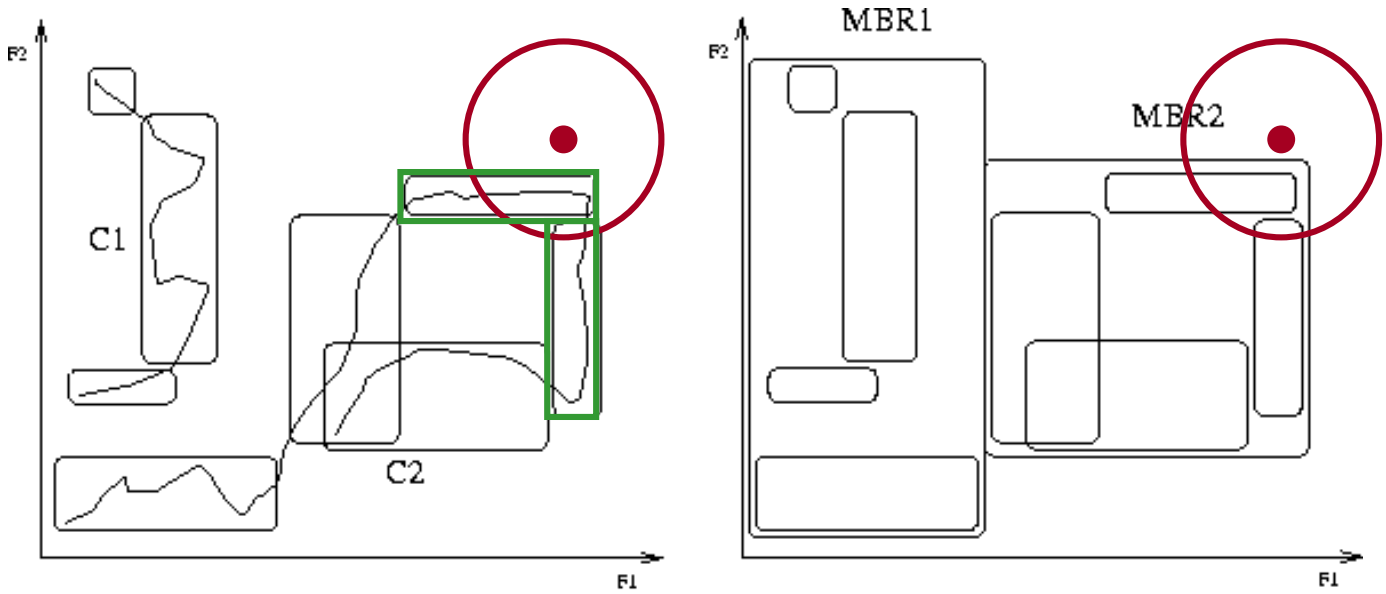
Sub-pattern matching



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

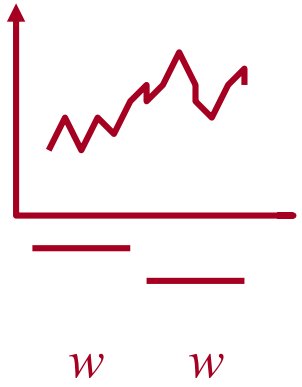
A: R-tree; find qualifying stocks and intervals

Sub-pattern matching

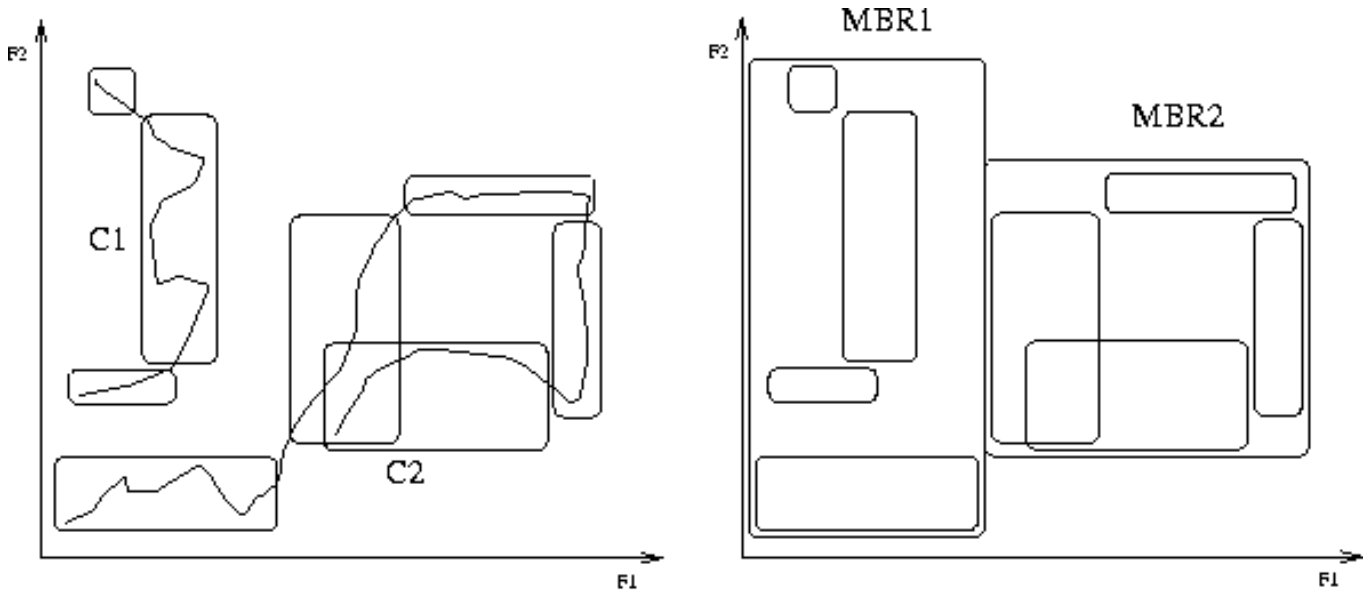


Q: how to do range queries of duration *w*?

A: R-tree; find qualifying stocks and intervals

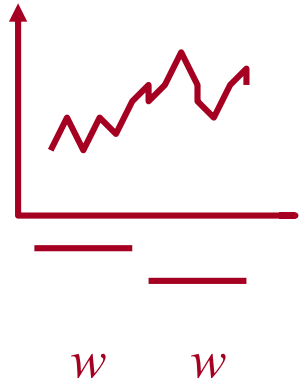


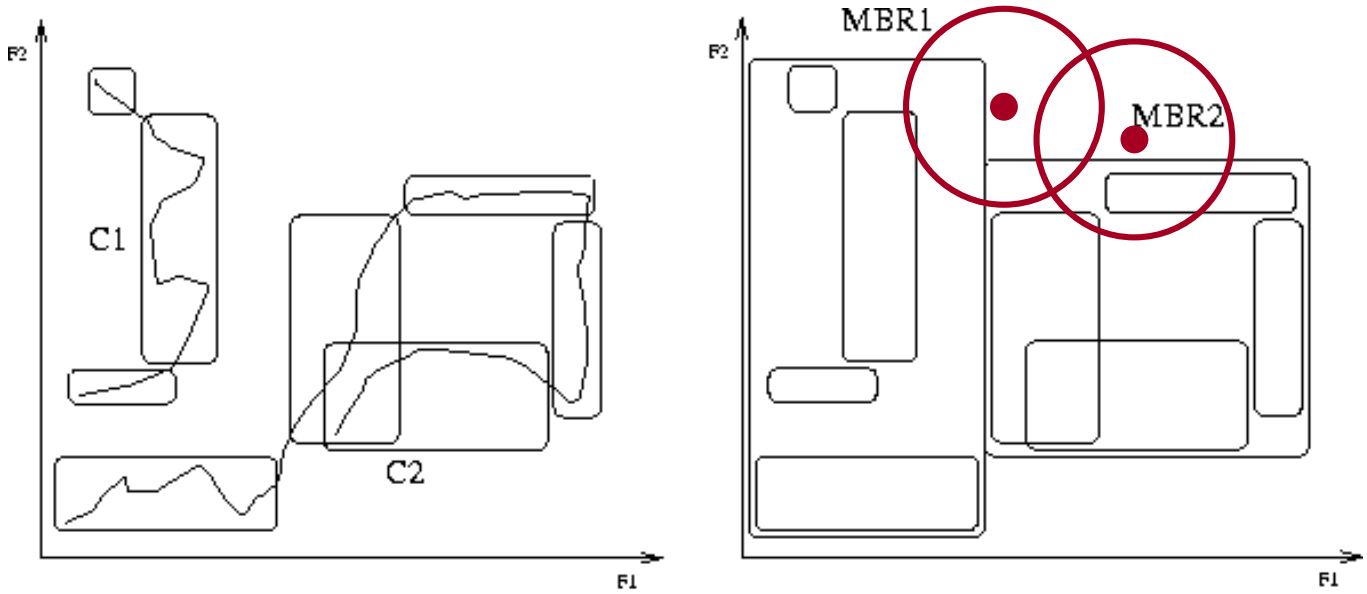
Sub-pattern matching



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

Sub-pattern matching





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

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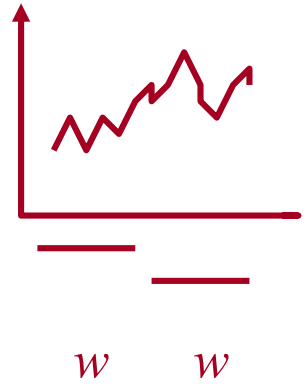
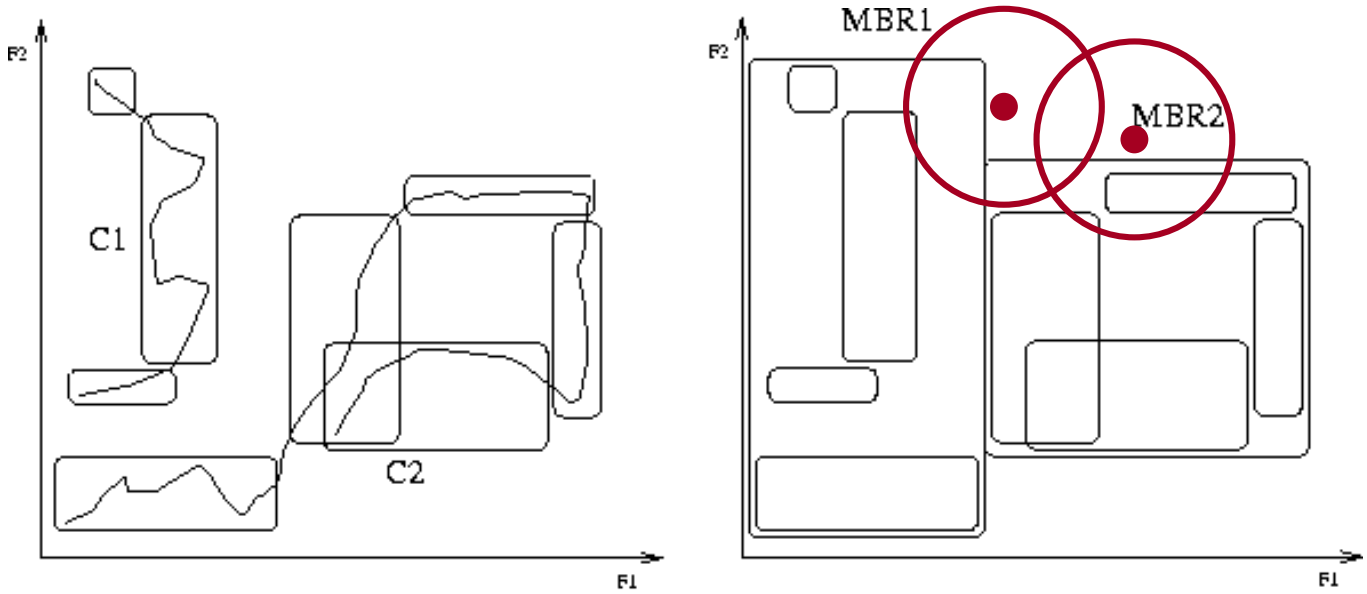
Sub-pattern matching





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)

Sub-pattern matching

(improvement [Moon+2001])

- use non-overlapping windows, for data

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?)

Multimedia - Detailed outline

- multimedia
  - Motivation / problem definition
  - Main idea / time sequences
  - images (color; shape)
  - sub-pattern matching
  - automatic feature extraction / FastMap

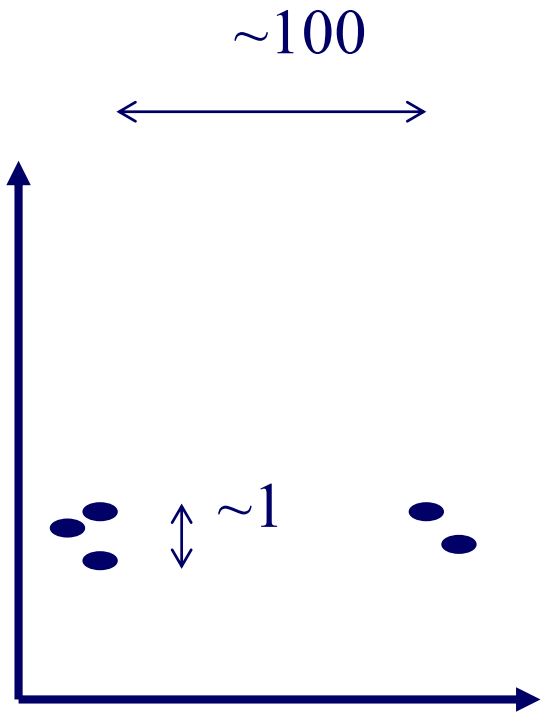
FastMap

Automatic feature extraction:

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

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



FastMap

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

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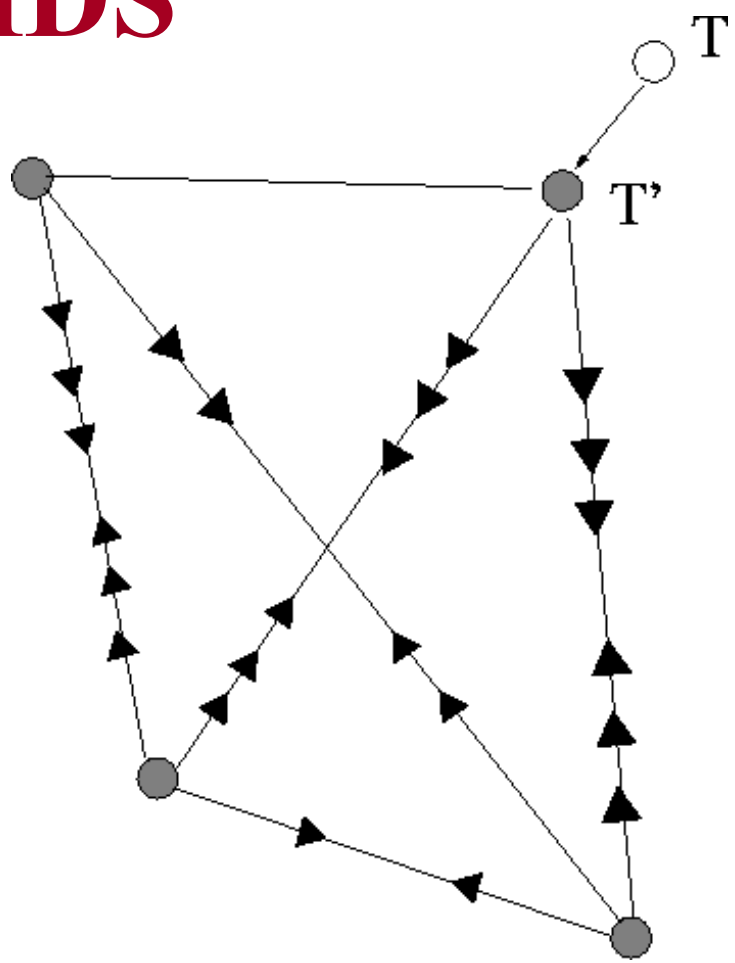
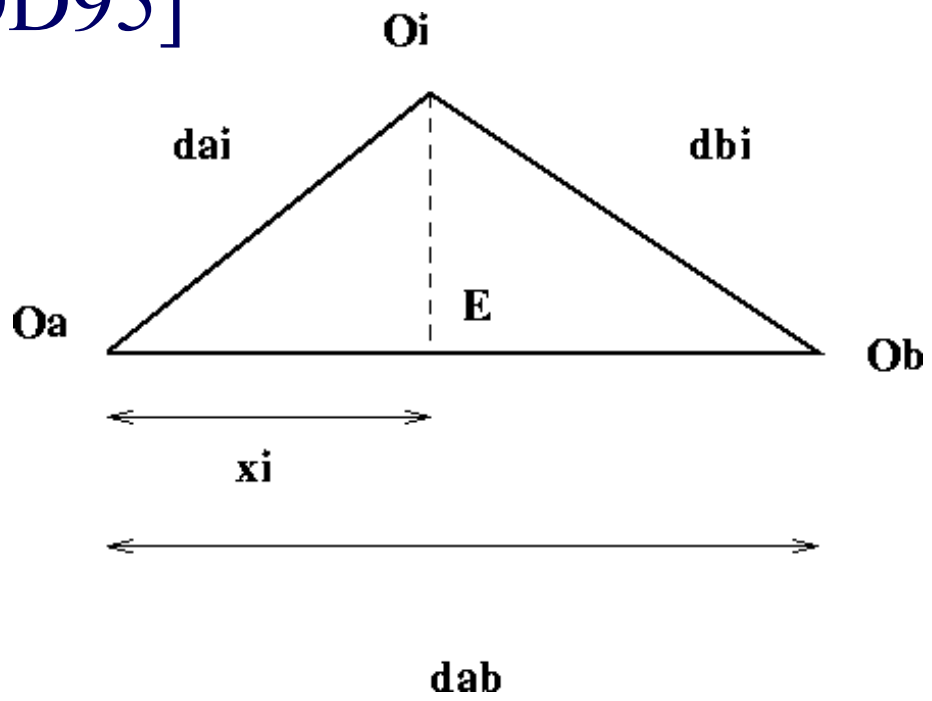
MDS

Multi Dimensional Scaling



Main idea: projections

We want a linear algorithm: FastMap [SIGMOD95]



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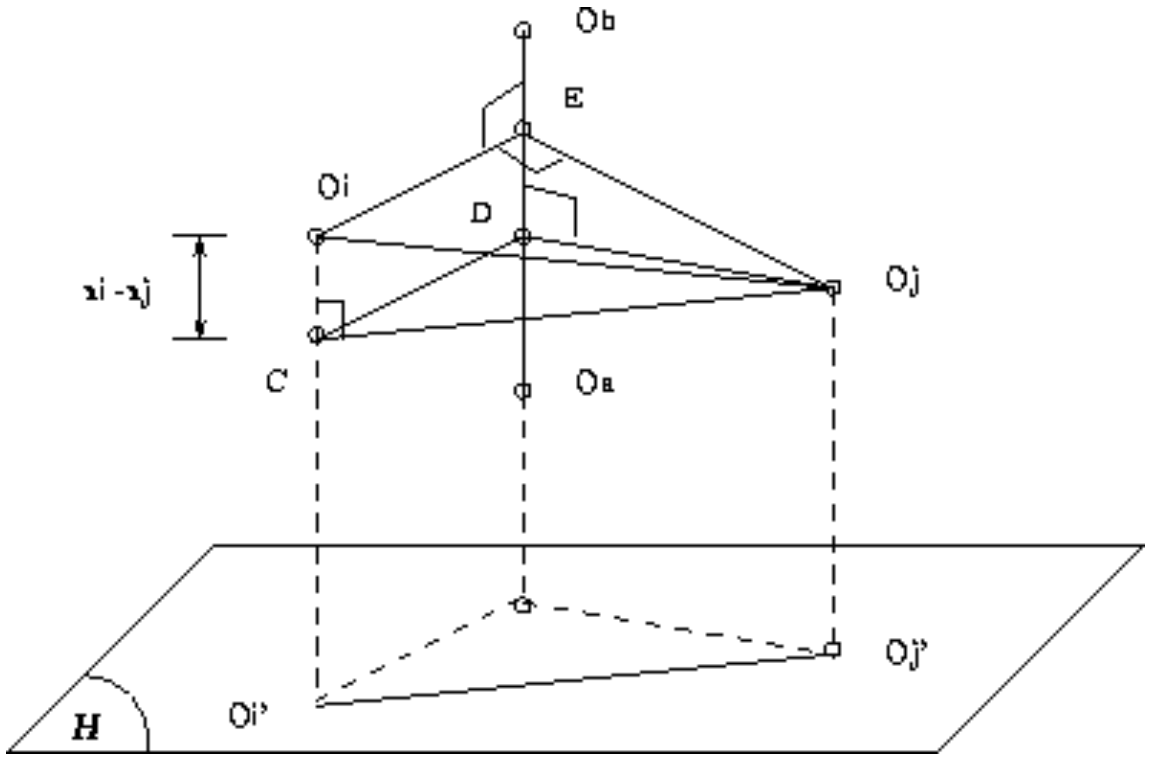
FastMap - next iteration



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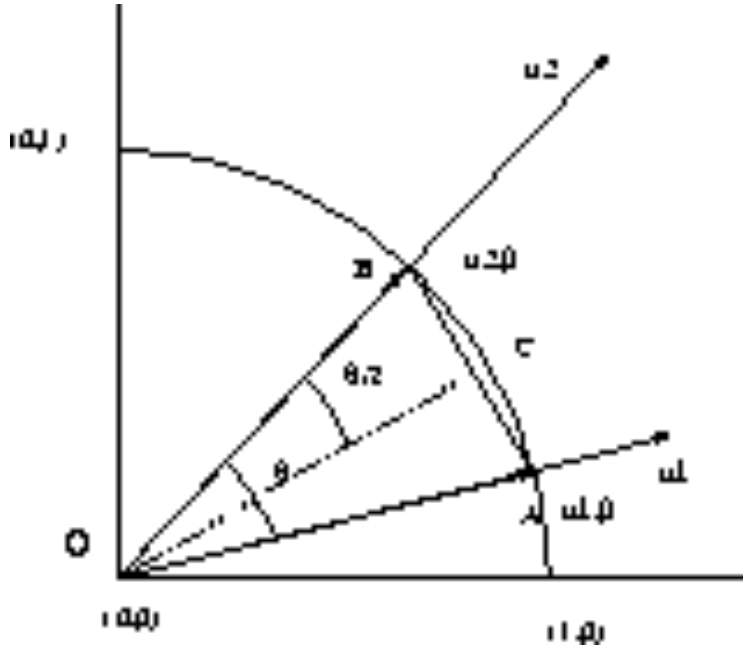
Results

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



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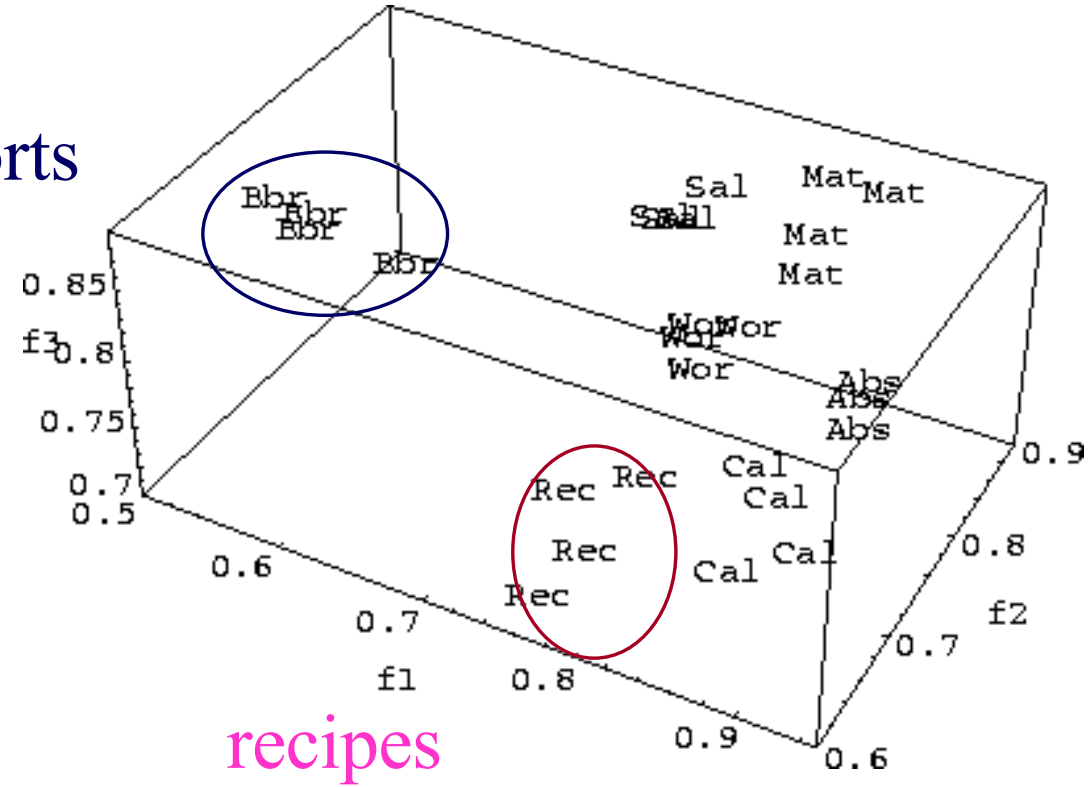
Results

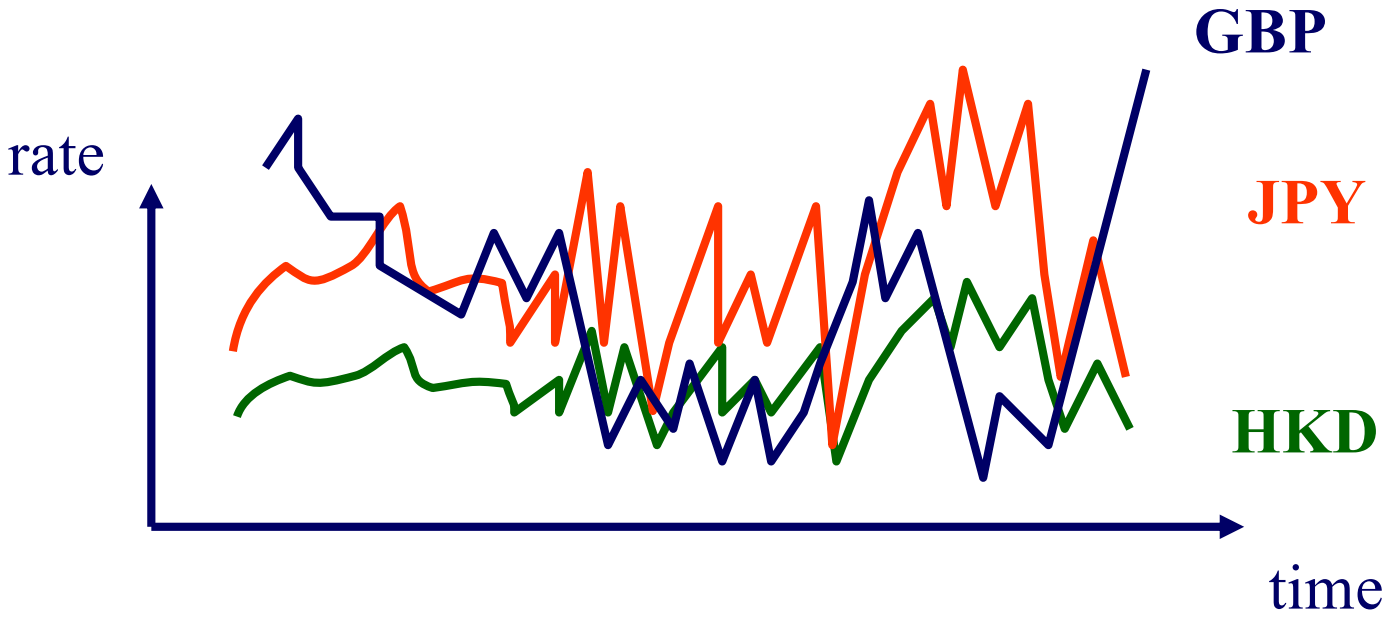
bb reports



recipes

Applications: time sequences

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



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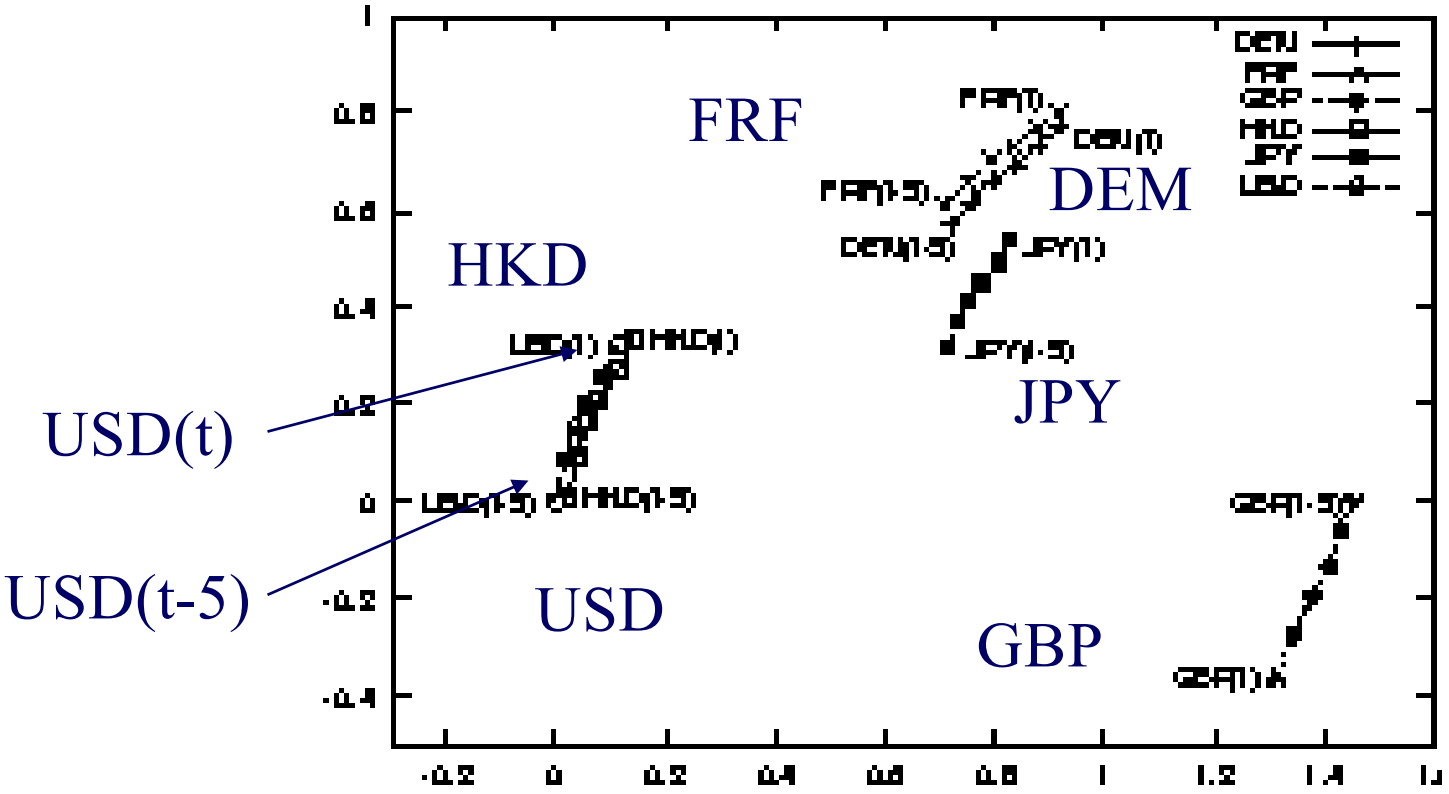
Applications - financial

- currency exchange rates [ICDE00]



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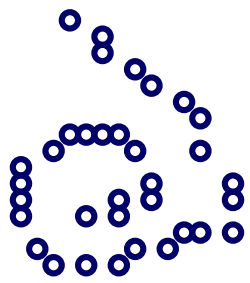
Variations

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



Variations

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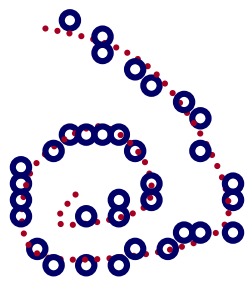

Variations

- tSNE (see sklearn) and JMLR
  - Nearby entities -> nearby points
  - Far apart entities -> ”don’t care”
- Umap (see scikit) and Arxiv
  - Nearby entities -> nearby points
  - Far apart entities -> sort-of far-apart points

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Variations

- tSNE: recommended – but: tune 'perplexity' (~50)

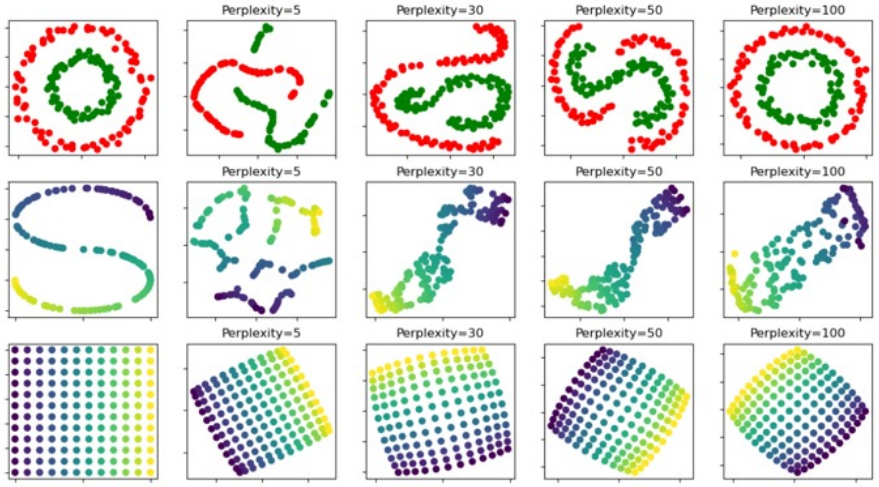
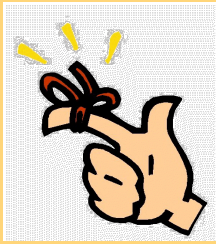


Image: from scikit-learn

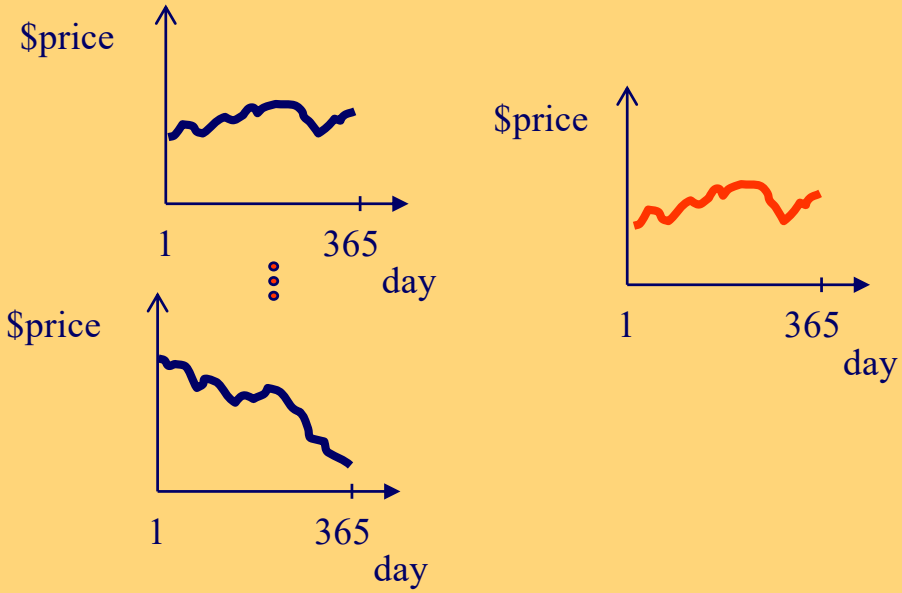
Conclusions

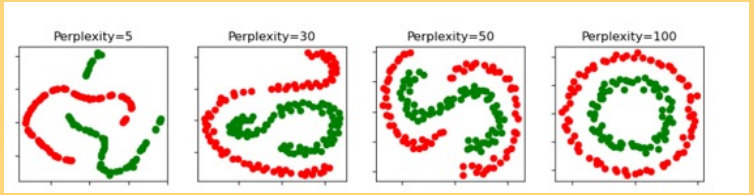
- GEMINI works for multiple settings
- MDS (FastMap/tSNE/UMap) can extract 'features' automatically (-> indexing, visual d.m.)



Solution

- Q: Find stocks similar to <MSFT>
- A: GEMINI: Extract features + SAM
  - A': and FastMap (tSNE/Umap), for feature extraction





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References

- Laurens van der Maaten, Geoffrey Hinton, *Visualizing Data using t-SNE*, JMLR 9(86):2579−2605, 2008 (scikit-learn :

```
from sklearn.manifold import TSNE
```

- Leland McInnes, John Healy, James Melville, *UMAP: Uniform Manifold Approximation and Projection for Dimension Reduction*, arxiv, 2018 (python library)