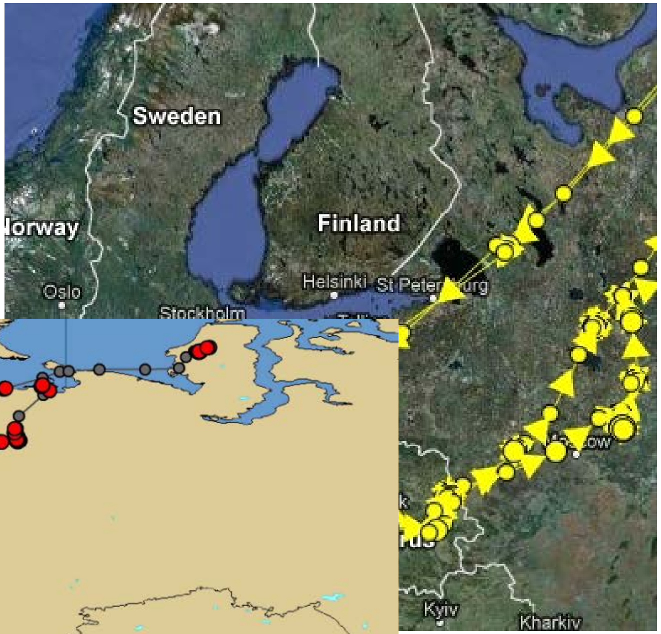
2IL76
Algorithms for Geographic Data

Spring 2015

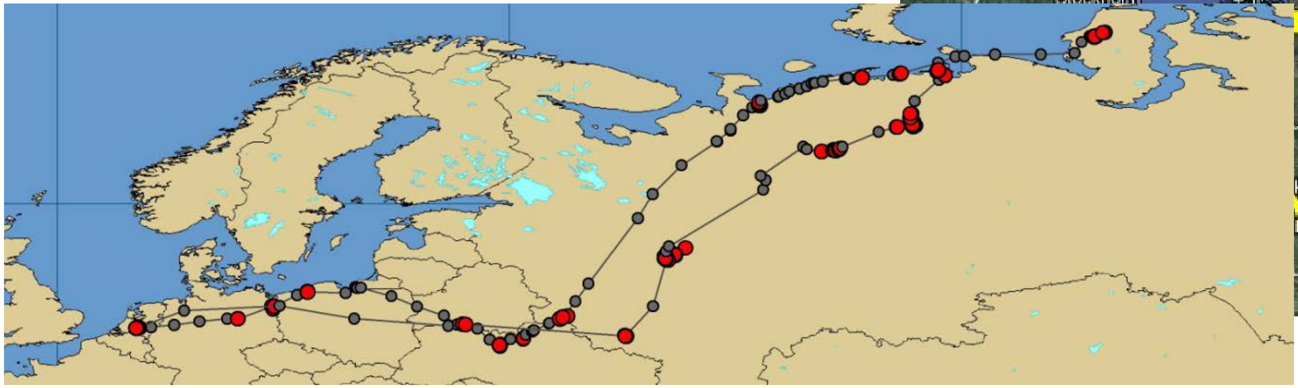
Lecture 6: Segmentation

Motivation: Geese Migration

- Two behavioural types
  - stopover
  - migration flight



- Input:
  - GPS tracks
  - expert description of behaviour



- Goal: Delineate stopover sites of migratory geese

Abstract / general purpose questions

Single trajectory

- simplification, cleaning
- *segmentation into semantically meaningful parts*
- finding recurring patterns (repeated subtrajectories)

Two trajectories

- similarity computation
- subtrajectory similarity

Multiple trajectories

- clustering, outliers
- flocking/grouping pattern detection
- finding a typical trajectory or computing a mean/median trajectory
- visualization

Problem

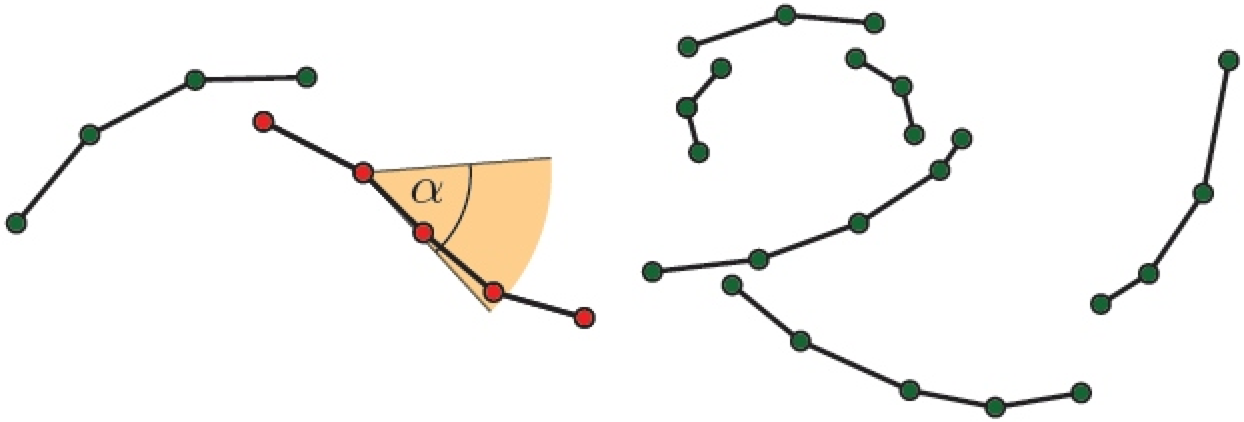
- For analysis, it is often necessary to break a trajectory into pieces according to the behaviour of the entity (e.g., walking, flying, …).

- **Input:** A trajectory T, where each point has a set of attribute values, and a set of criteria.
- **Attributes:** speed, heading, curvature…
- **Criteria:** bounded variance in speed, curvature, direction, distance…
- **Aim:** Partition T into a minimum number of subtrajectories (so-called *segments*) such that each segment fulfils the criteria.

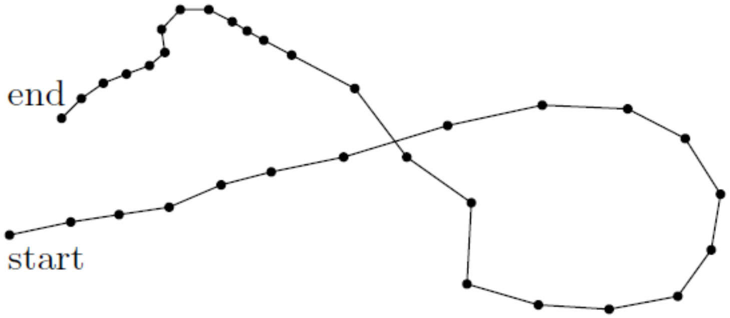
- *“Within each segment the points have similar attribute values”*

Criteria-Based Segmentation

Goal: Partition trajectory into a small number of segments such that a given criterion is fulfilled on each segment

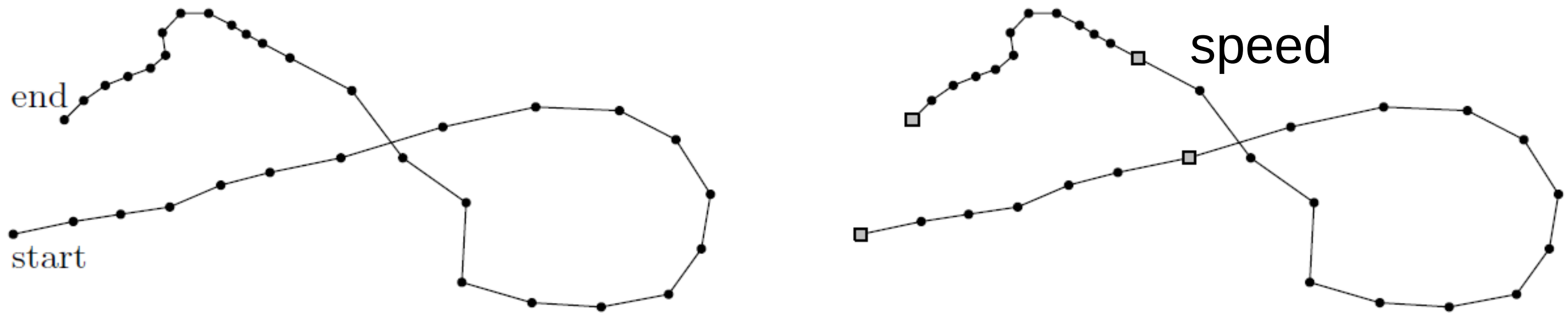


Example



- Trajectory T sampled with equal time intervals
- Criterion: speed cannot differ more than a factor 2?

Example



- Trajectory T sampled with equal time intervals
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- Criterion: direction of motion differs by at most 90º?

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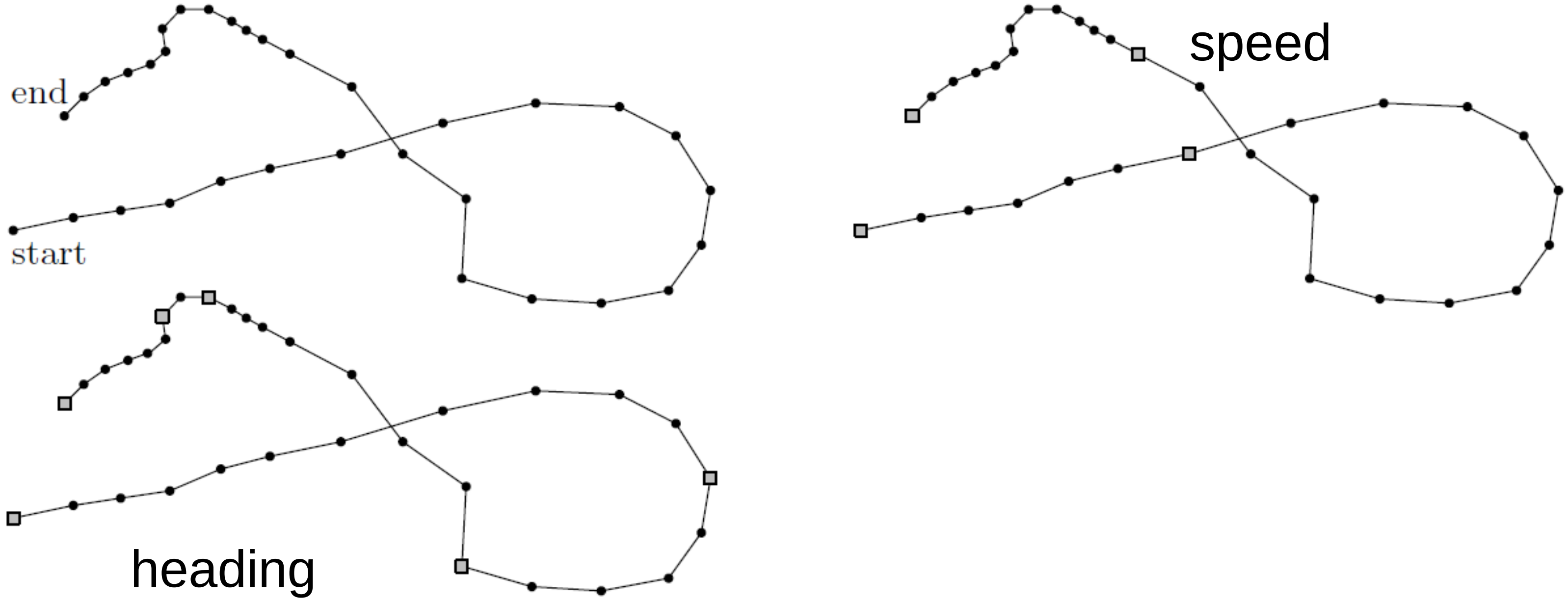

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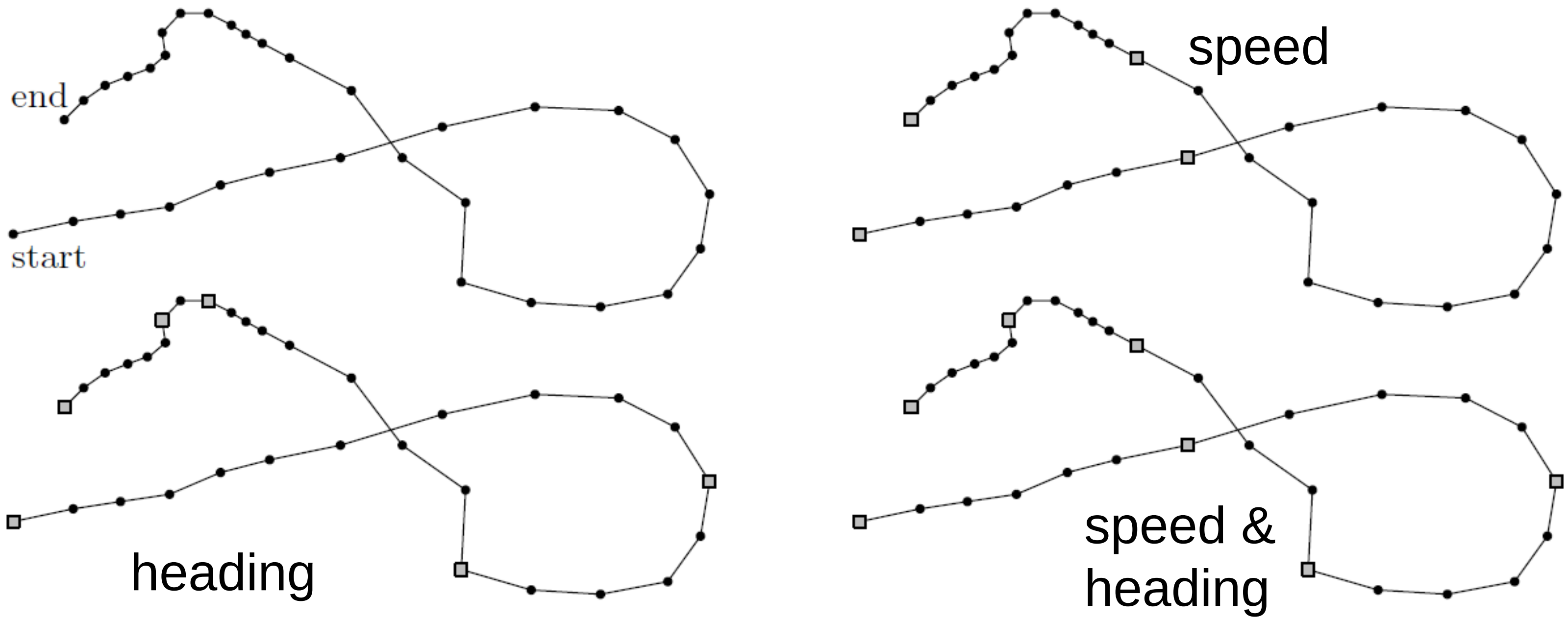

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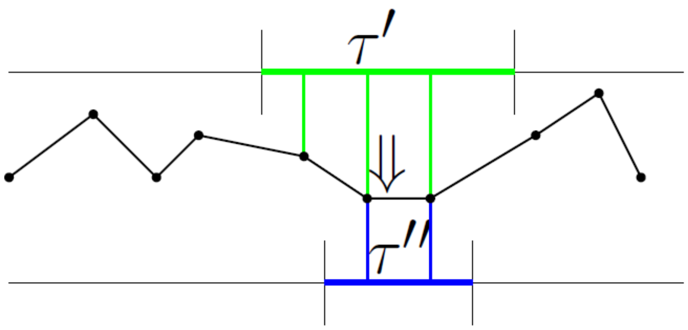
- Criterion: direction of motion differs by at most 90º?

Decreasing monotone criteria

- Definition: A criterion is decreasing monotone, if it holds on a segment, it holds on any subsegment.



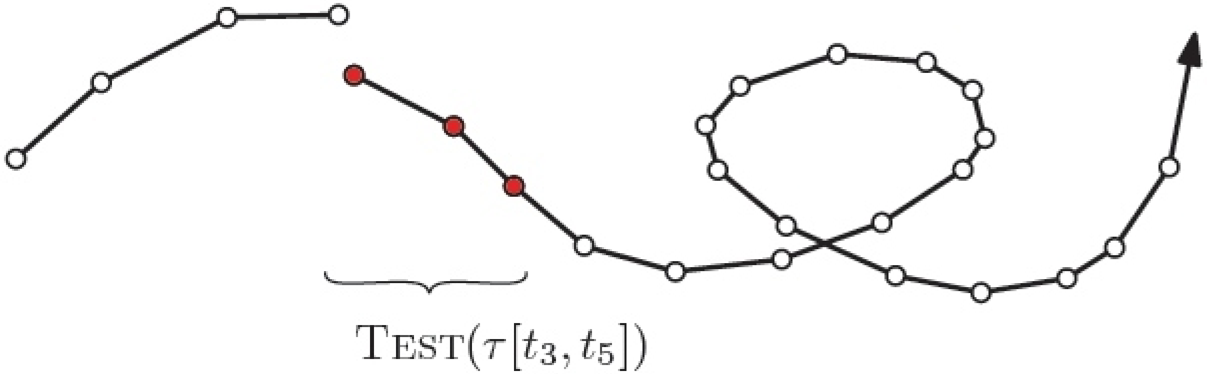
- Examples: disk criterion (location), angular range (heading), speed…

- Theorem: A combination of conjunctions and disjunctions of decreasing monotone criteria is a decreasing monotone criterion.

Greedy Algorithm

Observation:

If criteria are decreasing monotone, a greedy strategy works.



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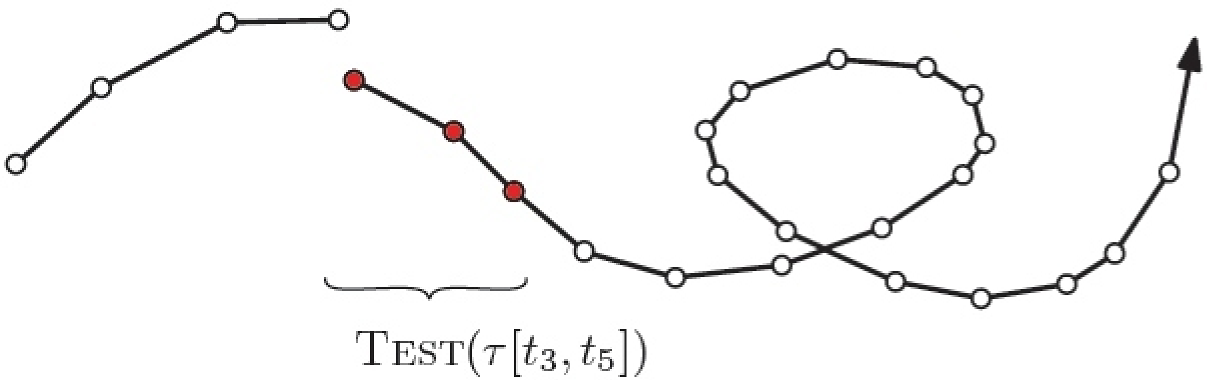
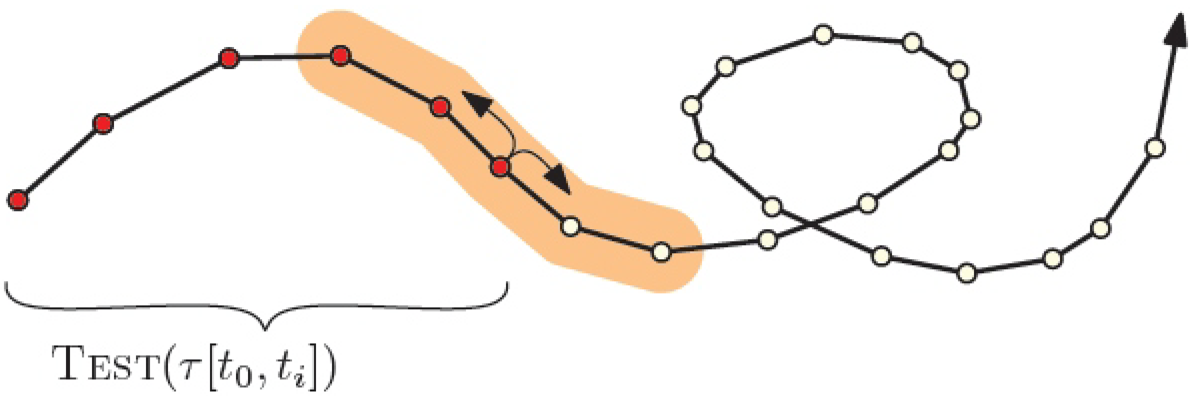


For many decreasing monotone criteria Greedy requires O(n) time, e.g. for speed, heading…

Greedy Algorithm

Observation:

For some criteria, iterative double & search is faster.



Double & search: An exponential search followed by a binary search.

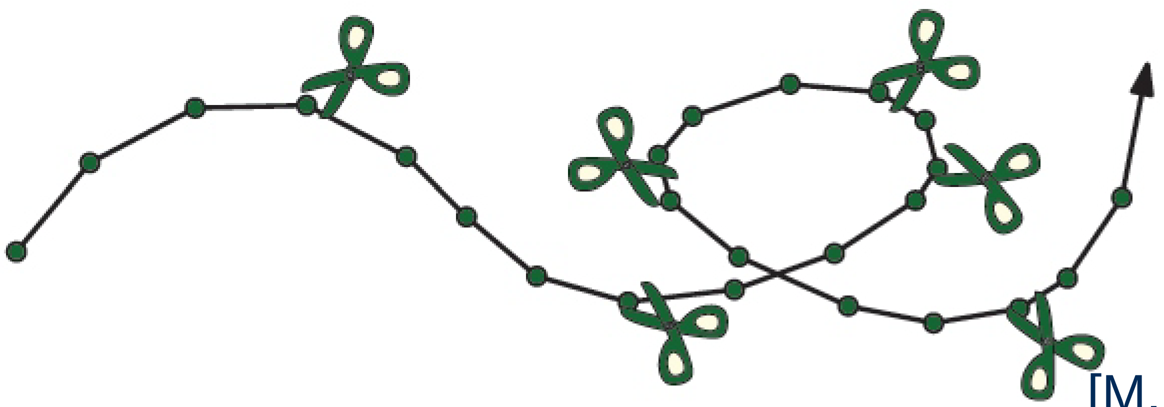
Criteria-Based Segmentation

Boolean or linear combination of decreasing monotone criteria

Greedy Algorithm

- incremental in O(n) time or constant-update criteria e.g. bounds on speed or heading
- double & search in O(n log n) time for non-constant update criteria e.g. staying within some radius

  Thus, solves Assignment 2, Ex.1)



[M.Buchin et al.’11]

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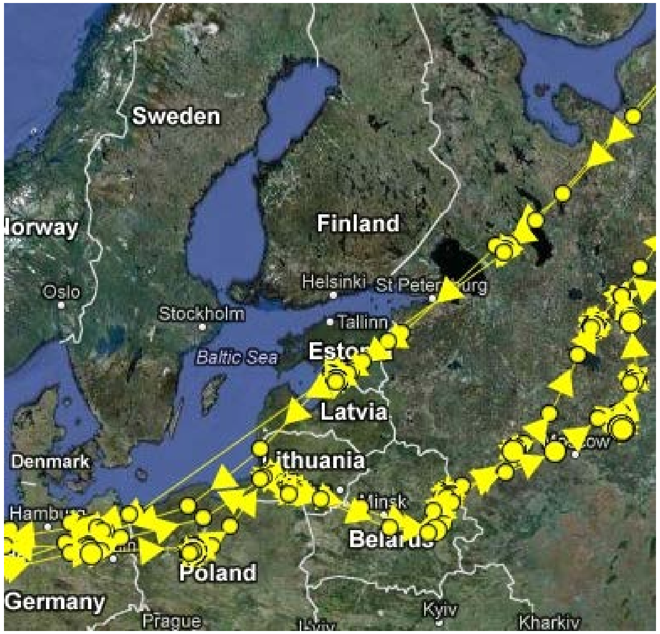

- Input:
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  - expert description of behaviour

- Goal: Delineate stopover sites of migratory geese

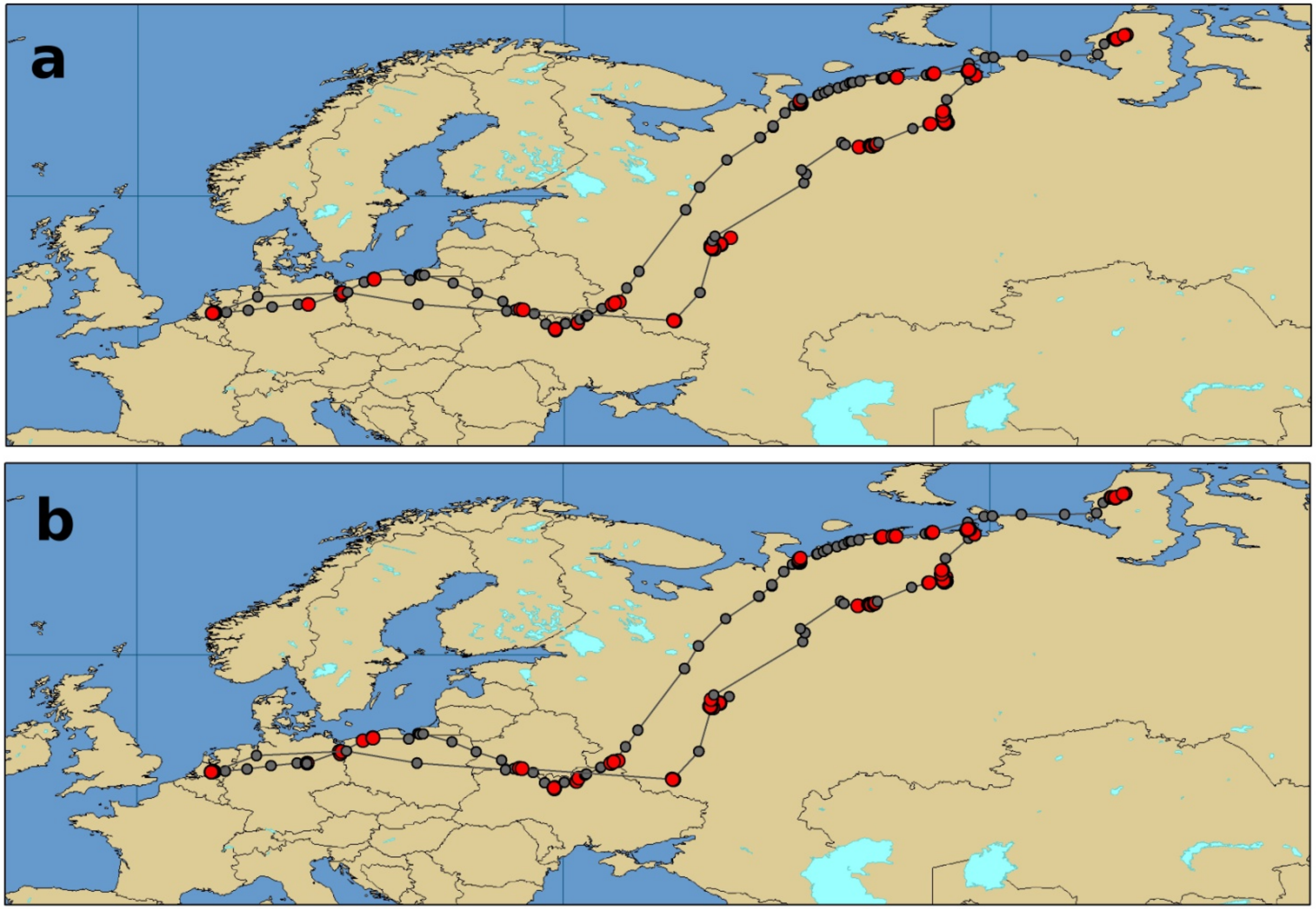
Case Study: Geese Migration

Data

- Spring migration tracks
  - White-fronted geese
  - 4-5 positions per day
  - March – June

- Up to 10 stopovers during spring migration
  - Stopover: 48 h within radius 30 km
  - Flight: change in heading <120°

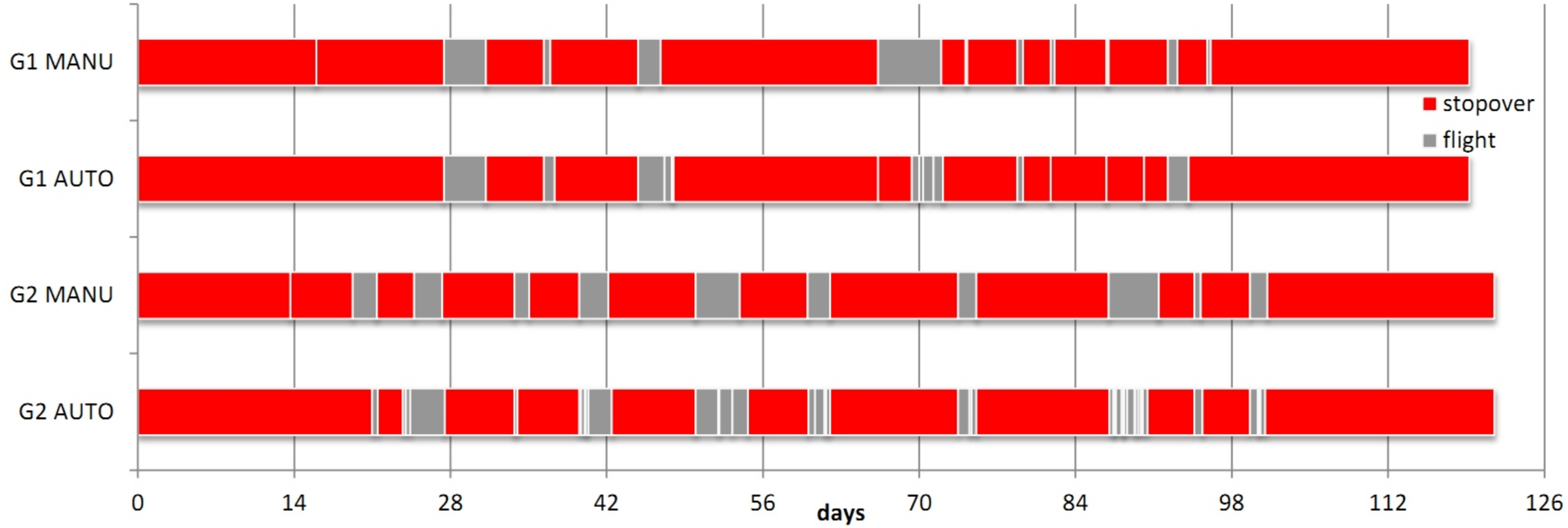
Comparison



manual

computed

Evaluation



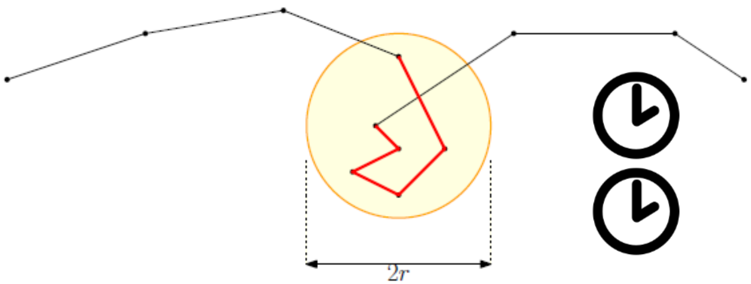
Few local differences:

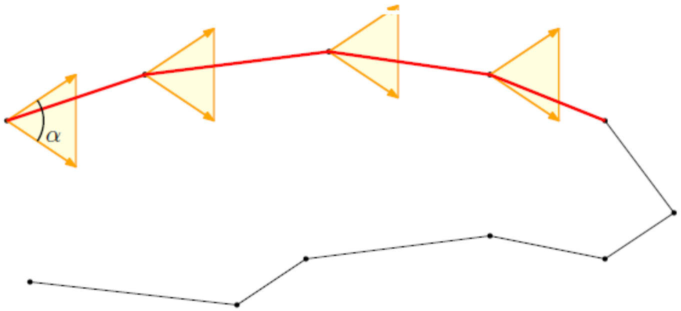
Shorter stops, extra cuts in computed segmentation

Criteria

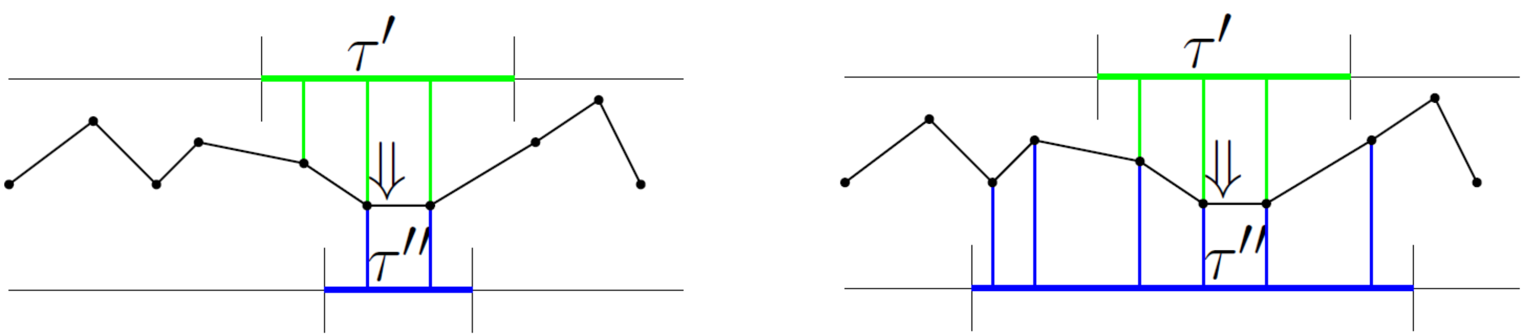
Within radius 30km AND At least 48h OR Change in heading <120°

stopover *migration flight*





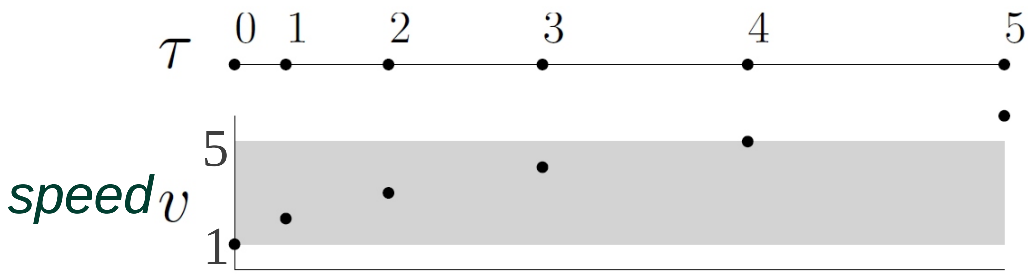
- A combination of decreasing and increasing monotone criteria



Decreasing and Increasing Monotone Criteria

- **Observation:** For a combination of decreasing and increasing monotone criteria the greedy strategy does not always work.

- **Example:** Min duration 2 AND Max speed range 4



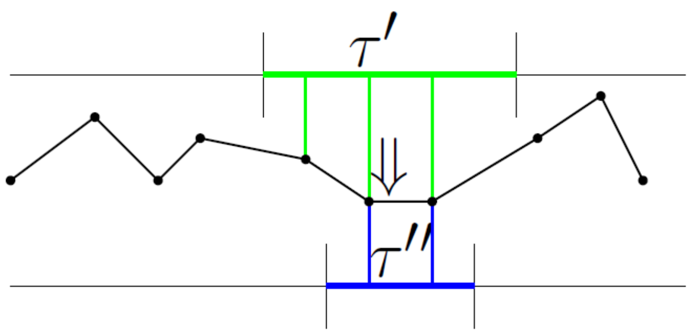
Non-Monotone Segmentation

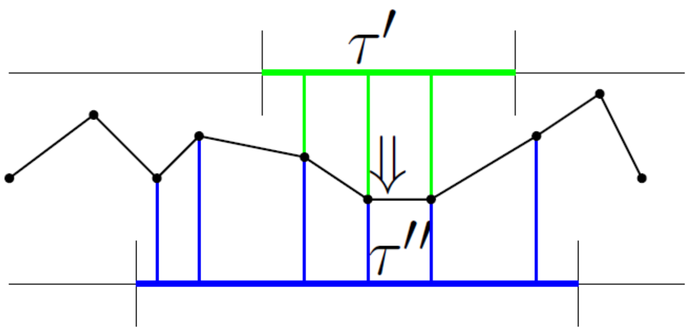
Many Criteria are not (decreasing) monotone:

- Minimum time
- Standard deviation
- Fixed percentage of outliers

- For these Aronov et al. introduced the start-stop diagram

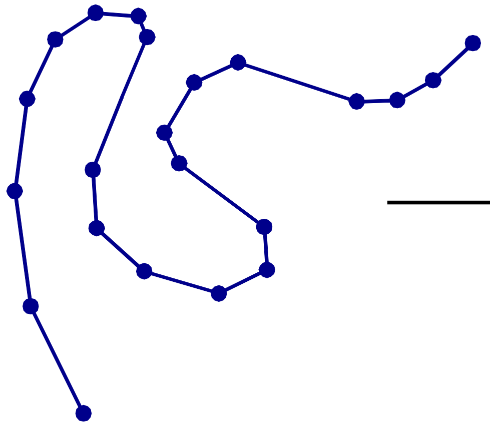
Example: Geese Migration

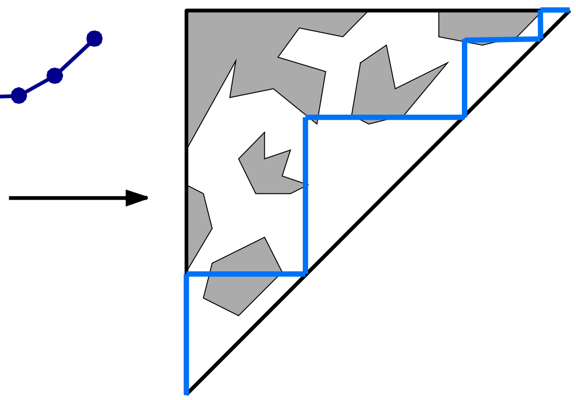




Start-Stop Diagram

Algorithmic approach





input trajectory compute start-stop diagram

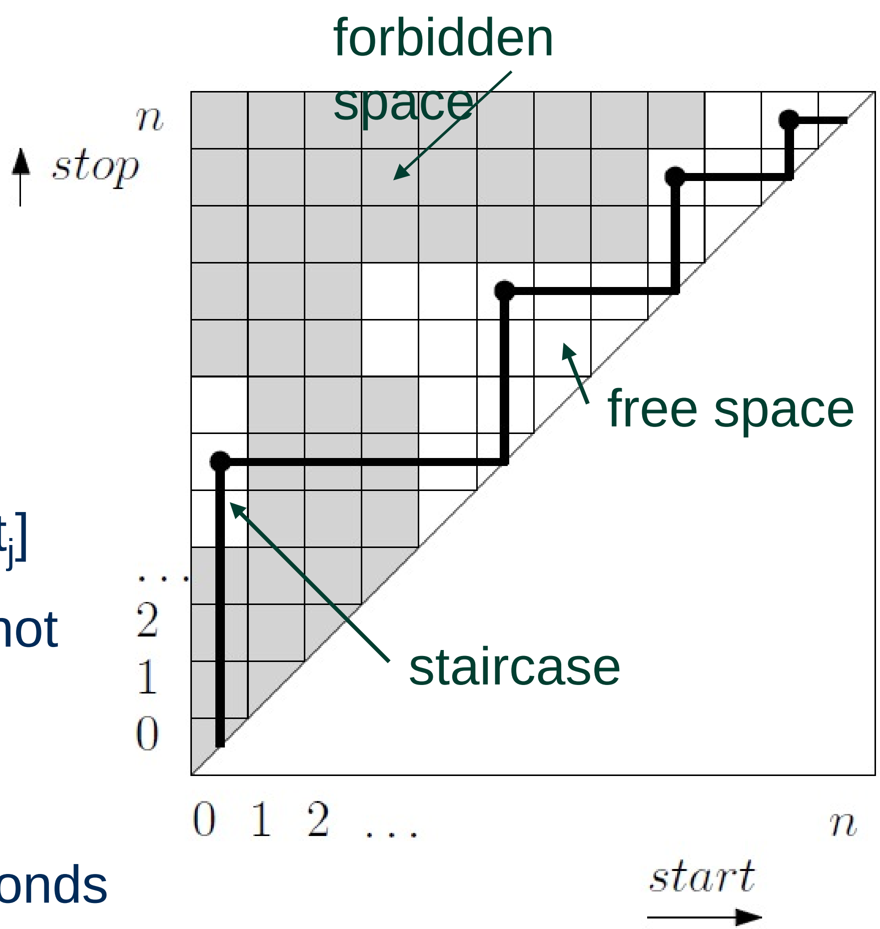
Start-Stop Diagram

Given a trajectory T over time interval I = $\{t_0,\ldots,t_\tau\}$ and criterion C

The start-stop diagram D is (the upper diagonal half of) the n x n grid,

where each point (i,j) is associated to segment $[t_i,t_j]$ with

- (i,j) is in free space if C holds on $[t_i,t_j]$
- (i,j) is in forbidden space if C does not hold on $[t_i,t_j]$



A (minimal) segmentation of T corresponds to a (min-link) staircase in D

Start-Stop Diagram

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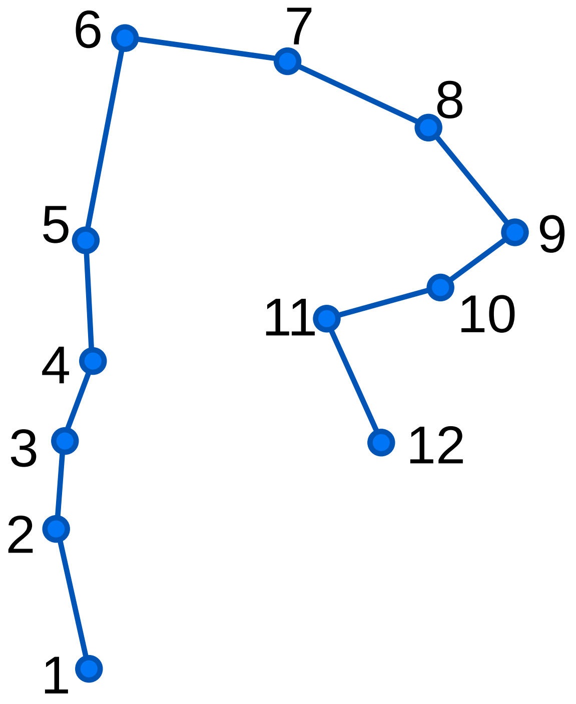

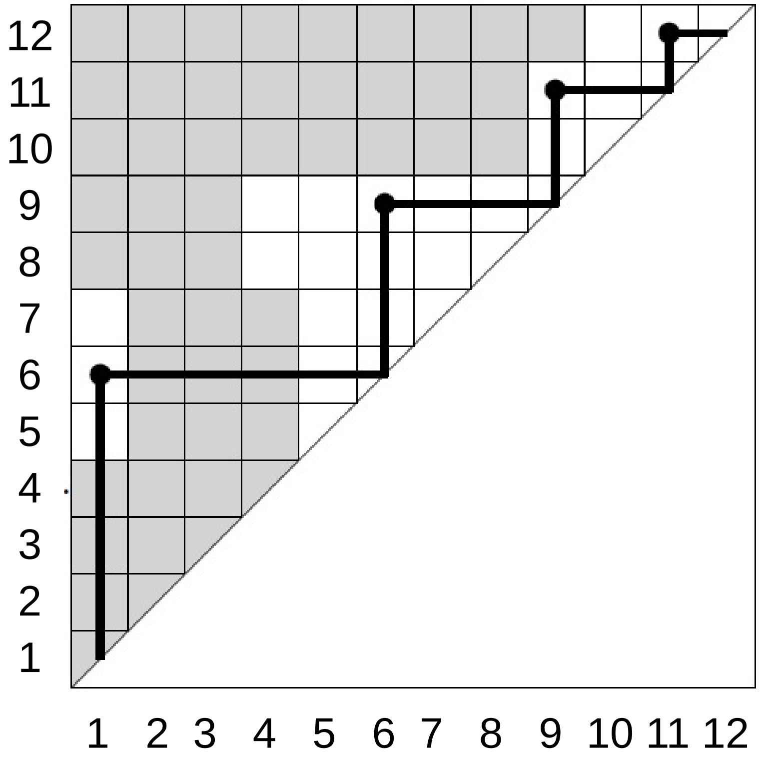

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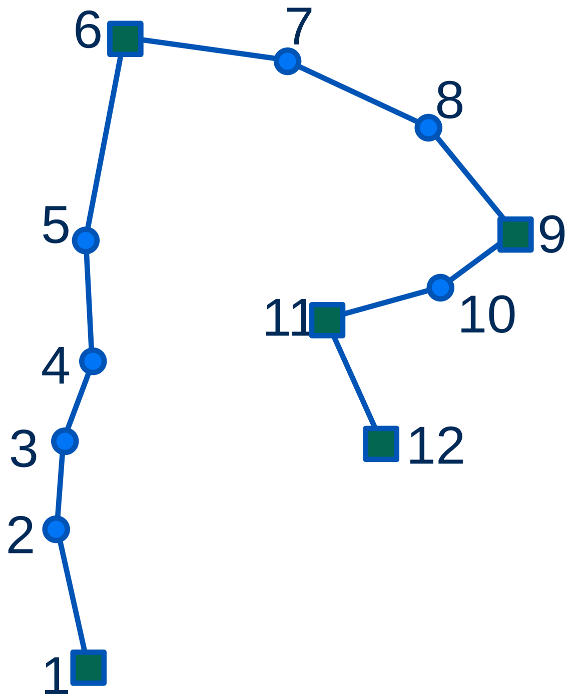
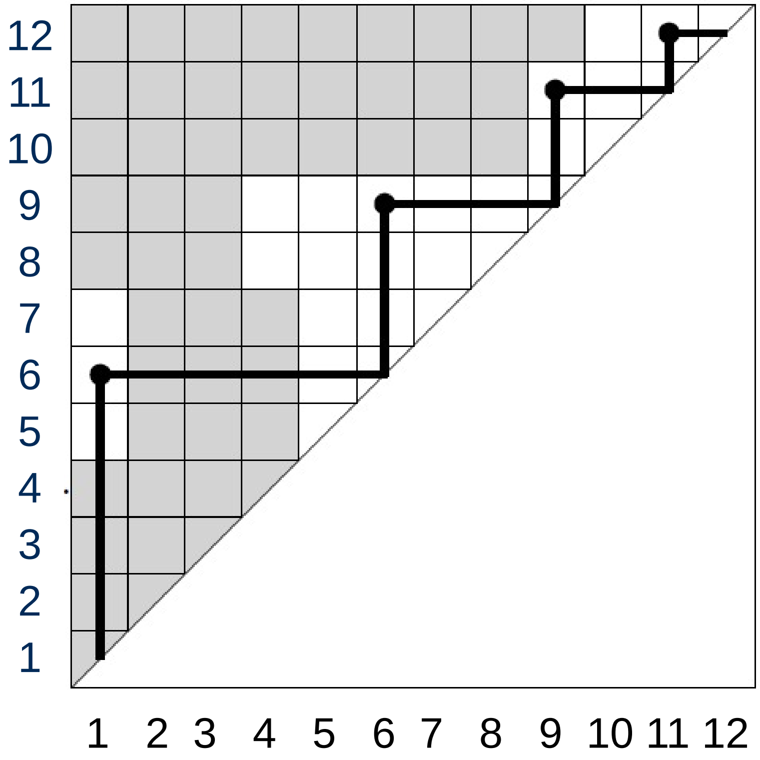
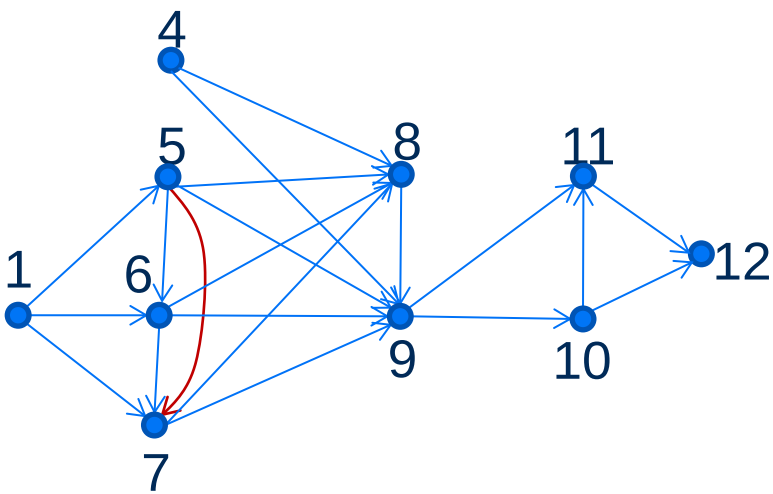


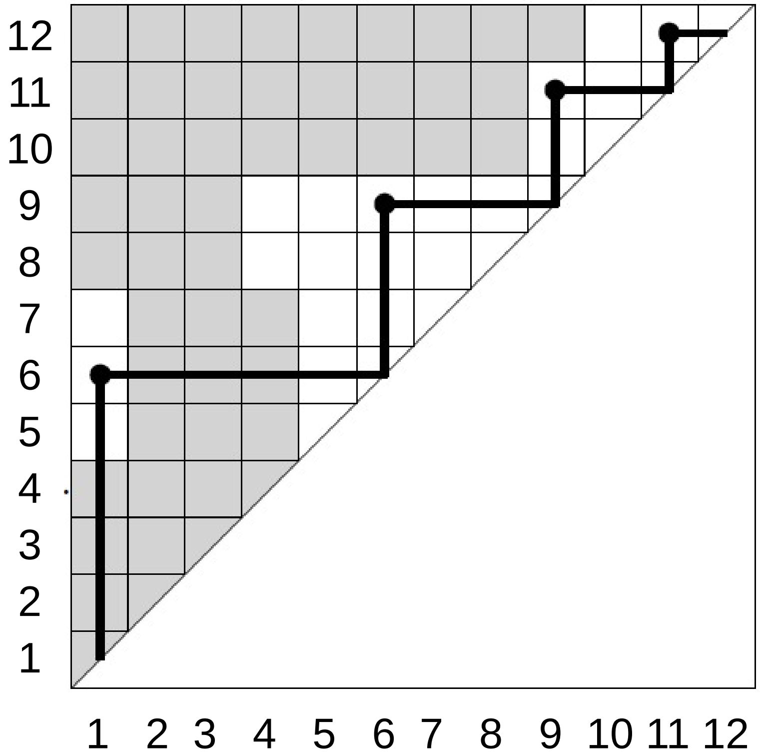


Start-Stop Diagram

Discrete case:

- A non-monotone segmentation can be computed in $O(n^2)$ time.





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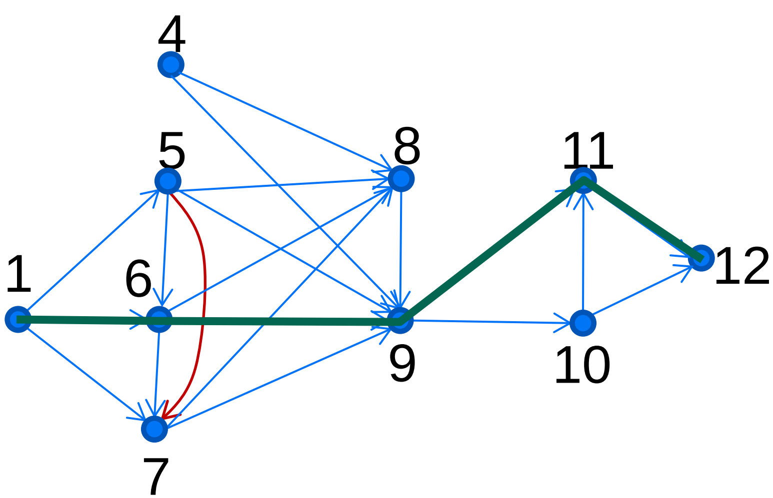

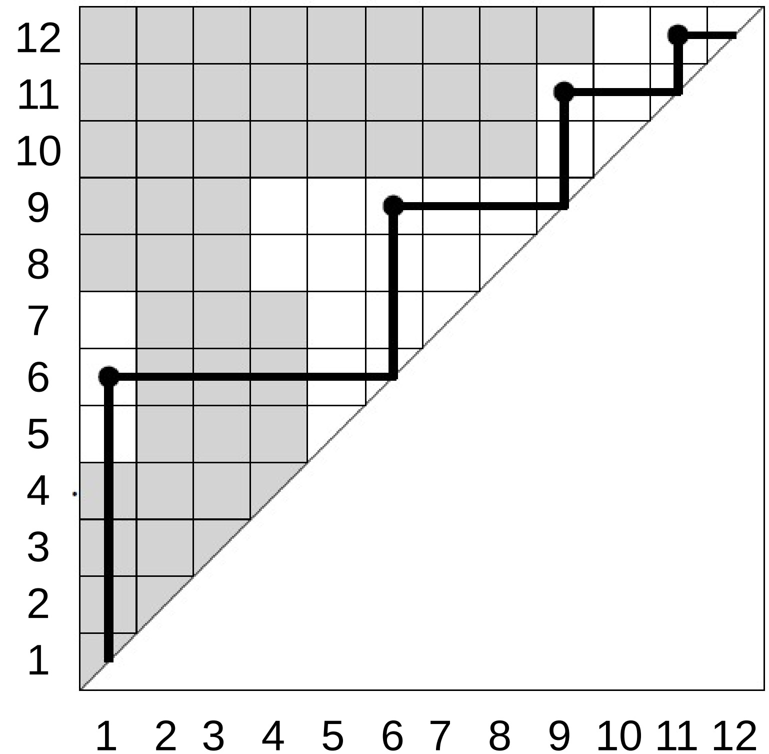

[Aronov et al.13]

Stable Criteria

Definition:

A criterion is stable if and only if $\sum_{i=o}^{n} v(i) = O(n)$ where

$v(i)$ = number of changes of validity on segments [0,i], [1,i], …, [i-1,i]

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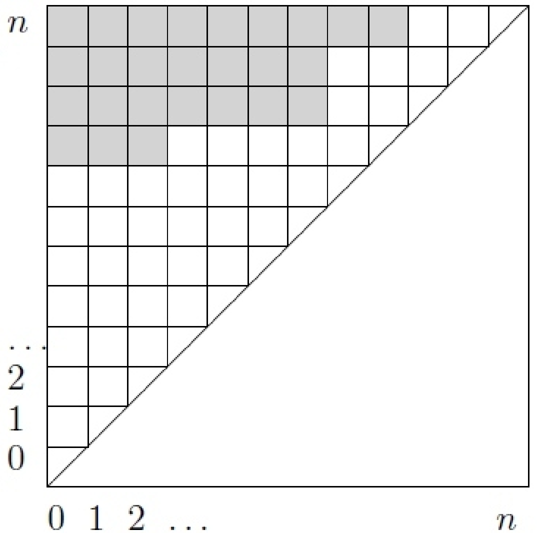
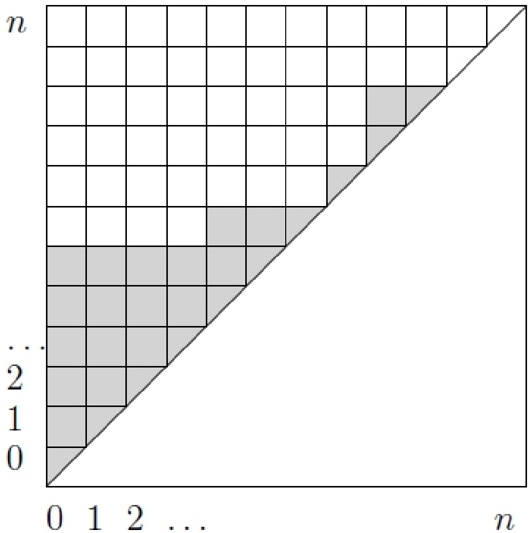
Observations:

Decreasing and increasing monotone criteria are stable.

A conjunction or disjunction of stable criterion are stable.



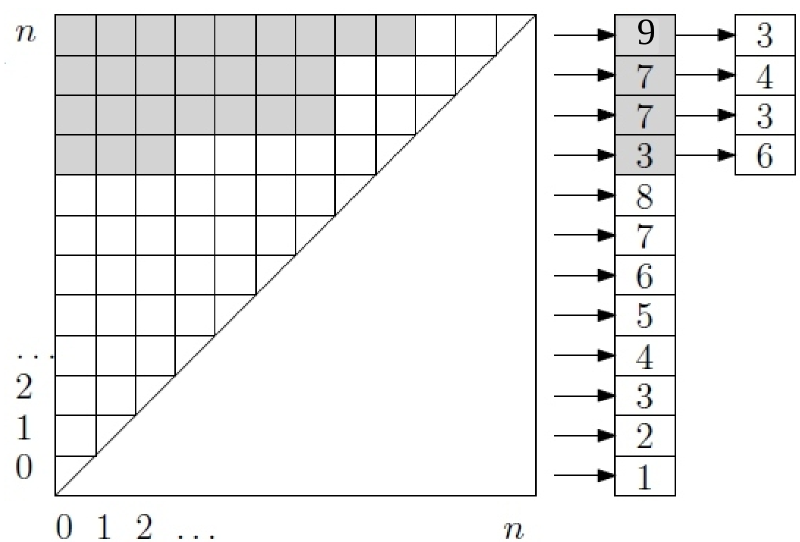


Compressed Start-Stop Diagram

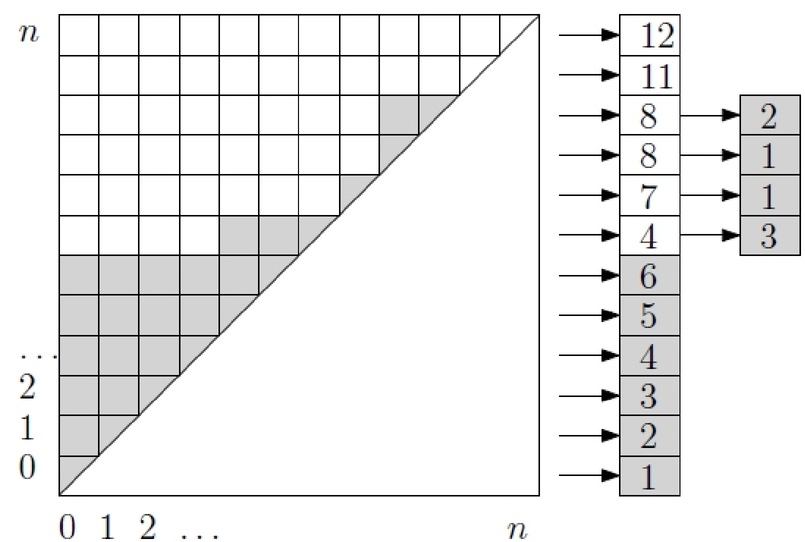
For stable criteria the start-stop diagram can be compressed by applying run-length encoding.

Examples:

decreasing monotone



increasing monotone



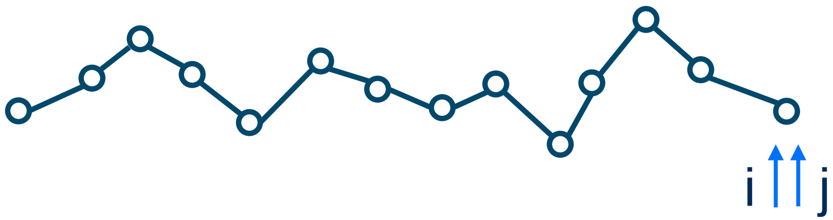
Computing the Compressed Start-Stop Diagram

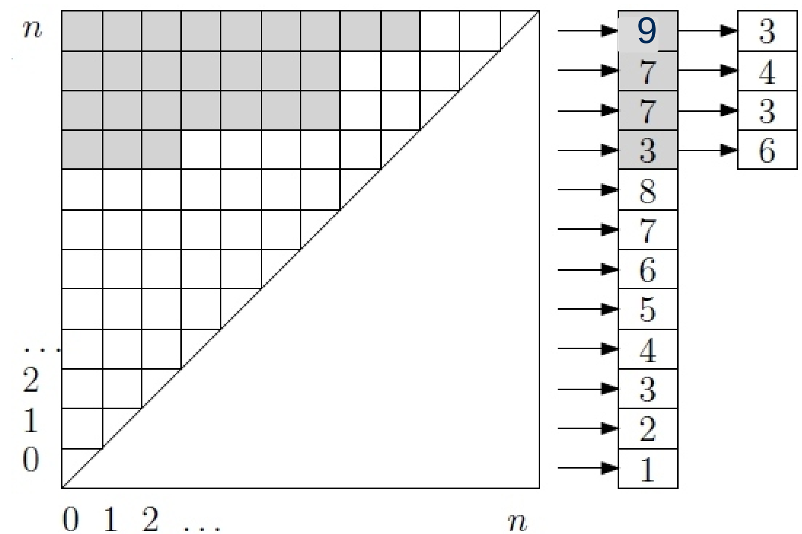
For a decreasing criterion consider the algorithm:

ComputeLongestValid(crit C, traj T)

Algorithm:

Move two pointers i,j from n to 0 over the trajectory. For every trajectory index j the smallest index i for which π[i,j] satisfies the criterion C is stored.



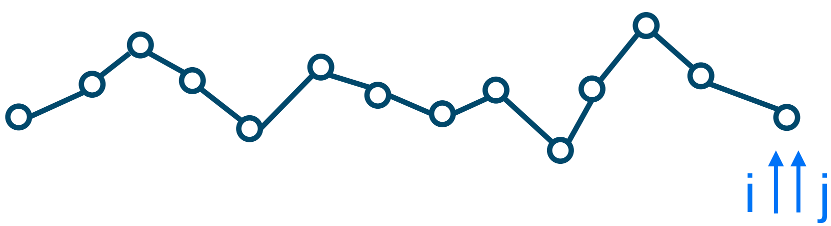


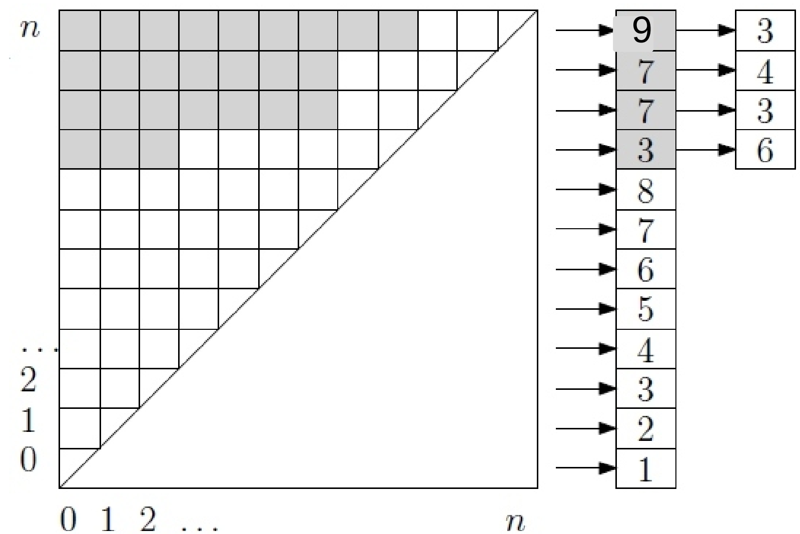
Computing the Compressed Start-Stop Diagram

For a decreasing criterion *ComputeLongestValid(crit C, traj T):*

Move two pointers i,j from n to 0

over the trajectory





Requires a data structure for segment [i,j] allowing the operations *isValid*, *extend*, and *shorten,* e.g., a balanced binary search tree on attribute values for range or bound criteria.

Runs in O(n·c(n)) time where c(n) is the time to update & query.

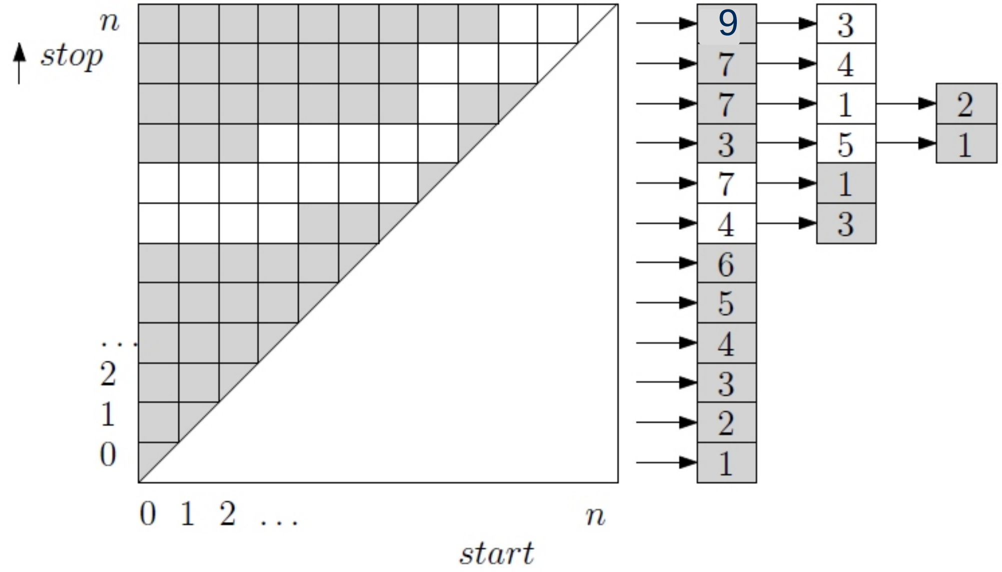
Analogously for increasing criteria.

Computing the Compressed Start-Stop Diagram

The start-stop diagram of a conjunction (or disjunction) of two stable criteria is their intersection (or union).

The start-stop diagram of a negated criteria is its inverse.

The corresponding compressed start-stop diagrams can be computed in O(n) time.



Attributes and criteria

Examples of stable criteria

- Lower bound/Upper bound on attribute
- Angular range criterion
- Disk criterion
- Allow a fraction of outliers
- …

Computing the Optimal Segmentation

Observation: The optimal segmentation for [0,i] is either one segment, or an optimal sequence of segments for [0,j<i] appended with a segment [j,i], where j is an index such [j,i] is valid.

Dynamic programming algorithm

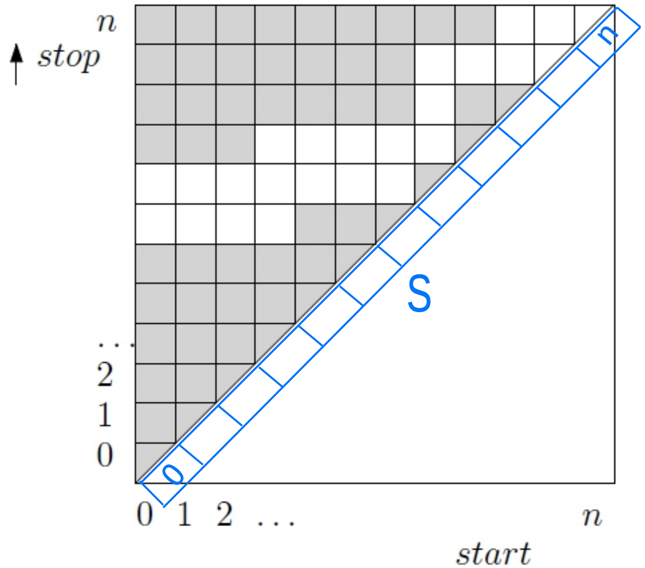
for each row from 0 to n

    find white cell with min-link

That is, iteratively compute a table S[0,n]

where entry S[i] for row i stores

- last: index of last link
- count: number of links so far



- runs in O(n^2) time

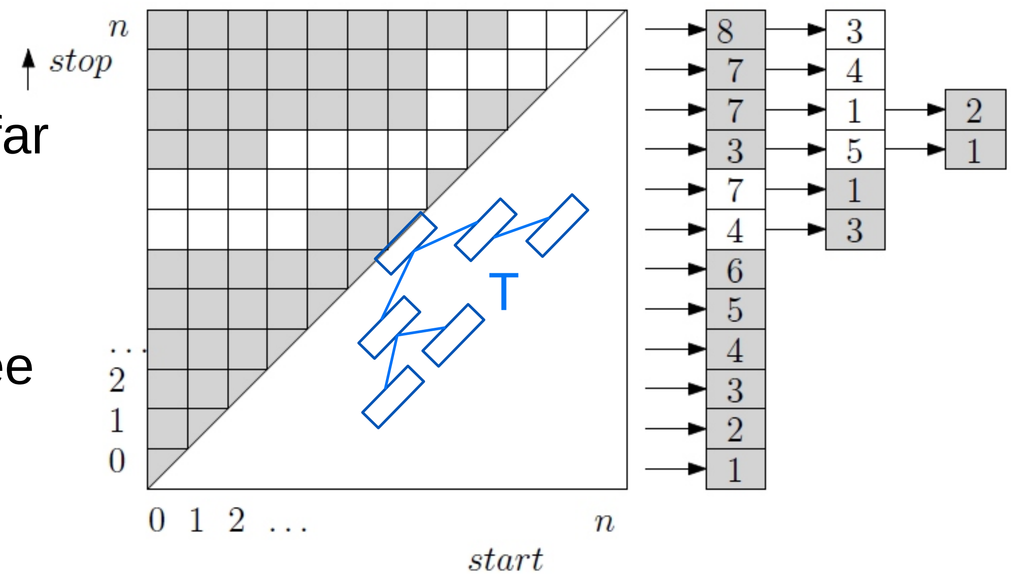
Computing the Optimal Segmentation

- More efficient dynamic programming algorithm for compressed diagrams

- Process blocks of white cells using a range query in a binary search tree T (instead of table S) storing
  - index: row index
  - last: index of last link
  - count: number of links so far

- augmented by minimal count in subtree

- runs in O(n log n) time



[Alewijnse et al.'14]

Beyond criteria-based segmentation

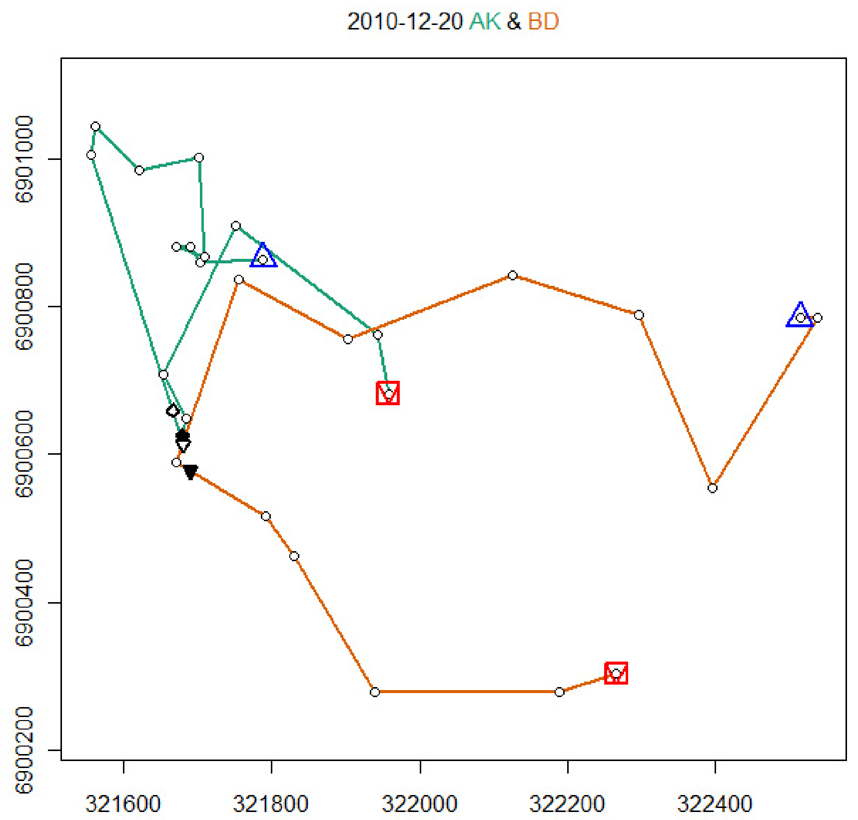
- When is criteria-based segmentation applicable?
- What can we do in other cases?

Excursion

MOVEMENT MODELS

Movement Models

- Movement data: sequence of observations, e.g. (x_i, y_i, t_i)
- Linear movement realistic?



Movement Models

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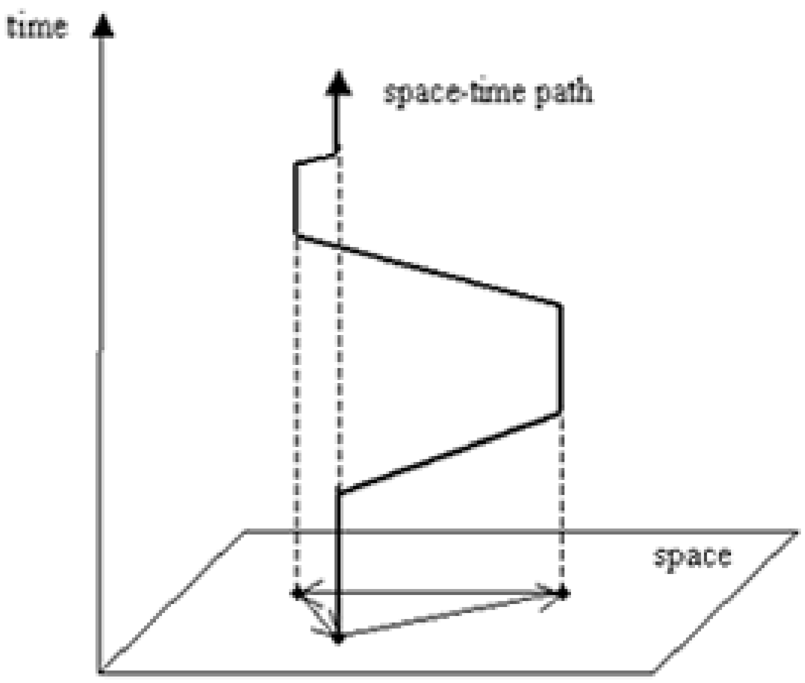
- Space-time Prisms



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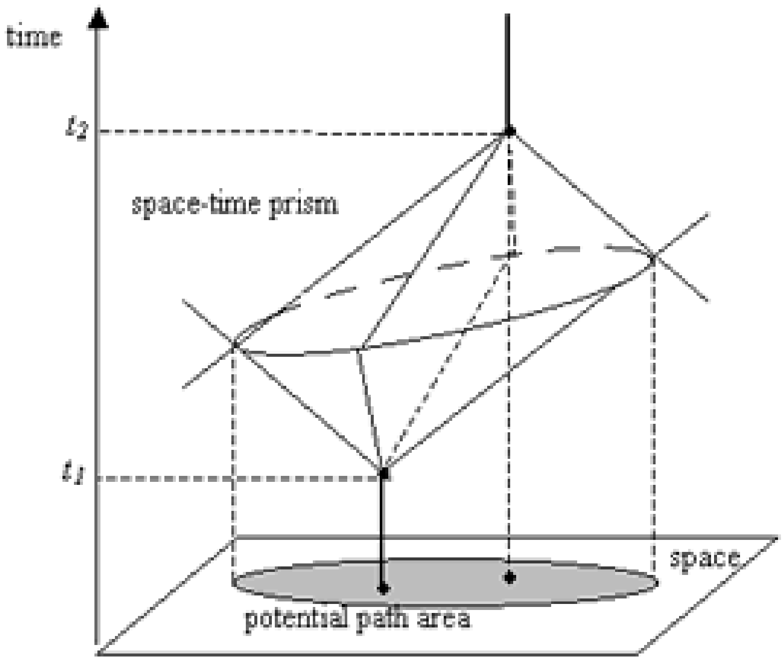

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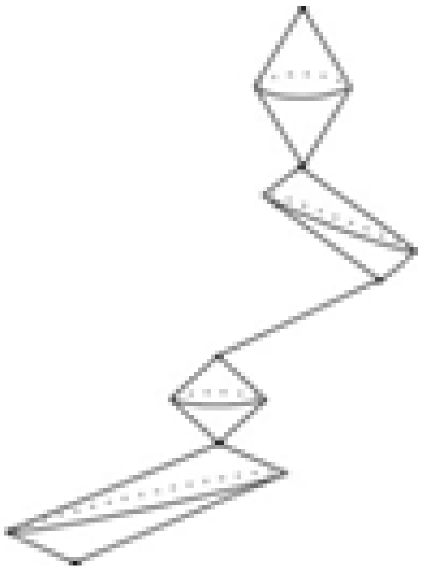
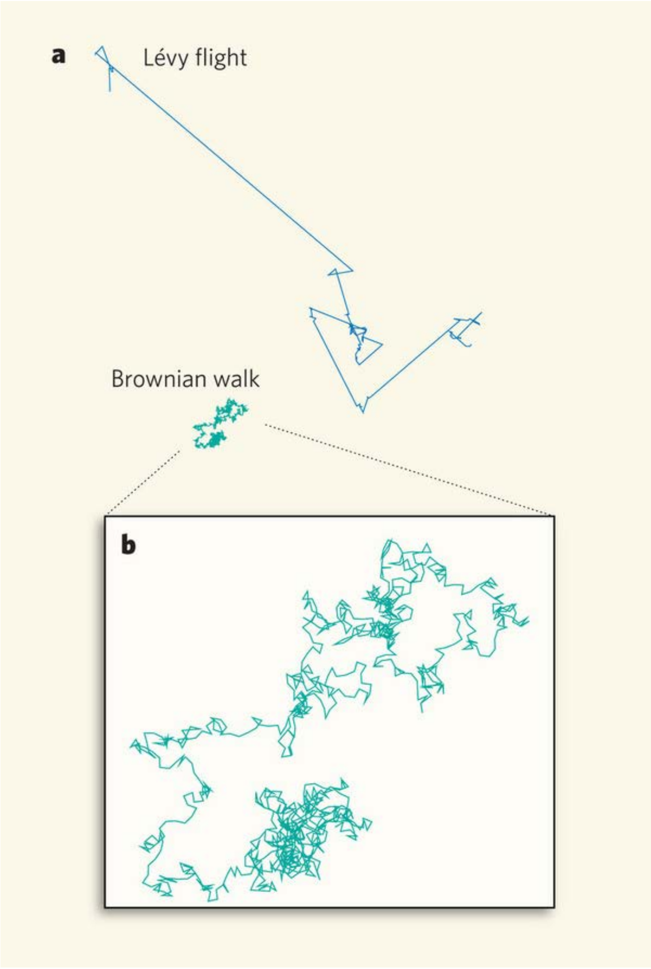


Movement Models

- Movement data: sequence of observations, e.g. (x_i,y_i,t_i)

- Linear movement realistic?
- Space-time Prisms
- Random Motion Models (Brownian bridges)



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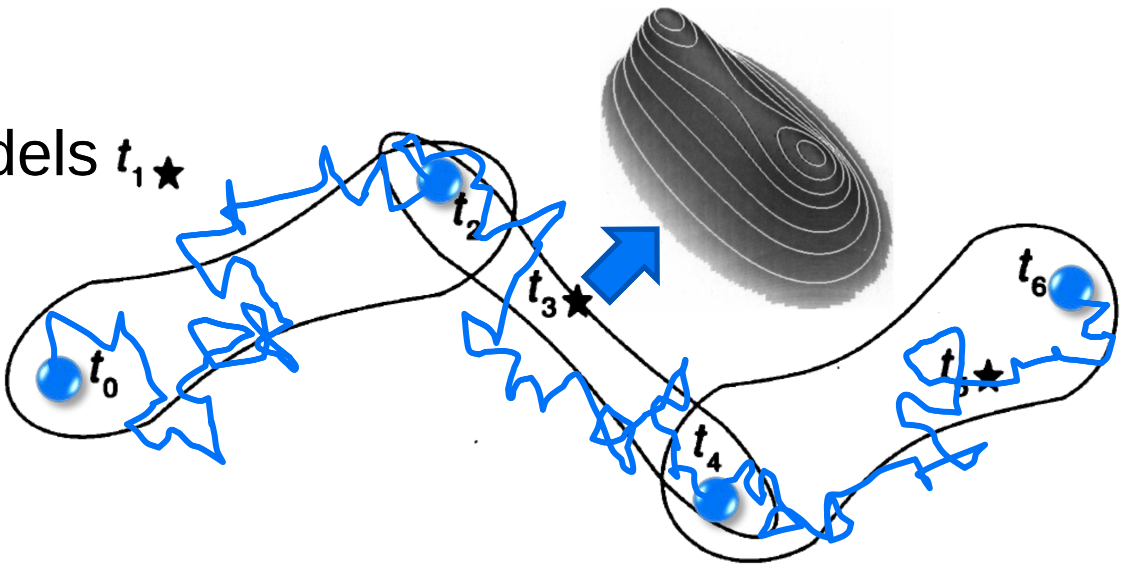
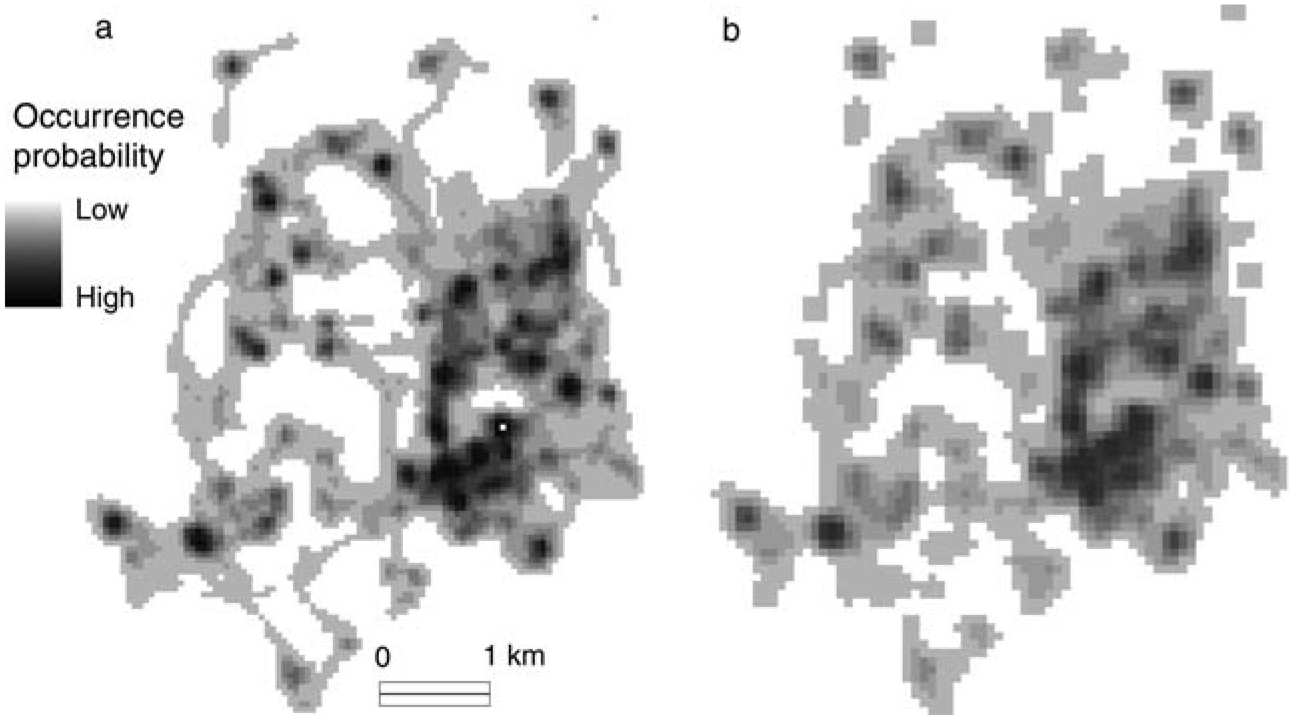


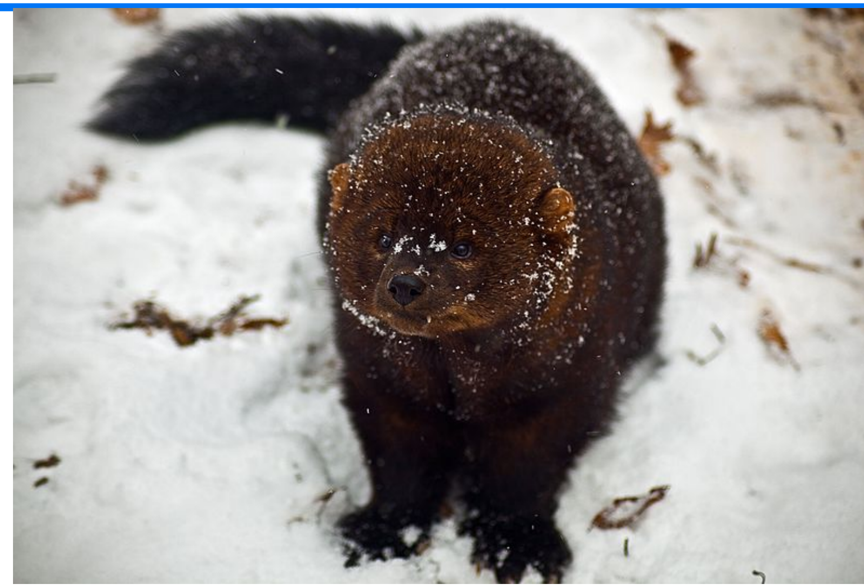
Brownian Bridges - Examples

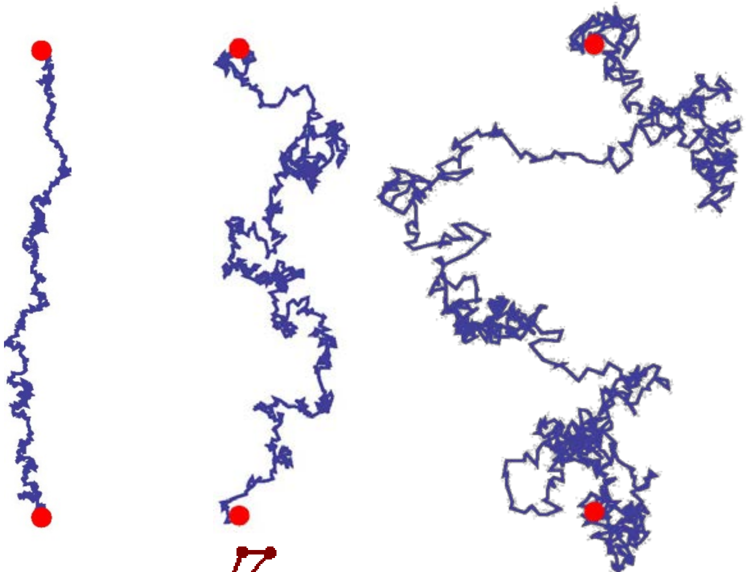


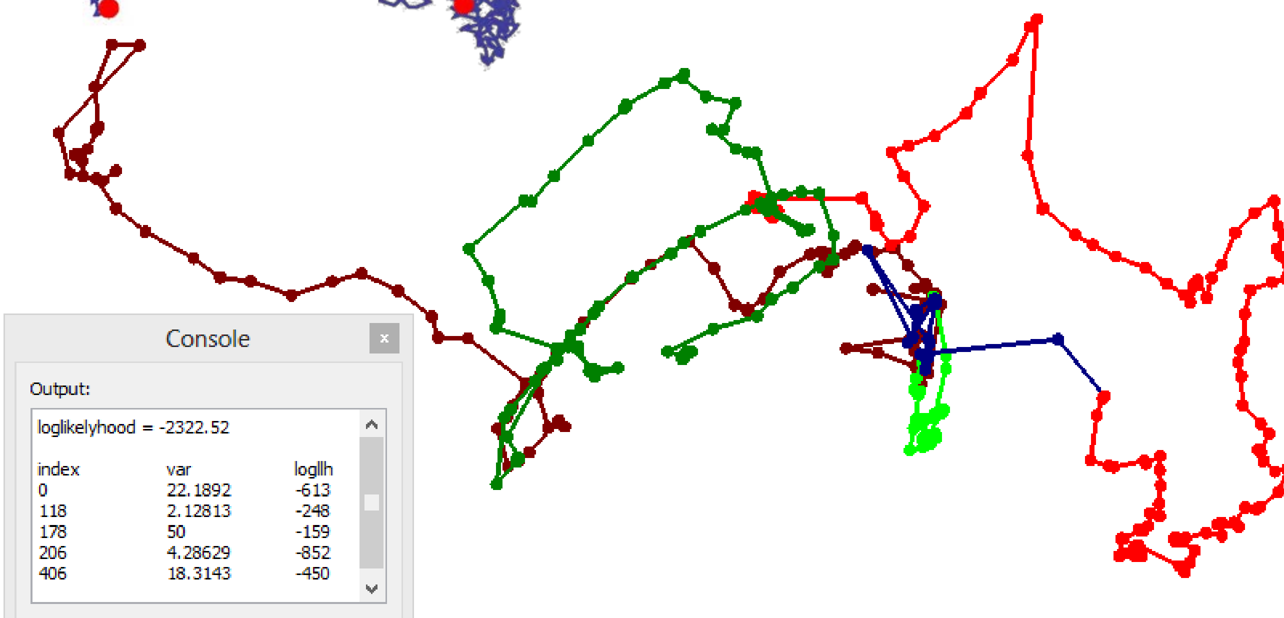
Brownian bridges

no bridges

Segment by diffusion coefficient







Summary

- Greedy algorithm for decreasing monotone criteria O(n) or O(n log n) time

  [M.Buchin, Driemel, van Kreveld, Sacristan, 2010]

- Case Study: Geese Migration

  [M.Buchin, Kruckenberg, Kölzsch, 2012]

- Start-stop diagram for arbitrary criteria $O(n^2)$ time

  [Aronov, Driemel, van Kreveld, Löffler, Staals, 2012]

- Compressed start-stop diagram for stable criteria O(n log n) time

  [Alewijnse, Buchin, Buchin, Sijben, Westenberg, 2014]

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