A Workshop on Eye Tracking: Why, When, and How?
ICA Commission of Cognitive Visualization
ICA Commission on Geovisualization
ICA Commission on Use and User Issues

Using EyeMMV Toolbox for eye movement analysis in cartographic experiments

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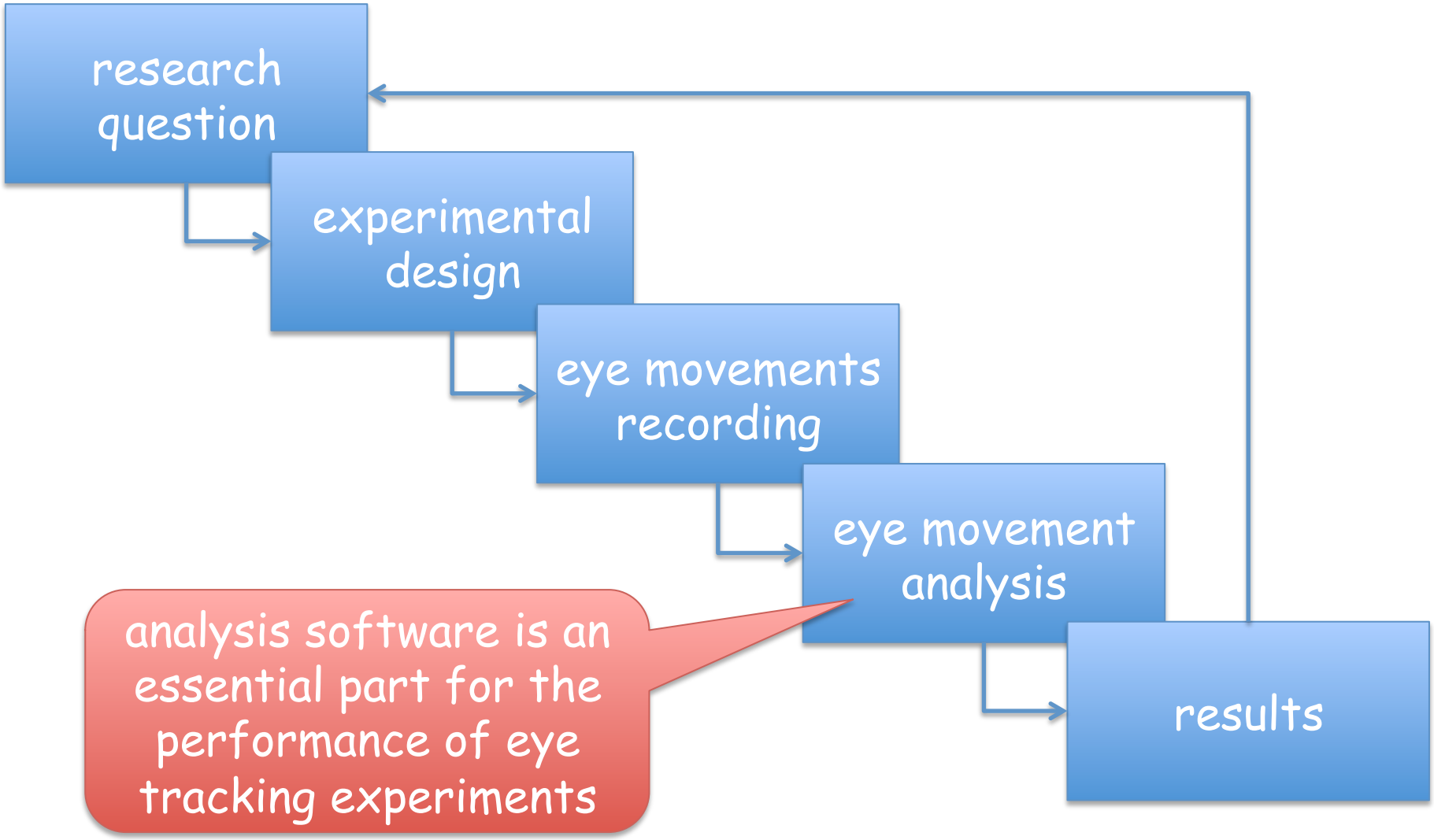
Contents

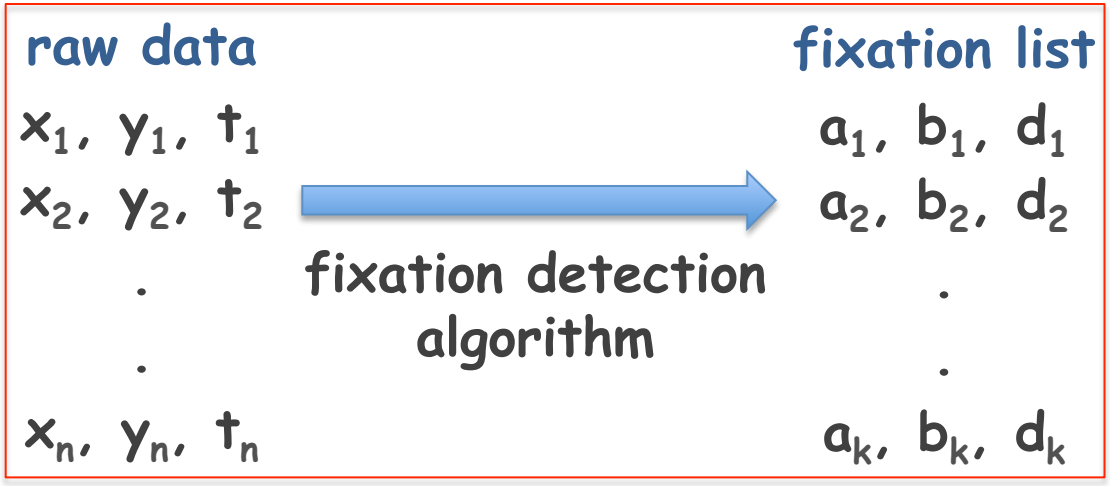
- eye movement analysis software & experimentation
- introducing EyeMMV Toolbox
- fixation detection with EyeMMV Toolbox
- eye movement metrics analysis with EyeMMV Toolbox
- the supported visualization techniques of EyeMMV Toolbox
- examples
- conclusions

A typical eye tracking experiment in simple steps



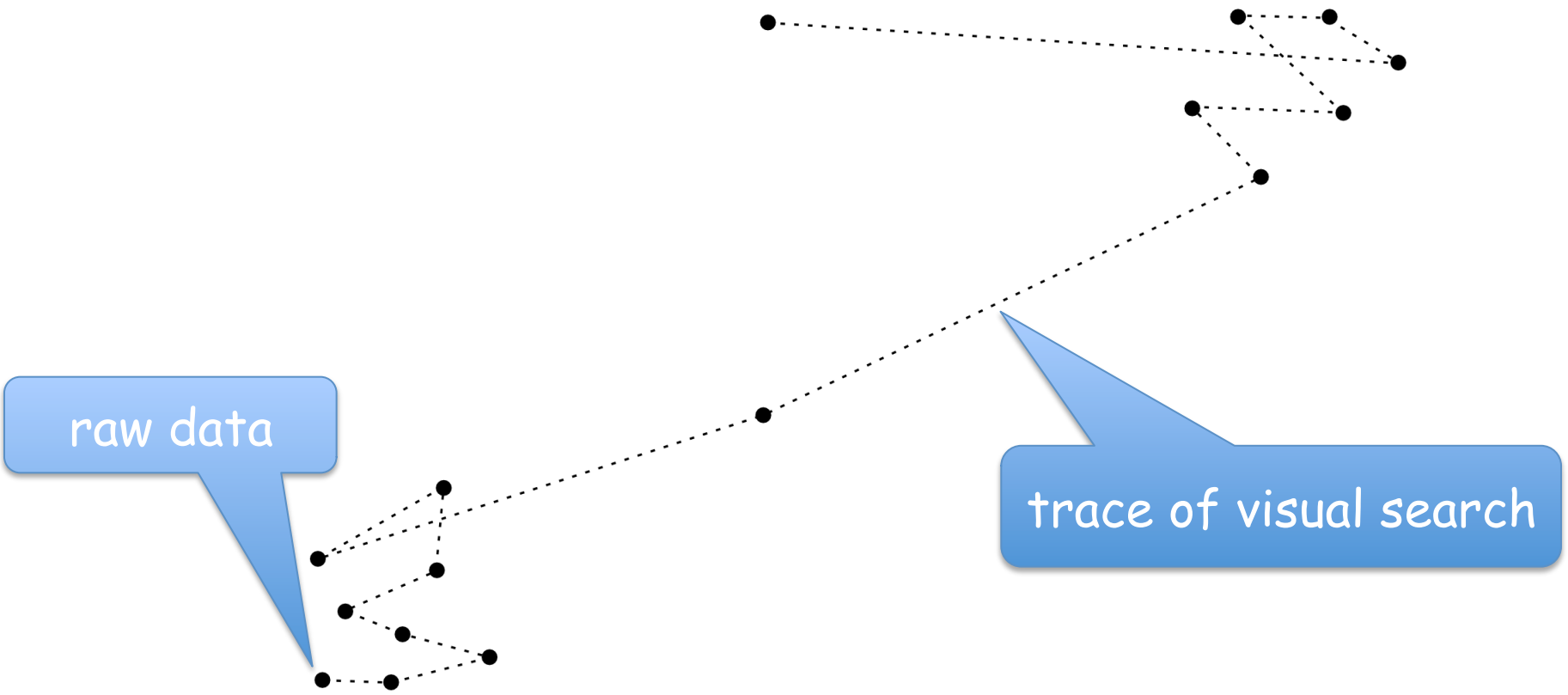
The main function of an analysis software

- detection of fixations among the eye tracking protocol
- modeling the raw data in fixations and saccades
- calculate derived metrics from fixations and saccades
- support different data visualization techniques

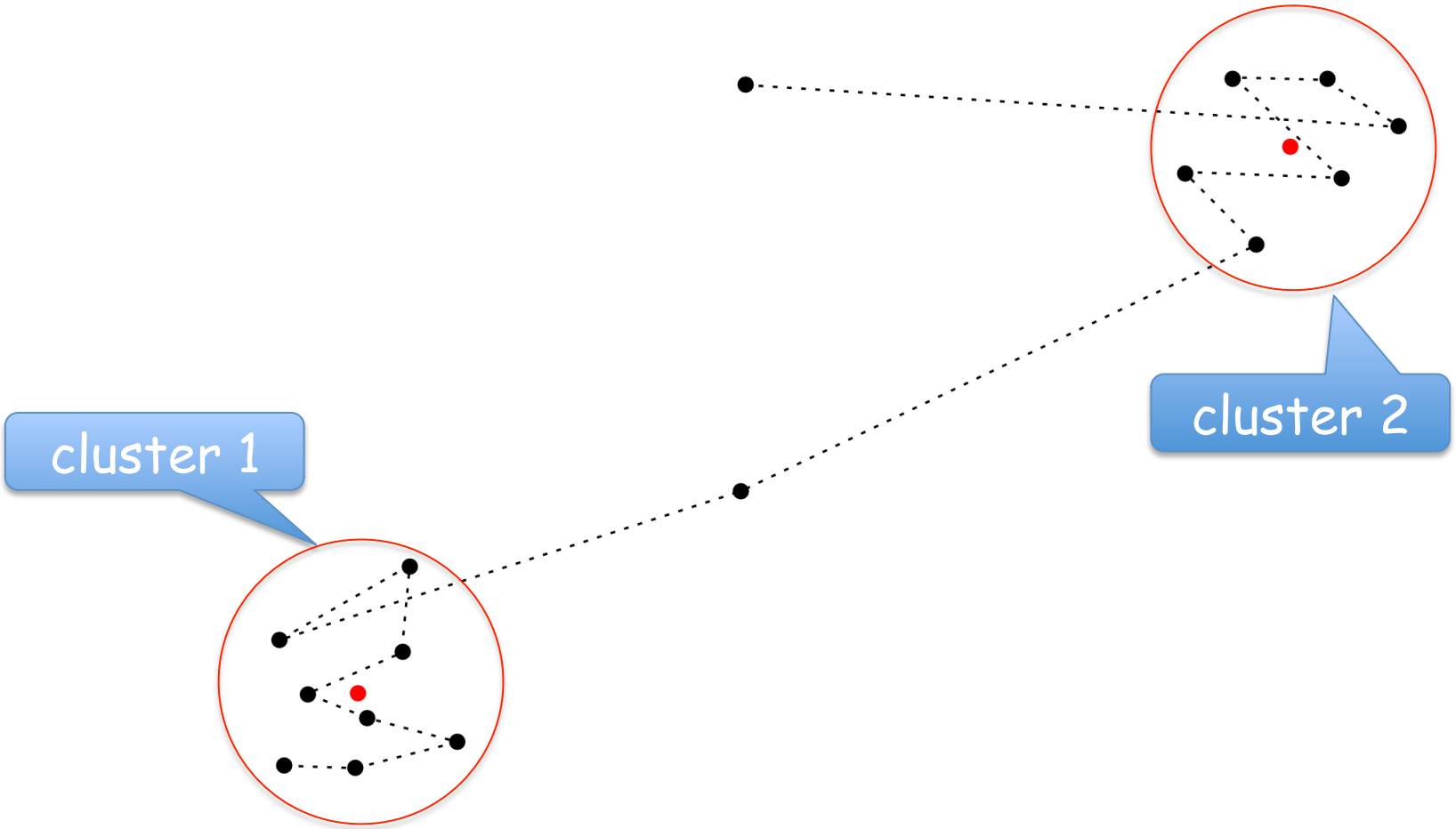


x, y, a, b: coordinates
t_i: passing time
d_i: fixation duration

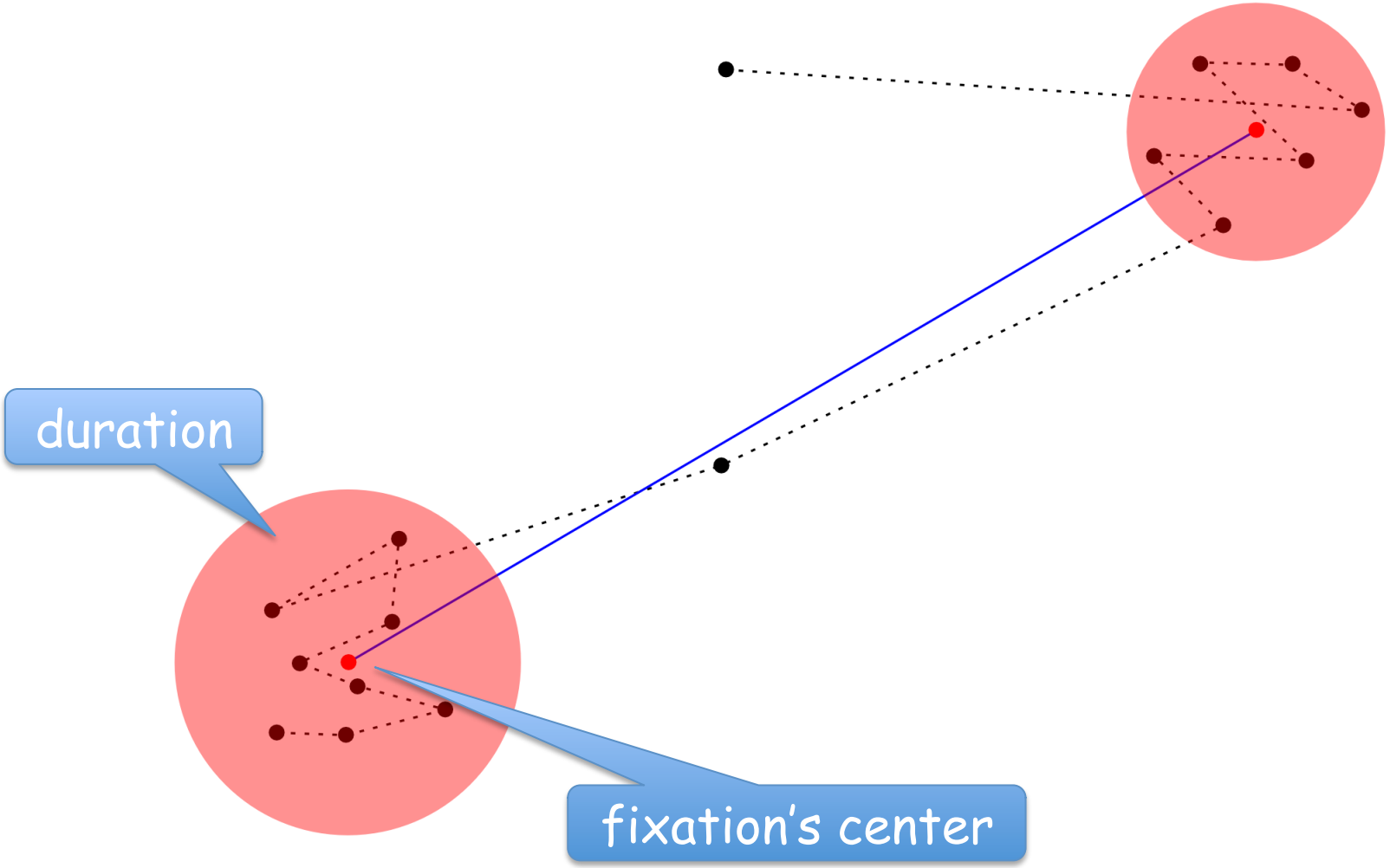
Detecting fixations in eye tracking protocols (1)



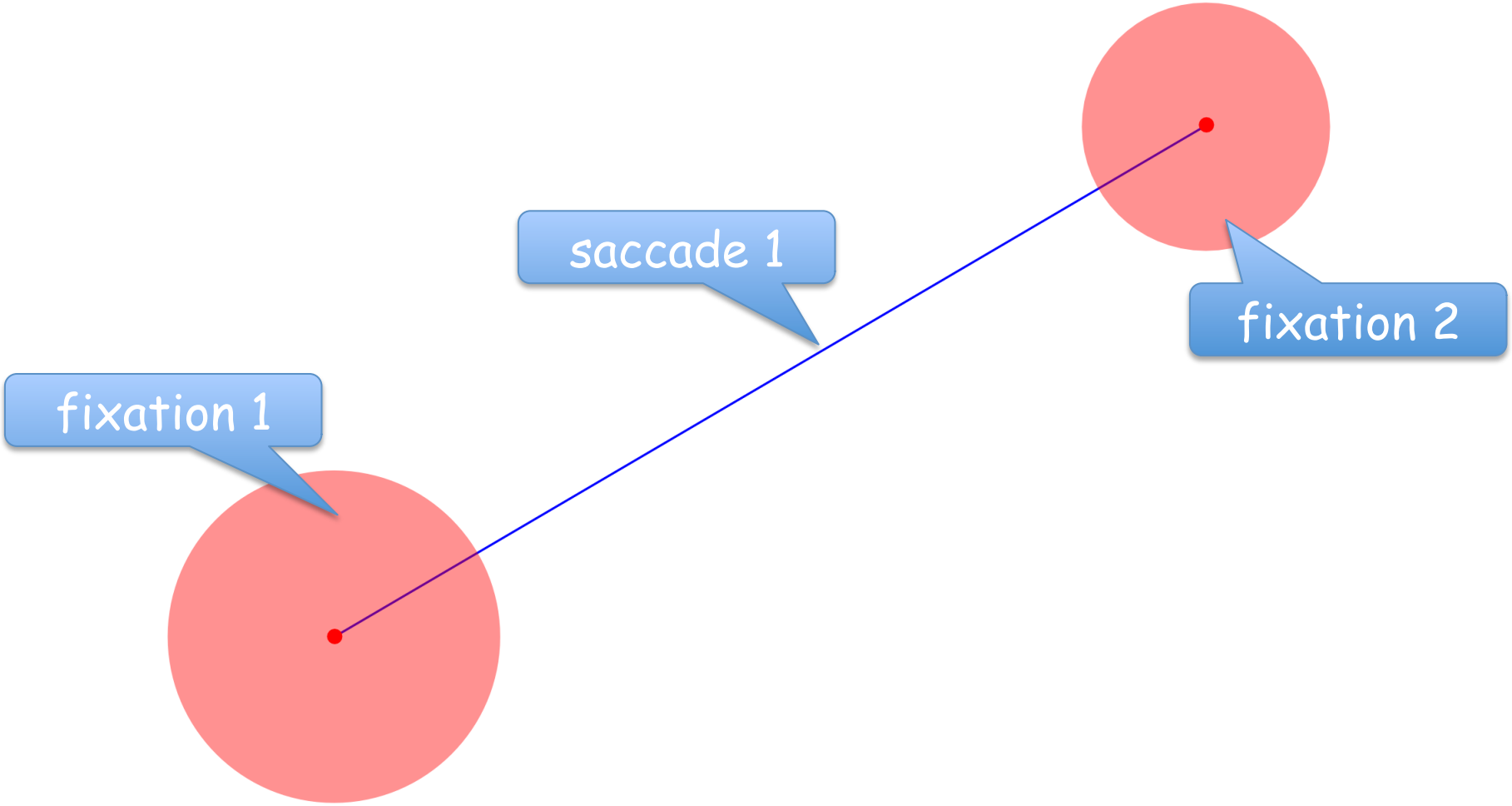
Detecting fixations in eye tracking protocols (2)



Detecting fixations in eye tracking protocols (3)



Detecting fixations in eye tracking protocols (4)



Introducing EyeMMV Toolbox (1)

- EyeMMV (Eye Movement Metrics & Visualizations) Toolbox
- a complete software for post-experimental eye movement analysis
- design and implementation in the scripting language of MATLAB (Mathworks®)
- fixation detection using an introduced algorithm based on spatial and temporal constraints
- support the analysis of main (fixation and saccades) and derived metrics (e.g. scanpath analysis)

Introducing EyeMMV Toolbox (2)

- support different visualization techniques
- list of MATLAB functions (Toolbox)
- EyeMMV can be imported in every MATLAB script or it can be easily running through MATLAB command line
- eye movements raw data: matrix format (advantageous run time through MATLAB environment)
- execution in every computer platform (Windows, Linux, Mac OS) where MATLAB is pre-installed

Fixation detection with EyeMMV (1)

The fixation detection algorithm is based on **two spatial parameters (t1, t2)** and on one **temporal parameter (minimum fixation duration: minDur)**.

Step 1

starting from the first record, the mean value of horizontal and vertical coordinates is computed **until the distance between mean point and the record < t1** (the list of records generates a fixation cluster).

Step 2

in each fixation cluster, if the **distance of one record > t2** the record is removed from the fixation cluster. The fixation center is calculated from the records which distances from the mean point is smaller than t2

Fixation detection with EyeMMV (2)

Step 3

the duration of each fixation is computed as the difference between the passing time of last record of the cluster from the first record of the cluster

Step 4

if fixation's duration is smaller than a predefined temporal threshold (minDur), the cluster is removed from the list of fixations

Note

as t2 spatial parameter the criterion of 3s can be used, where s corresponds to the standard deviation of the cluster

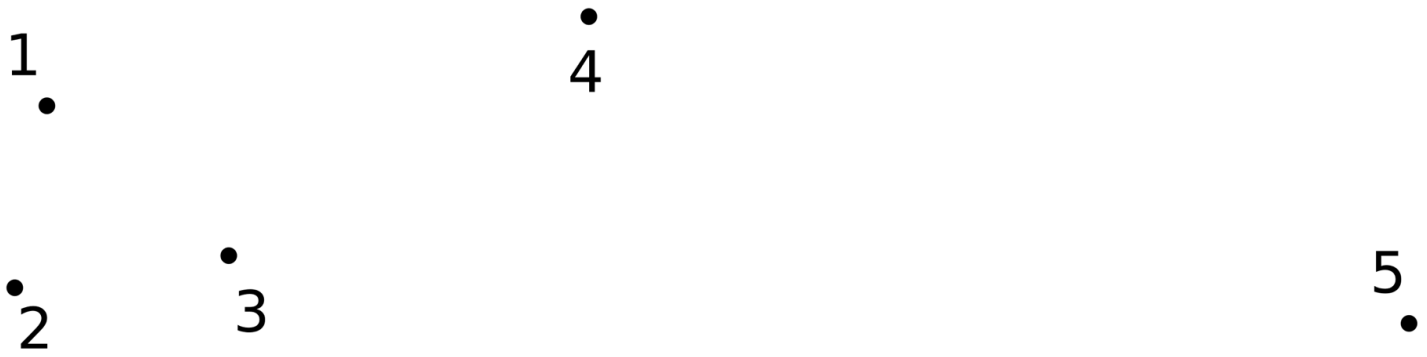
steps 1, 2, 3, 4

the computation of fixations is performed using spatial and temporal constraints

Fixation detection with EyeMMV: implementing the spatial parameters t1 and t2 (1)

raw data:

$(x_1, y_1, pt_1), (x_2, y_2, pt_2), (x_3, y_3, pt_3), (x_4, y_4, pt_4), (x_5, y_5, pt_5)$

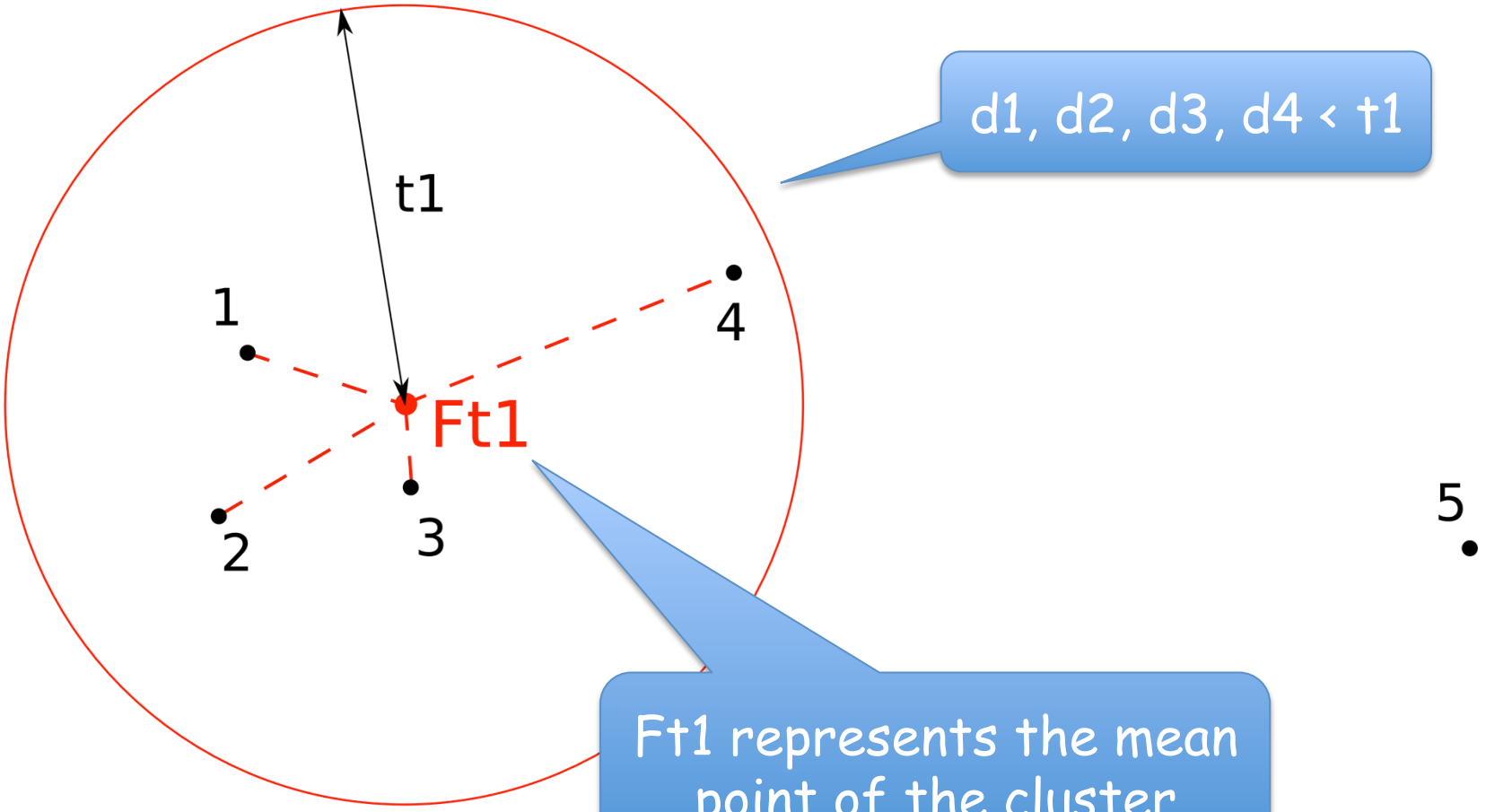


x: horizontal coordinate

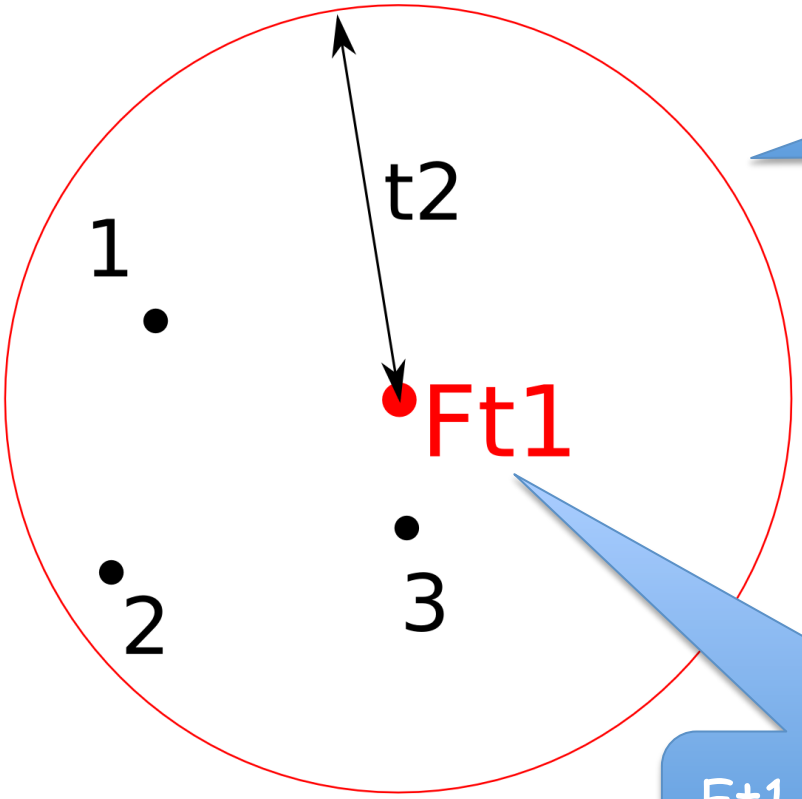
y: vertical coordinate

pt: passing time

Fixation detection with EyeMMV: implementing the spatial parameters t1 and t2 (2)



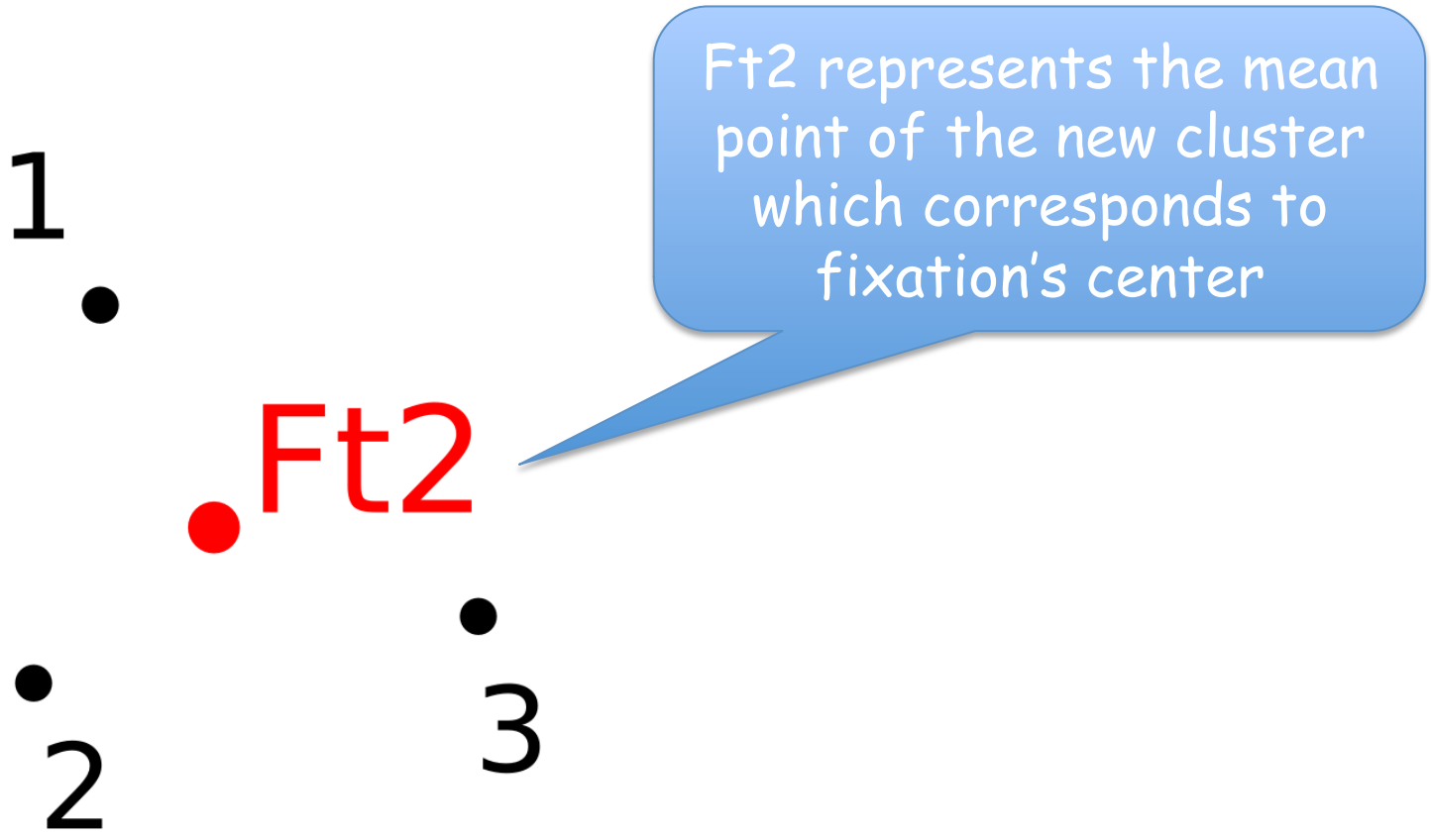
Fixation detection with EyeMMV: implementing the spatial parameters t1 and t2 (3)



check records' distances from mean point according to t2 parameter

Ft1 represents the mean point of the cluster

Fixation detection with EyeMMV: implementing the spatial parameters t1 and t2 (4)



Fixation detection with EyeMMV: implementing the temporal constraint

Example:

7 fixations after the implementation of the spatial parameters

fixation list (after t1,t2)

x_1, y_1, d_1
x_2, y_2, d_2
x_3, y_3, d_3
x_4, y_4, d_4
x_5, y_5, d_5
x_6, y_6, d_6
x_7, y_7, d_7

$d_1, d_2, d_4, d_5, d_7 >$ minimum duration

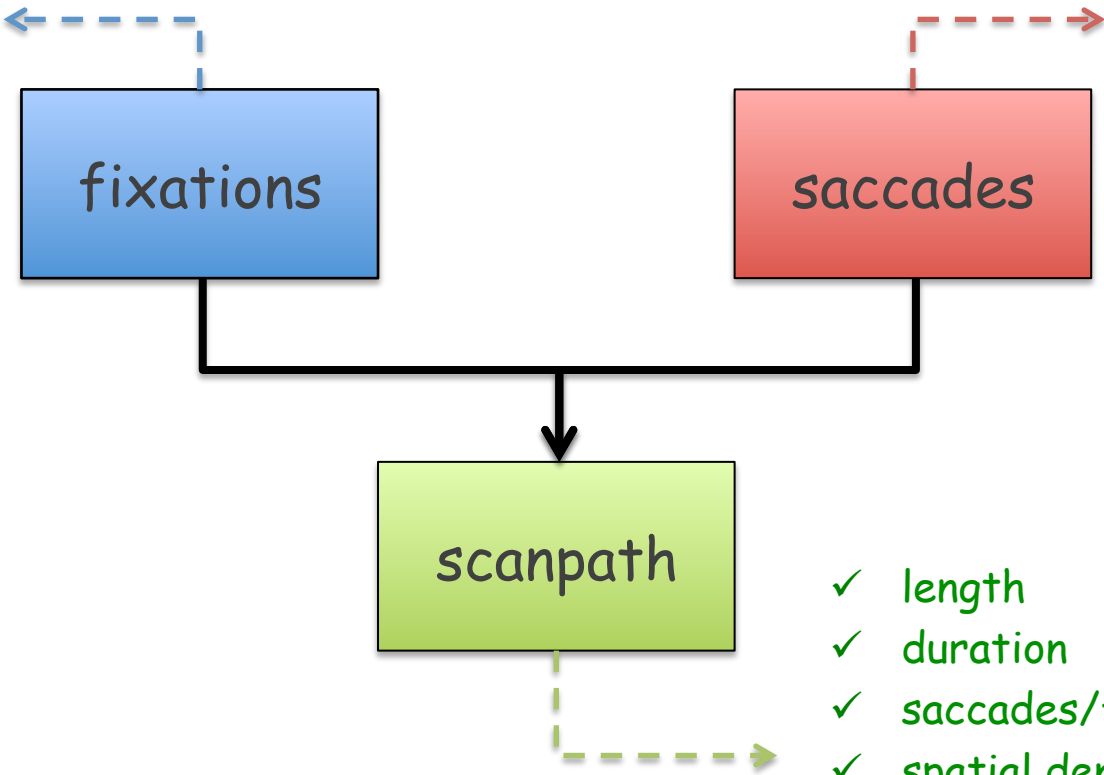
$d_3, d_6 <$ minimum duration

final list

x_1, y_1, d_1
x_2, y_2, d_2
x_4, y_4, d_4
x_5, y_5, d_5
x_7, y_7, d_7

EyeMMV Toolbox: the supported metrics

- ✓ coordinates: two lists (t1, t2,minDur) & (t1, 3s, minDur)
- ✓ durations
- ✓ start/end time
- ✓ total number
- ✓ mean duration
- ✓ time to first fixation
- ✓ list of repeat fixations
- ✓ total duration



- ✓ total number
- ✓ saccade list
- ✓ start/end fixation point
- ✓ duration
- ✓ amplitude
- ✓ direction angle

- ✓ length
- ✓ duration
- ✓ saccades/fixation ratio
- ✓ spatial density
- ✓ transition matrix
- ✓ transition density

EyeMMV Toolbox: the supported data visualization techniques

- diagram of horizontal and vertical coordinates along time (x-t and y-t diagram)
- diagram of raw data distribution (x-y)
- diagram of raw data distribution over stimulus (i-j)
- scanpath diagram over stimulus
- heatmap visualization
- space-time-cube visualization

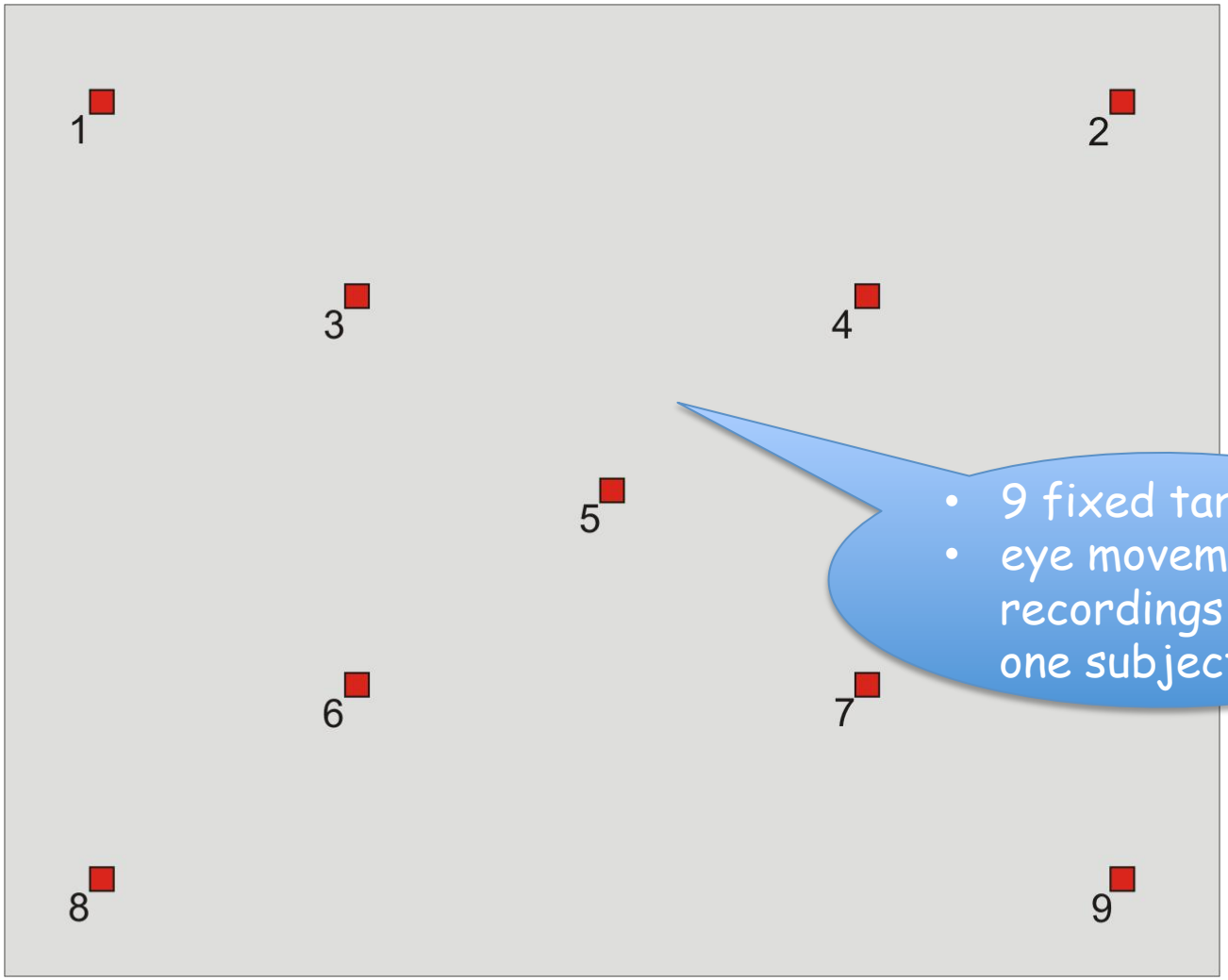
EyeMMV Toolbox: ROIs analysis

Defining a region of interest, EyeMMV is able to calculate different statistics:

- number of fixations in region
- list of fixations in region
- mean fixations' duration
- number (%) of fixations
- duration (%) of fixations

\+ ROIs diagram

Example 1: executing EyeMMV Toolbox with a simple stimulus



Example 1: fixation detection report

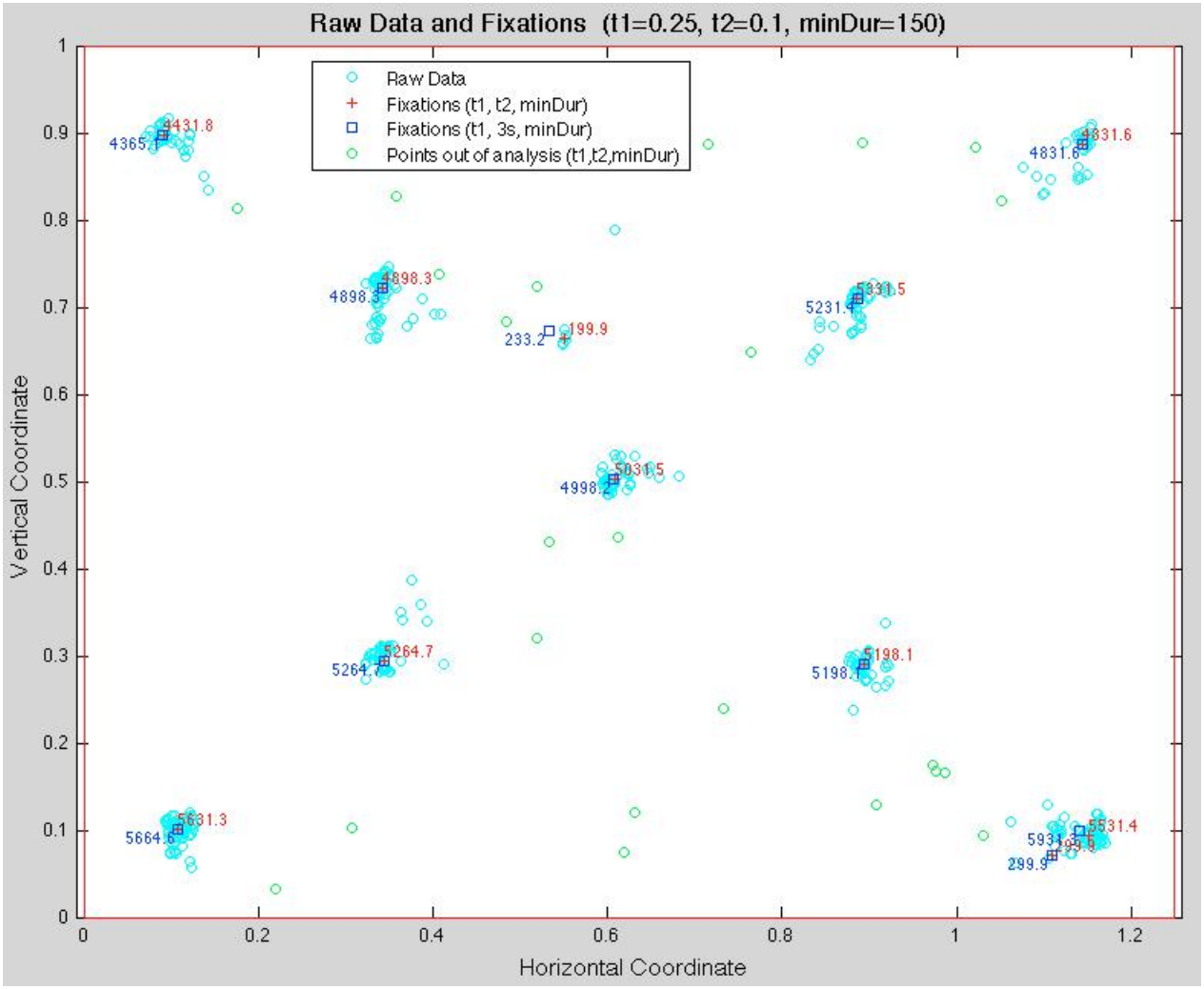
```
                Fixation Detection Report

Import Parameters:
  Spatial Parameter t1: 0.250
  Spatial Parameter t2: 0.100
  Minimum Fixation Duration: 150.00
  Maximum Coordinate in Horizontal Dimension: 1.25
  Maximum Coordinate in Vertical Dimension: 1.00

Number of Raw Data: 1448
Number of Data used in the analysis(t1,t2,minDur): 1411
Number of Data used in the analysis(t1,3s,minDur): 1411

Fixations:
  Total Number of Fixations(t1,t2,minDur): 11
  Total Number of Fixations(t1,3s,minDur): 11

t1,t2,minDur:
  ID-Xcenter-Ycenter-Nt1-Nt2-StartTime-EndTime-Duration
  1 0.5505 0.6639 8 7 2699.1000 2899.0000 199.9000
  2 0.0916 0.8975 135 134 2998.9000 7430.7000 4431.8000
  3 1.1437 0.8872 149 146 7597.3000 12428.9000 4831.6000
  4 0.3424 0.7220 151 148 12595.5000 17493.8000 4898.3000
  5 0.8857 0.7093 162 161 17593.7000 22925.2000 5331.5000
  6 0.6077 0.5027 153 152 22958.5000 27990.0000 5031.5000
  7 0.3436 0.2959 160 159 28056.7000 33321.4000 5264.7000
  8 0.8933 0.2917 162 157 33521.4000 38719.5000 5198.1000
  9 1.1099 0.0719 10 10 38786.2000 39086.1000 299.9000
  10 0.1070 0.1030 173 170 39186.0000 44817.3000 5631.3000
  11 1.1519 0.0961 181 167 44950.6000 50482.0000 5531.4000

t1,3s,minDur:
  ID-Xcenter-Ycenter-Nt1-N3s-StartTime-EndTime-Duration
  1 0.5326 0.6731 8 8 2699.1000 2932.3000 233.2000
  2 0.0908 0.8983 135 132 3065.6000 7430.7000 4365.1000
  3 1.1437 0.8872 149 146 7597.3000 12428.9000 4831.6000
  4 0.3424 0.7220 151 148 12595.5000 17493.8000 4898.3000
  5 0.8867 0.7105 162 158 17660.4000 22891.8000 5231.4000
  6 0.6072 0.5027 153 151 22991.8000 27990.0000 4998.2000
  7 0.3432 0.2949 160 157 28056.7000 33321.4000 5264.7000
  8 0.8933 0.2917 162 157 33521.4000 38719.5000 5198.1000
  9 1.1099 0.0719 10 10 38786.2000 39086.1000 299.9000
  10 0.1077 0.1026 173 171 39152.7000 44817.3000 5664.6000
  11 1.1401 0.1012 181 179 44950.6000 50881.9000 5931.3000

 Raw Data and Fixations are visualized successfully

End of Fixation Detection report
```

input parameters for the detection

fixations' detection (t1, t2, min duration)

fixations' detection (t1, 3s, min duration)

Example 1: visualizing raw data and fixations



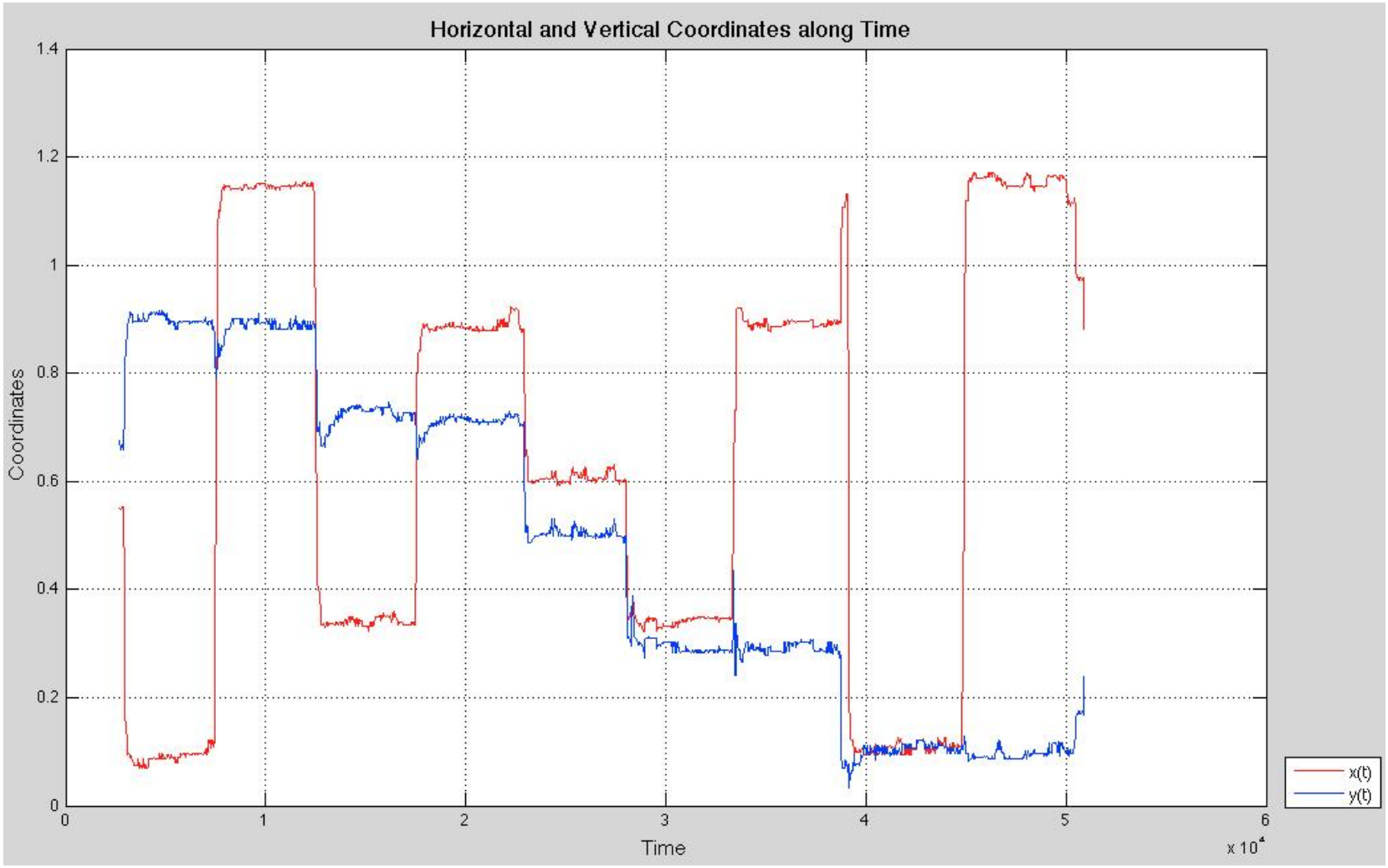
Example 1: fixation metrics and saccade analysis

```
Eye Movement metrics analysis

Input Parameters:
   Threshold for repeat fixations: 0.100
   Scanpath spacing (spatial density computation): 0.250
   Transition matrix spacing: 0.250

Fixation Metrics Analysis:
  Total number of fixations: 11
  Mean duration of fixations: 4240.9
  Time to first fixation: 2699.1
  Repeat Fixations:
    (Fixation_1_id-Fixation_2_id-Distance)
    9 11 0.048
  Total duration of all fixations: 46650.0

Saccades Analysis:
   Total number of saccades: 10
   Saccades list:
      (ID-X_Start_Point-Y_Start_Point-X_End_Point-Y_End_Point-
       Duration-Amplitude-Direction_angle-Start_Fixation-End_Fixation)
      1 0.5505 0.6639 0.0916 0.8975 99.9 0.515 296.978 1 2
      2 0.0916 0.8975 1.1437 0.8872 166.6 1.052 90.561 2 3
      3 1.1437 0.8872 0.3424 0.7220 166.6 0.818 258.351 3 4
      4 0.3424 0.7220 0.8857 0.7093 99.9 0.543 91.339 4 5
      5 0.8857 0.7093 0.6077 0.5027 33.3 0.346 233.382 5 6
      6 0.6077 0.5027 0.3436 0.2959 66.7 0.335 231.938 6 7
      7 0.3436 0.2959 0.8933 0.2917 200.0 0.550 90.438 7 8
      8 0.8933 0.2917 1.1099 0.0719 66.7 0.309 135.420 8 9
      9 1.1099 0.0719 0.1070 0.1030 99.9 1.003 271.776 9 10
      10 0.1070 0.1030 1.1519 0.0961 133.3 1.045 90.378 10 11
```

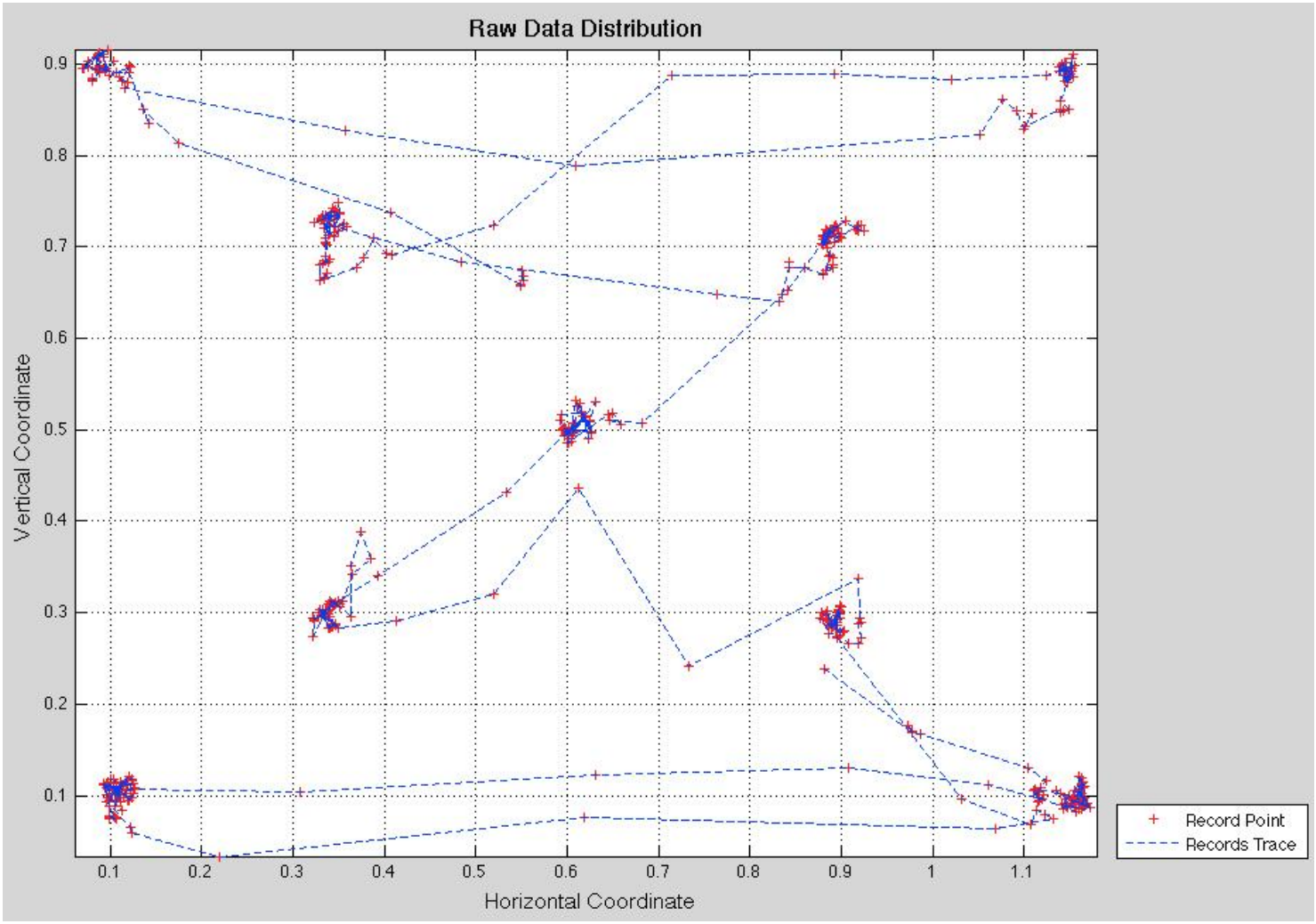
Example 1: scanpath analysis

```
Scanpath Analysis:
   Scanpath length: 6.517
   Scanpath duration: 47782.9
   Saccades/Fixations Ratio: 0.024
   Scanpath Spatial Density: 0.450
   Transition Matrix:
      -1-2-3-4-5-6-7-8-9-10-11-12-13-14-15-16-17-18-19-20
   1-   0   0   0   0   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
   2-   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
   3-   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
   4-   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
   5-   1   0   0   0   0   0   0   0   1   0   0   0   0   0   0   0   0   0   0   0
   6-   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
   7-   0   0   0   0   0   0   0   0   0   0   0   0   1   0   0   0   0   0   0   0
   8-   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
   9-   0   0   0   0   0   0   1   0   0   0   0   0   0   0   0   0   0   0   0   0
   10-   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
   11-   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
   12-   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   1
   13-   0   0   0   0   0   0   0   0   0   0   0   0   0   1   0   0   0   0   0   0
   14-   0   0   0   0   0   0   0   0   0   0   0   1   0   0   0   0   0   0   0   0
   15-   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
   16-   0   0   0   0   0   0   0   0   0   0   0   0   1   0   0   0   0   0   0   0
   17-   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
   18-   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
   19-   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
   20-   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   1   0   0   0   0
Transition Density: 0.025

-------------------------------------------------------------

End of Metrics Analysis Report
```

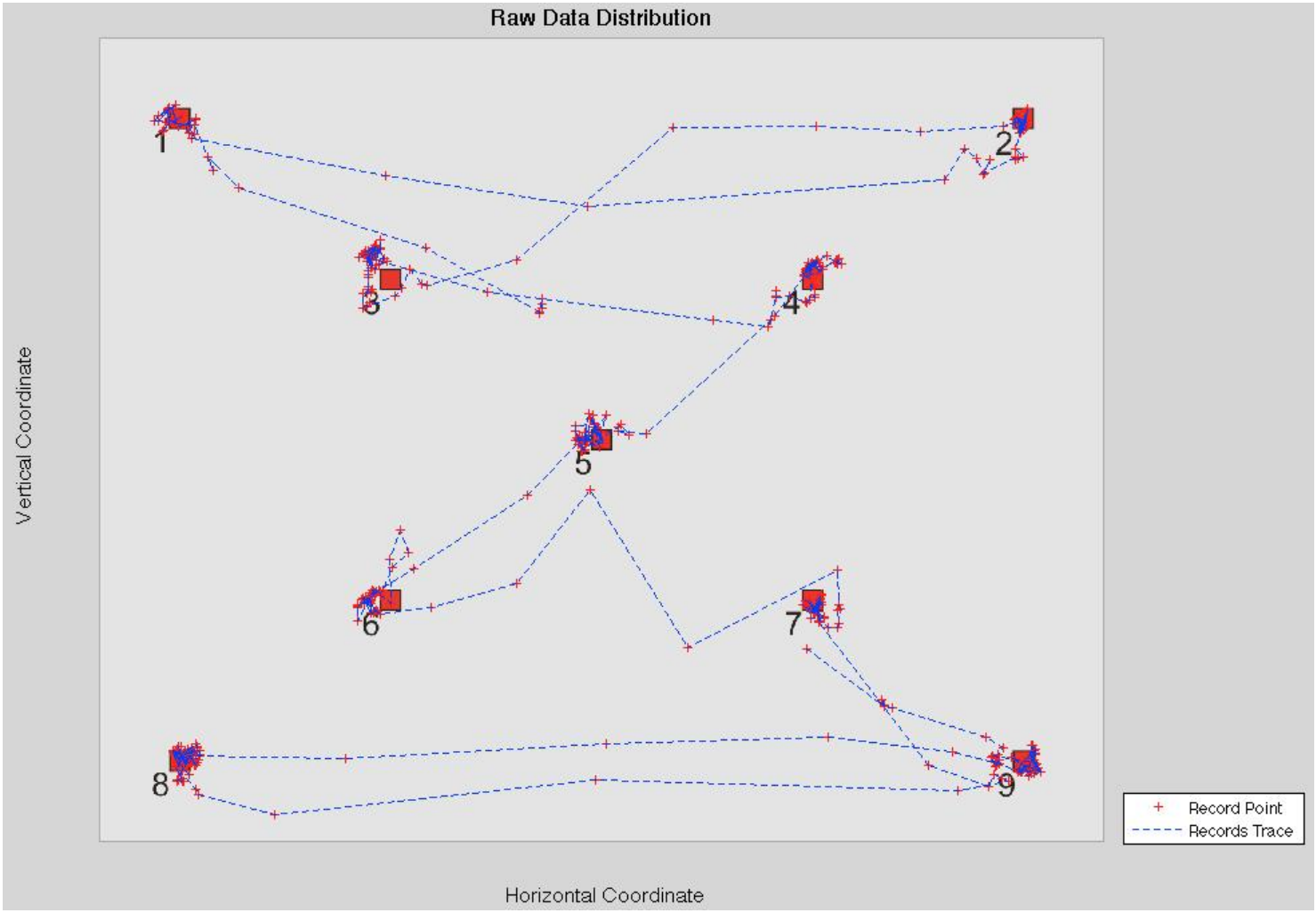
Example 1: visualizations (1)



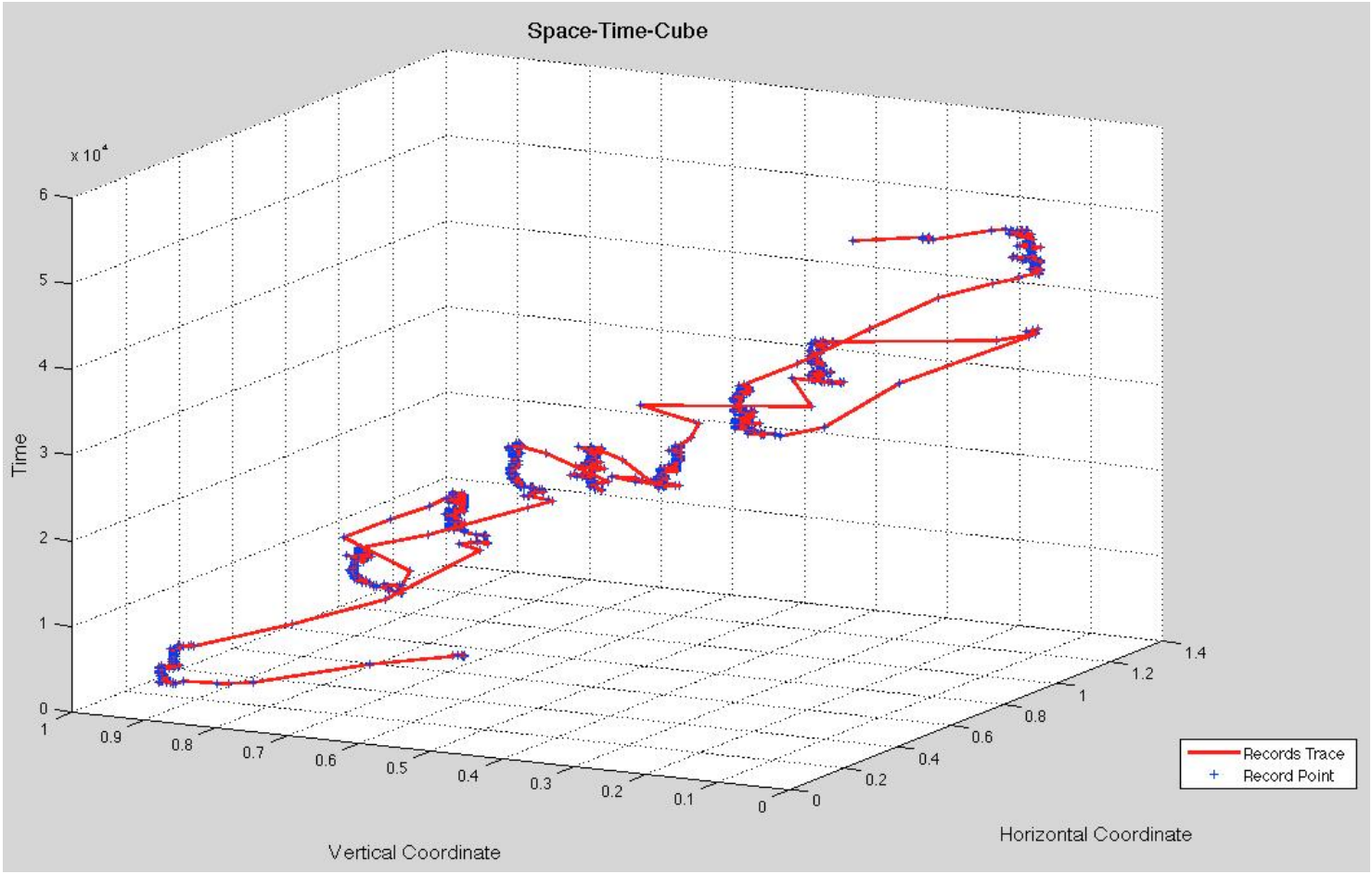
Example 1: visualizations (2)



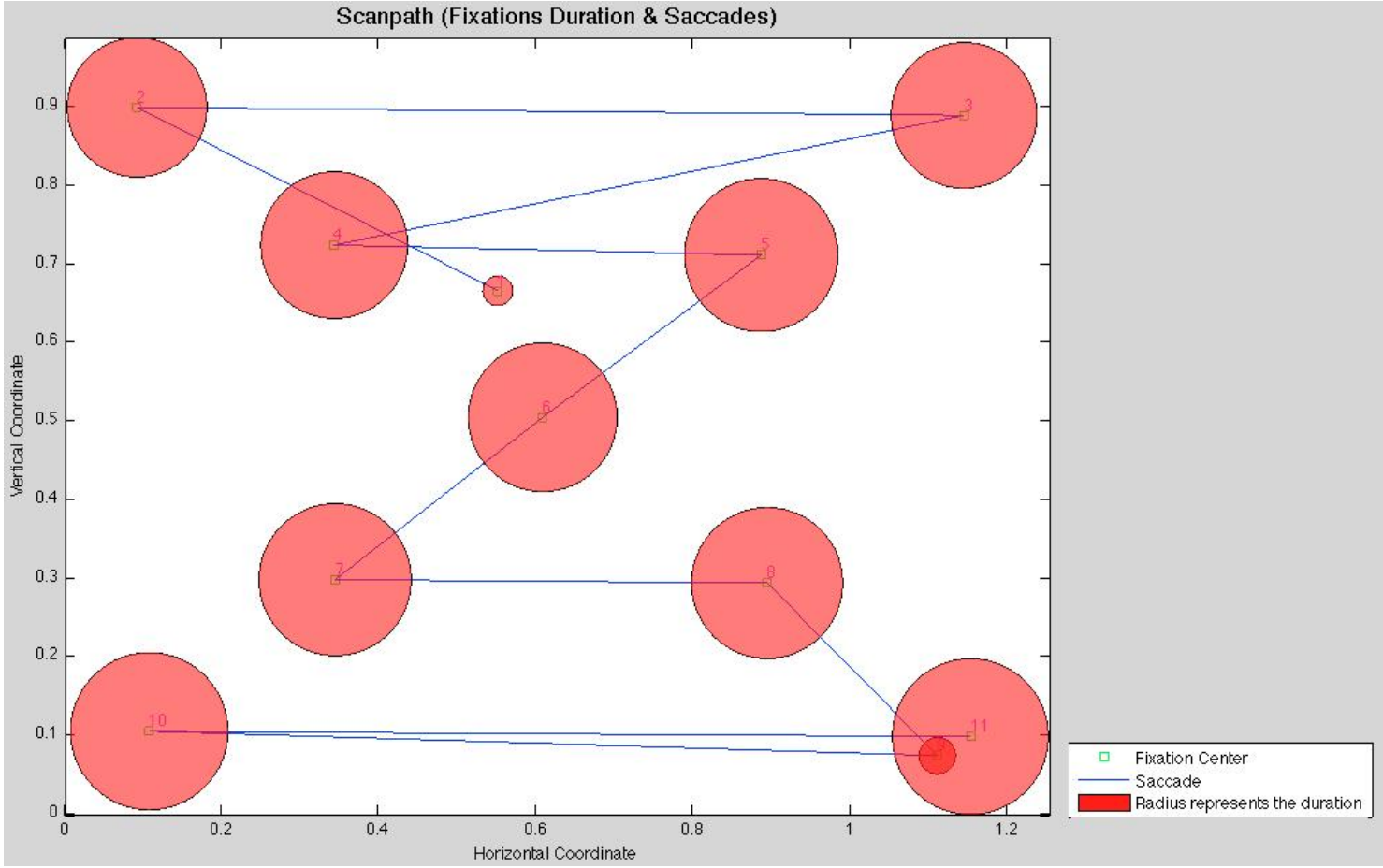
Example 1: visualizations (3)



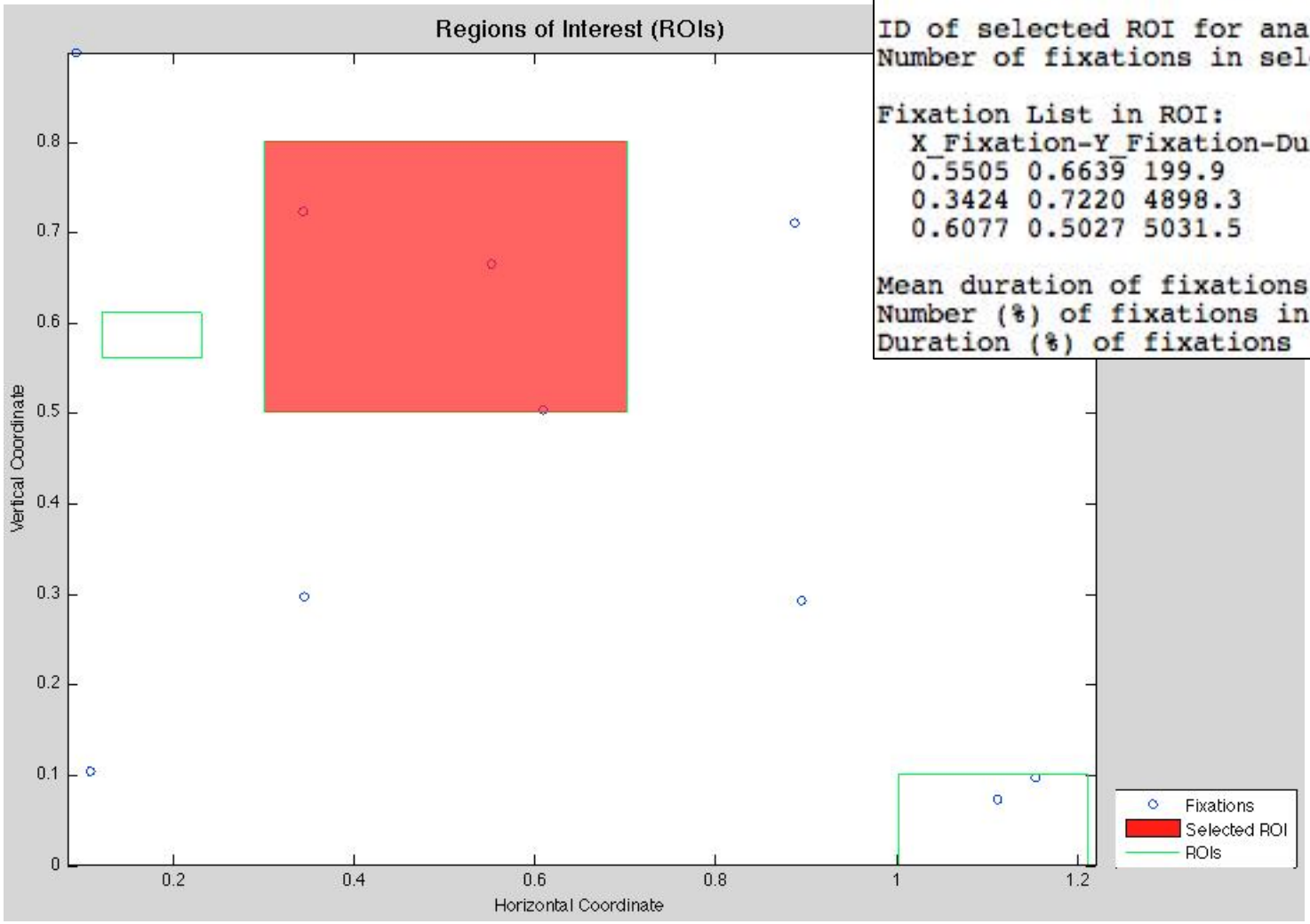
Example 1: visualizations (4)



Example 1: visualizations (5)

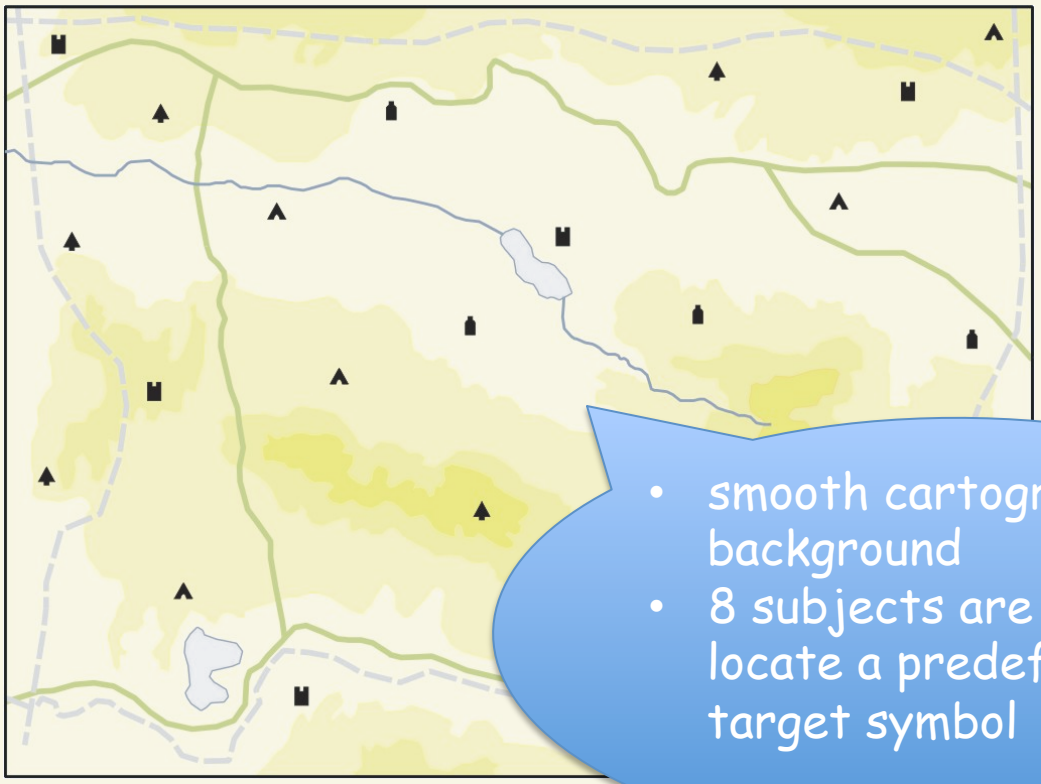


Example 1: ROIs analysis



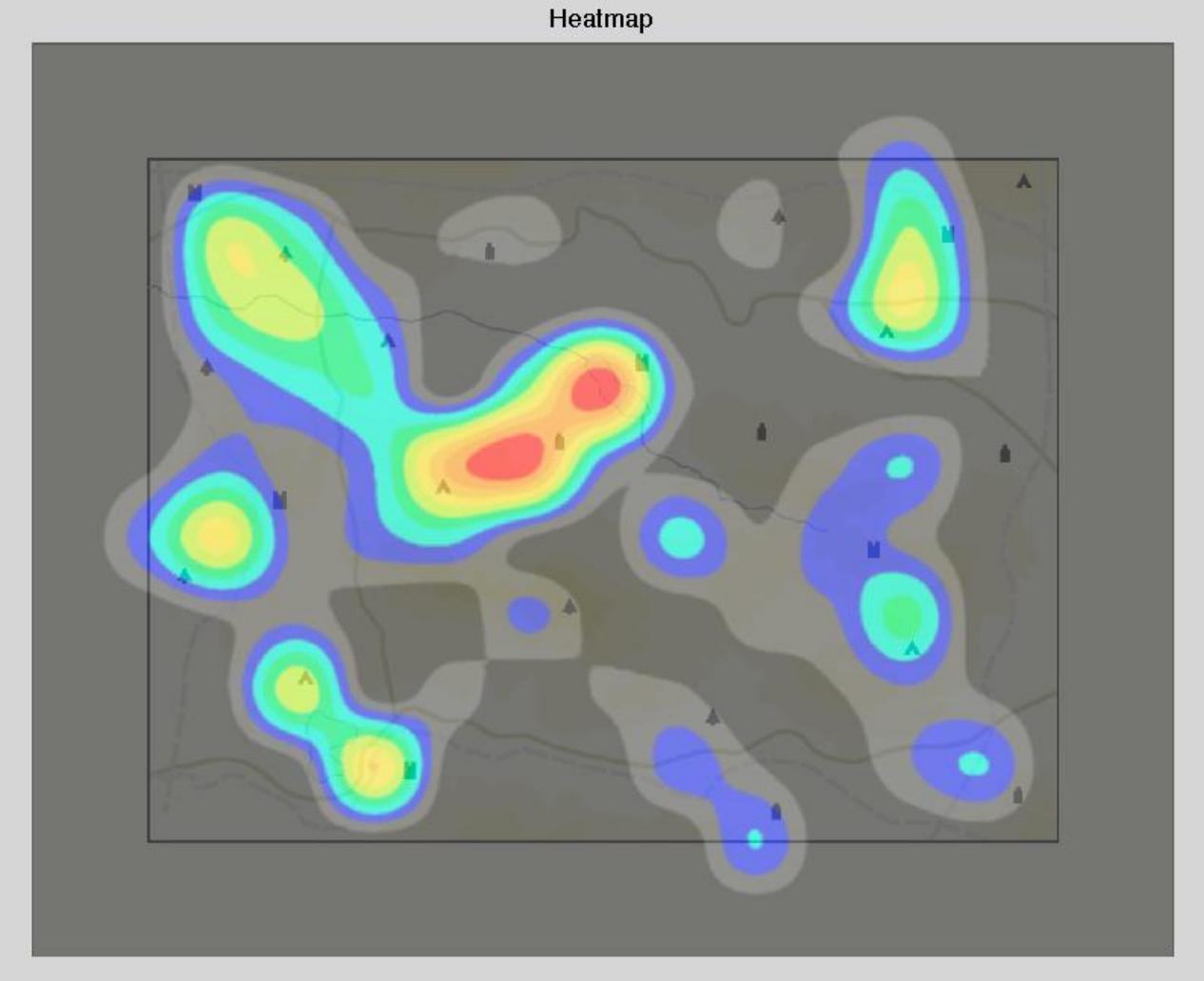

```
ROI Analysis

ID of selected ROI for analysis: 2
Number of fixations in selected ROI: 3

Fixation List in ROI:
  X_Fixation-Y_Fixation-Duration
  0.5505 0.6639 199.9
  0.3424 0.7220 4898.3
  0.6077 0.5027 5031.5

Mean duration of fixations in ROI: 3376.6
Number (%) of fixations in ROI: 27.27%
Duration (%) of fixations in ROI: 21.71%
```

Example 2: executing EyeMMV Toolbox using eye movement recording during the observation of cartographic background



- smooth cartographic background
- 8 subjects are asked to locate a predefined target symbol

Example 2: heatmap visualization



Conclusions

- EyeMMV is a complete MATLAB based Toolbox for post-experimental eye movement analysis
- fixation detection is based on an introduced algorithm based on spatial and temporal parameters
- supports all the well-known metrics and visualization techniques
- different approach from existing tools. There is no Graphical User Interface: list of functions (Toolbox)
- EyeMMV' s functions can be easily imported in every MATLAB script
- EyeMMV can be executed in every operating system (Windows, Linux and Mac OS)
- EyeMMV will be freely distributed through the internet

Thank you
for your attention