Agenda

- Experience in computer vision and machine learning:
  - Pedestrian detection
  - Vehicle detection
  - Current research
- Educational courses:
  - Educational course “Introduction to deep learning using the Intel® neon™ Framework” (RUS/ENG)
- CalciumCV: Computer vision software for calcium signaling in astrocytes

Nizhny Novgorod State University

Institute of Information Technologies, Mathematics and Mechanics

Computer Vision and Applications: Pedestrian and Vehicle detection

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(2012 – 2015)

Pedestrian detection problem

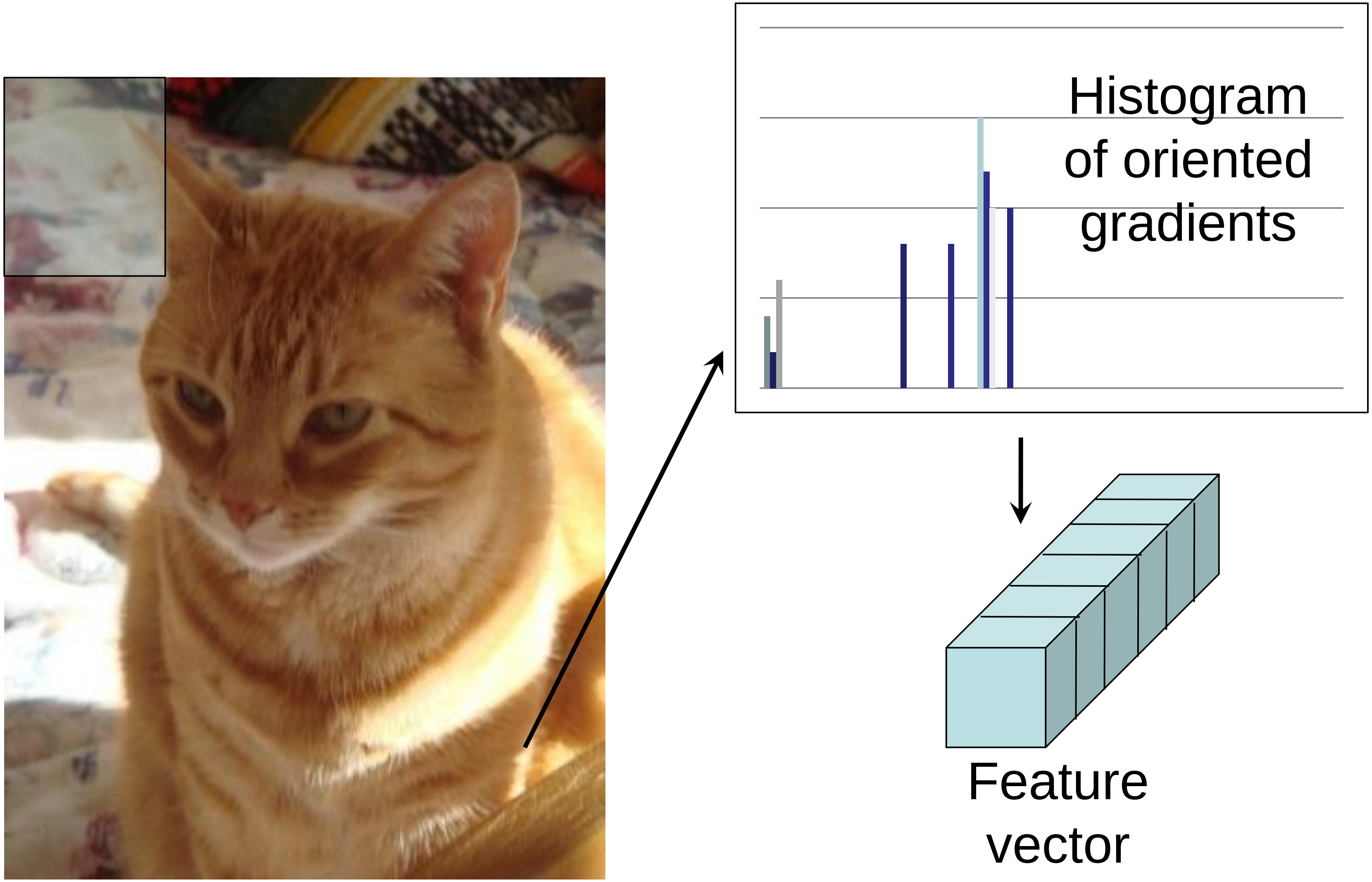
- I – initial image (in our case RGB)

- The pedestrian detection problem consists in mapping image to the set of pedestrian location:

$$\varphi: I \rightarrow B, \qquad B = \left\{b_k, k = \overline{0, |B|-1}\right\}$$

- The pedestrian location b_k is a bounding box constructed around the pedestrian on the initial image

Sliding “window” approach

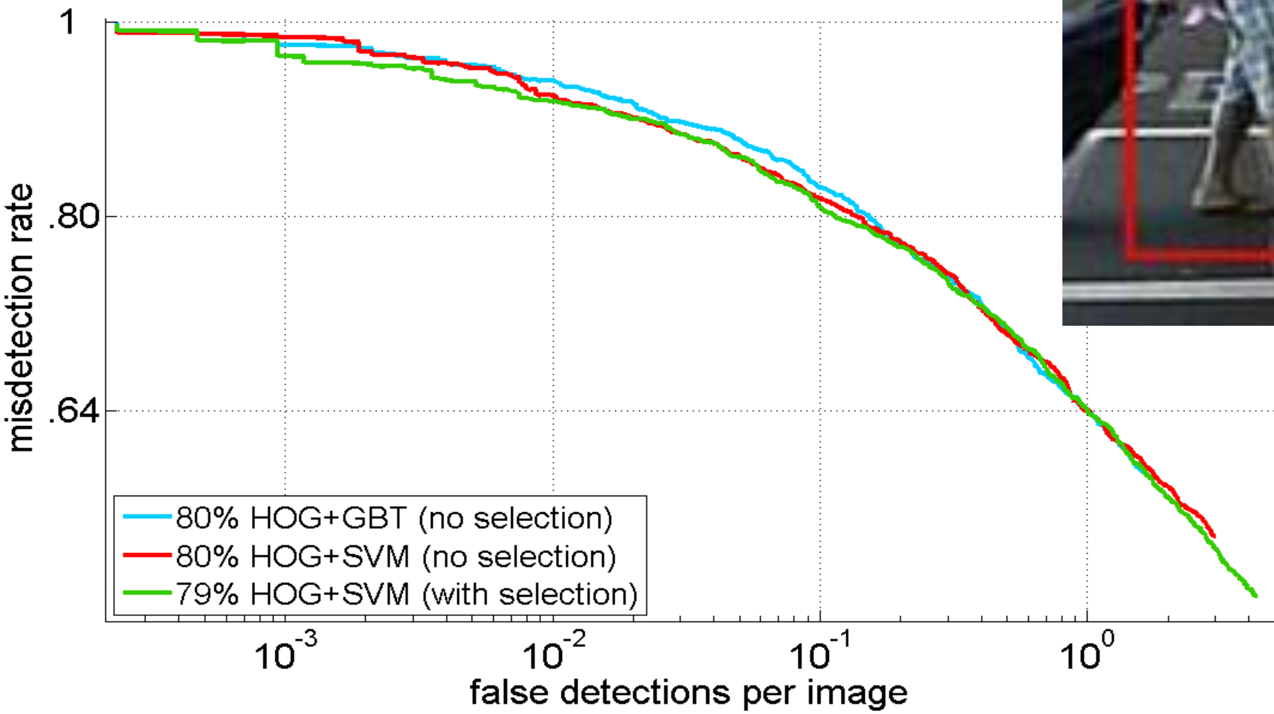


Experiments (1)

- Data:
  - TUD-MotionPairs for training
  - Caltech Pedestrian Dataset (4,250 RGB images 640x480) for testing
- Features:
  - Histogram of Oriented Gradients (HOG)
  - 3,024 features per detection window
  - 397 features selected*
- Classifiers:
  - Support Vector Machines (SVM)
  - **Gradient Boosting Trees (GBT) → OpenCV**

*** Tuv E., Borisov A., Runger G. Feature Selection with Ensembles, Artificial Variables, and Redundancy Elimination // Journal of Machine Learning Research. – 2009. – № 10. – P. 1341–1366.**

Experiments (2)



Video-based vehicle detection problem. Locations

- $I_0, I_1, \dots, I_{N-1}$ is a frames sequence, where N is a number of frames

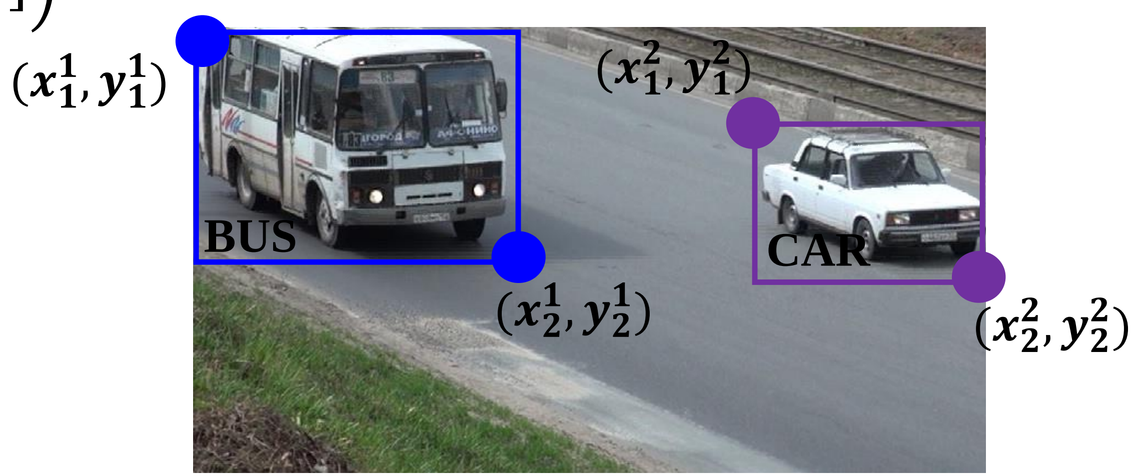
- The problem of vehicle video detection consists in mapping each frame I_k into the set of objects locations B_k:

$$\varphi: I_k \rightarrow B_k, \qquad B_k = \left\{ b_l^k, l = \overline{0, |B_k| - 1} \right\}$$

$$b_l^k = \left(\left(x_1^l, y_1^l\right), \left(x_2^l, y_2^l\right) [, s^l, c^l] \right)$$

$s^l \in \mathbb{R}$ is a confidence,

c^l is a vehicle class



Video-based vehicle detection problem. Tracks

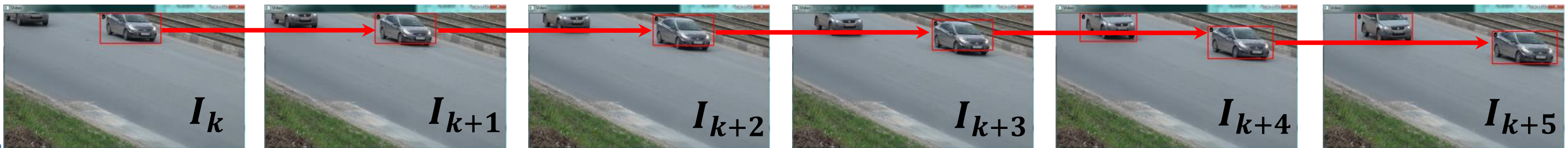
- The model requires construction of objects tracks

- The map ψ from the vehicles locations of the frame I_k to the vehicles locations of the frame I_{k+1}:

$$\psi: B_k \to B_{k+1} \cup \{b\}, b = \big((-1,-1),(-1,-1)[,s,c]\big)$$

- If I_k is the first frame where the object was detected, $r_0(k)$ is the bounding box index and q is the number of frames where the object is visible, then a ***track*** is a sequence of locations

$$T^k_{r_0(k)} = \left(b^k_{r_0}, b^{k+1}_{r_1}, \dots, b^{k+q-1}_{r_{q-1}}\right), \qquad b^{k+i}_{r_i} = \psi\left(b^{k+i-1}_{r_{i-1}}\right), i = \overline{1, q-1}$$



Software

- The software implementation uses OpenCV computer vision library

- Latent Support Vector Machines* is used as a detection algorithm
- The vehicle classifier (class CAR) was trained on PASCAL Visual Object Challenge 2007 data set and our data

*** Felzenszwalb P. F., Girshick R. B., McAllester D., Ramanan D. Object Detection with Discriminatively Trained Part Based Models // IEEE Transactions on Pattern Analysis and Machine Intelligence (PAMI'10). – 2010. – V. 32, № 9. – P. 1627–1645.**

Experiments (1)

- Test data:
  - ***track_10_5000-7000***: 25 FPS, 720x405, 2000 frames = 80 s, ~3000 bounding boxes, 58 tracks, vehicles of the only class CAR, that move in 4 lanes of the same direction
  - ***track_10_7000-8000***: 25 FPS, 720x405, 1000 frames = 40 s, ~1000 bounding boxes, 29 tracks, objects of two classes, CAR and BUS

Experiments (2)

Video	AP	TPR (%)	FDR (%)	FPF
track_10_5000-7000	0.68	74.8	19.9	0.27
track_10_7000-8000	0.68	71.3	32.4	0.38

- the average precision (AP)
- the true positive rate (TPR)*
- the false detection rate (FDR)*
- the average false positives per frame (FPF)*

*** overlapping square is more than 50%**

Current research

- More complicated traffic data
- Applying detectors based on deep learning (SSD, YOLO, etc.)
- Combining semantic segmentation and vehicle detection

Educational courses

Educational course "Introduction to deep learning using the Intel® neon™ Framework"

- Topics:
  – Introduction to deep learning
  – Multilayered fully-connected neural networks
  – Introduction to the Intel® neon™ Framework
  – Convolutional neural networks. Deep residual networks
  – Transfer learning of deep neural networks
  – Unsupervised learning: autoencoders, deconvolutional networks
  – Recurrent neural networks
  – Introduction to the Intel® nGraph™

- Links: Russian version, English version (2018)
- Authors: Kustikova V., Zolotykh N., Zhiltsov M.

Other educational materials

- ***Бовырин А.В., Дружков П.Н., Ерухимов В.Л., Золотых Н.Ю., Кустикова В.Д., Лысенков И.Д., Мееров И.Б., Писаревский В.Н., Половинкин А.Н., Сысоев А.В.*** Учебный курс “Разработка мультимедийных приложений с использованием библиотек OpenCV и IPP” [http://www.hpcc.unn.ru/?doc=602] (2012)

- ***Баркалов К.А., Мееров И.Б., Сысоев А.В., Сиднев А.А., Кустикова В.Д., Козинов Е.А., Бастраков С.И., Донченко Р.В., Малова А.Ю., Сафонова Я.Ю.*** Учебный курс “Параллельные численные методы” [http://www.hpcc.unn.ru/?doc=491] (2012)

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CalciumCV: Computer vision software for calcium signaling in astrocytes

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A. Zaikin, M. Ivanchenko, I. Meyerov, and A. Semyanov

(2016 – 2018)

Introduction

- Astrocytes are electrically inactive brain cells
- Imaging of calcium activity is a basic method for calcium activity analysis. Recently, several approaches to measure automatically the parameters of individual events been suggested, however, none of these methods has become a standard
- The state-of-the-art approaches for image preprocessing are based on deep learning
- The labeling data is performed by experts, but there are astrocyte activities which may be invisible for some of them that is why the labeling is a subjective process. Therefore, the application of deep learning to the astrocyte activity analysis is complicated
- We improved the previously developed method: Wu Y.W., et al. Spatiotemporal calcium dynamics in single astrocytes and its modulation by neuronal activity, 2014

Problem statement (1)

- The proposed method analyses time-lapse imaging records for the calcium activity of an astrocyte
- Each frame displays a spatial distribution of fluorescence intensity in several planes parallel to the substrate, yielding a set of planar images that reflect calcium activity
- We introduce and consider a maximal projection, defined as the maximal intensity at each point over this set:

$$V = \{V_s, 0 \le s \le k-1\}, V_s = \left(V_{ij}^{(s)}\colon\ 0 \le i \le h-1, 0 \le j \le w-1\right),$$

where k is a number of frames, and V_s is a frame with a resolution $w \times h$

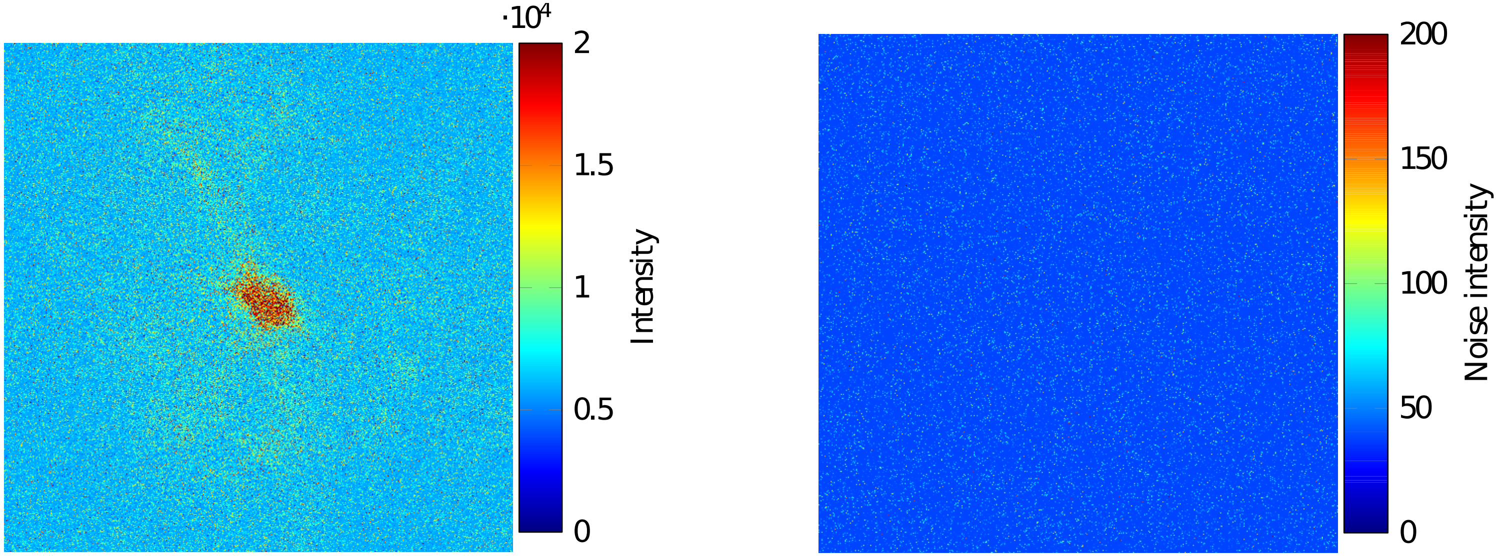
Problem statement (2)

- Moreover, we have a movie that corresponds to the camera noise and represents a video without astrocyte:

$$N = \{N_r, 0 \le r \le n-1\}, N_r = \left(N_{ij}^{(r)}: 0 \le i \le h-1, 0 \le j \le w-1\right),$$

where n is a number of frames, and N_r is a noise frame

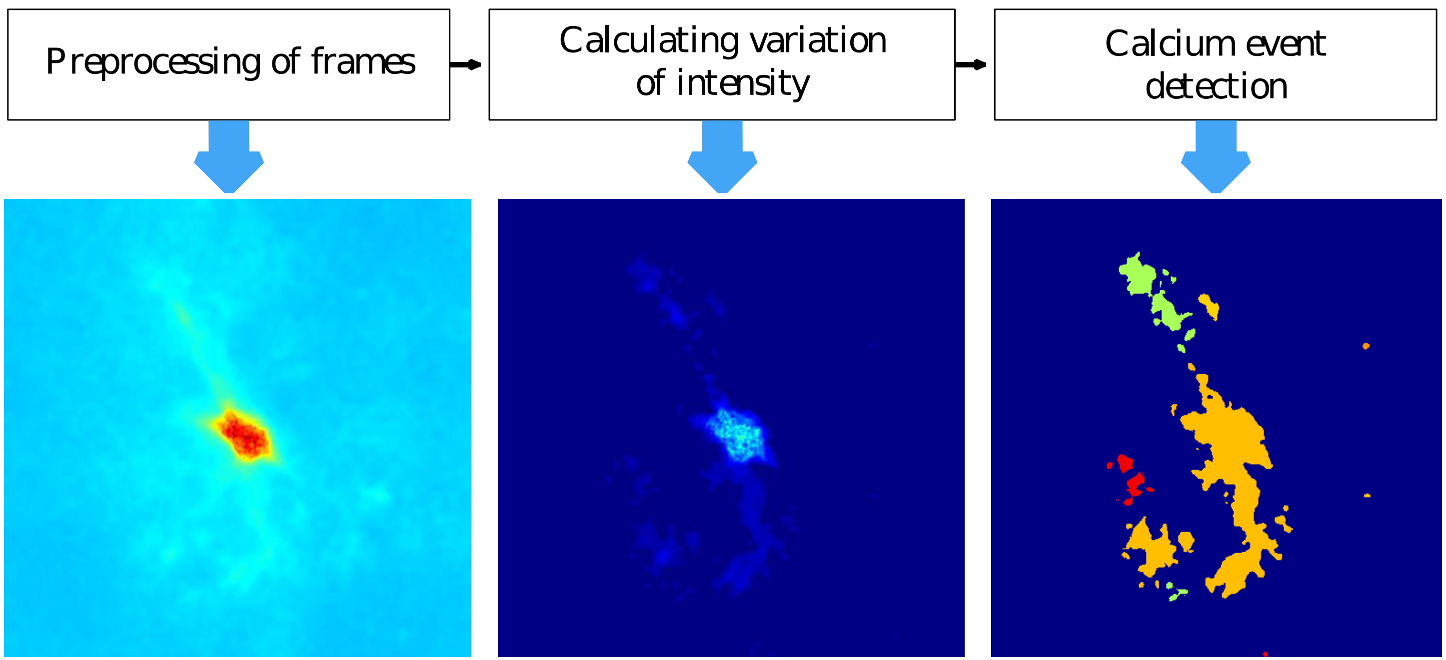
- The principle of noise generation on videos is unknown; the noise model is Gaussian noise



Method

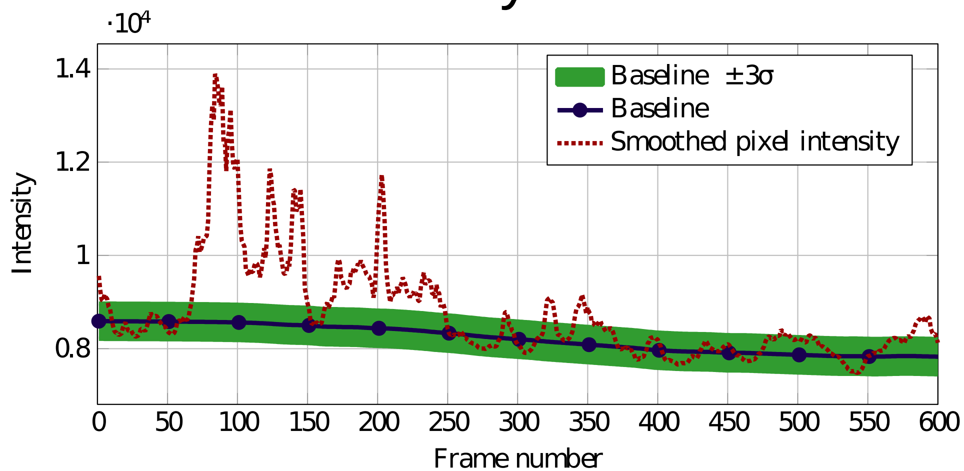
The proposed method includes the following steps:

1. Video preprocessing
2. Calculating a baseline of the fluorescence intensity and its relative variation
3. Detecting calcium events based on the relative intensity variation



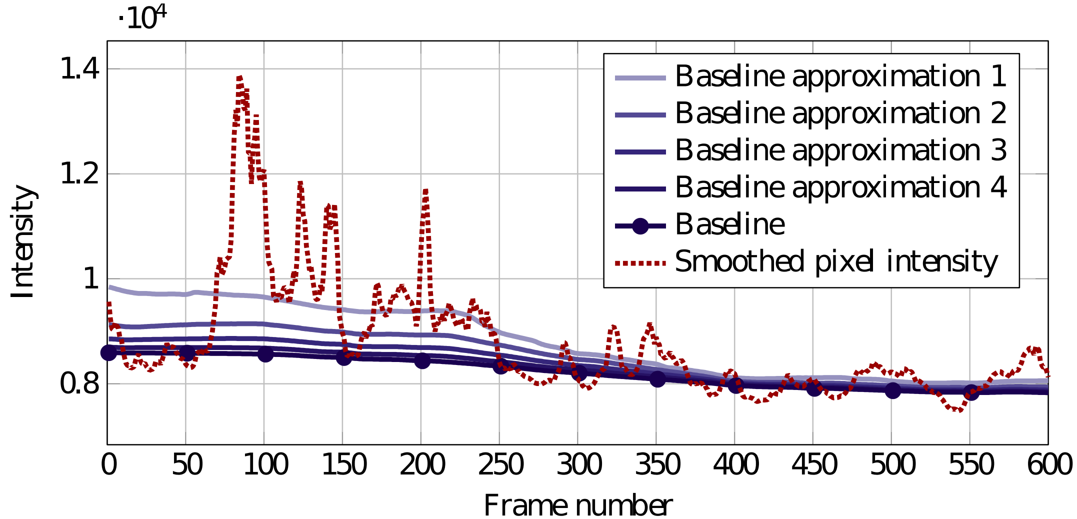
Step 1. Video preprocessing

- Aligning an image (eliminating jitter) based on normalized cross-correlation
- Calculating noise parameters based on the input noise video, identifying points of ***undefined activity*** and subtracting the camera noise
- Filtering frames using block-matching and 3D filtering method (BM3D)
- Evaluating a noise level on the filtered video relative to the baseline level. We construct a set of activity moments



Step 2. Calculating a baseline of the fluorescence intensity and its relative variation

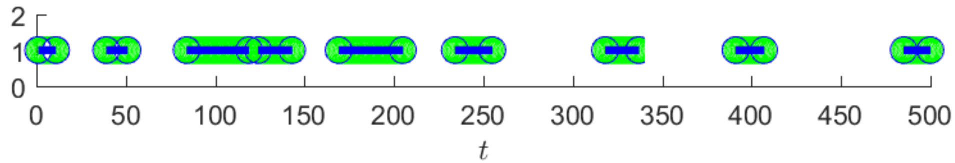
- Calculating the baseline intensity for each pixel assumes an iterative approximation by applying moving average for the current estimate of a baseline



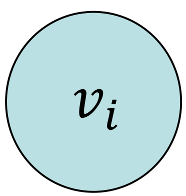
- The formula for the relative intensity variation for each pixel is standard one and is used to compute calcium fluorescence $\frac{dF}{F_0} = \frac{F - F_0}{F_0}$, where F_0 is a baseline pixel intensity, F is a pixel intensity realization in time

Step 3. Detecting calcium events based on the relative intensity variation (1)

- Identifying time gaps where each pixel is active
  - Clustering the activity moments using DBSCAN method



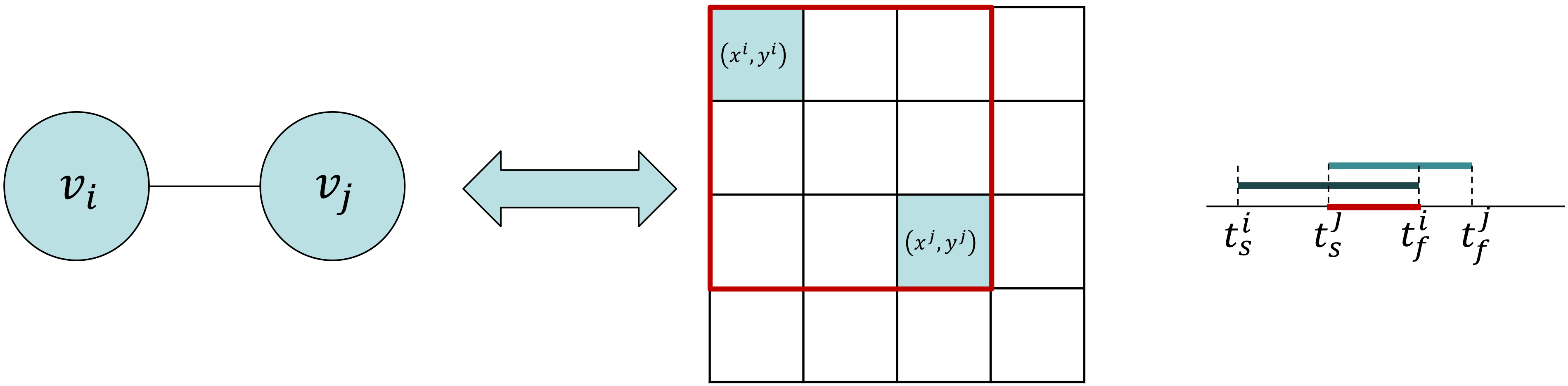
- Combining these time gaps over space and time based on sliding window approach
  - Representing the constructed time gaps for the set of all pixels as a set of graph vertices



$v_i = \{(x^i, y^i), (t_s^i, t_f^i)\}$, (x^i, y^i) is a pixel displacement, (t_s^i, t_f^i) is an activity time gap, t_s^i is a start frame identifier, t_f^i is a final frame identifier

Step 3. Detecting calcium events based on the relative intensity variation (2)

– Two vertices are connected by an edge if the corresponding pixels belong to the same window location and the corresponding time gaps intersect



– Constructing connectivity components for this graph

– Each connectivity component represents an astrocyte event

Implementation

- The proposed method is implemented in C++ programming language, tools for statistical events analysis are implemented in MATLAB
- The code is distributed free and open source
- The source code can be downloaded from GitHub: https://github.com/UNN-VMK-Software/astro-analysis
- We also submit a short test movie and step-by-step tutorial for building and executing developed program, and for fine-turning method parameters

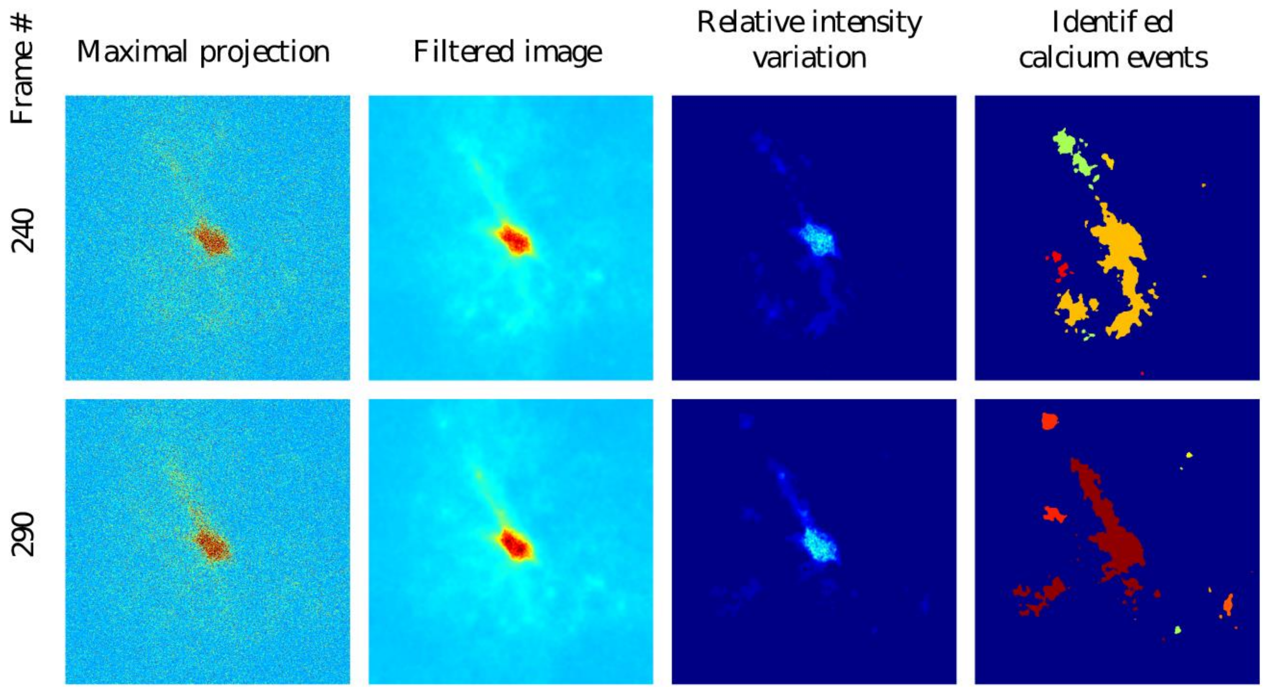
Experimental data

- We used 10 records with a duration from 100 to 3000 frames, with frame resolution is not exceeding 512×512 pixels

#	Resolution	Duration	Number of detected events
1	512×512	1500	465
2	451×441	3000	1204
3	421×512	3000	2048
4	512×512	100	65
5	512×512	1000	458
6	512×512	1000	591
7	500×390	1000	260
8	512×512	200	61
9	512×512	500	97
10	512×512	600	364

Results (1)

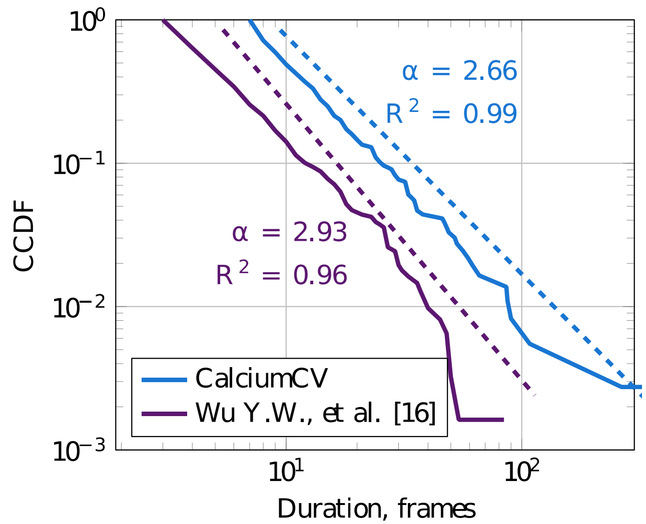
- The correctness of event detection in a given subject area is determined today by the method of expert assessments
- Identification of calcium events was confirmed by visual inspection

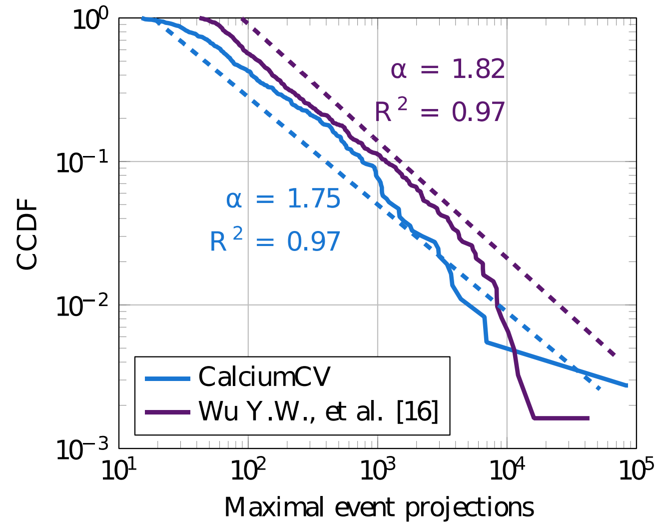


- The proposed method adequately yields the regions of calcium activity

Results (2)

- We implemented a statistical analysis of calcium events
- The complementary cumulative distribution functions for durations and maximal projections of events are approximated well by power laws, as confirmed by Kolmogorov-Smirnov test
- The typical values of the exponents are consistent with the previously reported data in Wu Y.W., et al., 2014



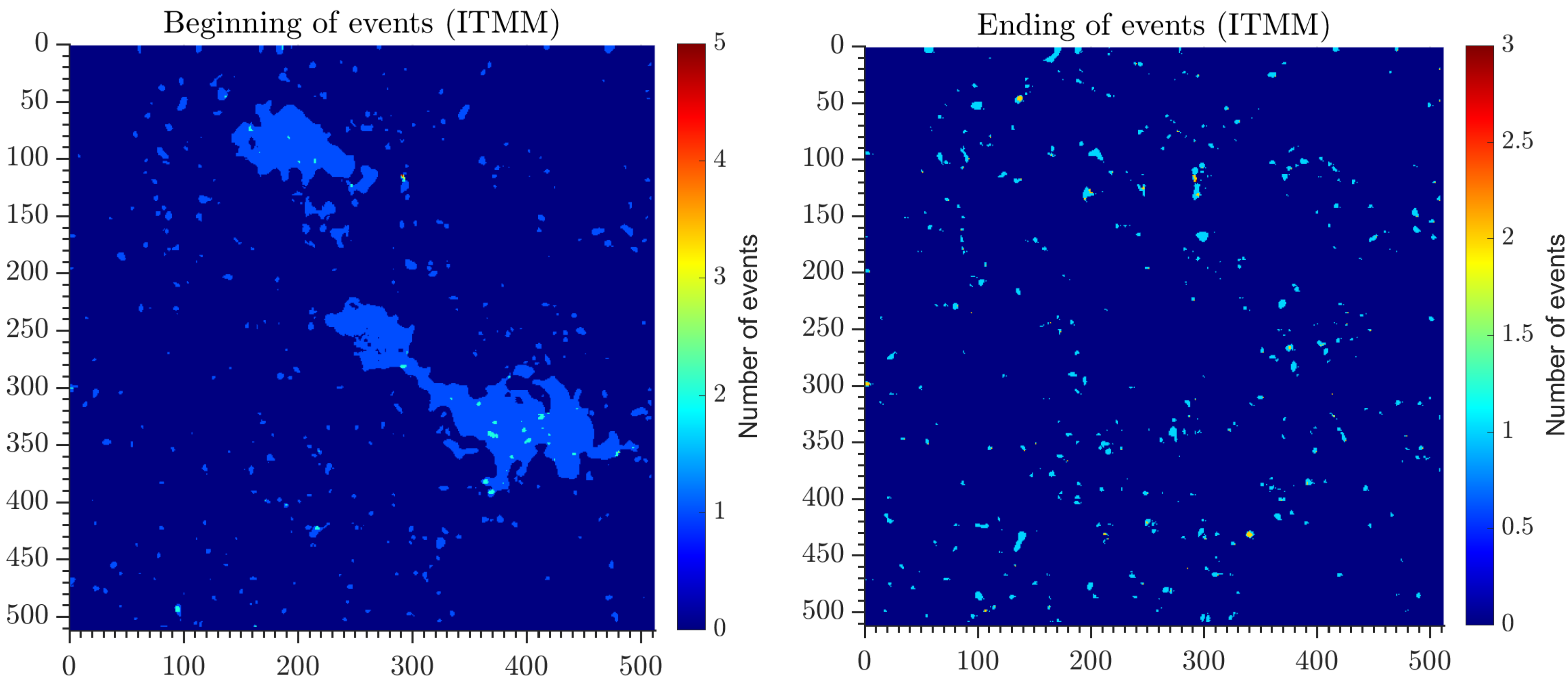


Space-time measurements (1)

- Spatial histogram of event start and end
- Spatial activity histogram
- Vectors of the event front spread
- One-dimensional histograms of the number of splits and merges within an event, the difference of splits and merges
- Compactness index for each video frame
- Two-dimensional histogram of the event count with different number of splits and merges
- Correlations between different measurements
- …

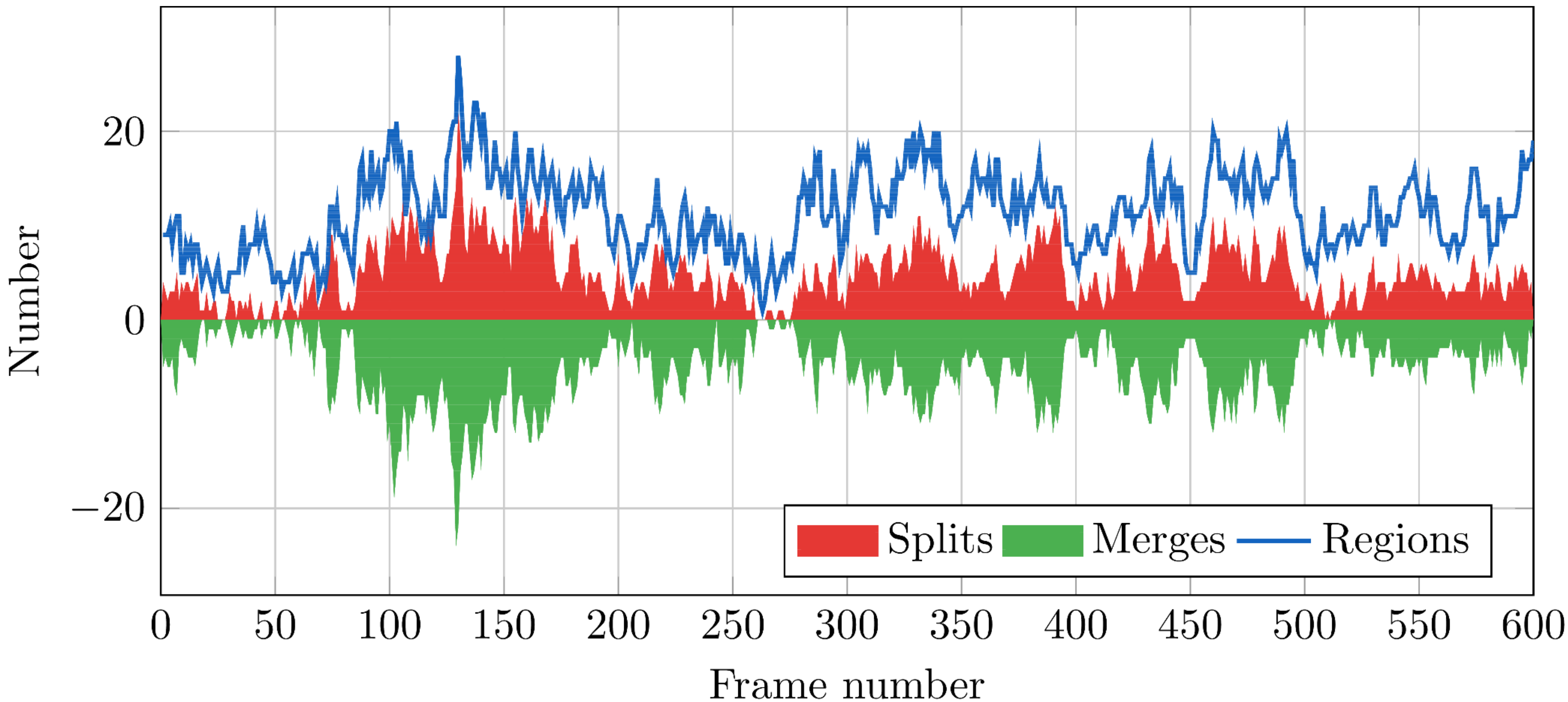
Space-time measurements (2)

- Spatial histogram of event start and end



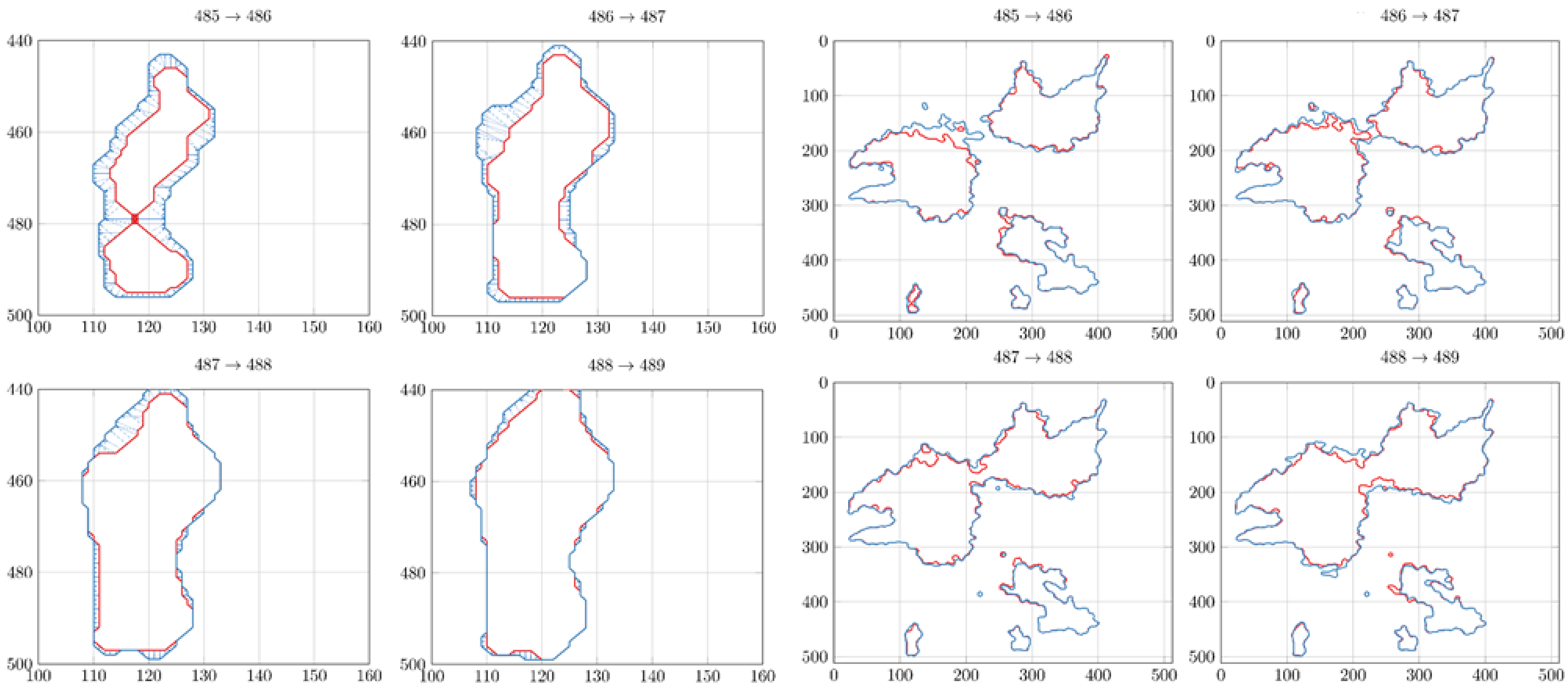
Space-time measurements (3)

- Number of region splits and merges



Space-time measurements (4)

- Event front spread



Conclusion

- We have demonstrated a method for detecting calcium activity in astrocytes
- The novelty of the proposed method consists in estimating noise parameters and constructing the baseline level corresponding to the inactive state of astrocyte
- The software is available at GitHub for testing on raw experimental data: https://github.com/UNN-VMK-Software/astro-analysis
- Our program can be used by researchers analyzing spatiotemporal properties of calcium events in astrocytes and other cell types
- The proposed method is open for future development

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