FUZZY LOGIC BASED DETECTION OF NEURON BIFURCATIONS IN MICROSCOPY IMAGES

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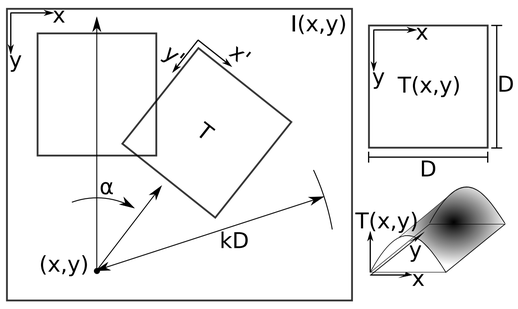
Introduction

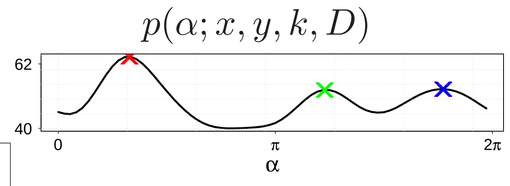
Quantitative analysis of neuronal cell morphology from microscopic image data requires accurate reconstruction of the axonal and dendritic trees. The most critical points to be detected in this process are the bifurcations. We present a new solution for fully automatic detection of bifurcations in microscopic images. Common signal discontinuities and bifurcation configuration diversity are tackled with a new filtering and profile analysis scheme. Uncertainty and nonlinearity of the final decision are treated with fuzzy logic (FL) and an appropriate set of IF-THEN rules.

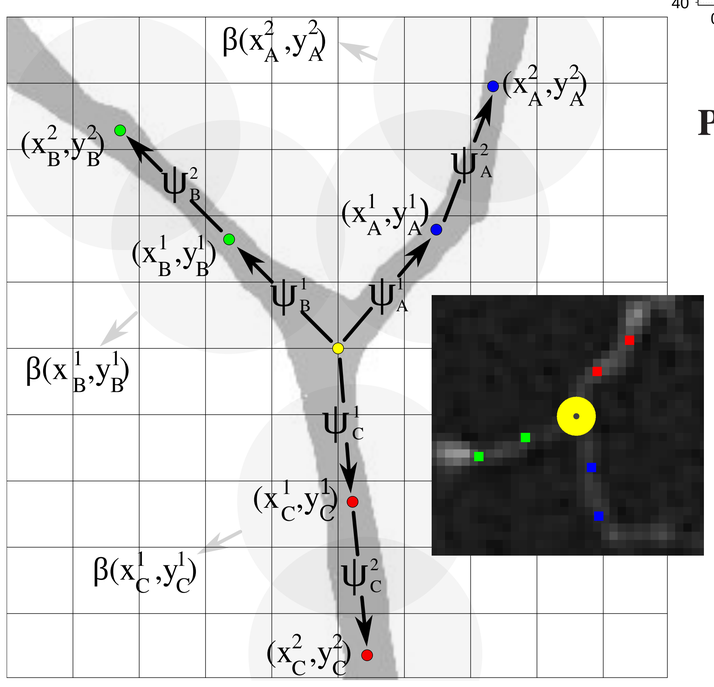
Method

Local filtering and profiling:
Applying a set of oriented filters $T(x', y')$ distributed around a given location (x, y) by rotation over angle $\alpha \in [0, 2\pi)$ and translation over a distance kD results in an angular response profile p. Kernels are profiled with normalized Gaussian weights.



$p(\alpha; x, y, k, D)$





ψ - median intensity along the line segments
β - estimated local background value

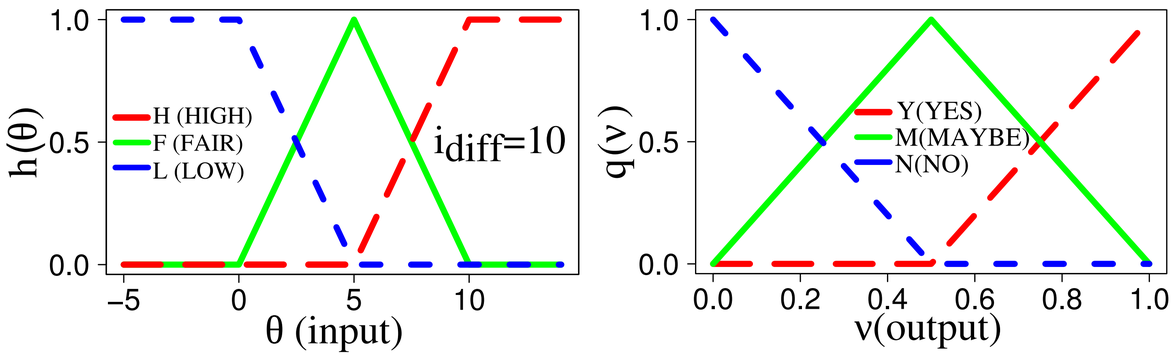
Peak detection & association:
Extracted peaks represent follow-up locations (red, green, blue clusters). Tracking is recursively expanded by extracting the next generation of peak locations continuing from the follow-up locations already obtained.

FL system: inputs

$$\theta_s^t = \psi_s^t - \beta(x_s^t, y_s^t)$$

$$s \in \{A, B, C\}, t \in \{1, 2\}$$

FL system: membership functions



FL system: IF-THEN rules

1. $\bigcap_{s,t}(\theta_s^t = \mathrm{H}) \Rightarrow v = \mathrm{Y}$
2. $(\theta_s^t = \mathrm{F}) \cap \Big(\bigcap_{(s_1,t_1)\neq(s,t)} (\theta_{s_1}^{t_1} = \mathrm{H}) \Big) \Rightarrow v = \mathrm{M}$
3. $(\theta_s^t = \mathrm{F}) \cap (\theta_{s_1 \neq s}^t = \mathrm{F}) \cap \Big(\bigcap_{s_2 \neq s, s_1} (\theta_{s_2}^t = \mathrm{H}) \Big) \Rightarrow v = \mathrm{M}$
4. $\bigcup_{s,t} \Big((\theta_s^t = \mathrm{F}) \cap (\theta_s^{t_1 \neq t} = \mathrm{F}) \Big) \Rightarrow v = \mathrm{N}$
5. $\bigcup_{s,t} \Big((\theta_s^t = \mathrm{F}) \cap (\theta_{s_1 \neq s}^{t_1 \neq t} = \mathrm{F}) \cap (\theta_{s_2 \neq s, s_1}^{t_2 \neq t, t_1} = \mathrm{F}) \Big) \Rightarrow v = \mathrm{N}$
6. $\bigcup_{s,t} (\theta_s^t = \mathrm{L}) \Rightarrow v = \mathrm{N}$

$s, s_1, s_2 \in \{A, B, C\}$ and $t, t_1, t_2 \in \{1, 2\}$

Fuzzy set operations union ($\cup$) and intersection ($\cap$) operating on the membership values, are defined as *max* and *min* respectively.

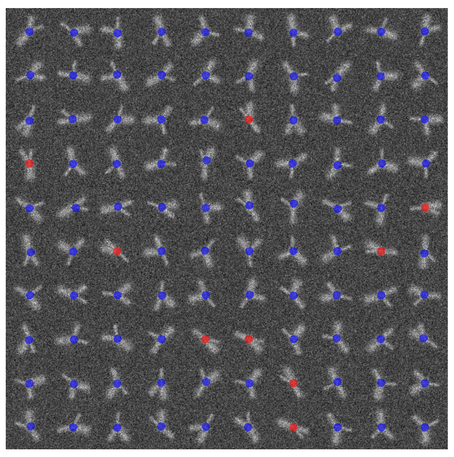
Evaluation on Synthetic Data

Synthetic bifurcations are generated as intersections of linear segments in images with different levels of SNR, random splitting angles and combination of branch diameters. Detection performance was assessed in terms of the amount of true-positive (TP), false-positive (FP), and false-negative (FN) detections.

C_i configurations DDD=3,5,7 pix.		C1	C2	C3	C4	C5	C6	C7
SNR	perf.[%]							
1	R	23	22	20	14.3	10.1	11.5	7
	P	100	100	100	100	100	100	100
2	R	96.2	94	96.3	90	89.5	94.7	94.4
	P	100	100	100	100	100	100	100
3	R	99.1	97.5	97.8	92.5	90.8	93.2	94
	P	100	100	100	100	100	100	100

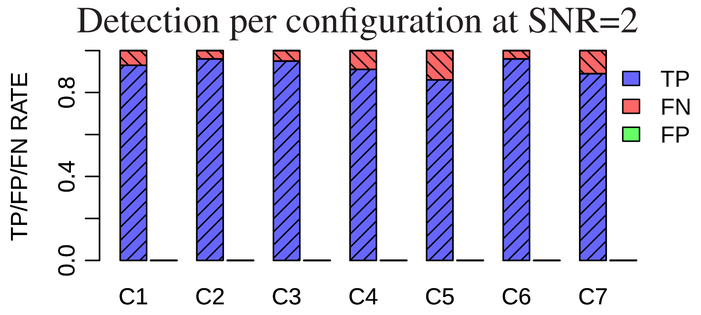
Recall R = TP/(TP + FN), precision P = TP/(TP + FP)

Detection performance is high for SNR $\geq$ 2, drops significantly for SNR $\approx$ 1



100 synthetic bifurcations of C_4 at SNR=2 detected with $D = 7$ and $i_{\text{diff}} = 6$

Detection per configuration at SNR=2

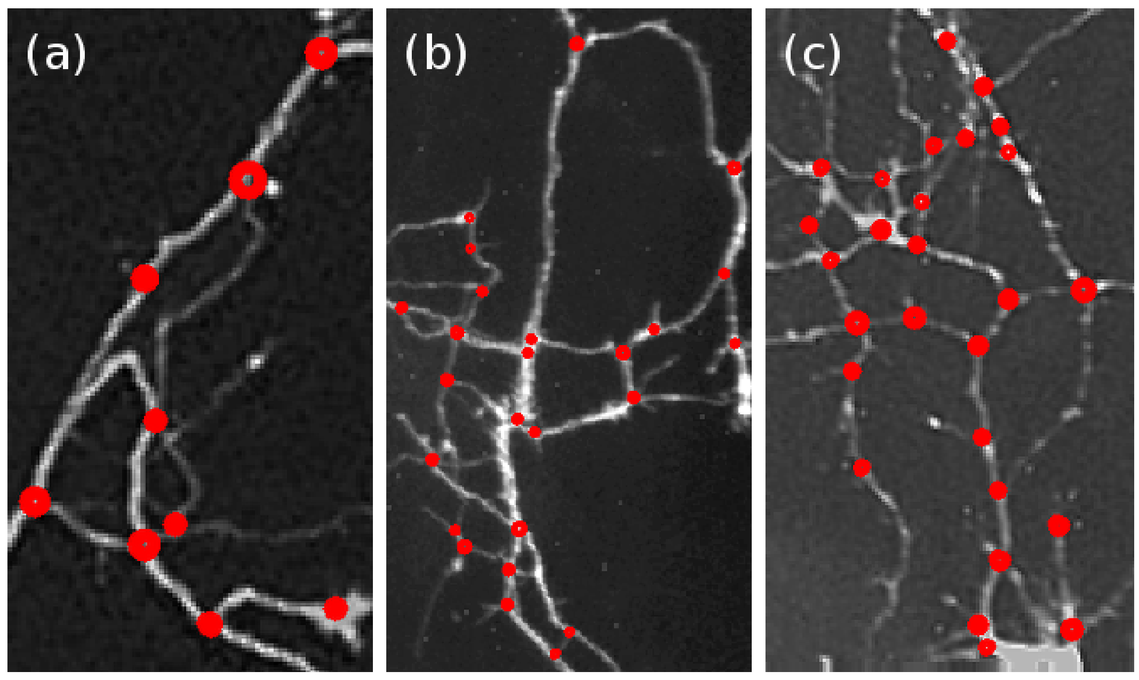


Evaluation on Real Data

Nine fluorescence microscopy neuron images with a total of 724 annotated bifurcations.

	I	II	III	IV	V	VI	VII	VIII	IX
R	92	91	88	91	87.5	94.2	97.2	82.3	90
P	95	91	83	90	97.2	89.1	92.2	86.7	90
♯ bif.	43	80	106	100	41	39	159	134	22

The average recall was 90.4% and the average precision was 90.5%.



(a, b, c) Bifurcation detection on different neurons.

References

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[3] S. Jiang, X. Zhou, T. Kirchhausen, and S.T.C. Wong. Tracking molecular particles in live cells using fuzzy rule-based system. *Cytometry Part A*, 71:576-584, 2007.

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