Bag-of-Features Acoustic Event Detection for Sensor Networks

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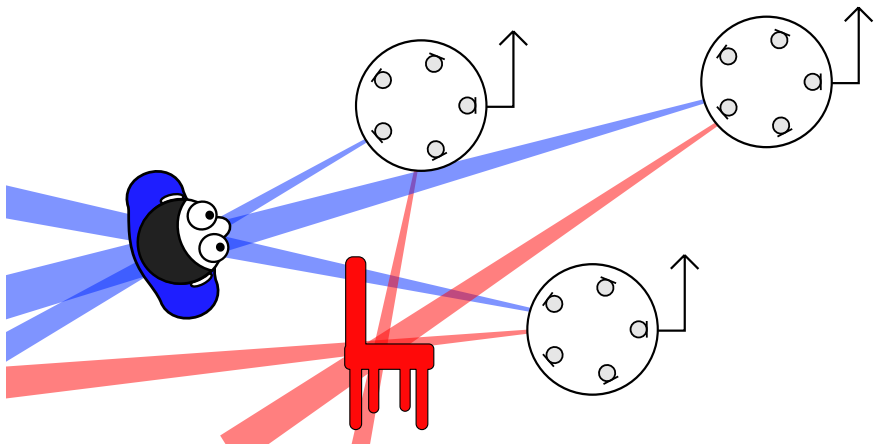
Motivation

Acoustic Sensor Networks (ASNs)

- are increasingly available: smartphones, laptops, hearing aids, ...
- offer the possibility of collaborative processing



Acoustic Event Detection (AED)

- useful for ASN applications [1]
- distributed sensors can improve performance [2]
- can we do better than heuristics? [3]

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[1] A. Plinge, F. Jacob, R. Haeb-Umbach, and G. A. Fink. Acoustic microphone geometry calibration: An overview and experimental evaluation of state-of-the-art algorithms. *IEEE Signal Process. Mag.*, 33(4):14–29, July 2016

[2] H. Phan, M. Maass, L. Hertel, R. Mazur, and A. Mertins. A multi-channel fusion framework for audio event detection. In *IEEE Workshop App. Signal Process. to Audio & Acoustics*, 2015

[3] P. Giannoulis, G. Potamianos, A. Katsamanis, and P. Maragos. Multi-microphone fusion for detection of speech and acoustic events in smart spaces. In *European Signal Process. Conf.*, pages 2375–2379, Lisbon, Portugal, Sept. 2014

Method Overview

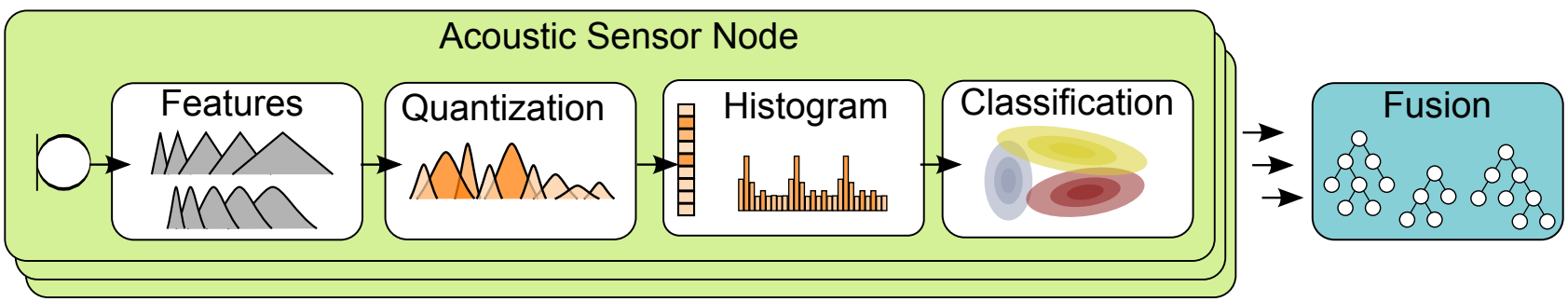
Bag-of-Features

- approach originating in text retrieval
- successful in AED [1]
- fast and online

Multi-channel fusion

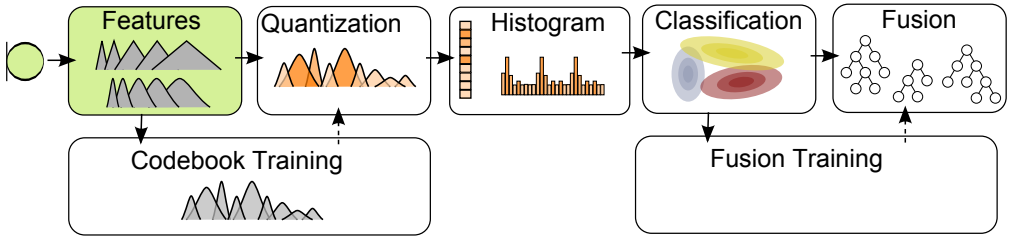
- individual microphones or arrays as sensor node
- heuristic fusion: vote, max, product, ...
- learning based fusion: classifier stacking

Processing pipeline

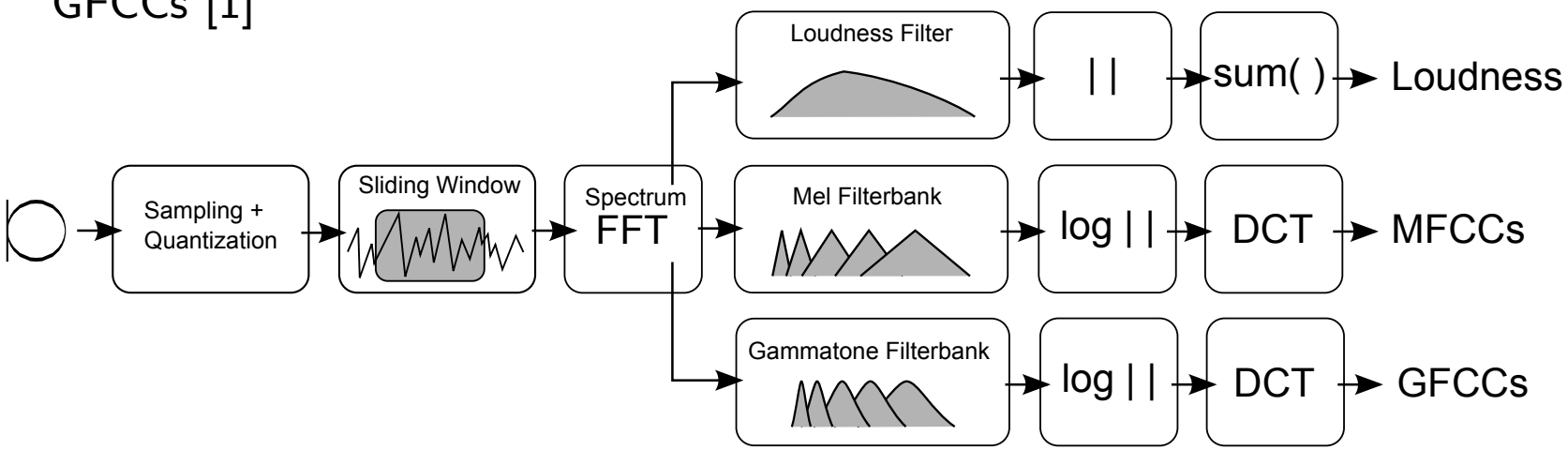


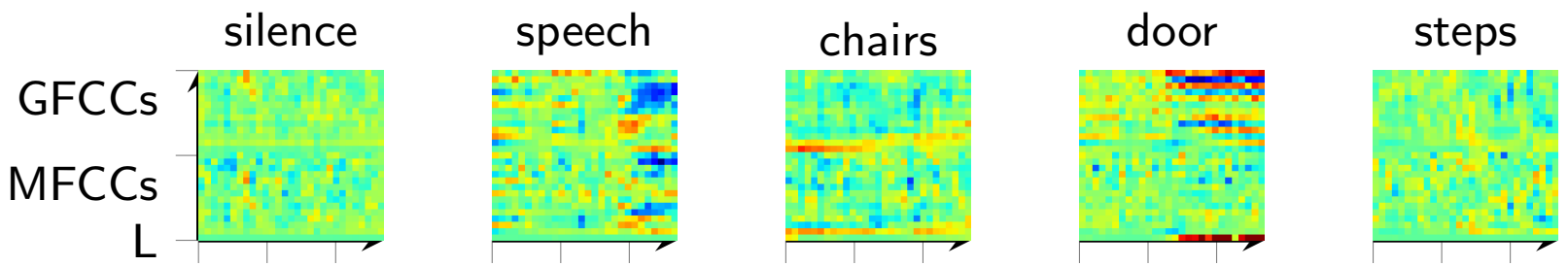
[1] A. Plinge, R. Grzeszick, and G. A. Fink. A bag-of-features approach to acoustic event detection. In *IEEE Int. Conf. Acoustics Speech & Signal Process.*, Florence, Italy, May 2014

Method (1/5) Features



- sliding window
- for each frame k, compute y_k perceptual loudness, MFCCs, and GFCCs [1]



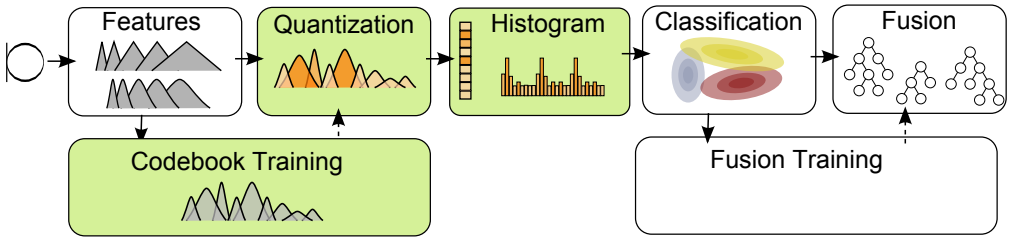


[1] X. Zhao, Y. Shao, and D. Wang. CASA-based robust speaker identification. *IEEE Trans. Audio, Speech, Language Process.*, 20(5):1608–1616, 2012

[2] A. Plinge, R. Grzeszick, and G. A. Fink. A bag-of-features approach to acoustic event detection. In *IEEE Int. Conf. Acoustics Speech & Signal Process.*, Florence, Italy, May 2014

[3] code at `http://patrec.cs.tu-dortmund.de/resources`

Method (2/5) Quantization



- compute class-wise GMM by EM
- concatenate to super-codebook

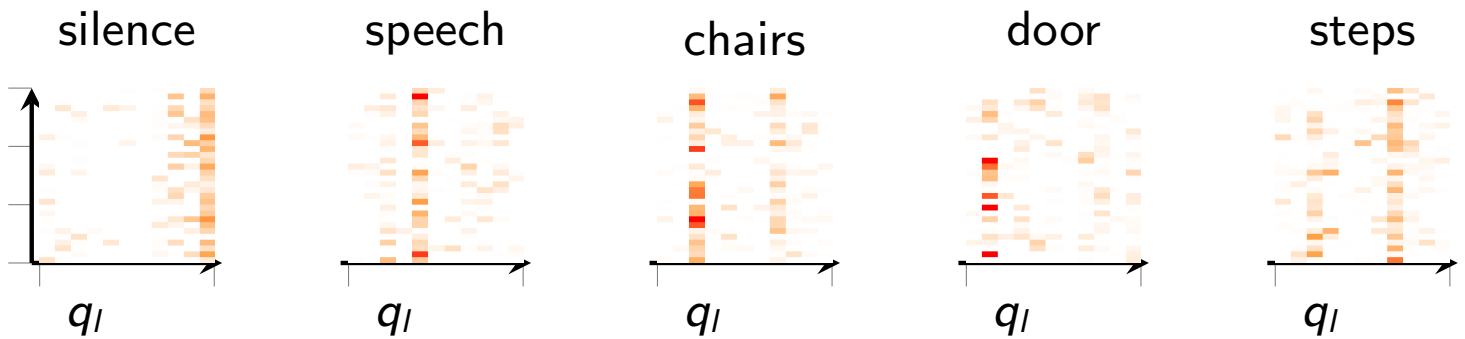
$$v_{l=(I\cdot c+i)} = (\mu_{i,c}, \sigma_{i,c})$$

- quantize each frame k by super-codebook

$$q_{k,l}(\boldsymbol{y}_k, v_l) = \mathcal{N}(\boldsymbol{y}_k | \mu_l, \sigma_l)$$

- histogram over a window of K frames

$$b_l(Y_n, v_l) = \frac{1}{K} \sum_{k=1}^{K} q_{k,l}(\boldsymbol{y}_k, v_l)$$



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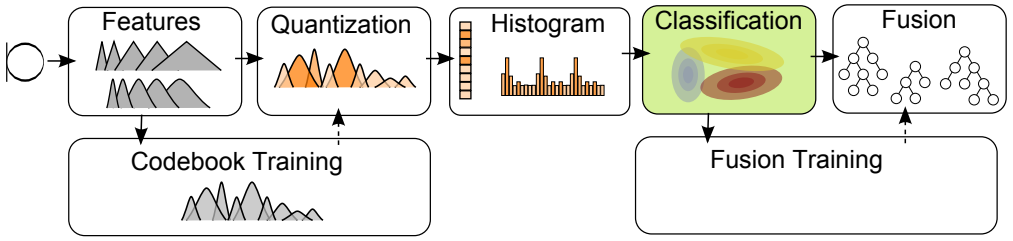
Method (3/5) Classification



Multinominal Bayes classification

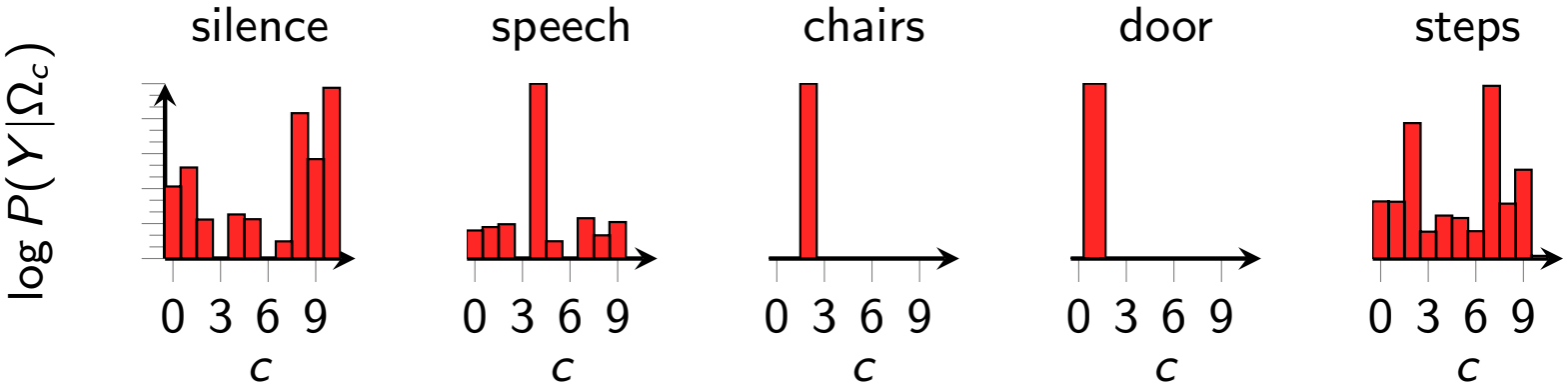
- train with Lidstone smoothing

$$P(v_l|\Omega_c) = \frac{\alpha + \sum_{Y_n \in \Omega_c} b_l(Y_n, v_l)}{\alpha L + \sum_{m=1}^{L} \sum_{Y_n \in \Omega_c} b_m(Y_n, v_m)}$$

- all classes equally likely, i.e., have the same prior

→ maximum likelihood classification

$$P(Y_n|\Omega_c) = \prod_{v_l \in \mathbf{v}} P(v_l|\Omega_c)^{b_l(Y_n, v_l)}$$



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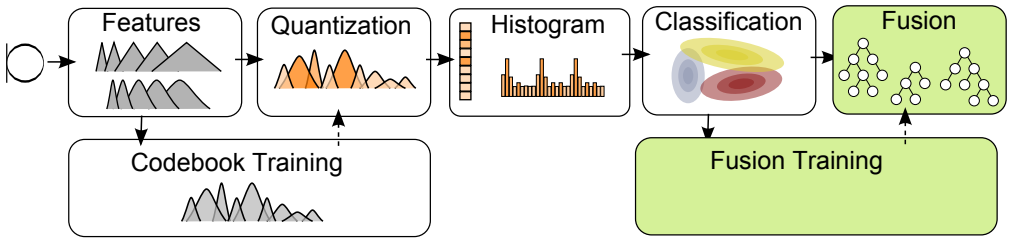
Method (4/5) Fusion

BoF Models

- per channel,
- per array, or
- global



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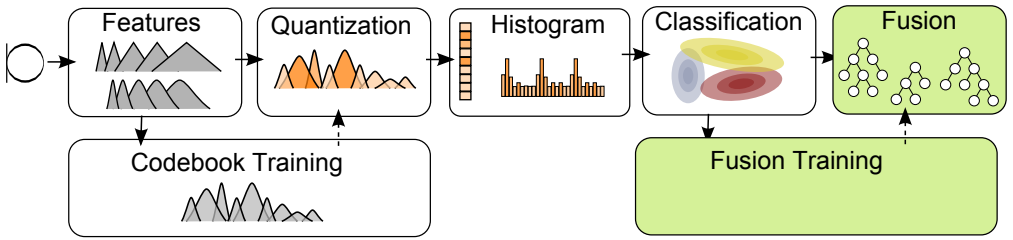

BoF Models

- per channel,
- per array, or
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Heuristic fusion [1]

- majority voting

$$\hat{c}_{(m)} = \underset{c}{\operatorname{argmax}}\ P_m(\boldsymbol{Y}_{m,n}|\Omega_c)$$

$$\hat{c} = \operatorname{argmax}_{c'} |\{\hat{c}_{(m)} = c'\}|$$

$$\operatorname{argmax}_{c'} \left| \left\{ \begin{array}{ccc} P_1(\boldsymbol{Y}_{1,n}|\Omega_1) & \dots & P_1(\boldsymbol{Y}_{1,n}|\Omega_C) \\ P_1(\boldsymbol{Y}_{1,n}|\Omega_2) & \dots & P_M(\boldsymbol{Y}_{2,n}|\Omega_C) \\ \vdots & & \vdots \\ \underbrace{P_1(\boldsymbol{Y}_{1,n}|\Omega_C)}_{\operatorname{argmax}_c = c'} & \dots & \underbrace{P_M(\boldsymbol{Y}_{M,n}|\Omega_C)}_{\operatorname{argmax}_c = c'} \end{array} \right\} \right|$$

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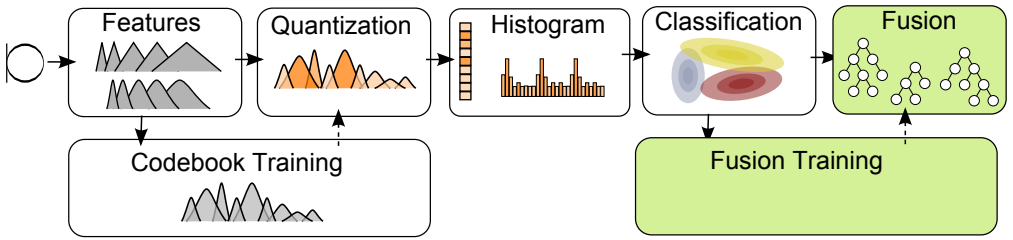

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- maximum rule

$$\hat{c} = \underset{c}{\operatorname{argmax}}\ \max_{m}\ P_m(\boldsymbol{Y}_{m,n}|\Omega_c)$$

$$\operatorname{argmax}_c \left\{ \begin{array}{c} \max_m\{P_1(\boldsymbol{Y}_{1,n}|\Omega_1) \ldots P_M(\boldsymbol{Y}_{M,n}|\Omega_1)\} \\ \max_m\{P_1(\boldsymbol{Y}_{1,n}|\Omega_2) \ldots P_M(\boldsymbol{Y}_{M,n}|\Omega_2)\} \\ \ldots \\ \max_m\{P_1(\boldsymbol{Y}_{1,n}|\Omega_C) \ldots P_M(\boldsymbol{Y}_{M,n}|\Omega_C)\} \end{array} \right\}$$

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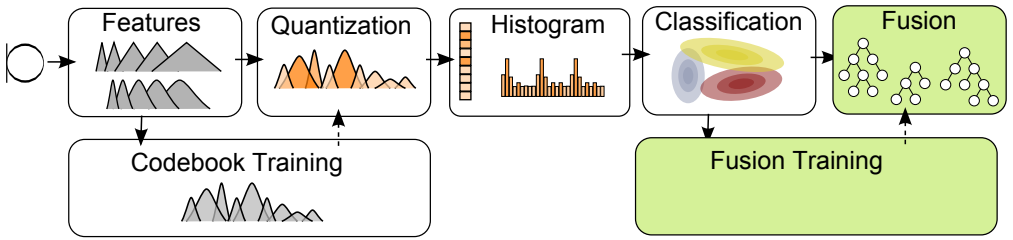
Method (4/5) Fusion



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- maximum rule

$$\hat{c} = \underset{c}{\operatorname{argmax}}\ \max_{m}\ P_m(\boldsymbol{Y}_{m,n}|\Omega_c)$$

- product rule

$$\hat{c} = \underset{c}{\operatorname{argmax}} \prod_{m} P_m(\boldsymbol{Y}_{m,n}|\Omega_c)$$

$$\operatorname{argmax}_c \left\{ \begin{array}{c} P_1(\boldsymbol{Y}_{1,n}|\Omega_1) \cdot P_2(\boldsymbol{Y}_{2,n}|\Omega_1) \cdot \ldots P_M(\boldsymbol{Y}_{M,n}|\Omega_1) \\ P_1(\boldsymbol{Y}_{1,n}|\Omega_2) \cdot P_2(\boldsymbol{Y}_{2,n}|\Omega_2) \cdot \ldots P_M(\boldsymbol{Y}_{M,n}|\Omega_1) \\ \vdots \\ P_1(\boldsymbol{Y}_{1,n}|\Omega_C) \cdot P_2(\boldsymbol{Y}_{2,n}|\Omega_C) \cdot \ldots P_M(\boldsymbol{Y}_{M,n}|\Omega_1) \end{array} \right\}$$

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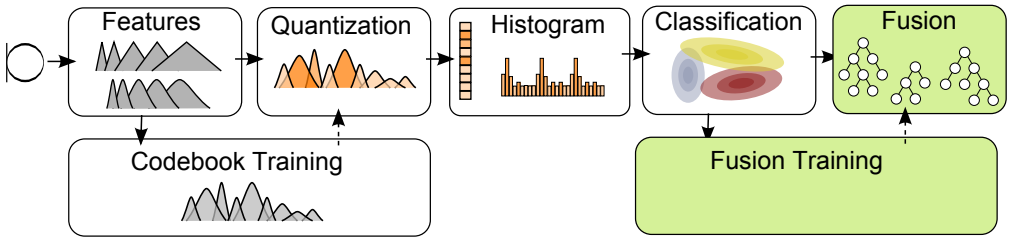
Method (5/5) Fusion



Learned Fusion [1]

- classifier stacking – use a meta-learner instead of heuristics
- classification of the class-channel matrix

$$\hat{c} = \mathcal{F} \begin{pmatrix} P_1(\boldsymbol{Y}_{1,n}|\Omega_1) & \dots & P_M(\boldsymbol{Y}_{M,n}|\Omega_1) \\ P_1(\boldsymbol{Y}_{1,n}|\Omega_2) & \dots & P_M(\boldsymbol{Y}_{M,n}|\Omega_2) \\ & \ddots & \\ P_1(\boldsymbol{Y}_{1,n}|\Omega_C) & \dots & P_M(\boldsymbol{Y}_{M,n}|\Omega_C) \end{pmatrix}$$

- train a random forest classifier $\mathcal{F}$
  using data not used for training the models
- invariance through channel-sorting

$$\underset{m}{\operatorname{argsort}} \max_{c} \; P_m(\boldsymbol{Y}_{m,n}|\Omega_c)$$

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[1] J. Kürby, R. Grzeszick, A. Plinge, and G. A. Fink. Bag-of-features acoustic event detection for sensor networks. In *Detection and Classification of Acoustic Scenes and Events (DCASE) Workshop*, Budapest, Hungary, Sept. 2016

Evaluation ITC: dataset

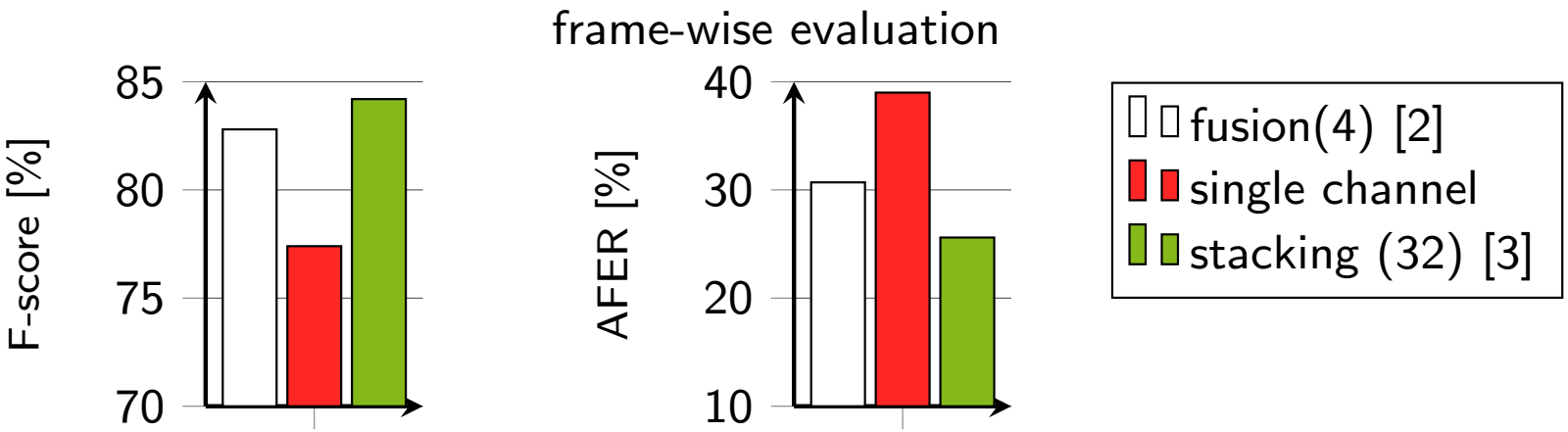
ITC-Irst dataset [1]

- smart conference room
- seven t-shaped arrays at the walls
- four microphones on the table
- *door knock, door slam, steps, chair moving, spoon (cup jingle), paper wrapping, key jingle, keyboard typing, phone ring, applause, cough, laugh, door open, phone vibration, mimo pen buzz, falling object,* and *unknown/background*

[1] A. Temko, R. Malkin, C. Zieger, D. Macho, C. Nadeu, and M. Omologo. Clear evaluation of acoustic event detection and classification systems. In R. Stiefelhagen and J. Garofolo, editors, *Multimodal Technologies for Perception of Humans*, volume 4122 of *Lecture Notes in Computer Science*, pages 311–322. Springer Berlin Heidelberg, 2007

Evaluation ITC: Literature Comparison

- three training session days with events occurring at different positions
- third session used for training the stacking classifier
- forth session for test
- 12 first classes as foreground [1]



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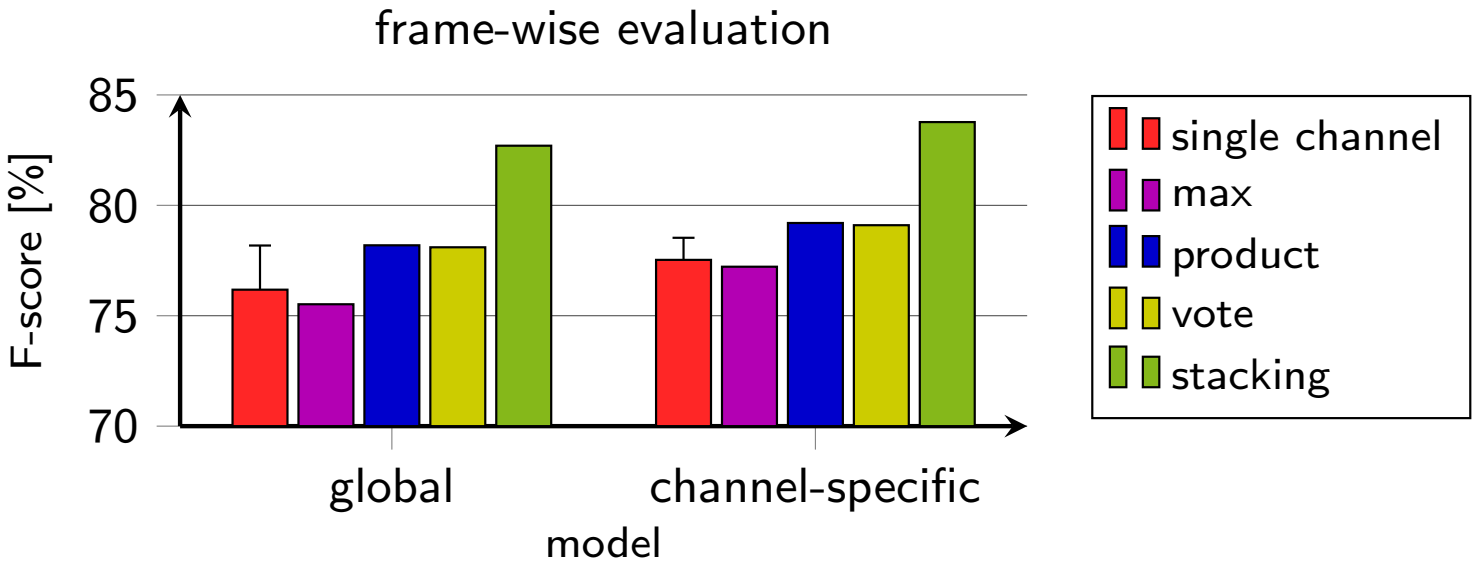
Evaluation ITC: Fusion strategies

- three training session days with events occurring at different positions
- third session used for training the stacking classifier
- forth session for test



- channel-specific models perform better
- stacking better than heuristics

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Evaluation: FINCA dataset

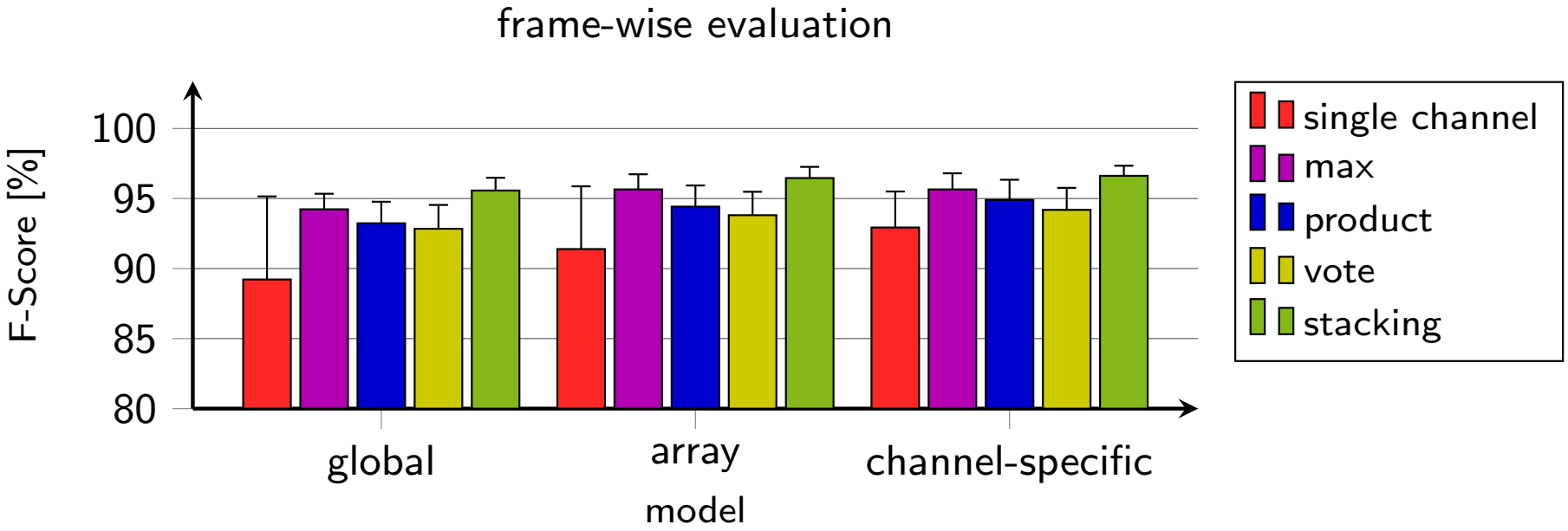
FINCA dataset [1]

- new real-world recordings
- smart conference room
- two microphone arrays at the ceiling and two in the table
- circular, 8 mic, 10cm diameter
- *applause*, *chairs*, *cups*, *door*, *doorbell*, *doorknock*, *keyboard*, *knock*, *music*, *paper*, *phonering*, *phonevibration*, *pouring*, *screen*, *speech*, *steps*, *streetnoise*, *touching*, *ventilator*, and *silence*.

[1] dataset available at `http://patrec.cs.tu-dortmund.de/resources`

Evaluation FINCA: Fusion strategies

- five 2/3 – 1/3 splits for training and test
- 1/3 of training used for the stacking classifier
- silence as background



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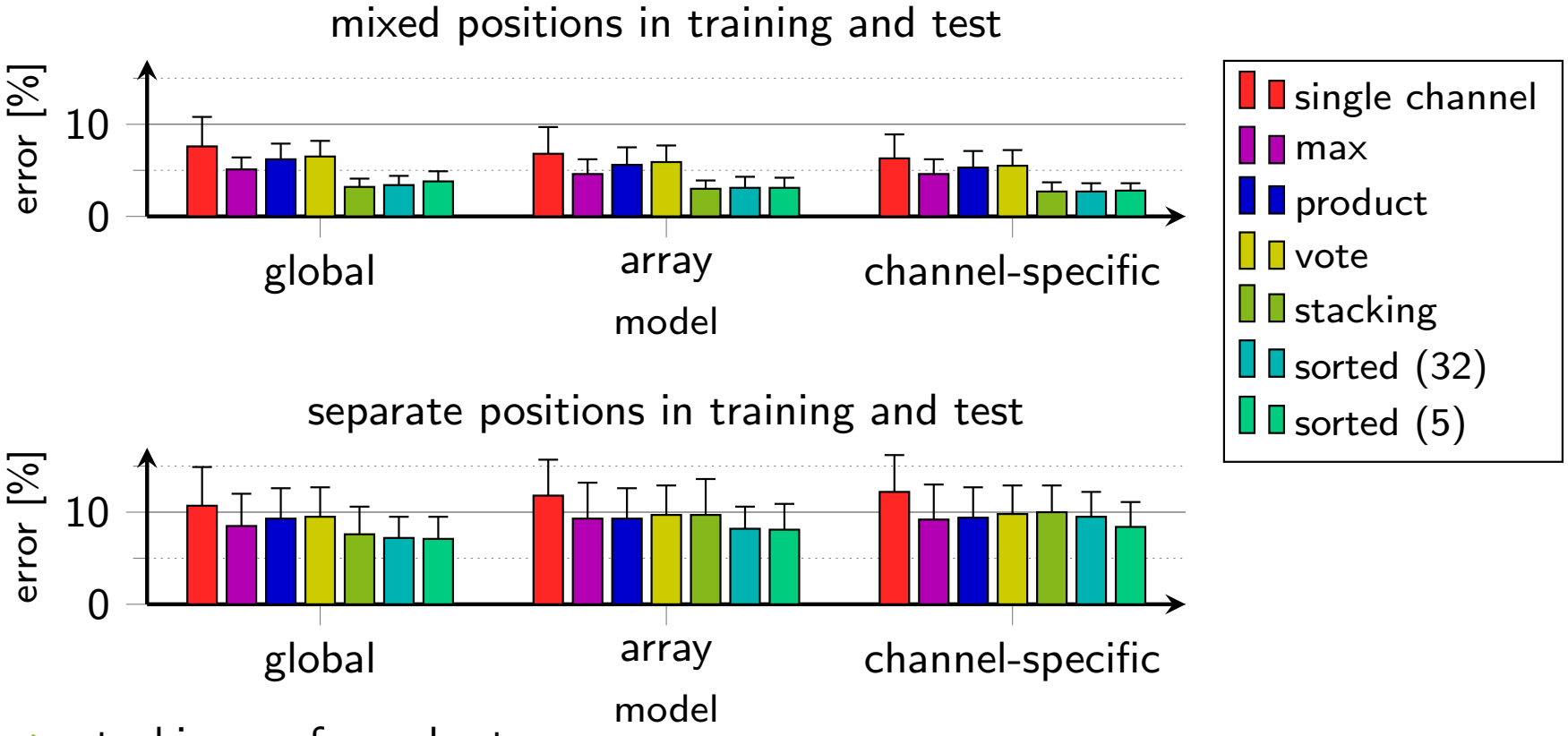
Evaluation FINCA: Position invariance

- classification of nine classes occurring at different positions in the room



- stacking performs best
- sorting mitigates effect of unseen positions
- global models better for unseen positions

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Conclusion

- acoustic sensor networks allow multi-channel AED
- extension [1] of Bag-of-Features online AED [2]
- multi-channel fusion improves the results
- classifier stacking outperforms heuristic strategies
- channel re-ordering by sorting can improve position invariance

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[2] R. Grzeszick, A. Plinge, and G. A. Fink. Temporal acoustic words for online acoustic event detection. In *Proc. 37th German Conf. Pattern Recognition*, Aachen, Germany, 2015

[3] `http://patrec.cs.tu-dortmund.de/resources`

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A. Plinge and S. Gannot.
Multi-microphone speech enhancement informed by auditory scene analysis.
In *Sensor Array and Multichannel Signal Process. Workshop*, Rio de Janeiro, Brazil, July 2016.

A. Plinge, R. Grzeszick, and G. A. Fink.
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In *IEEE Int. Conf. Acoustics Speech & Signal Process.*, Florence, Italy, May 2014.

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