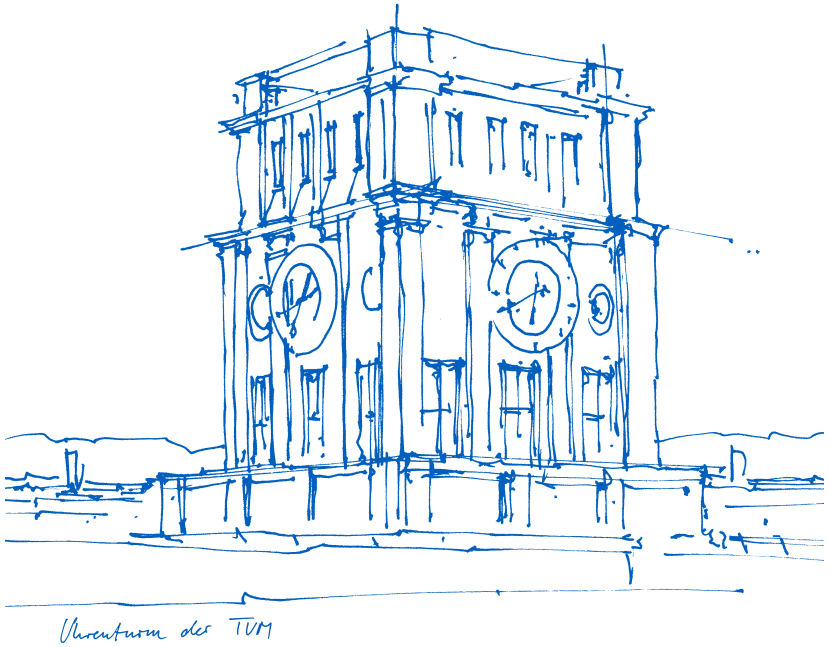
Automatic Classification of Crispiness: Integration of Mechanical and Acoustical Sensor Data

Solange Sanahuja[a], Manuel Fédou, Heiko Briesen[a]

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Center for Life and Food Sciences Weihenstephan

Chair of Process Systems Engineering



MATLAB Expo

Munich, 27. June 2017

The challenge for crispy snacks



Multimodal integration of sensory receptor impulses

QUALITY
- Pleasure
- Freshness

CONTROL
- R&D
- Factory

REQUIREMENTS
- Brittle: porous, not tough neither soft
- Dry: sensitive to humidity

MEASUREMENTS
- Sensory panels: time-/cost-intensive
- Instrumental analysis: lack of reliable & accurate methodology

Bourne 2002; Saeleaw & Schleining 2011; Van Vliet & Primo-Martín 2011
soberingthoughts.info; thenounproject.com; www.clipartbest.com; www.iconfinder.com

Overview

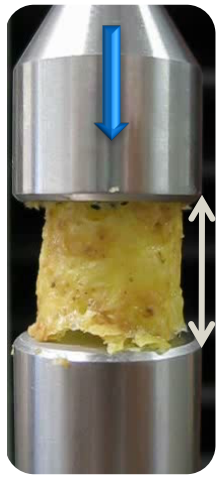
1) Instrumental sounds → crisps freshness distinction by humans?
2) Multimodal texture characterization → improved accuracy of crisps freshness classification?
3) Spectral features vs. traditional temporal features → impact on classification?



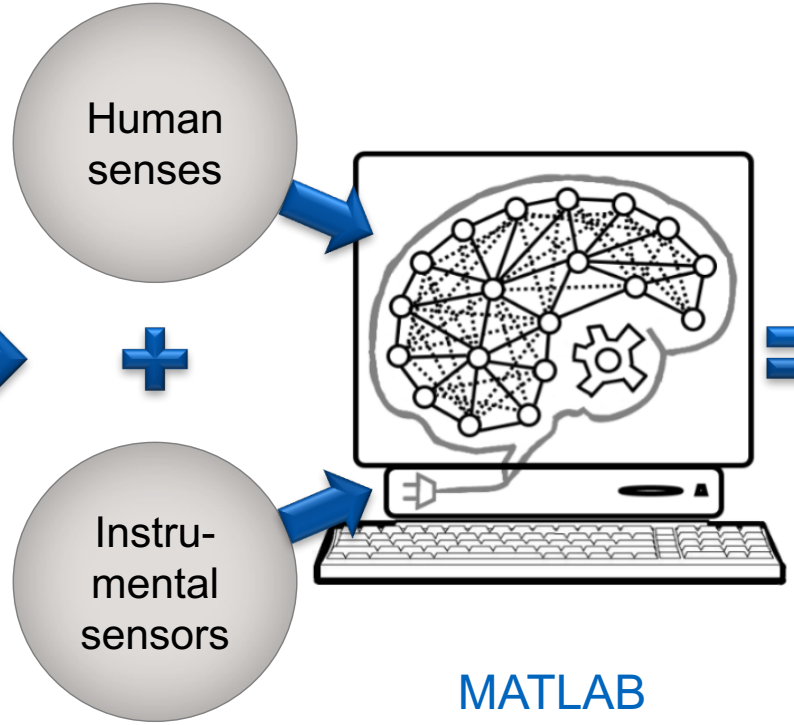
Corn starch extrudates



Humidification



Crushing



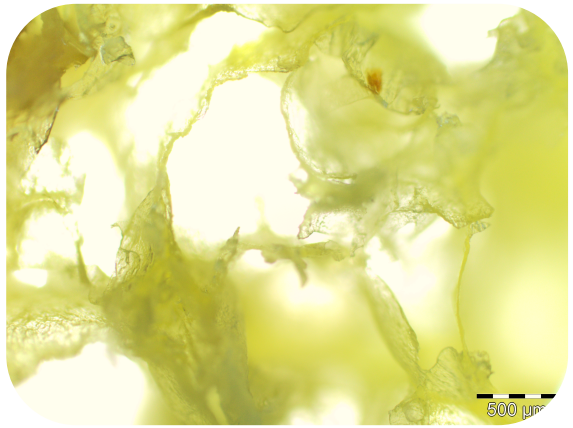
MATLAB algorithms & models



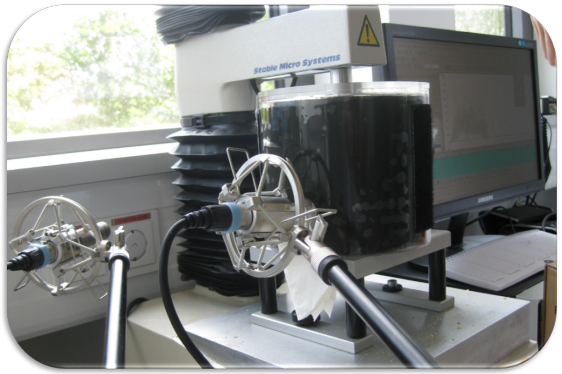
Freshness level

www.shutterstock.com

Multimodal data aquisition



Light microscopy [500µm bar]

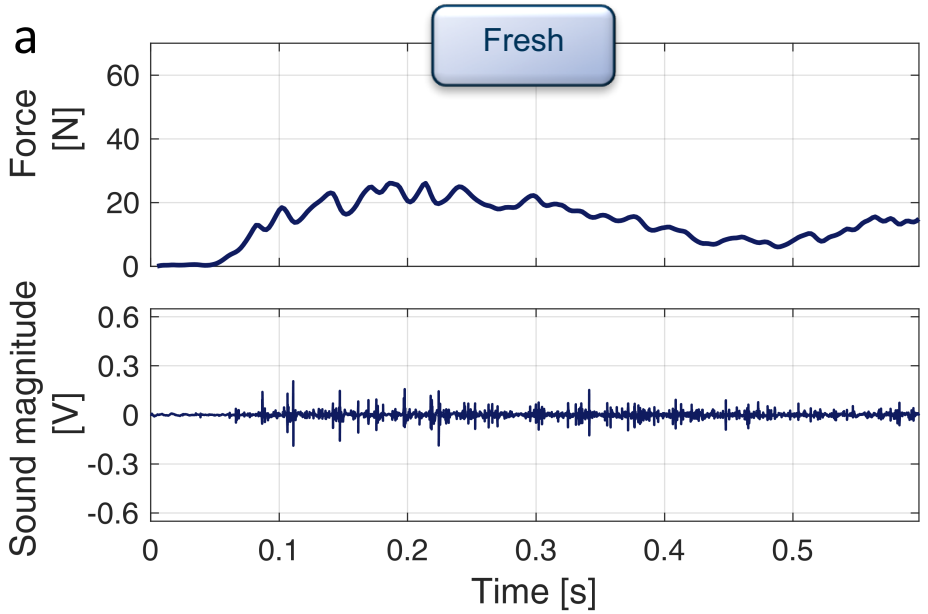


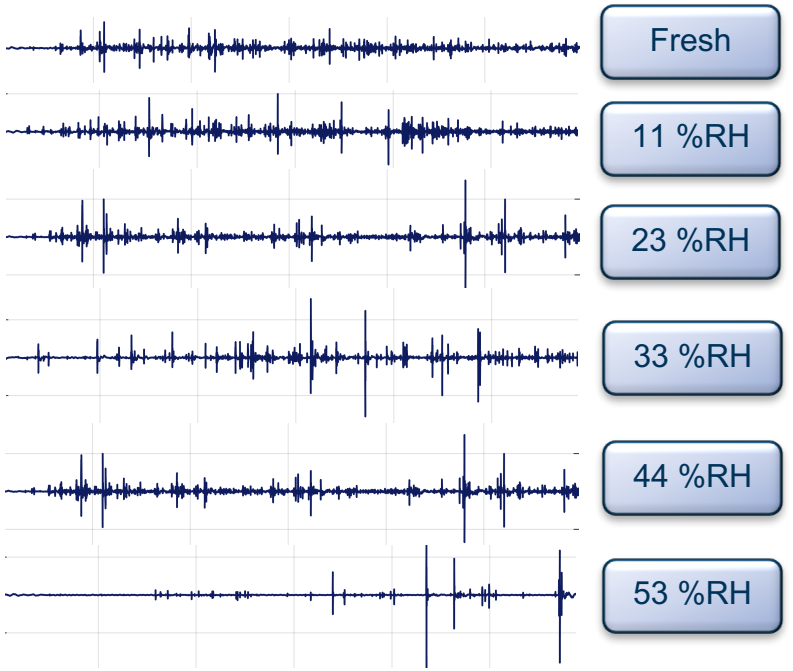
Compression test + sound recording

1 Instrumental analysis — **2 Sensory analysis**

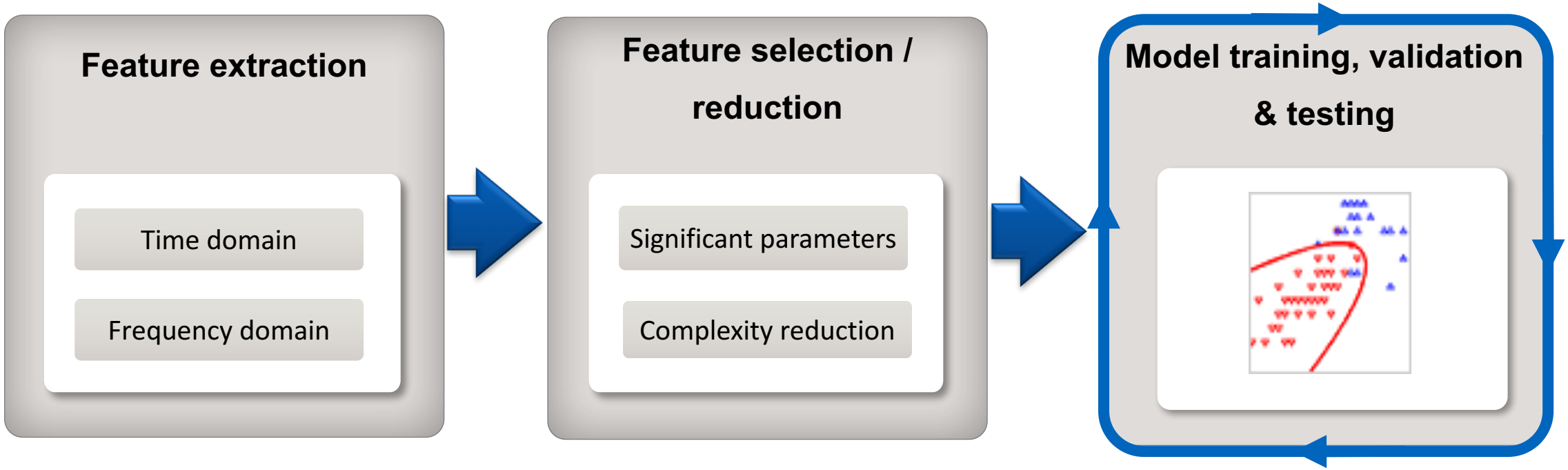
~100 / sample type → Mechanical measurement → Acoustical recording → Trained panel (>16) → Hedonic panel (78)

Significant sound characteristics	Consumer preferences	Expert knowledge





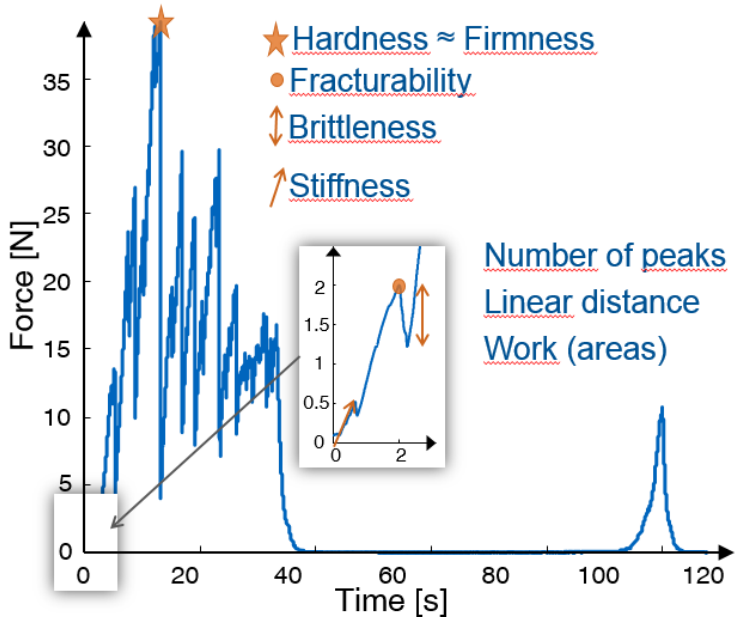
Automatic classification strategy



Temporal vs. Spectral analysis

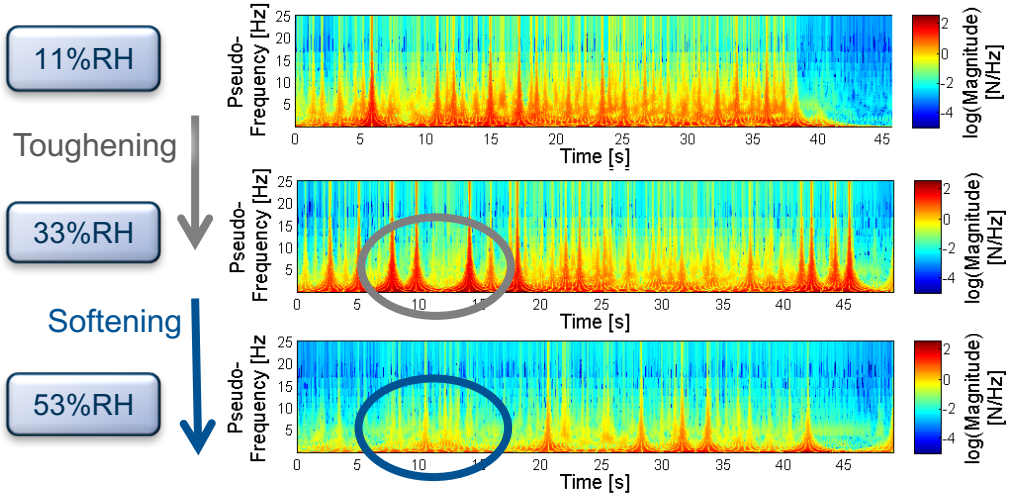
70 features:

Time domain

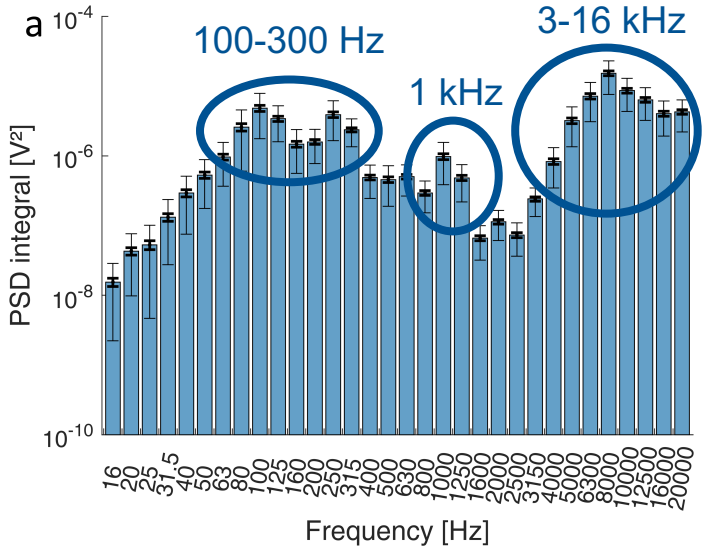


→ No reproducible & reliable prediction of crispiness using single texture parameters

Frequency domain



→ STFT, CWT & HHT suitable for irregular multi-fracture phenomena



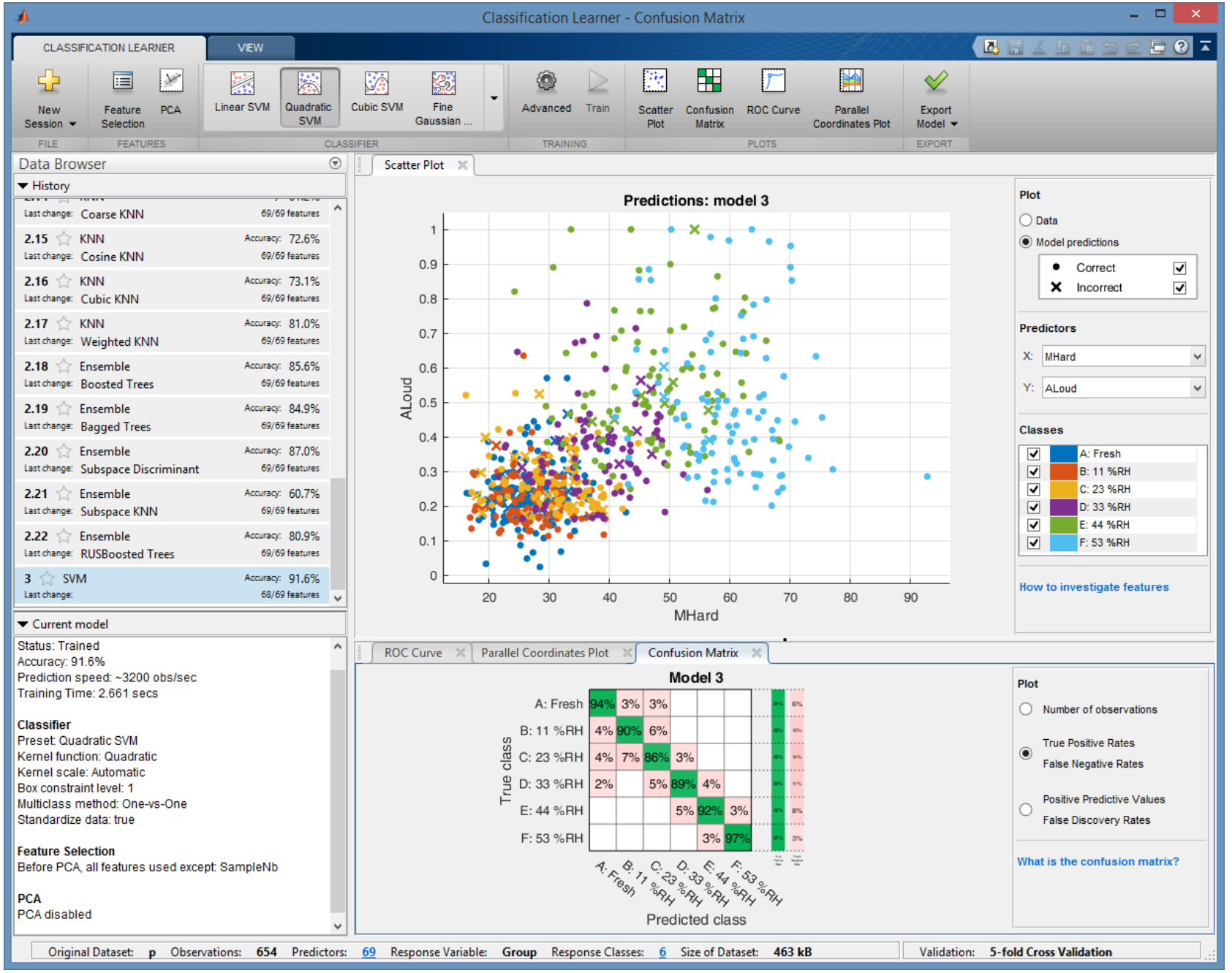
→ Fourier spectrum in octaves suitable for classification

Sanahuja & Briesen, 2015

Classification Learner App

Algorithms screening:

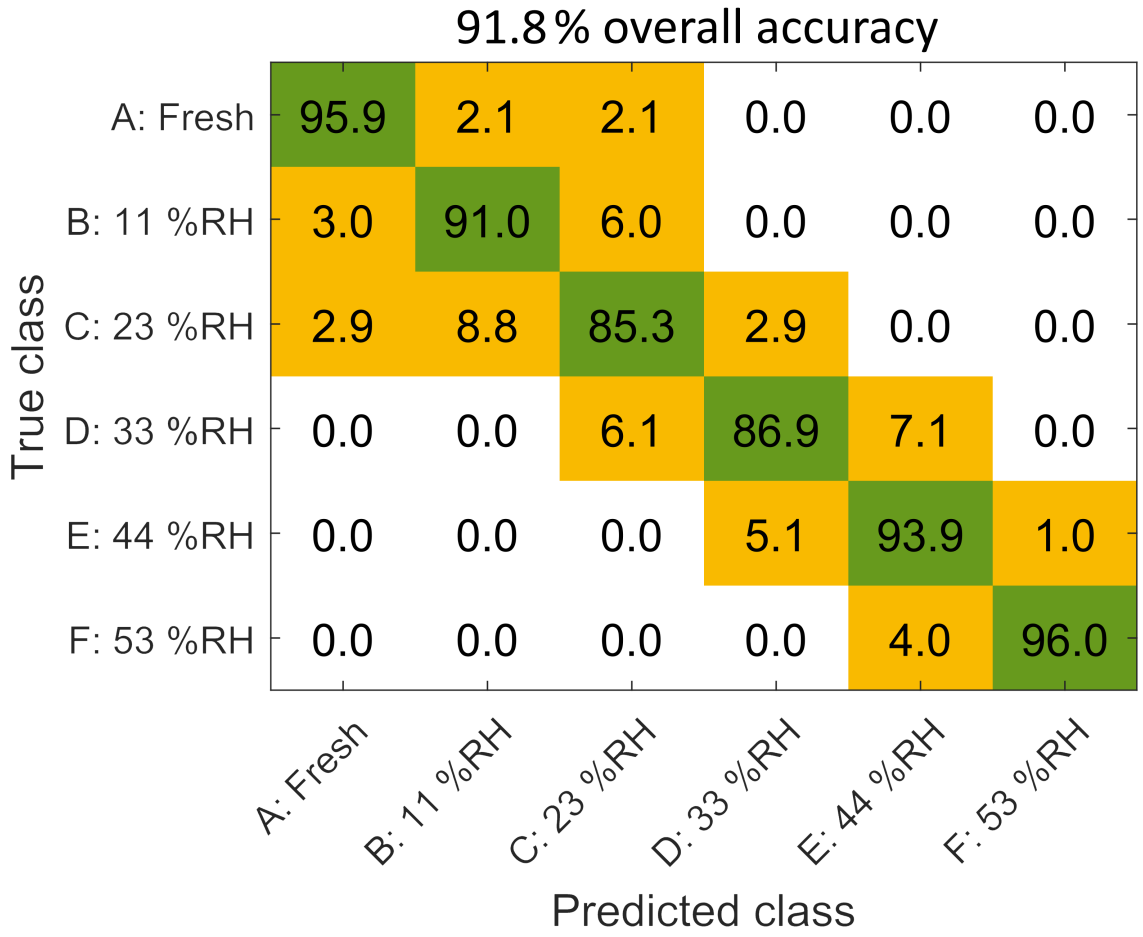
- Decision trees
- Discriminant analysis
- Nearest neighbor
- Ensemble classifiers
- Support vector machines (SVM)
- Artificial neural networks (ANN)



Classification results

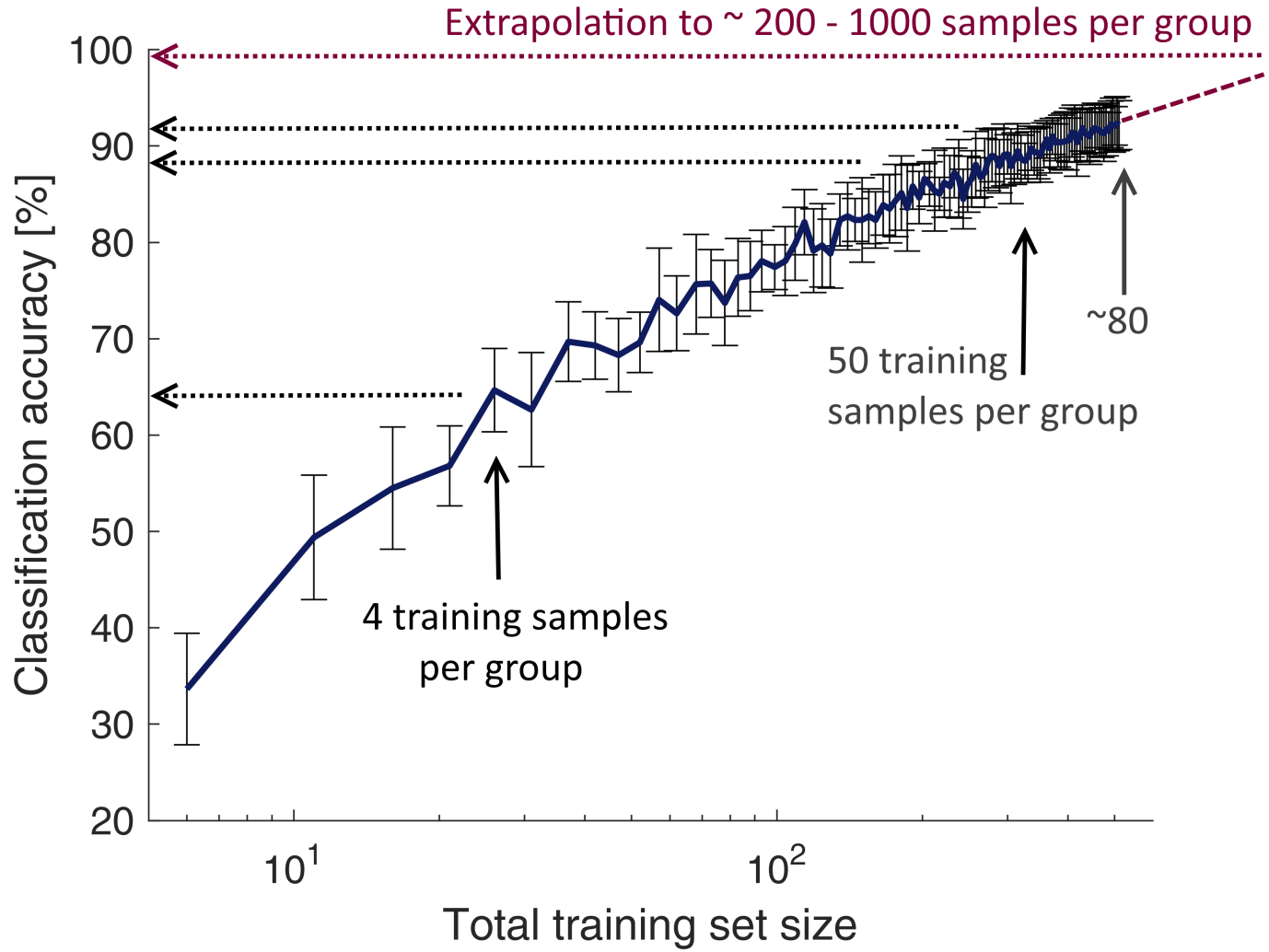
- Non-linear relationships between food physics and freshness
  → mimics psychophysics of sensory integration

- Best predictions using
  - selected temporal
  - third-octave spectral features
  - from mechanics & acoustics



Quadratic SVM: 5-fold cross-validation, 20% test data, measured at 10 mm/s crushing

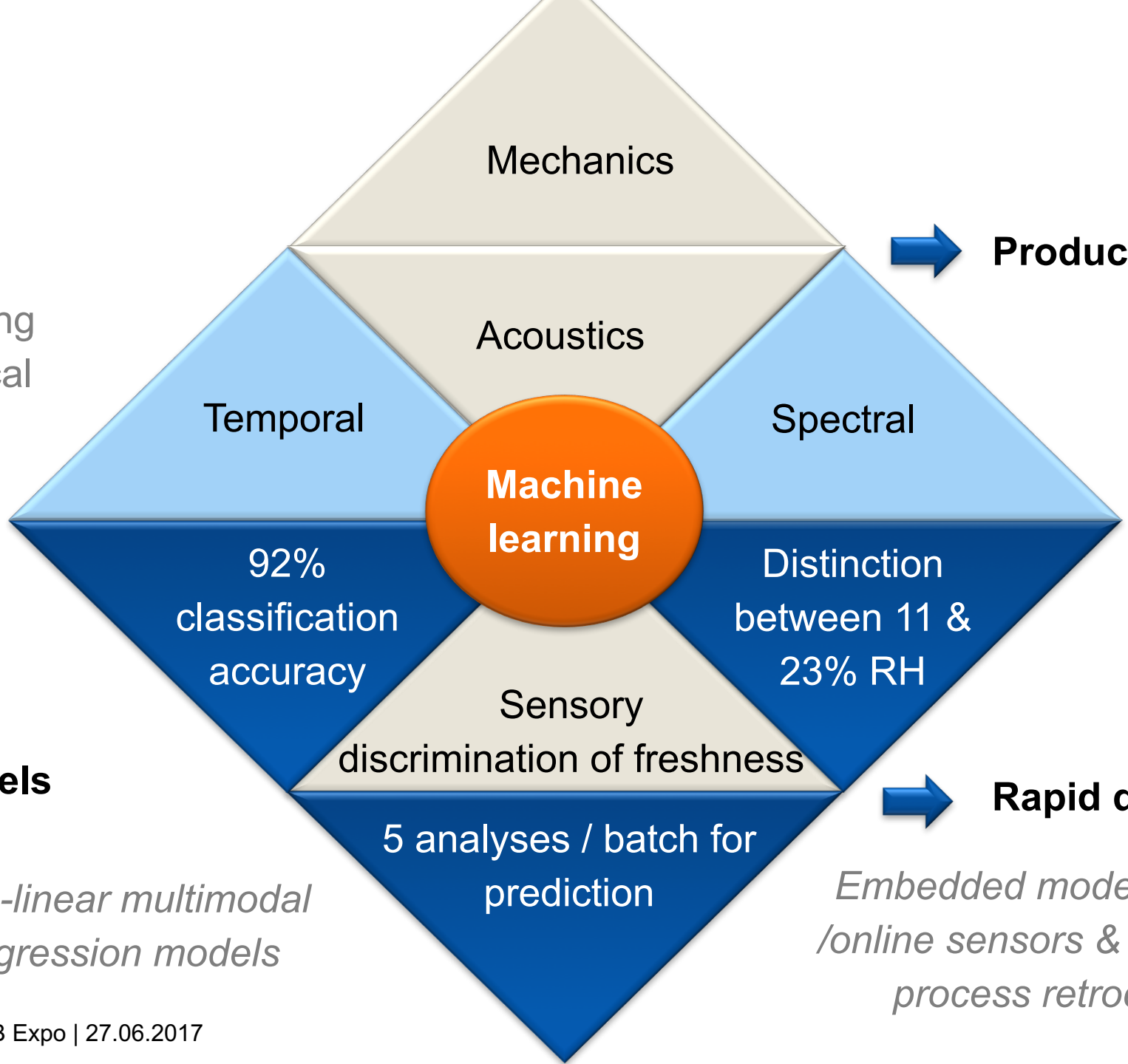
Learning Curve



High potential for improvement using more training data

Conclusion

Impact factors:
loudness, pitch, homogeneity of crushing acoustical & mechanical patterns, toughness, brittleness



Product optimization

Classification models

Non-linear multimodal regression models

Rapid quality control

Embedded models with in-/online sensors & production process retrocontrol

Thanks

- Horst-Chrisitan Langowski (institute access)
- Cornelia Stramm + Sven Sängerlaub + Verena Jost + Astrid Pant + Oliver Miesbauer + Andreas Strehlke (humidity control, packaging materials)
- Raffael Osen (TA access + extruder)

TUM Diversity Laura Bassi-award

- Hubert Kollmannsberger (sensory)
- Carlotta Ziegltrum, Simone Maurer, Katja Jontes
- Many colleagues (advice, discussion, sensory panel)



Externals

- Henri Braun (EMD)
- Lisa Drobny (Winopal, TA-help)
- Michael Mudra, Uwe Beis (acoustics)

Let‘s ride food science waves!



www.photoshop-bg.net

References

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- Sanahuja, S., & Briesen, H. (2015). Dynamic Spectral Analysis of Jagged Mechanical Signatures of a Brittle Puffed Snack. *Journal of Texture Studies, 46*(3), 171-186.
- Van Vliet, T., & Primo-Martín, C. (2011). Interplay between product characterisitics, oral physiology and texture perception of cellular brittle foods. *Journal of Texture Studies, 42*, 82–94.

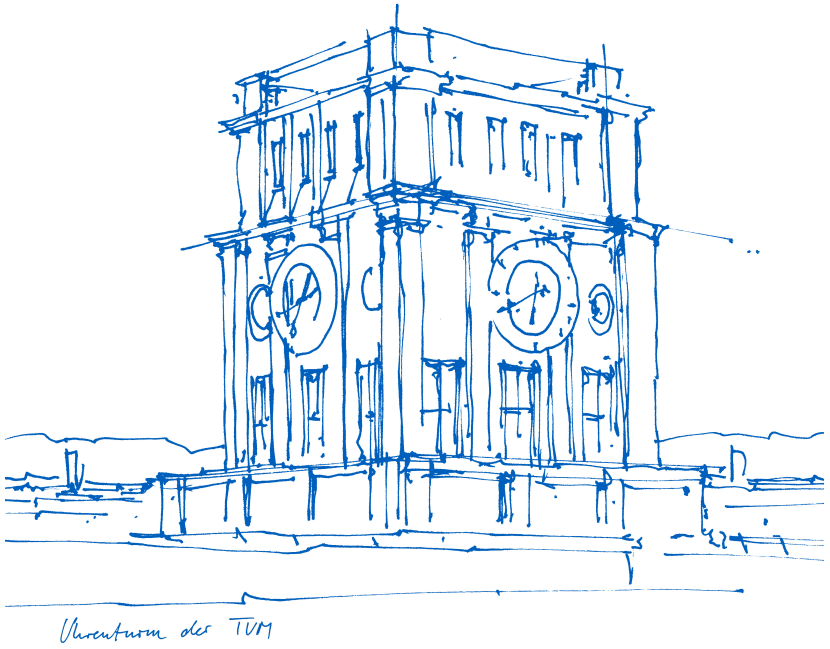
Automatic Classification of Crispiness: Integration of Mechanical and Acoustical Sensor Data

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Backup-slides

- Crispy project timeline
- Sensory freshness classes
- PCA representation
- Automatic classification strategy
- SVM results
- ANN results

Crispy project

Timeline

2014 Prework on mechanical & spectral analyses

✓ Food Oral Processing Conference:
Dynamic alternatives to fractal and Fourier methods for analysis of crispy / crunchy food products

2015 ✓ Journal of Texture Studies, 46, 171-185:
Dynamic spectral analysis of jagged mechanical signatures of a brittle puffed snack

Mechanical, acoustical and sensory data collection

2016 ✓ Modelling & Poster at MATLAB Expo:
Strategies to classify sounds and mechanics using dynamic spectral information

2017 ✓ Submitted paper

Technische Universität München
Process Systems Engineering

Strategies to classify crispy sounds and mechanics using dynamic spectral information

Solange Sanahuja, Heiko Briesen

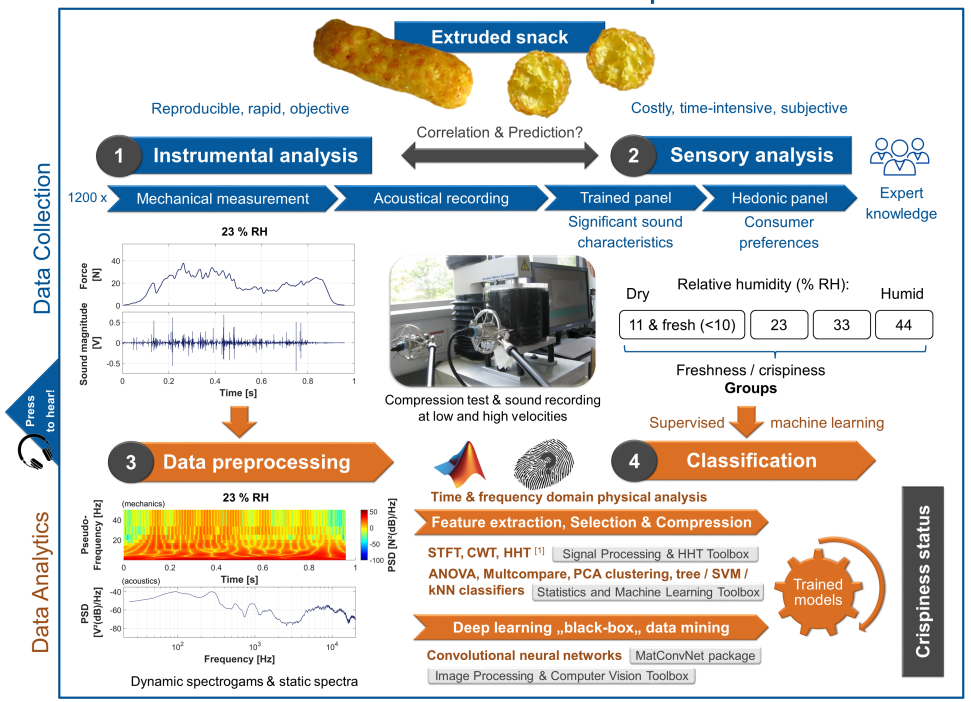
Motivation

- Crispy food textures = stimulating, fresh, pleasant & have highest impact on consumer preference and quality evaluation [1]
- Food industry and research requirements for quality control and development
- **Crispiness evaluation = essential but causes persistent difficulties in practice, in particular for differentiating low-humidity crispness levels (10 to 20 % RH)** [1]

Goals

- Optimizing crispy products = appropriately stiff and brittle during chewing & release pleasant rhythmic sounds of particular pitch and loudness avoiding use of sensory panels
- Improvement of avaiable texture measurements and data analysis methods
- **Freshness levels classification from instrumental data corresponding to sensory crispiness grades, mimicking multisensory & temporal integration during oral breakdown**

Multimodal texture characterization process



Conclusion

- **Classification needs more than simple mechanical features**
- Instrumental crushing sounds → perception of food freshness
- Dynamic spectral analysis → mathematical analytic description & display of whole complexity of foods' signature
- Multimodal classification → multitude of modern methods & optimum not straightforward, but improved accuracy

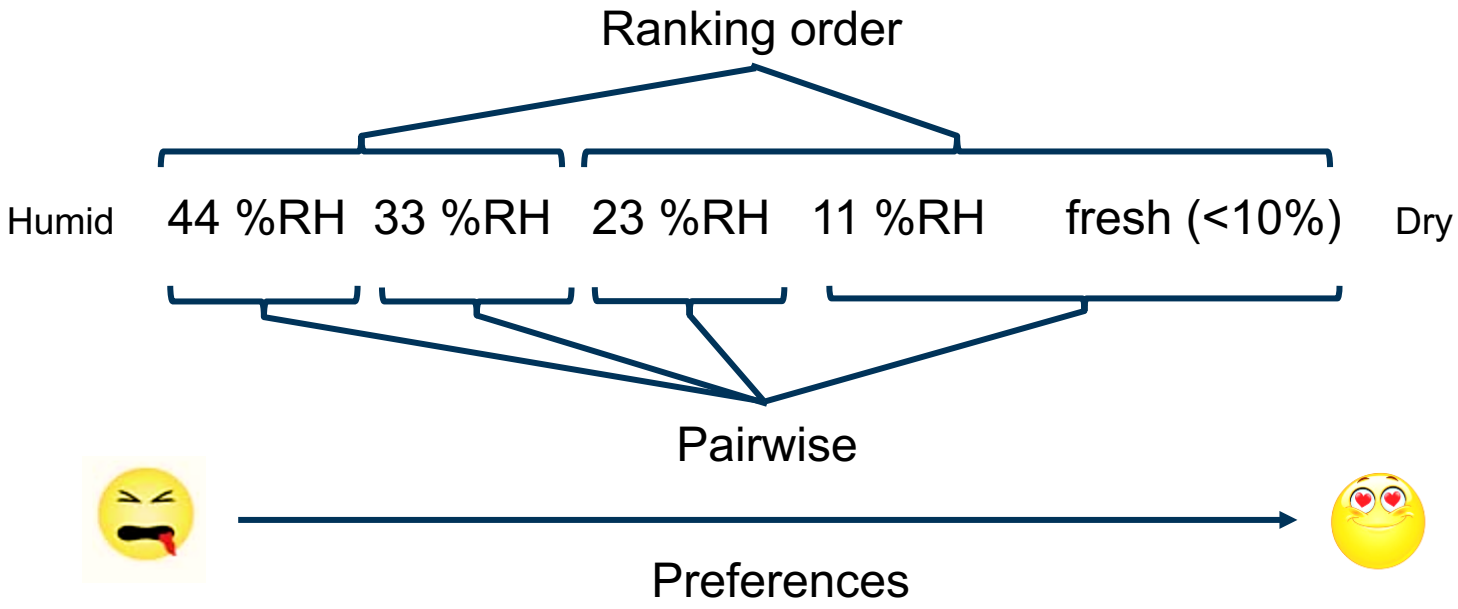
Further Improvements

- Synchronized denoising & bone-conducted sounds using transfer function models of isolation box and human head

[1] Sanahuja, S. and Briesen, H. 2015. Dynamic spectral analysis of jagged mechanical signatures of a brittle puffed snack. Journal of Texture Studies, 46, 171-186.

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Contact: solange.sanahuja@gmx.de

Humans perceive & evaluate freshness of chips only based on instrumental texture analysis sound records

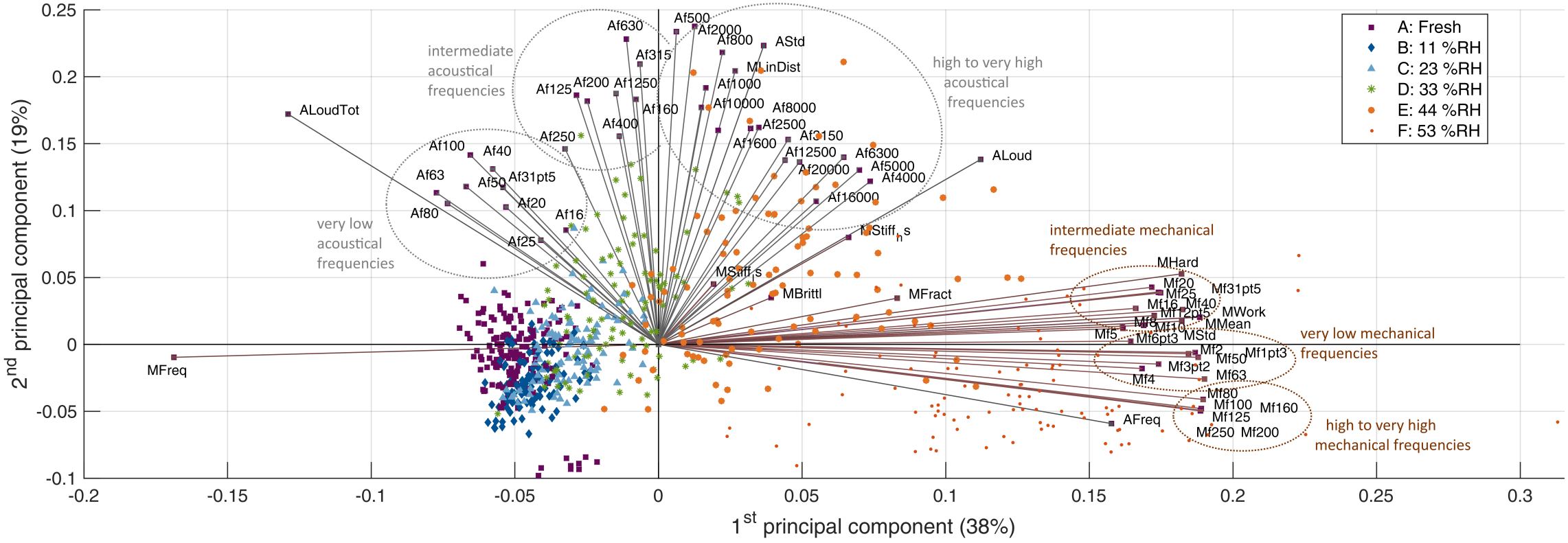


- Significant differences (Friedman-Test, $\alpha = 0.01$) & ranking (Page-Test, $\alpha < 0.05$)
- 2 groups (LSD „Least Significant Difference“)

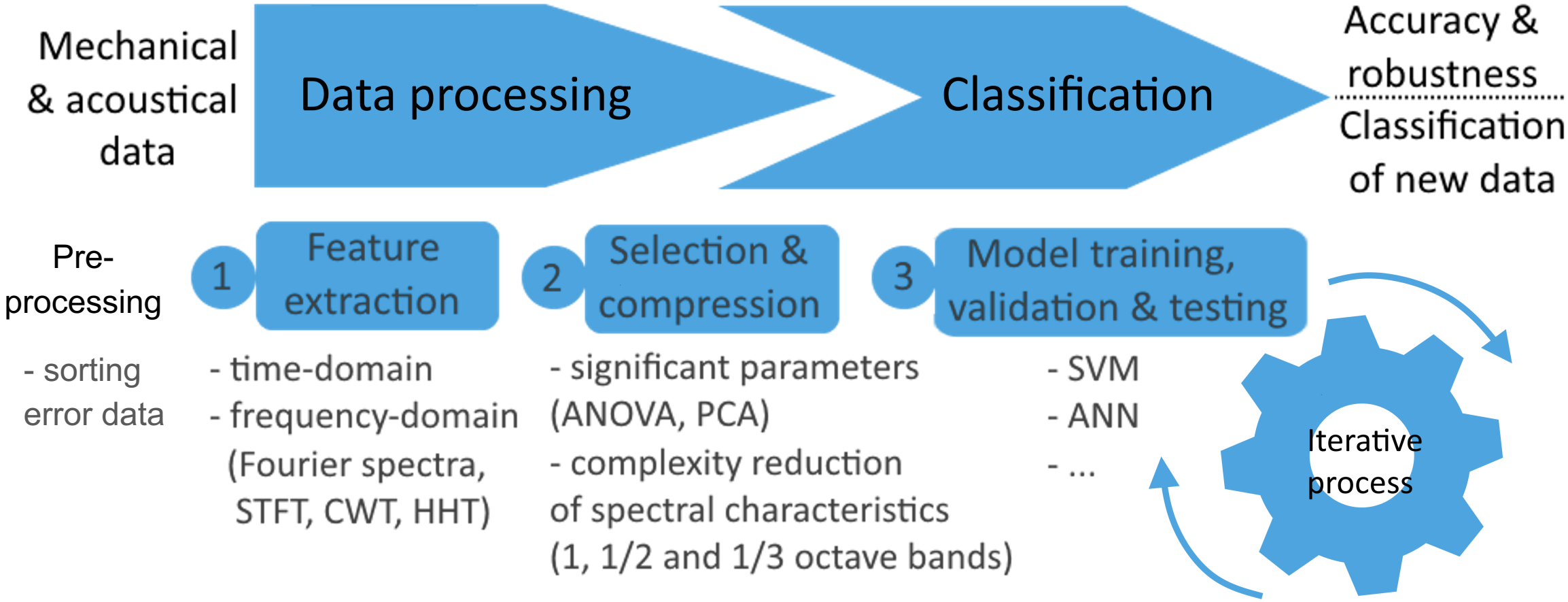
DIN 5495; 8586; 8587; 10950; 10961

Full PCA

Linear relationships not sufficient for modelling psychophysics phenomenon of crispiness sensation



Automatic classification strategy



Classification models & results

Modeling & evaluation

- 10 x 5-fold cross-validation: suited for small datasets
  → average accuracy & variability estimation
- Training/validation with 80%, test with 20% random samples for each sub-model

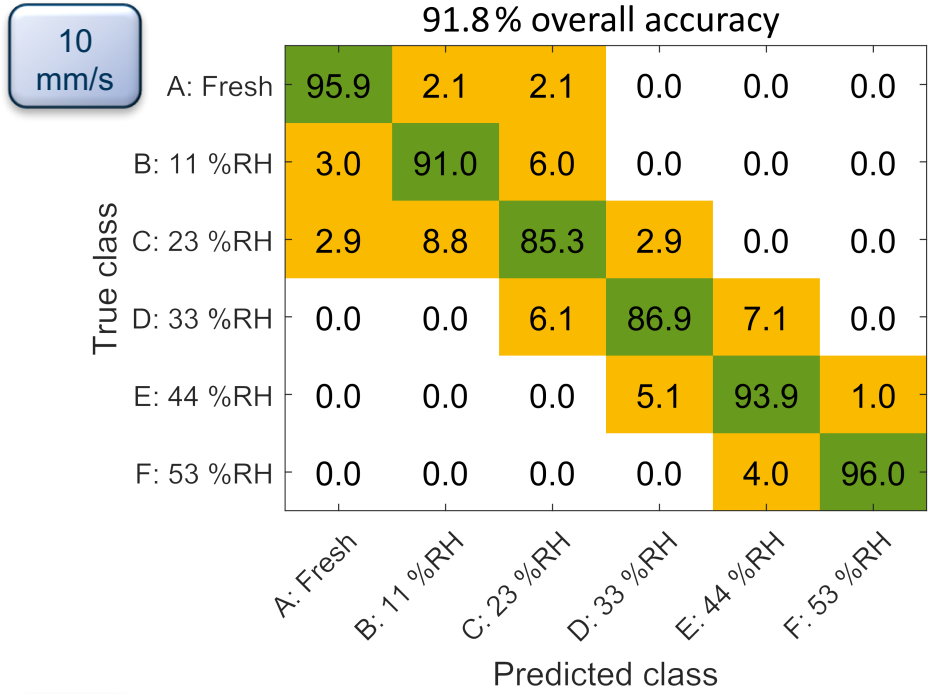
Model selection

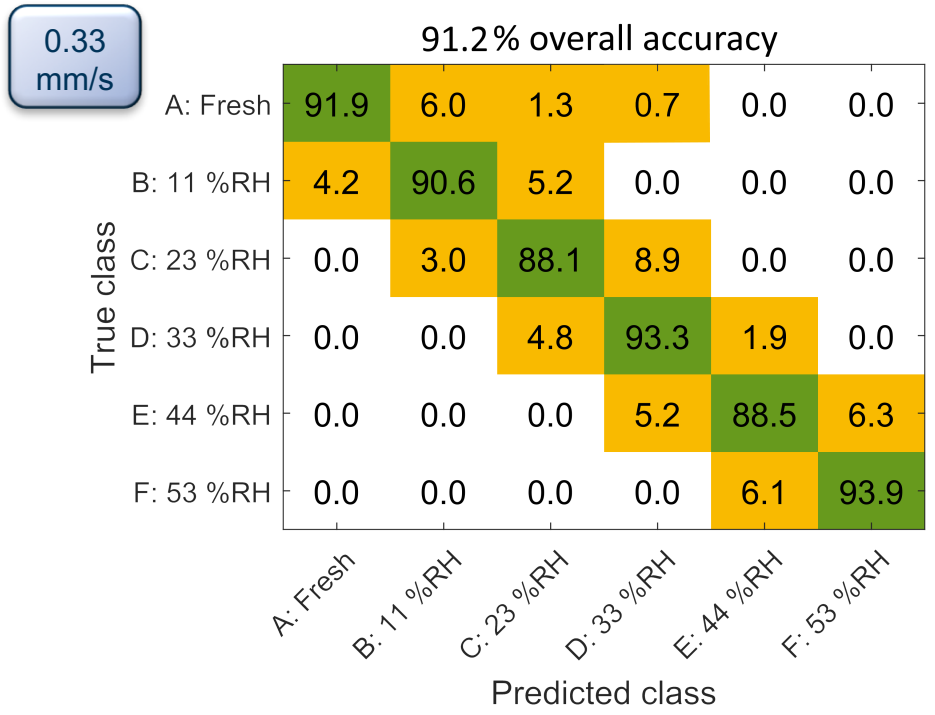
- Psychophysics models: non-linear relationships between food physics and sensory sensation

→ Best models: Quadratic SVM & ANN with disabled PCA preselection (linear)

Results

- Best predictions using selected temporal + third-octave spectral features from mechanics & acoustics
- Crushing velocity: better overall accuracy at 10 mm/s but better distinction between 11 & 23% RH at 0.33 mm/s





ANN results

Confusion matrices

- one of the best ANN models
- 1 layer of 10 hidden neurons
- high-velocity selected temporal combined with third-octave spectral mechanical and acoustical features

Overall accuracies [%] on the test sets:

(a) 1 layer of 10 hidden neurons;
(b) 3 layers of 20 hidden neurons;
(c) 1 layer of 250 hidden neurons.

Domain	Features	Octave bands	Number of features	Test velocity	ANN model		
					(a)	(b)	(c)
Time & Frequency	Combined selected	1/3	68	10 mm/s	85.8±3.8	85.1±4.9	80.9±5.8

