A New Automatic Pattern Recognition Approach for the Classification of Volcanic Tremor at Mount Etna, Italy

M. Masotti[1], S. Falsaperla[2], H. Langer[2], S. Spampinato[2], R. Campanini[1]

[1] Medical Imaging Group, Department of Physics, University of Bologna
[2] Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania

Outline

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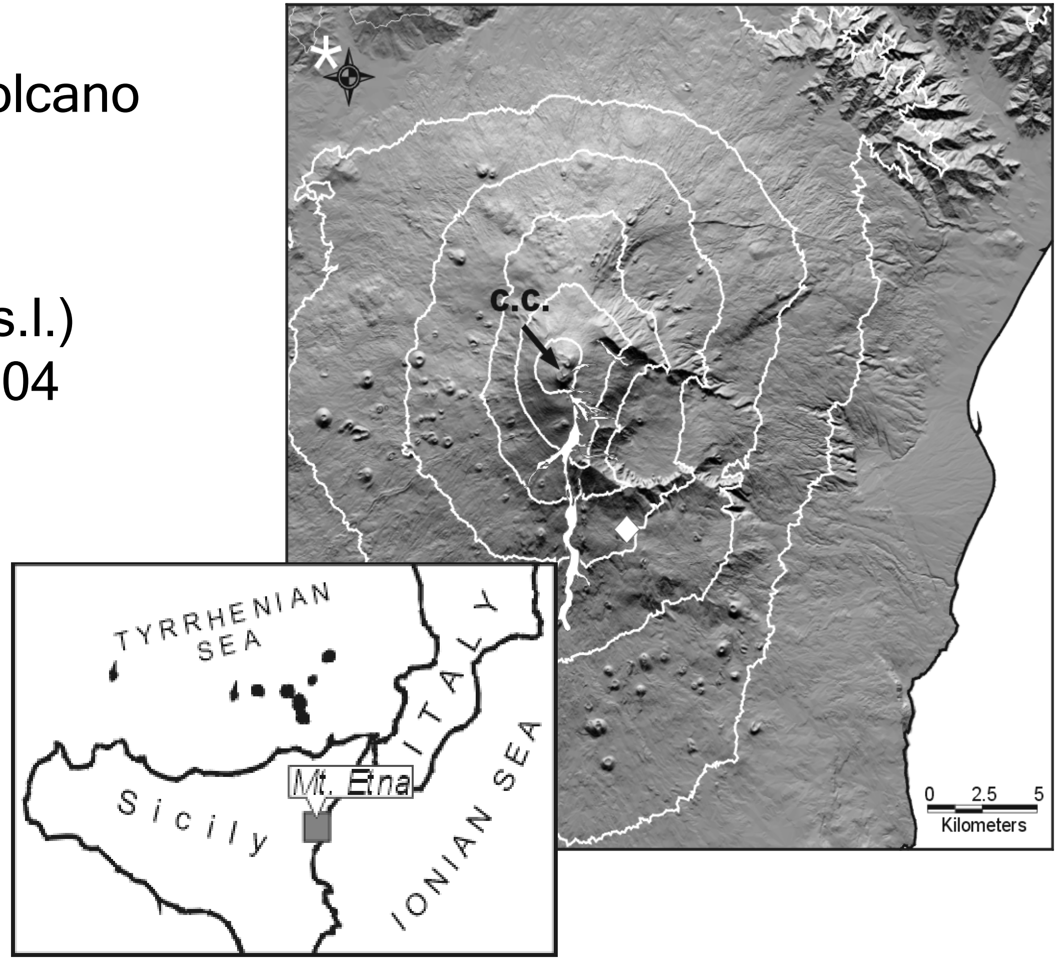
Mount Etna

Mount Etna is the largest active volcano in Europe:

- Type: Basaltic stratovolcano
- Location: Sicily, Italy (3350 m a.s.l.)
- Latest eruptions: 2001, 2002, 2004

Mount Etna's volcanic monitoring represents a key issue



Volcanic Tremor

For basaltic volcanoes (e.g. Mount Etna)…

- Volcanic tremor is a persistent seismic signal marking different states of the volcano’s activity:

Pre–eruptive

Lava fountain

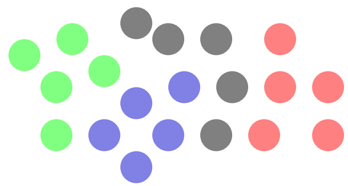
Eruptive

Post–eruptive

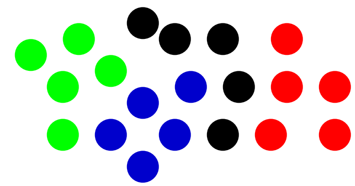
- Volcanic tremor provides reliable information for alerting governmental authorities during a crisis and permits surveillance even when direct access to the eruptive theatre is not possible

Automatic Pattern Recognition Approach

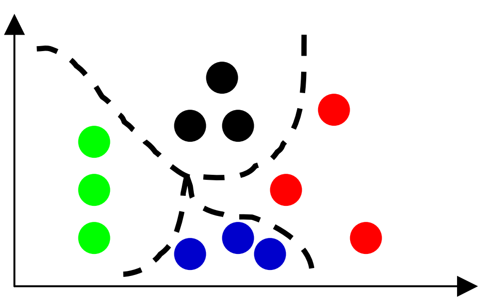
How to develop an automatic classifier
able to recognize different states of the volcano's activity
from the analysis of its volcanic tremor?



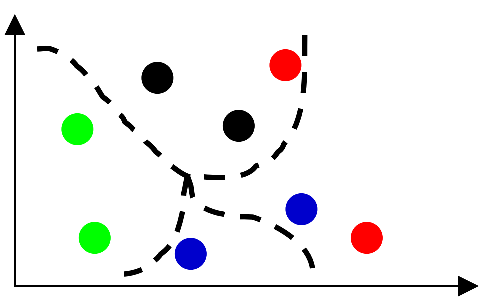
Data Collection & Labeling



Feature Extraction



Training of the Classifier



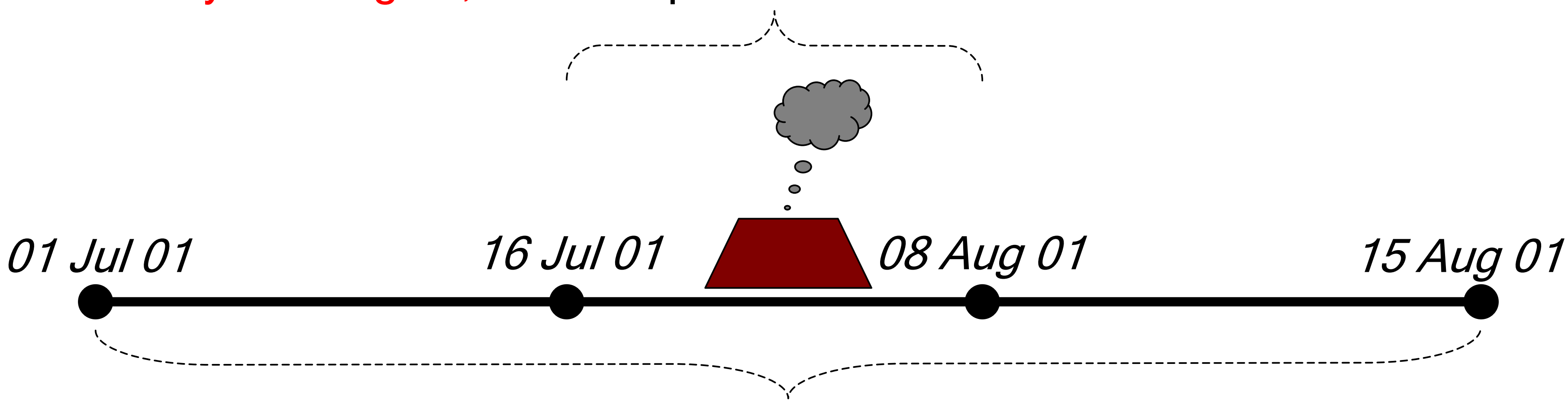
Test of the Classifier

Outline

1. Introduction
2. Data and Methods
3. Results
4. Discussion

Data :: Collection

The 17 July–08 August, 2001 eruption is considered…



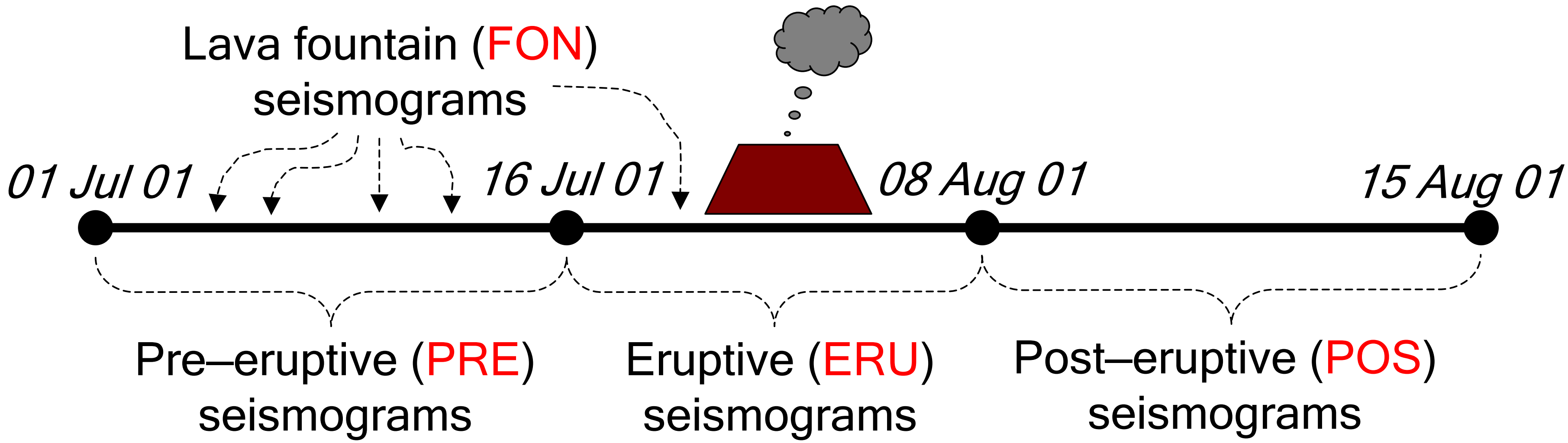
Analysis is performed over 01 July–15 August, 2001

Seismograms are recorded at the 3–component station ESPD:

- 142 seismograms for the East–West (EW) component
- 142 seismograms for the North–South (NS) component
- 142 seismograms for the Vertical (Z) component

Data :: Labeling

Seismograms are labeled according to their recording date...



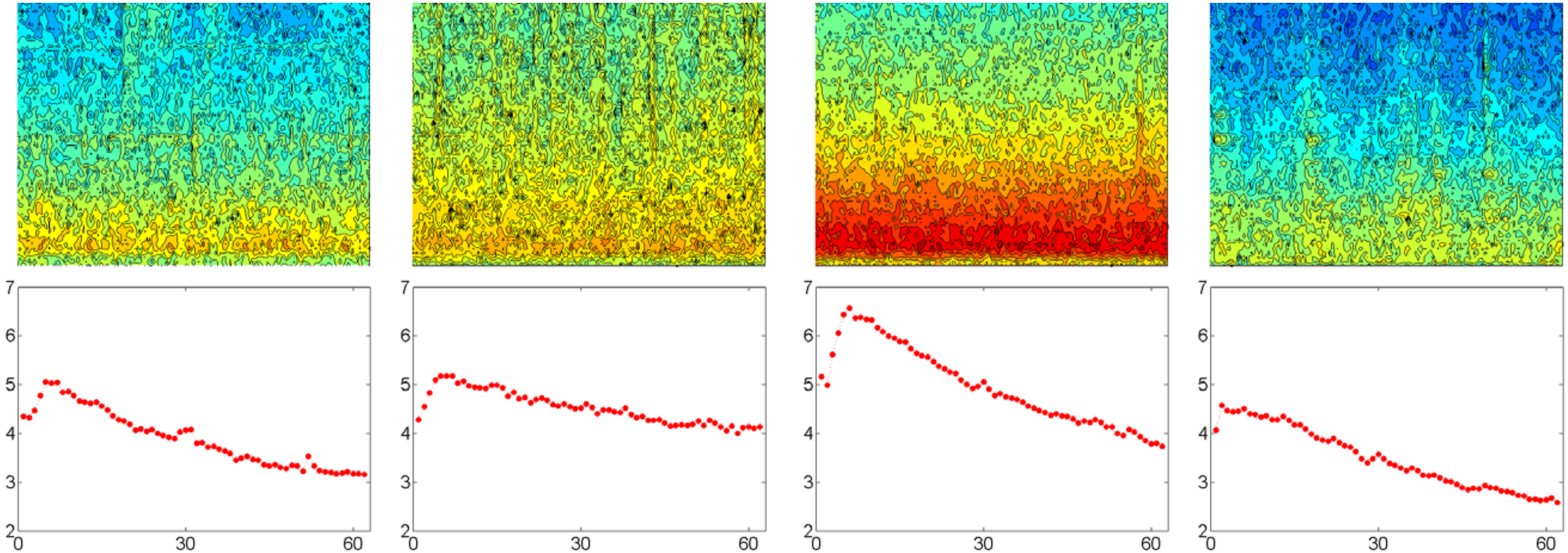
By considering the three components of each seismogram as different patterns...

	N. of patterns for each class			
	PRE	FON	ERU	POS
Full set	154	55	180	37

Features

Features are computed by…

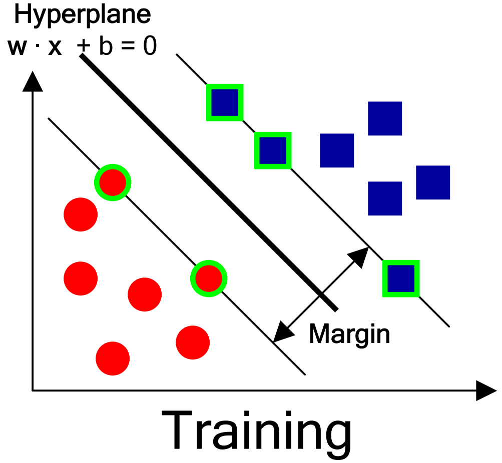
1. Calculating the spectrogram of each seismogram (10 min., 0–15 Hz)
2. Averaging the rows of each spectrogram (62–dimensional feature vector)



Pre–eruptive Lava fountain Eruptive Post–eruptive

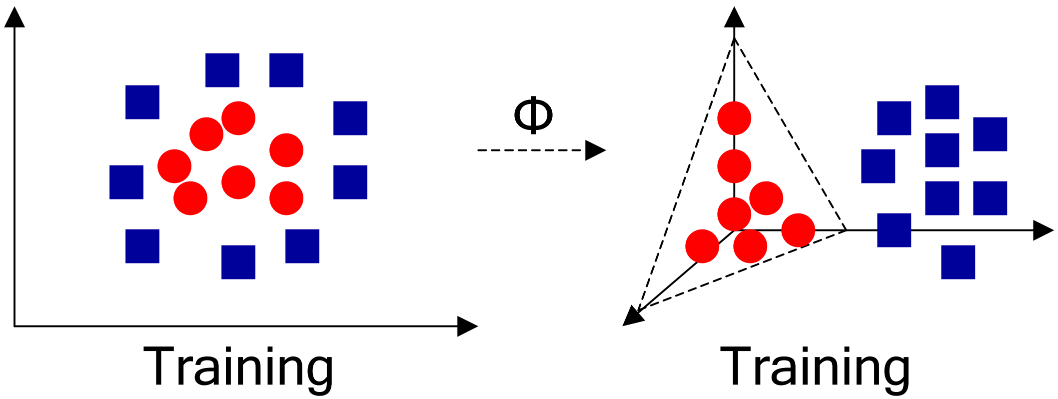
Classification

For classification, a Support Vector Machine (SVM) classifier is chosen…



1. SVM finds the hyperplane
   $w \cdot x + b = 0$
   maximizing the margin
   between the two classes
   in the training set

2. If feature vectors are not
   linearly separable,
   the problem is mapped
   into a higher feature space
   by means of a
   kernel function $\Phi(x)$



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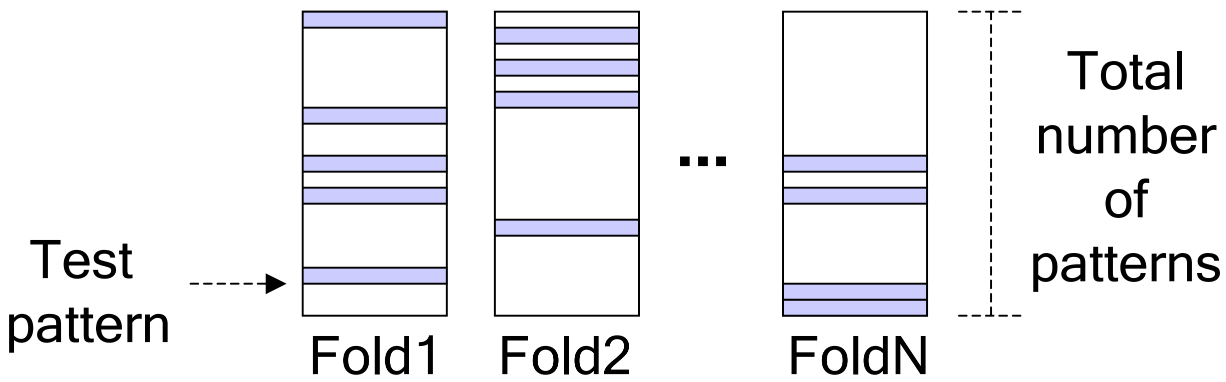
Cross–Validation :: Data Partitioning

First, performances are studied using cross–validation + random subsampling…



By considering the three components of each seismogram as different patterns, for one fold…

	N. of patterns for each class			
	PRE	FON	ERU	POS
Full set	154	55	180	37
Train set	124	44	144	30
Test set	30	11	36	7

Cross–Validation :: Performances

By repeating 100 times train and test...

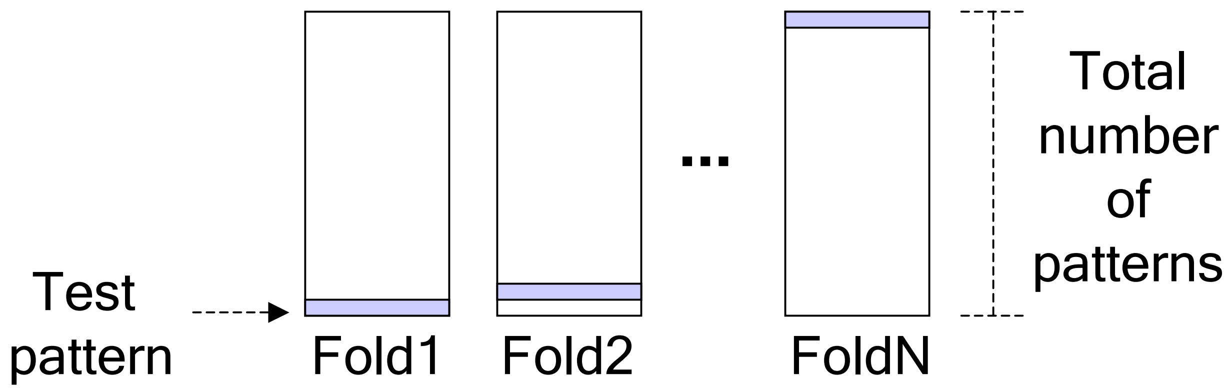
1. Global average classification performances: (94.7 ± 2.4)%
2. Single–class average classification performances: (%)

		Predicted Class			
		PRE	FON	ERU	POS
Actual Class	PRE	94.2 ± 5.2	5.4 ± 4.8	0.4 ± 1.3	0.0 ± 0.0
	FON	20.2 ± 12.6	76.4 ± 13.7	3.4 ± 5.1	0.0 ± 0.0
	ERU	0.0 ± 0.3	0.3 ± 1.3	99.6 ± 0.4	0.1 ± 0.6
	POS	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	100.0 ± 0.0

3. Similar results when EW, NS, and Z are taken into account separately

Leave–One–Out :: Data Partitioning

Second, performances are studied using leave–one–out...



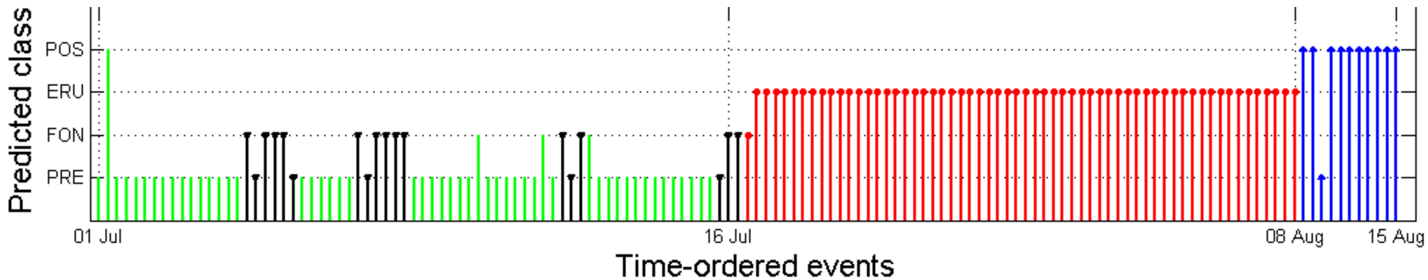
By considering the three components of each seismogram as different patterns, for one (example) fold...

	N. of patterns for each class			
	PRE	FON	ERU	POS
Full set	154	55	180	37
Train set	153	55	180	37
Test set	1	0	0	0

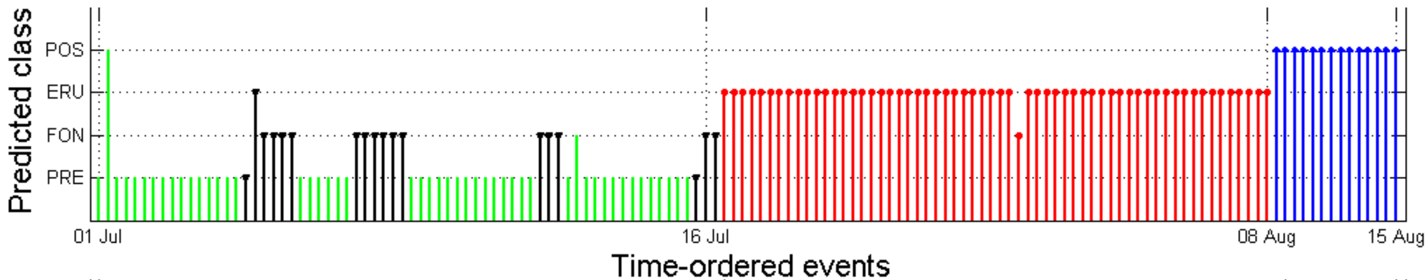
Leave–One–Out :: Performances

By repeating 142 times (on each single component) train and test...

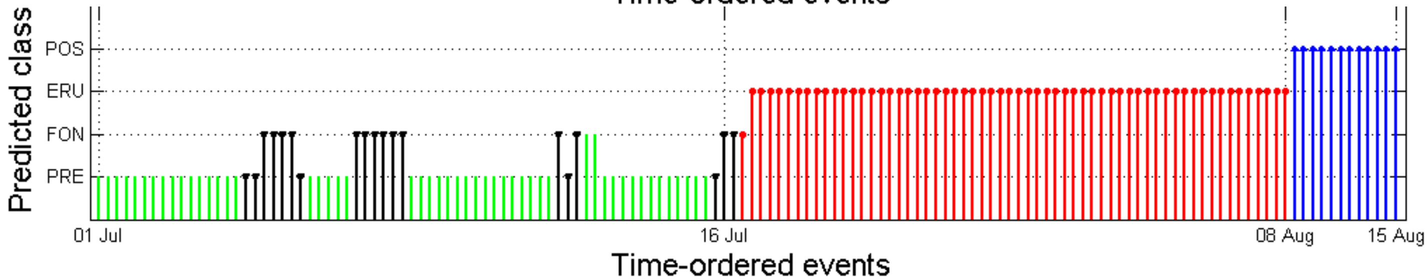
EW



NS



Z



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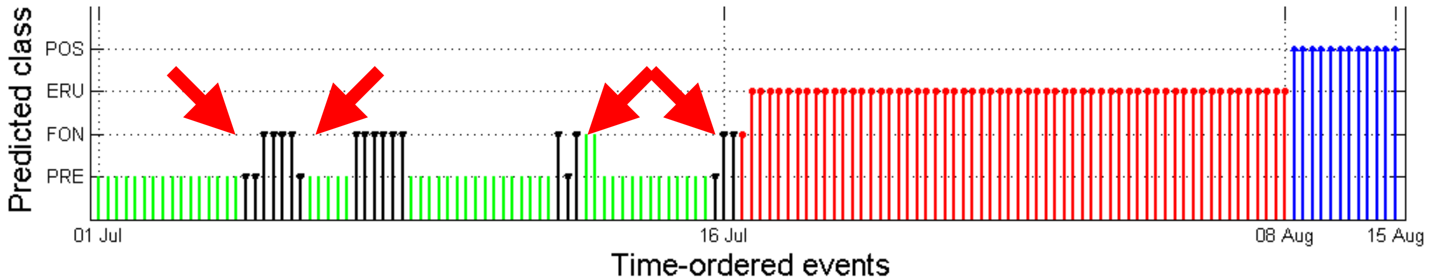
Misclassified Events

Focusing on the Z component for brevity…
(but analogous considerations can be drawn for EW and NS)

- Misclassifications are mostly concentrated near class transitions
- Reasonably because of:
  1. Intrinsic fuzziness in the transition from one volcanic state (i.e. class) to the other
  2. Human imprecisions in labeling

→ Intra–class variability

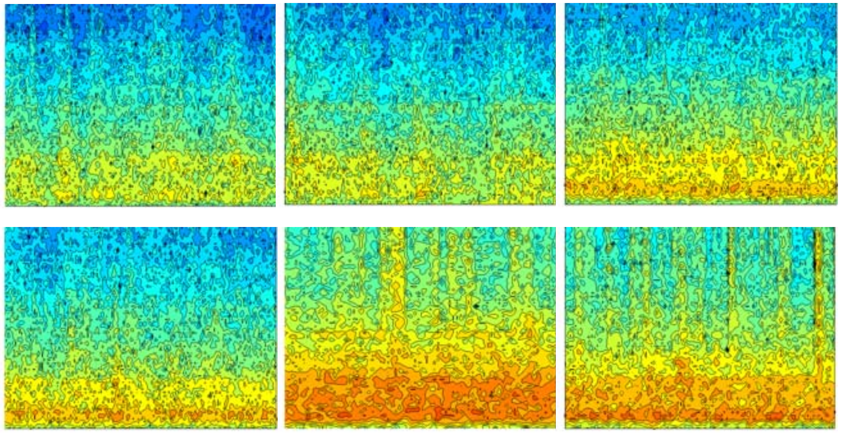
Z



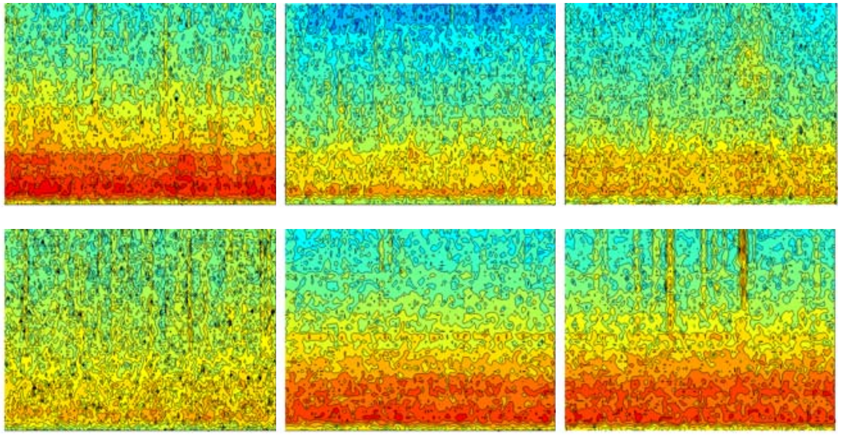
Intra–Class Variability :: PRE and FON

Focusing on the Z component for brevity…
(but analogous considerations can be drawn for EW and NS)

PRE variability: quite high
some PRE events
are similar to
FON events



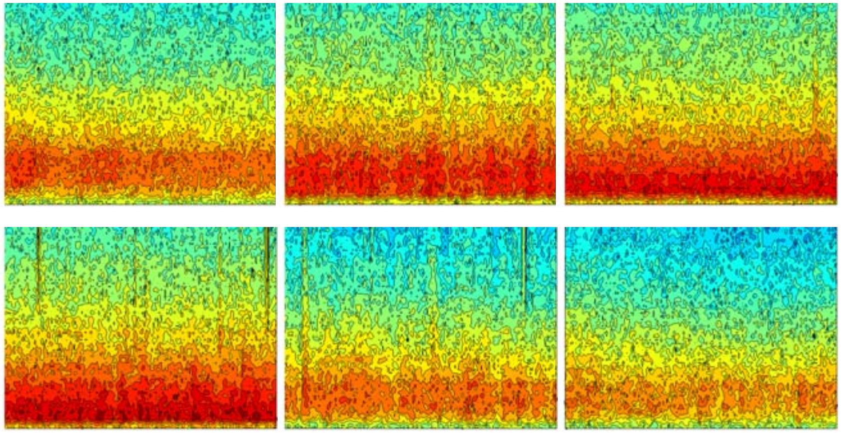
FON variability: high
many FON events
are similar to
PRE or ERU events



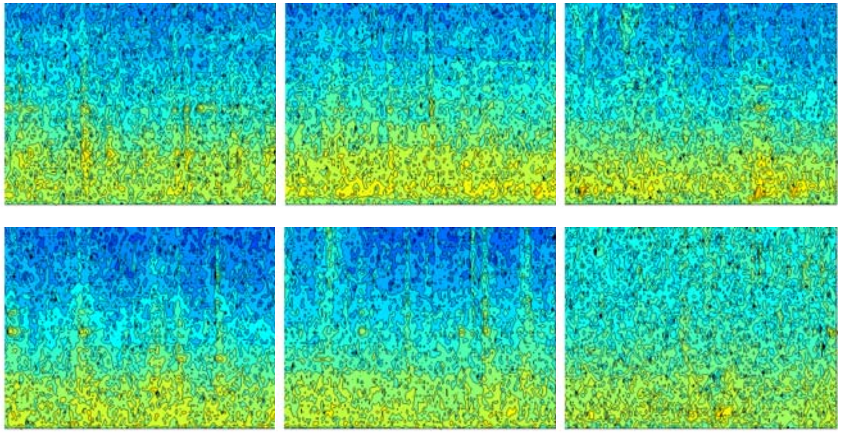
Intra–Class Variability :: ERU and POS

Focusing on the Z component for brevity…
(but analogous considerations can be drawn for EW and NS)

ERU variability: quite low
few ERU events
are similar to
FON events



POS variability: low
very few POS events
are similar to
PRE events



Summary and Conclusions

Summarizing…

- Volcanic tremor recorded at Mount Etna is automatically classified
- Data: 01 July–15 August, 2001
- Features: Spectrogram–based
- Classifier: Support Vector Machine (SVM)
- Classification error: < 6%

Concluding…

- Practical utility: on–line classification
- Practical/Scientific utility: off–line classification of huge (past) databases
- Practical/Scientific utility: the SVM classifier is a mathematical tool linking volcanic tremor to different states of the volcano's activity in a reproducible way