FEBUS OPTICS Distributed Fiber Sensing

DAS et solutions d'apprentissage machine pour la détection et classification temps réel d'événements acoustiques

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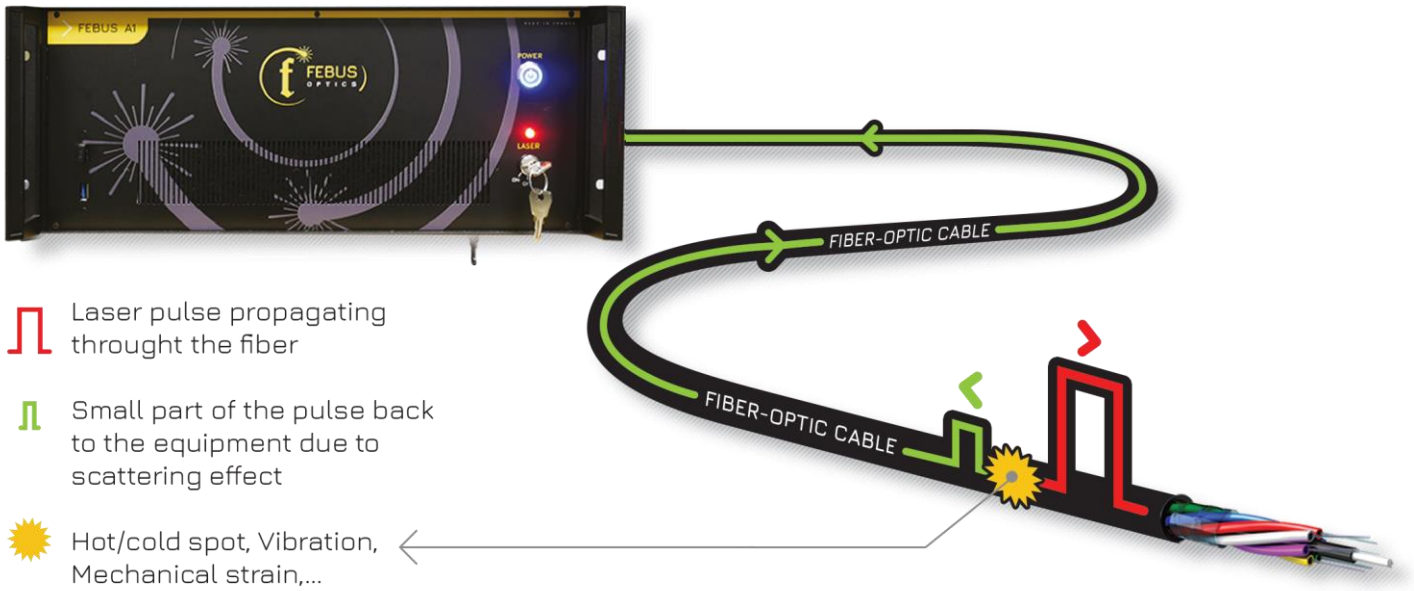
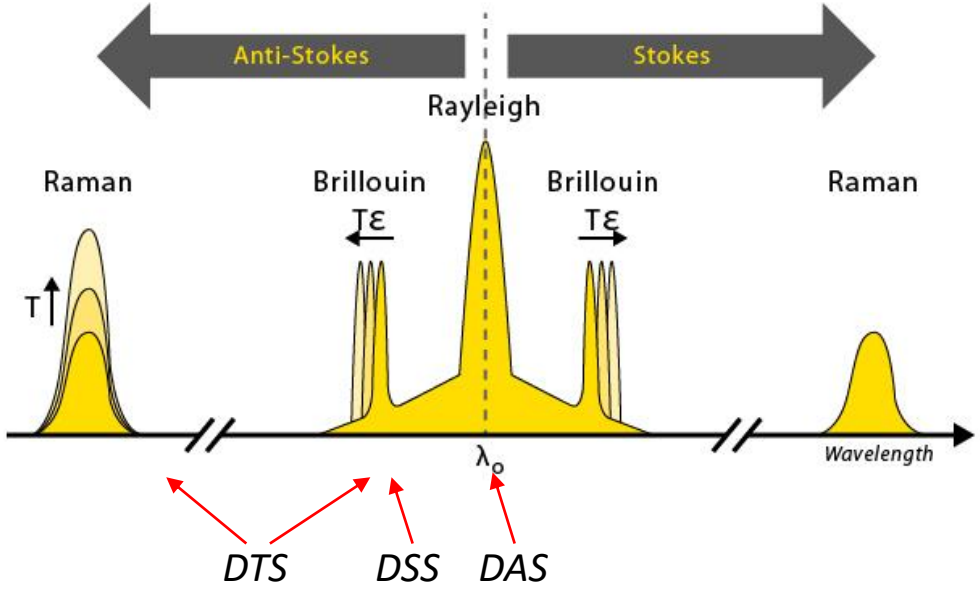
General principle of Distributed FO Sensing

General principle of fiber optic distributed sensing



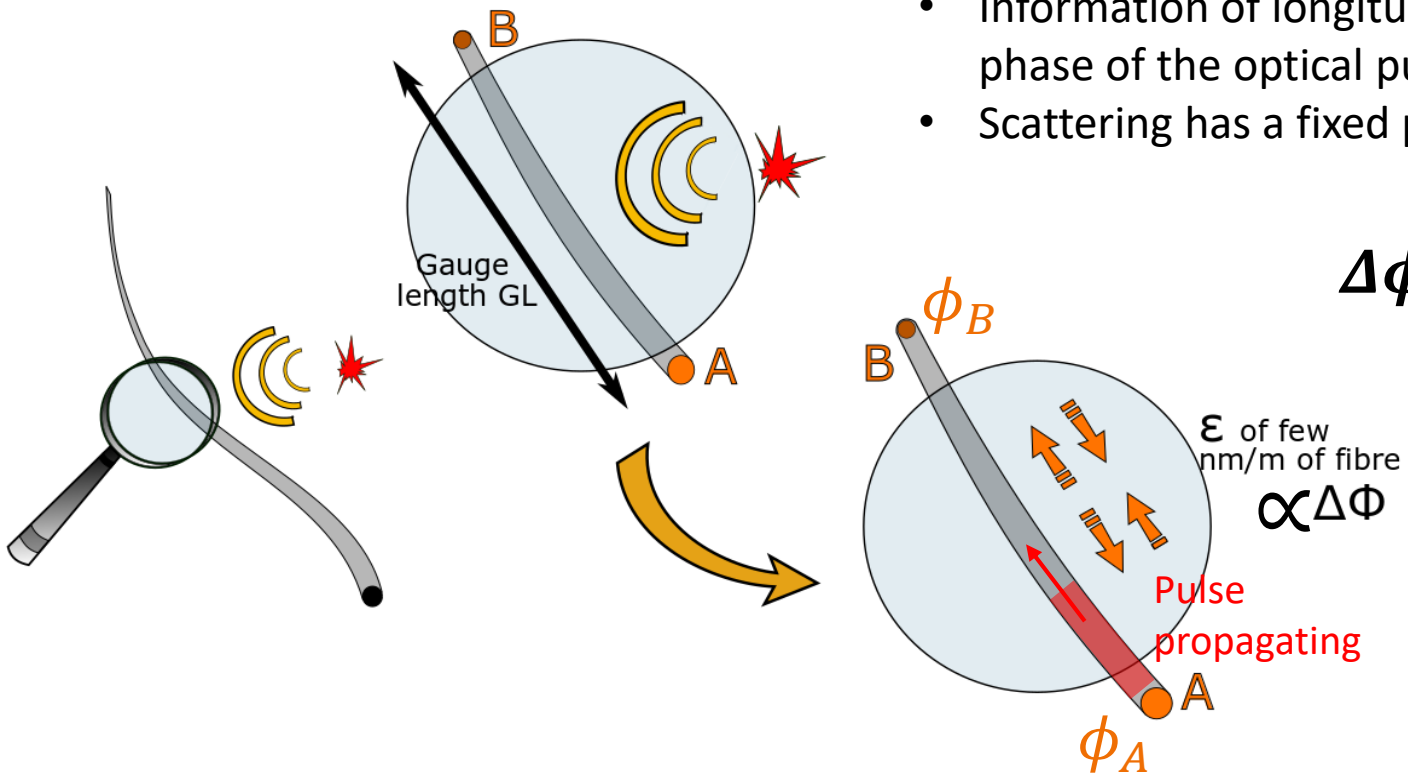


- A pulse of light is sent through the fiber
- Back-scattering effect occurs continuously everywhere along the fiber
- The backscattering light contains information from where it was generated
- Operation is repeated to increase S/N (DTS, DTSS) or access the dynamic (DAS)

- ***DTS: Distributed Temperature Sensing***
- ***DSS: Distributed Strain Sensing***
- ***DAS: Distributed Acoustic Sensing***

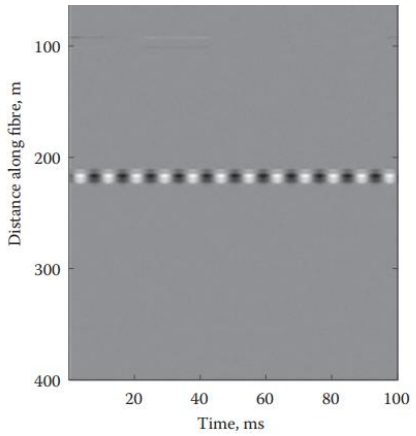
From optic to acoustic

df-OTDR - Phase-based DAS and Gauge length



- Information of longitudinal strain applied on the optical fiber is contained on the phase of the optical pulse travelling to it
- Scattering has a fixed phase relation to the incident light

$$\Delta\phi = \phi_B - \phi_A \qquad \varepsilon = \frac{\lambda \cdot \Delta\phi}{4\pi n G L \xi}$$



-> Need direct access to the phase of the pulse

-> Need to differentiate the phase of the light through the gauge length

δϕ-OTDR - Phase-based DAS

Acquisition parameters

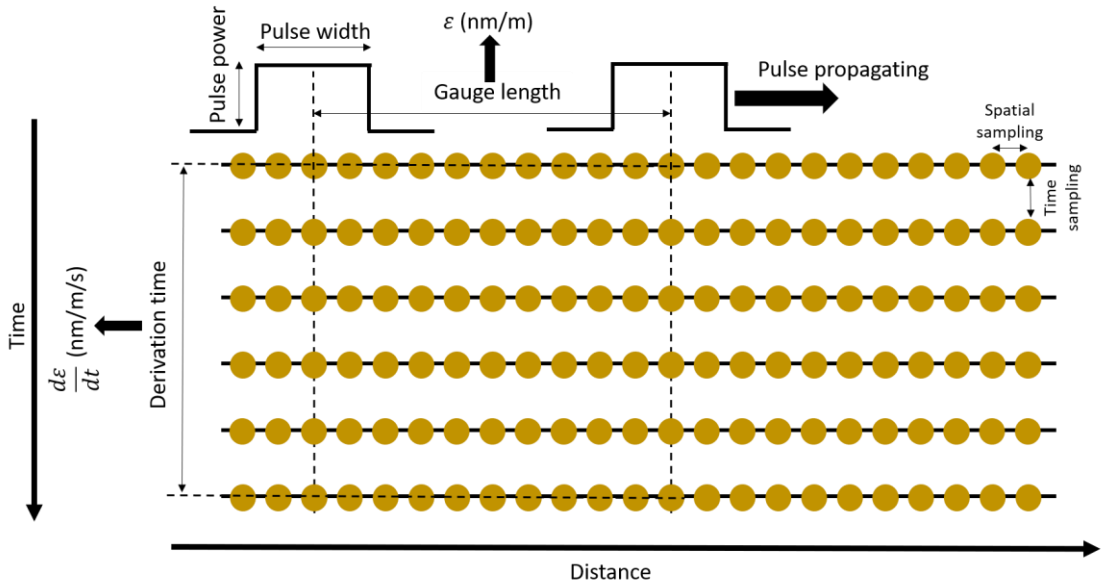
	Differential phase measurement			
What is measured:	Direct detection		Coherent detection	
Phase of a beat frequency	Dual pulse		Heterodyne	
Quasi-static phase using multiple inputs		Receiving interferometer		Homodyne
Differentiation:	Optical domain		Electrical or software domain	

A.H. Hartog, *An Introduction to Distributed Optical Fibre Sensors*, CRC Press, 2017

$$\varepsilon = \frac{\lambda . \Delta\phi}{4\pi n G L \xi}$$

- Parameters to adjust :
  - Fiber distance
  - Optical power
  - Pulse width
  - Pulse rate frequency
  - Spatial sampling resolution

  - *Gauge length*
  - *Derivation time (if strain-rate)*

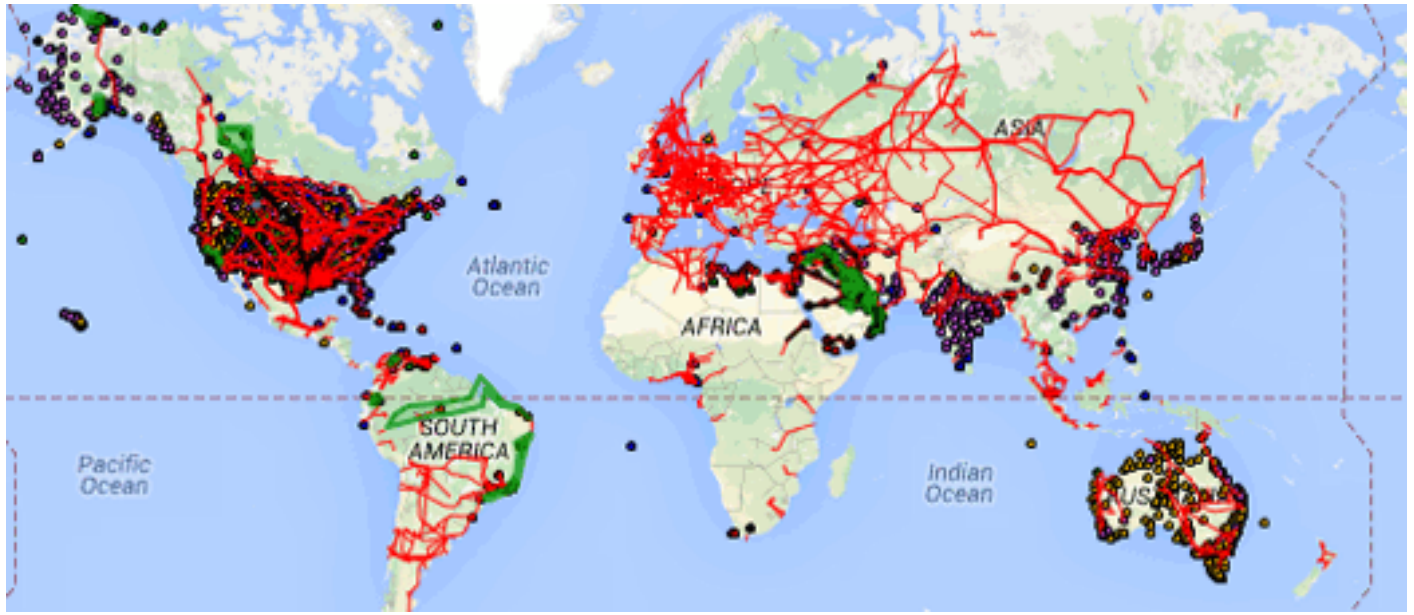


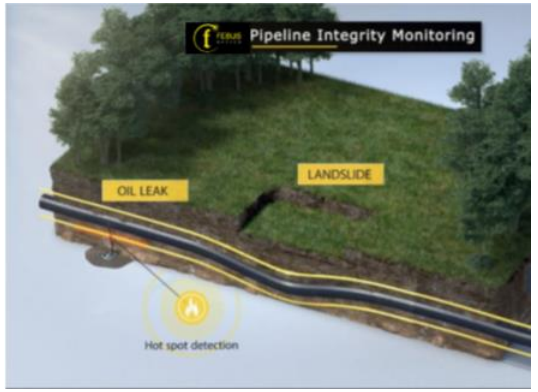
Context

Pipeline Monitoring

Risk identification:

- Leaks,
- Natural hazards,
- Anthropogenic hazards,
- Intrusion



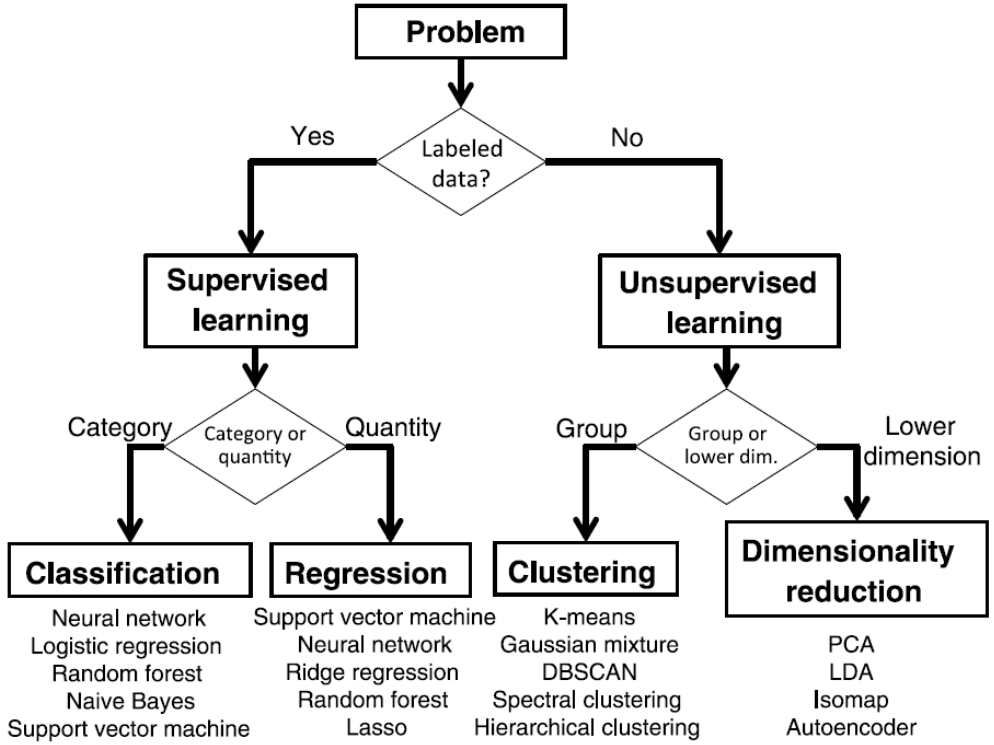


Challenges:

- Use of DAS for risk identification.
- Handle the large amounts of data generated by DAS acquisitions.
- Release an accurate alert if necessary.

Solution:

Use of **Machine Learning** techniques for event classification.

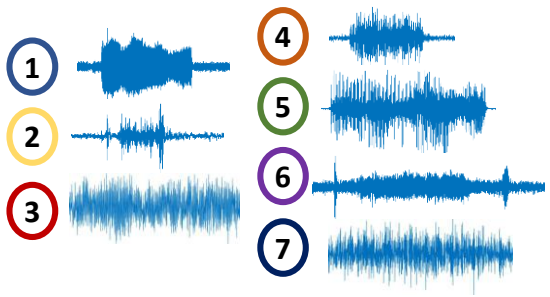


The algorithm

The Random Forest algorithm

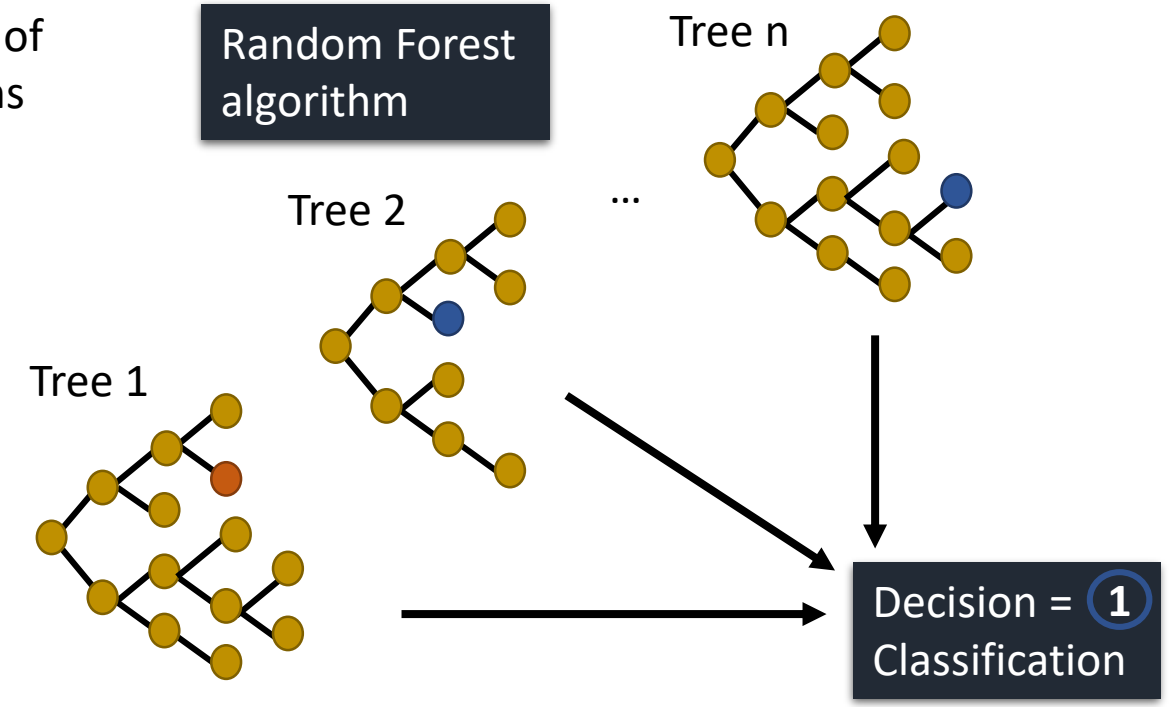
- A supervised Machine Learning algorithm developed by Breiman in 2001
- Proved its interest in seismology for classification of environmental sources, tectonic events or nuclear explosions
- Use of a large number of decision trees constituing a forest.

Training set:
Class determination

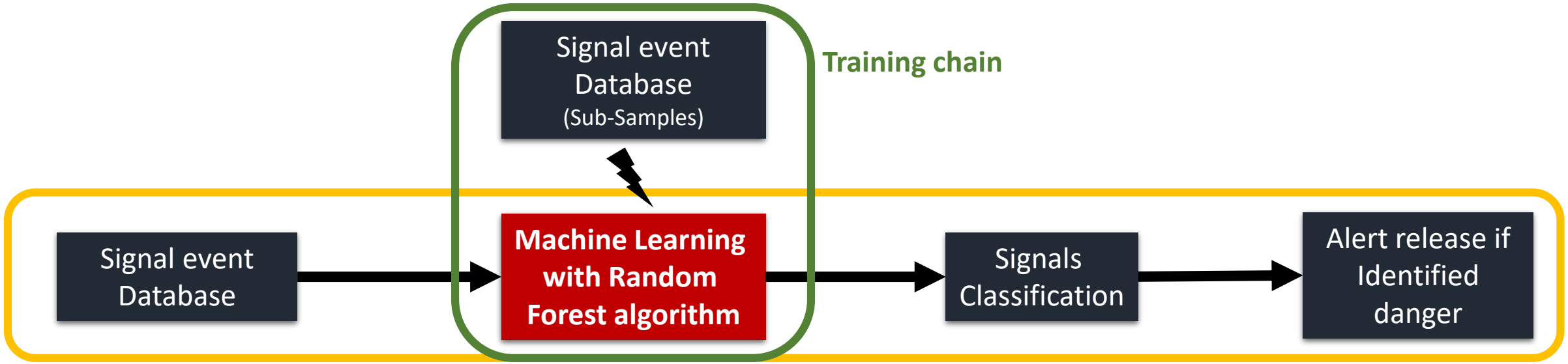


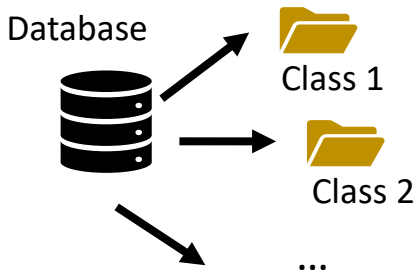
Discriminating attributes:

- **Duration**
- **skewness**
- **f_{max}**
- **Kurtosis**
- **Spectral properties**
- **50+ features**



The Processing chain

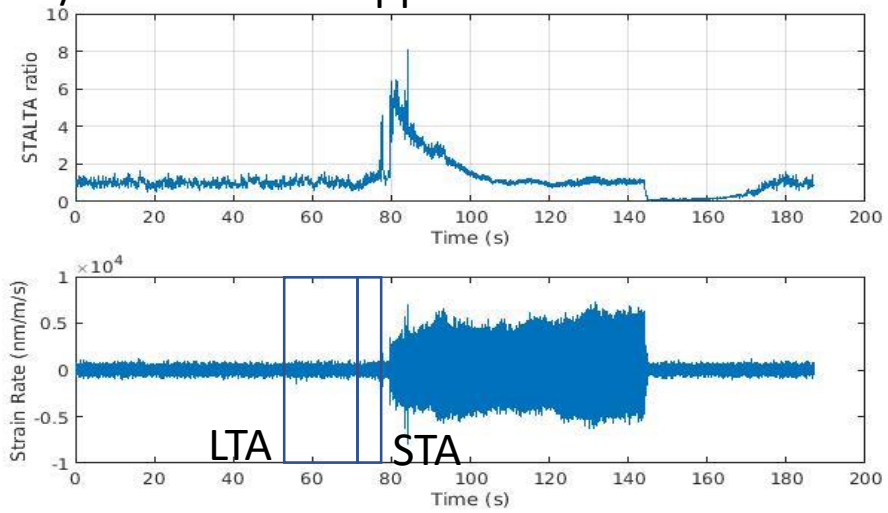




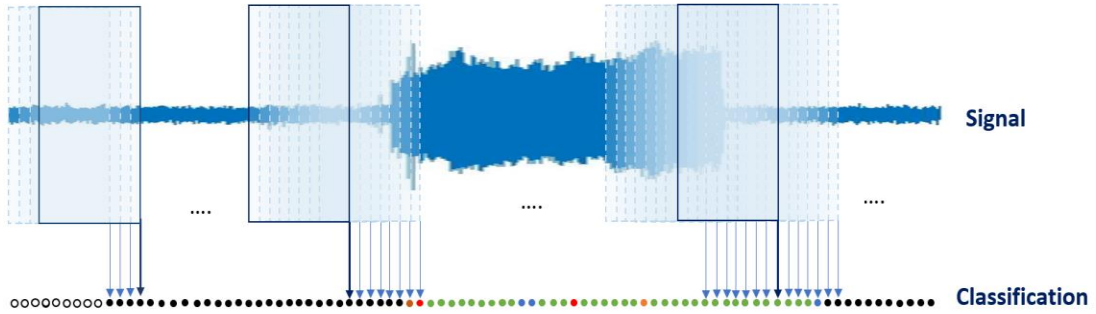
Implementation of the algorithm for real time monitoring

- For now, the used approach was a succession of signal detection and classification.
- Our approach is based on an analysis and classification in flow with a fixed time window.
- Addition of a new class: the ambient noise.

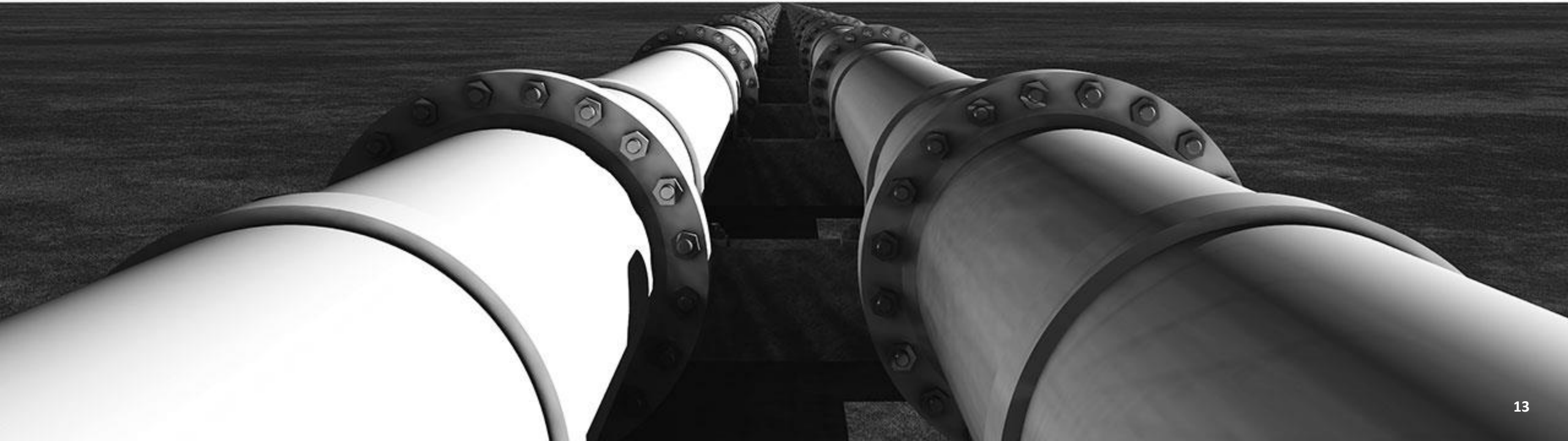
STA/LTA detection approach



Flow approach



The event catalogue



The event catalogue

FEBUS Optics's test Center

Located in Pau, South-West of France.
State-of-the-art test center to simulate site conditions.
Designed to qualify Distributed Fibre Sensing in various conditions.

Numerous applications can be tested:

- Pipeline leak detection of both gas and liquid with pressure up to 50 bars: 3 different sizes, positions and orientations of leaks
- Third party intrusion
- Ground movement/landslides
- PIDS
- Cable/umbilical monitoring
- And more on demand

The event catalogue

- **Various fibre-optic cables**: Single-Mode, Multi-Mode fibres in tight or loose tube, directly buried in the ground or inside conduits and at various distances from a **buried pipe**.

- Different events: falling objects, compactor, foot steps, vehicles.

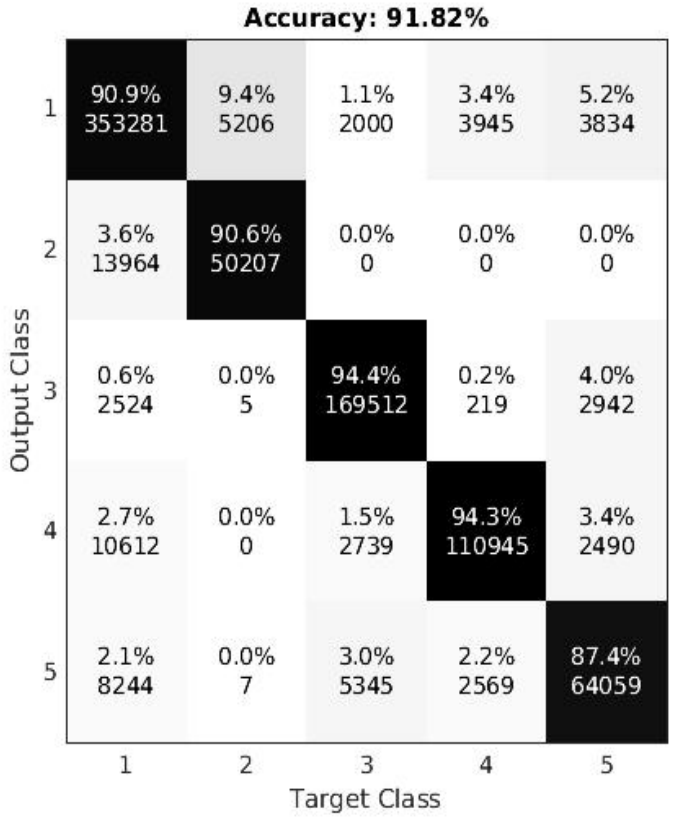
Class	Number of windows
Ambient noise	388625
Falling objects	55425
Compactor	179600
Vehicle	117680
Pedestrian	73325

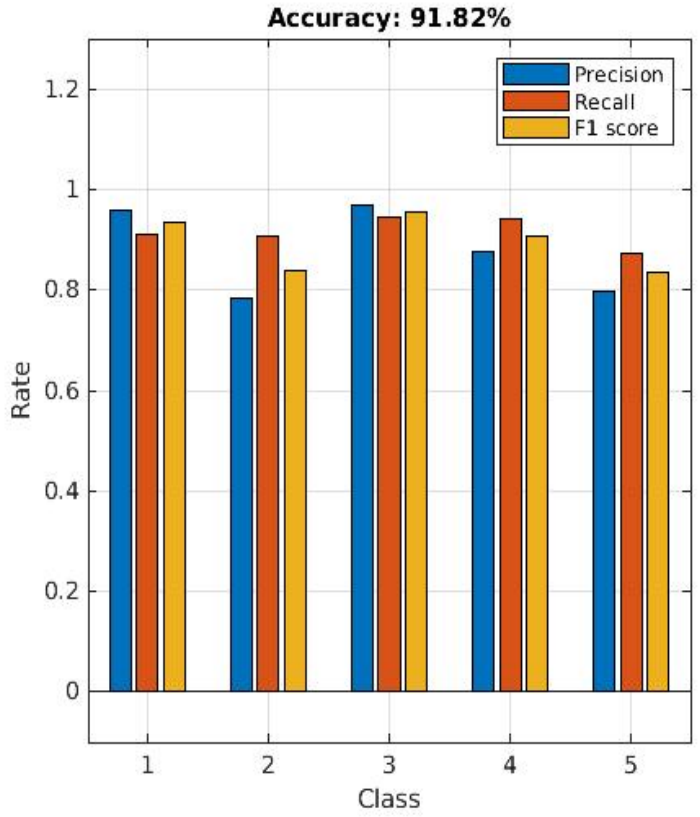
- Events recorded with FEBUS A1-R DAS system.

Results of classification

Results of classification

1: ambient noise
2: falling objects
3: compactor
4: vehicle
5: pedestrian





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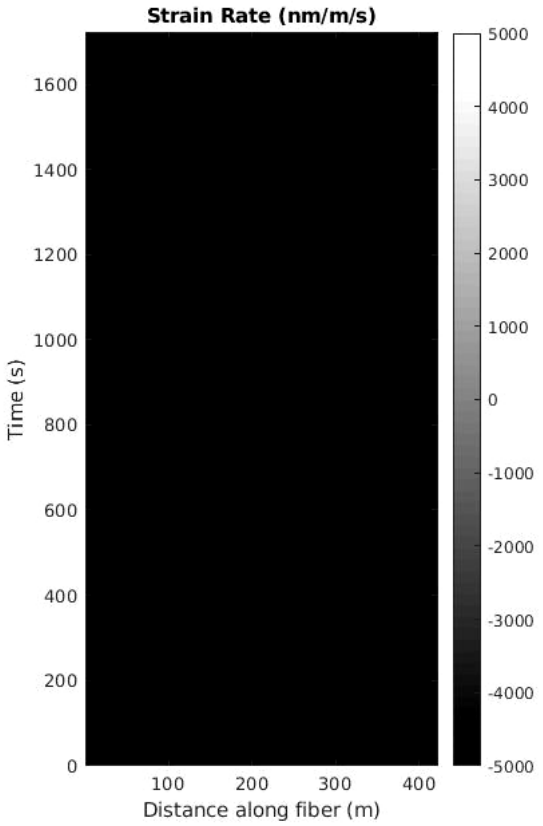
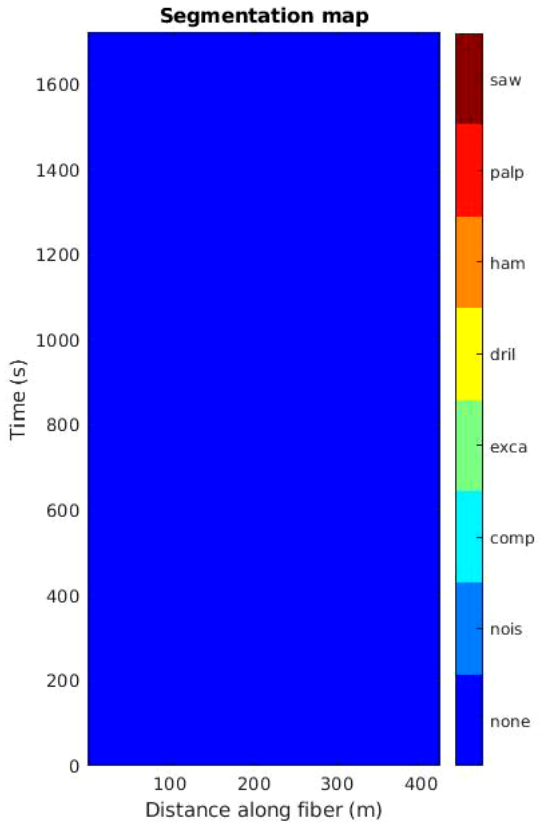
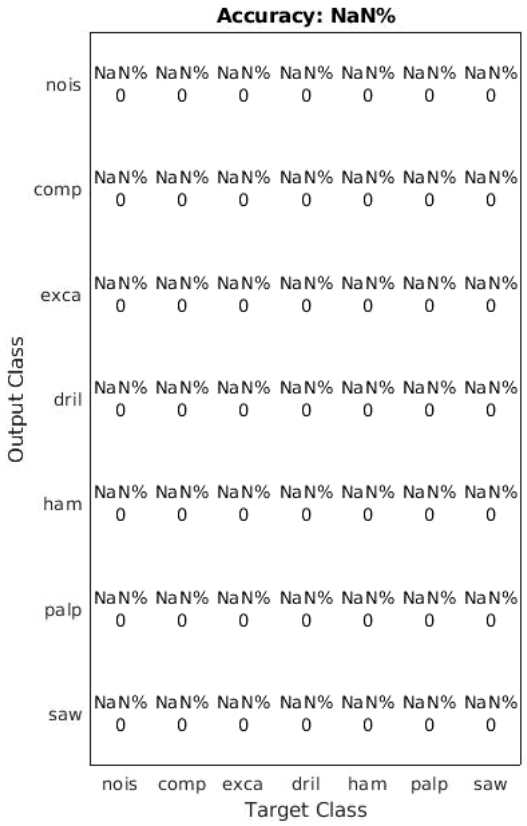
Results of classification

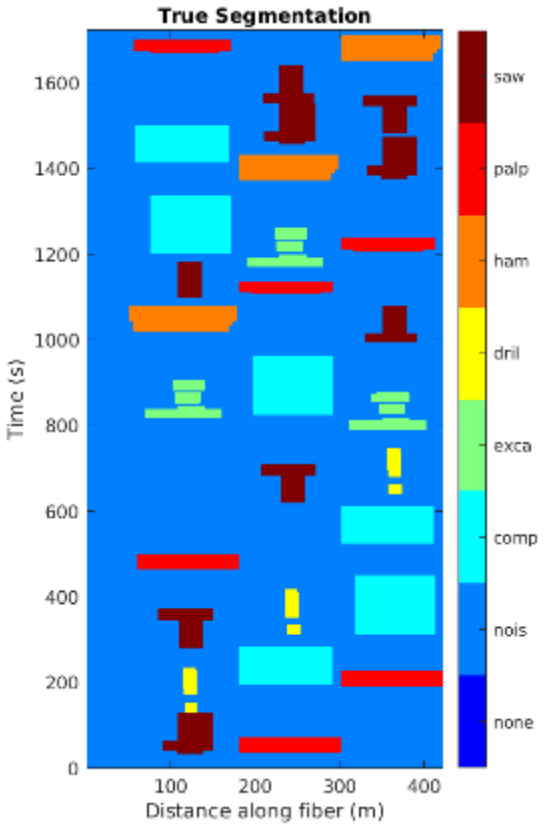
Real time classification in the field

Classe	Effectif
Compacteur	13 962
Excavation	2 567
Forage	1 123
Marteau	7 805
Palplanche	5 038
Scie	6 368
Bruit	131 962









Conclusions

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- We demonstrated in this work the ability of the Random Forests algorithm, a supervised Machine Learning algorithm, to detect and classify events recorded with DAS system.

- The training dataset, well labelled and equilibrated, appears of a large importance to obtain the best quality of event identification.

- Other tests are planned to be conducted in order to be able to detect other types of sources in various contexts. This will enable to experience, test the limits, and improve the efficiency of our classification algorithm.

- In addition to features based on temporal characteristics of the signal, new features are developed based on spatial characteristics.

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