Barcelona Supercomputing Center
Centro Nacional de Supercomputación

EXCELENCIA SEVERO OCHOA

A Machine Learning approach for parameter screening in Earthquake simulation.

José Carlos Carrasco-Jiménez, Ph.D.

High Performance Machine Learning Workshop 2018

24th September, 2018

Introduction

EARTHQUAKES
Natural hazard

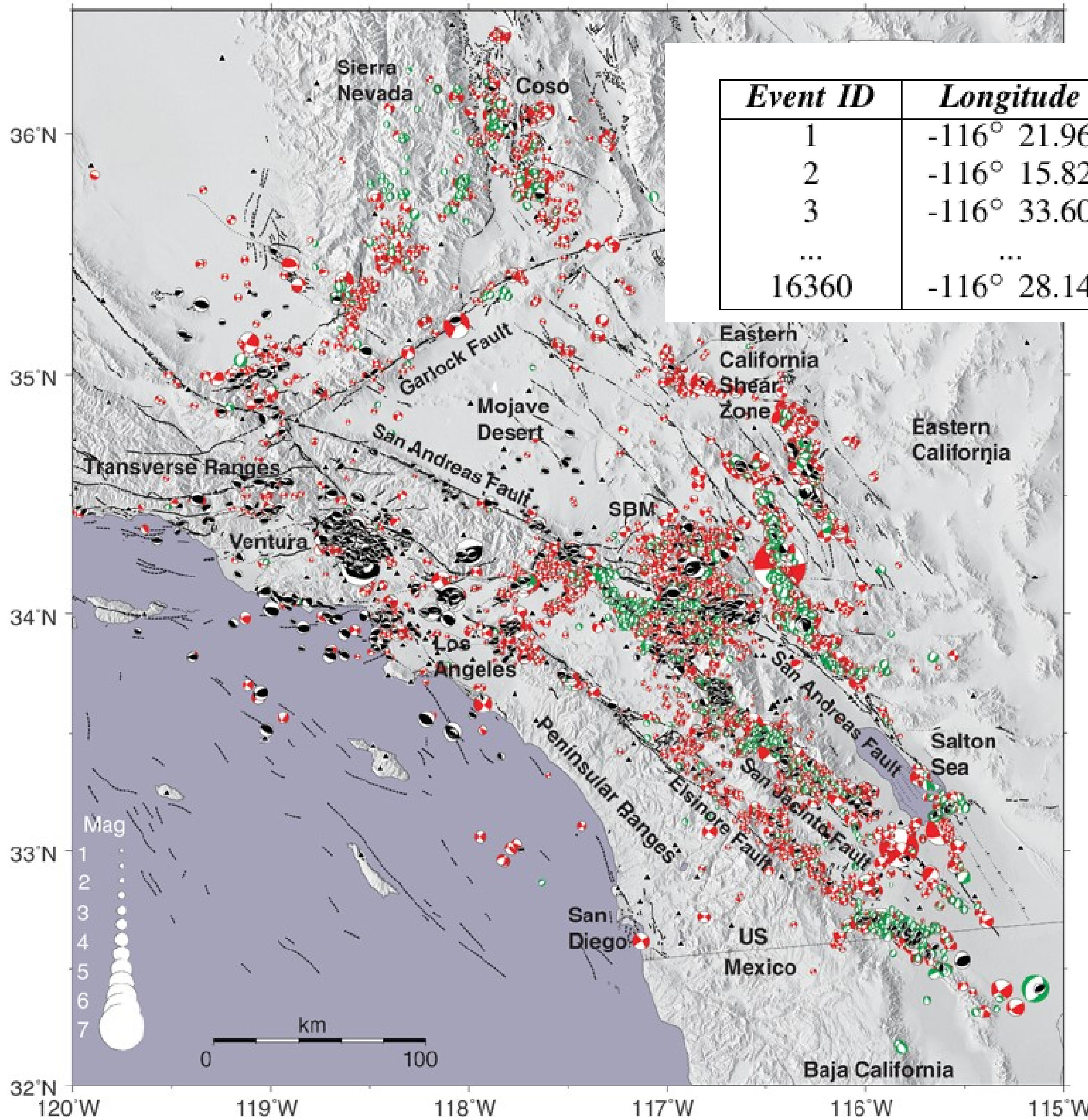
Earthquakes are the result of rupture in the Earth's Crust.

Aftershocks are defined as sequence of earthquakes with lower magnitude than the mainshock that triggered them.

Nepal 2015, Mw = 8.1

Our observational span is still too short to be able to draw strong (predictive) conclusions about when, where, and how big the next earthquake will be.

Barcelona Supercomputing Center
Centro Nacional de Supercomputación



Seismic catalogs

Event ID	*Longitude*	*Latitude*	M_w	*Time [days]*
1	-116° 21.96	34° 13.26	4.3	.285E-02
2	-116° 15.82	34° 26.71	4.8	.352E-02
3	-116° 33.60	34° 24.60	4.2	.3567E-02
...	...	...	...	...
16360	-116° 28.14	34° 24.30	0.9	.365E+03

Statistical measures

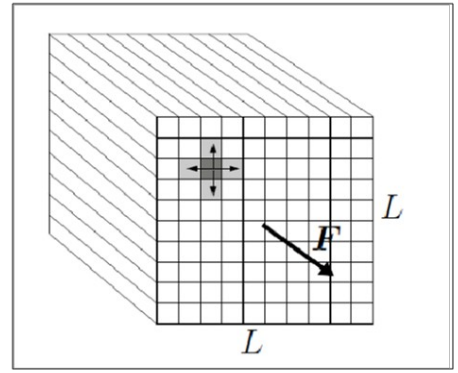
Statistical Measures	Aftershock Sequences		
	LND	*HM*	*NOR*
$< M >$	2.52	2.50	2.6
D_0 (Eq. 1)	1.61	1.51	1.46
M_{max}	6.3	5.8	5.6
M_c	2.1	2.1	2.1
b (Eq. 3)	1.0	1.03	0.94
q (Eq. 5)	1.49	1.47	1.49
$H(\Delta)$ (Eq. 2)	0.64	0.67	0.62
p_{MOL} (Eq. 4)	1.43	1.32	1.32

Seismic activity in Southern California

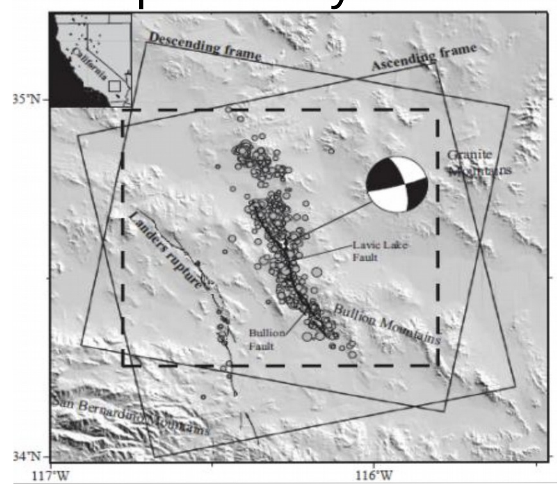
Barcelona Supercomputing Center
Centro Nacional de Supercomputación

FIBER BUNDLE MODEL

- numerical simulations
- discrete element model developed to study the rupture process in heterogeneous materials (e.g. textiles, composites, Earth's crust, etc.)



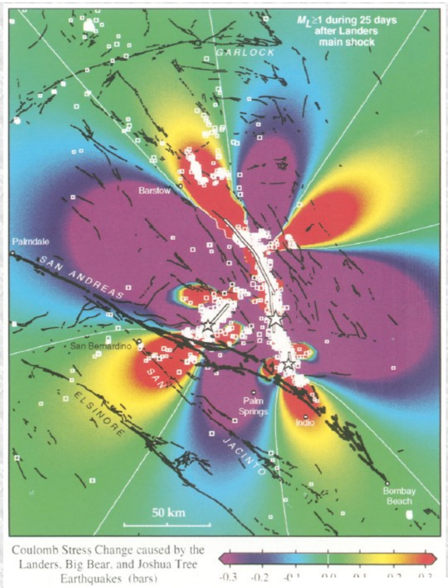
- describes the interactions of individual cells
- transfer load rules
- initial load probability distribution function



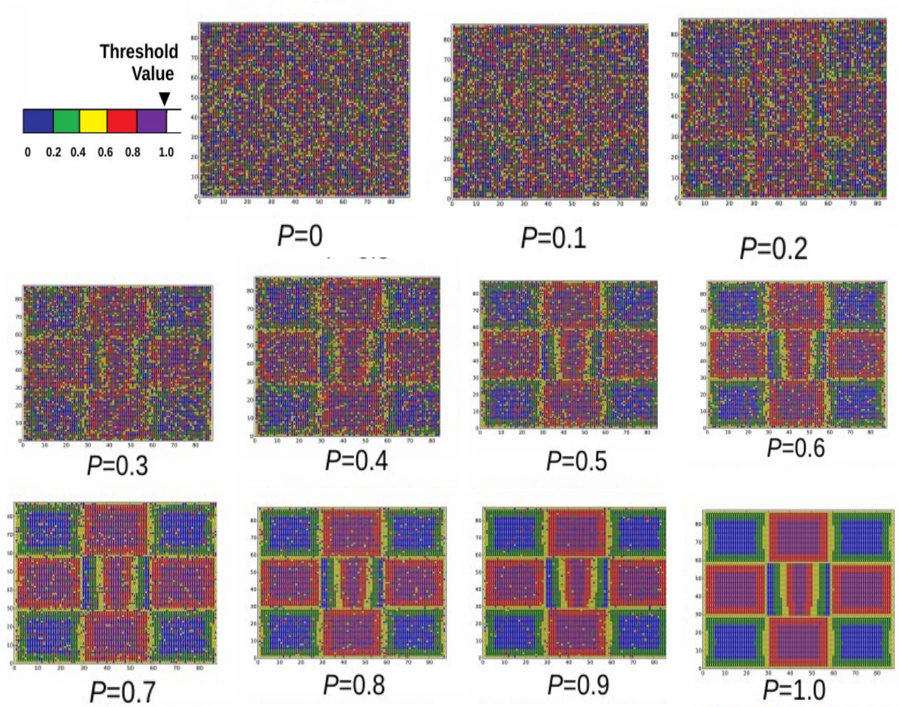
- ability to model aftershocks
- aftershocks located around the active faults

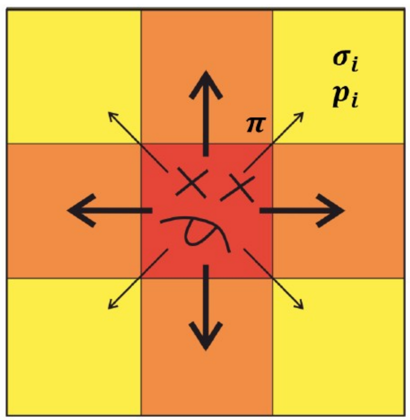
Barcelona Supercomputing Center
Centro Nacional de Supercomputación

captures spatio-temporal distribution of seismic events



Coulomb Stress Change caused by the Landers, Big Bear, and Joshua Tree Earthquakes (bars)





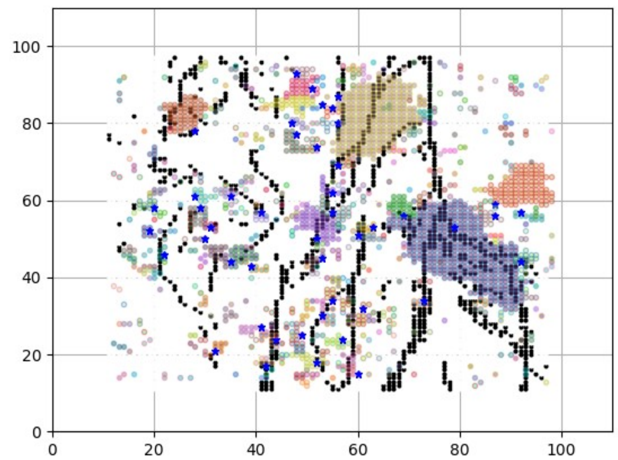
Load transfer to the neighbors

Input parameters:
P: initial organization probability
π: transfer value
N: lateral grid size

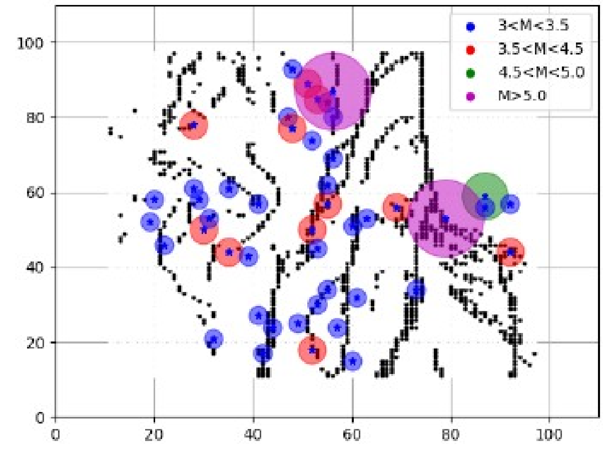
Barcelona Supercomputing Center
Centro Nacional de Supercomputación

AFTERSHOCKS: Statistical patterns

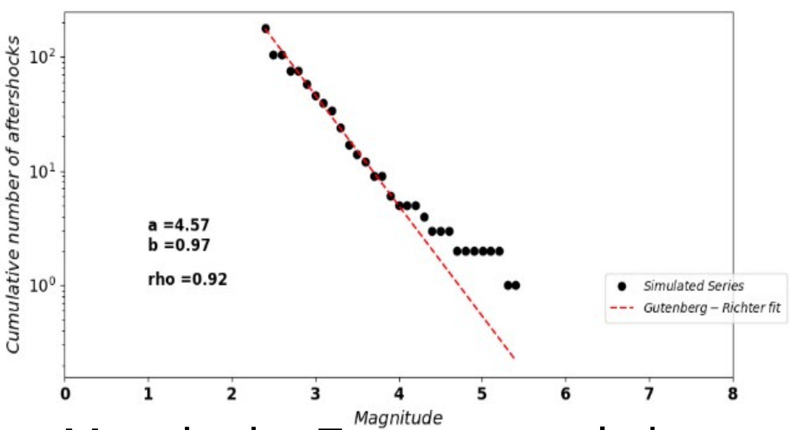
Modeling spatial distribution around faults and its magnitude



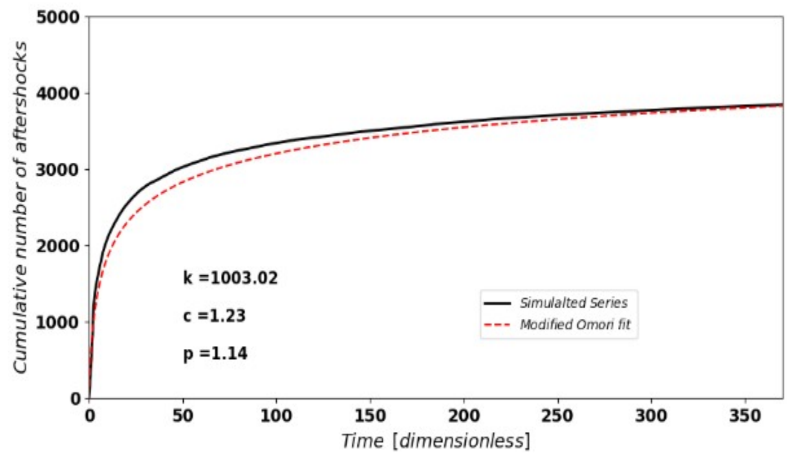
Raw spatial distribution



Magnitude spatial representation



Magnitude- Frequency relation
Gutenberg-Richter law



Omori-Utsu law: Describes in a power law the aftershock time behavior

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Objective

To estimate the FBM parameters that better reproduce real seismic characteristics.

Methodology

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

REAL DATA

Three aftershocks that occurred in Southern California:

1) Landers (LND) – 1992, M = 7.3, # of seismic events = 30547
2) Northridge (NOR) – 1994, M = 6.7, # of seismic events = 11252
3) Hector Mine (HM) – 1999, M = 7.1, # of seismic events = 16360

Statistical Measures	Aftershock Sequences		
	LND	*HM*	*NOR*
$< M >$	2.52	2.50	2.6
D_0 (Eq. 1)	1.61	1.51	1.46
M_{max}	6.3	5.8	5.6
M_c	2.1	2.1	2.1
b (Eq. 3)	1.0	1.03	0.94
q (Eq. 5)	1.49	1.47	1.49
$H(\Delta)$ (Eq. 2)	0.64	0.67	0.62
p_{MOL} (Eq. 4)	1.43	1.32	1.32

TABLE III
STATISTICAL MEASURES FOR THE REAL AFTERSHOCK SEQUENCES.

SYNTHETIC DATA

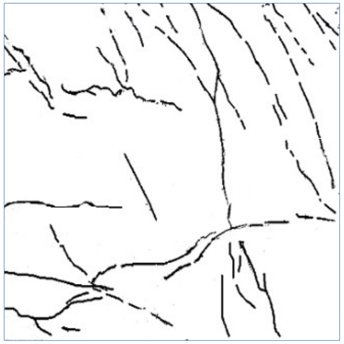
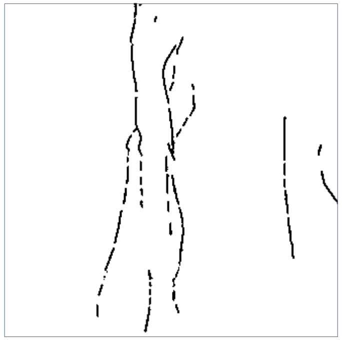
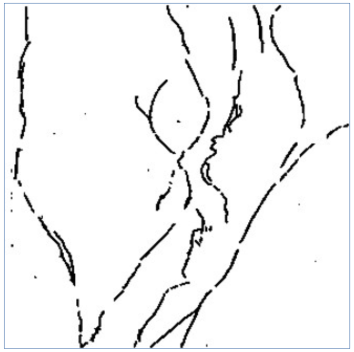
P: initial organization probability
π: transfer value
N: lateral grid size

Simulation

Input Parameters

(P, N, π_{frac})

+

Seismic catalog

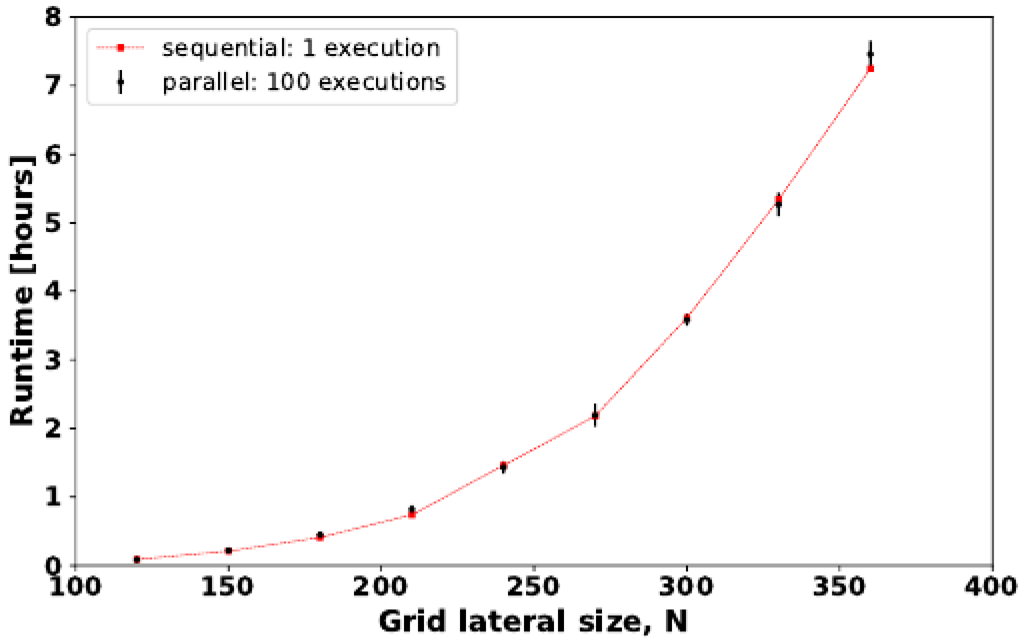
Event ID	*X*	*Y*	*Ruptured Area [cells]*	*time [dimensionless]*
1	7	30	30	0.946E-04
2	45	66	15	0.284E-02
3	14	22	65	0.556E-01
...	...	...	...	...
2540	87	72	9	0.125E+04

Statistical values

	Aftershock Sequences		
	LND	***HM***	***NOR***
Params. / Stat. Vals.	$P = 0$ $N = 240$ $\pi_{frac} = 0.95$	$P = 0$ $N = 240$ $\pi_{frac} = 0.85$	$P = 0$ $N = 210$ $\pi_{frac} = 0.85$
$< M >$	2.37 ± 0.01	2.32 ± 0.01	2.30 ± 0.01
D_0 (Eq. 1)	1.61 ± 0.01	1.61 ± 0.01	1.52 ± 0.01
M_{max}	5.87 ± 0.21	4.9 ± 0.48	5.49 ± 0.36
M_{min}	$2.06 \pm$ 1.21e-7	$2.07 \pm$ 1.14e-7	$2.06 \pm$ 1.21e-7
b (Eq. 3)	0.73 ± 0.06	1.07 ± 0.17	0.78 ± 0.10
q (Eq. 5)	1.61 ± 0.03	1.50 ± 0.05	1.57 ± 0.03
$H(\Delta)$ (Eq. 2)	0.52 ± 0.03	0.53 ± 0.03	0.52 ± 0.02
p_{MOL} (Eq. 4)	1.21 ± 0.58	1.12 ± 0.27	1.29 ± 0.46

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

High Performance Computing



FBM is sequential

Mare Nostrum 4 supercomputer
Total peak performance:
13,7 Pflops/s

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Machine Learning

- Support Vector Machines (SVM) with radial basis kernel and sigmoid kernel

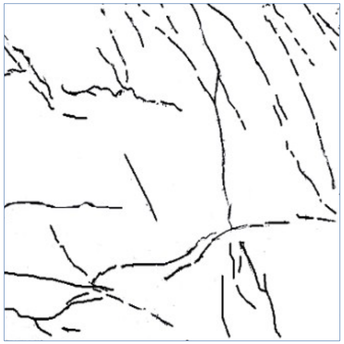
- Flexible Discriminant Analysis (FDA)

- Random Forest (RF)

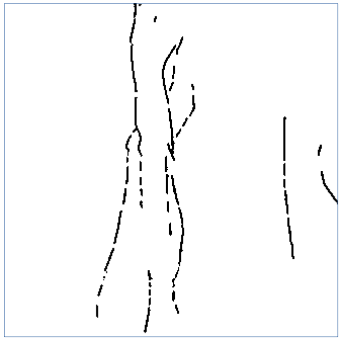
```
Data: feature set
Result: average performance
initialization;
while i = 1 to 50 do
    # Apply cross validation;
    performance = CrossValidation(sampled, classifier,
     k=5);
end
# return the average performance;
avg-performance;
```

Experimental Setting

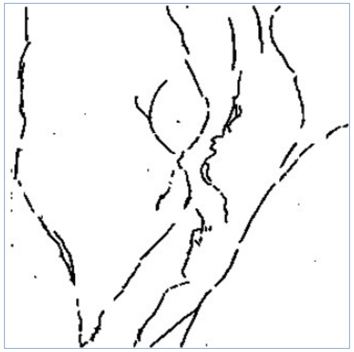
1) Three geometrical Fault Configurations



LND



HM



NOR

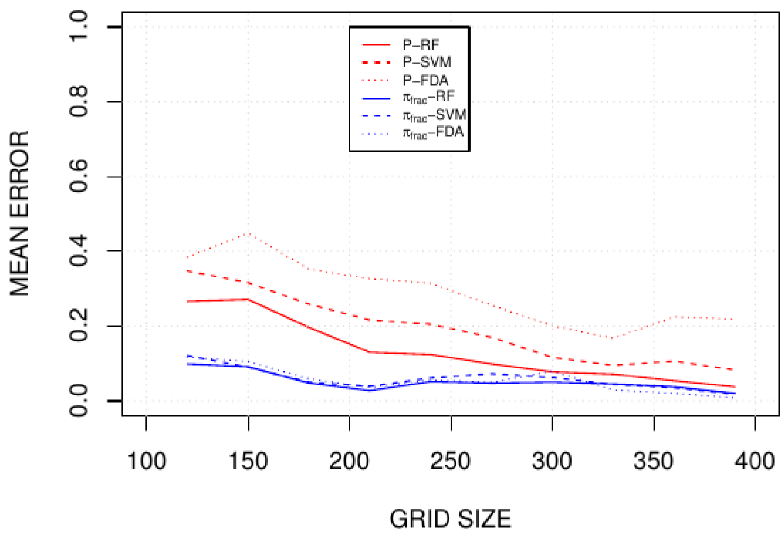
2) Parameters

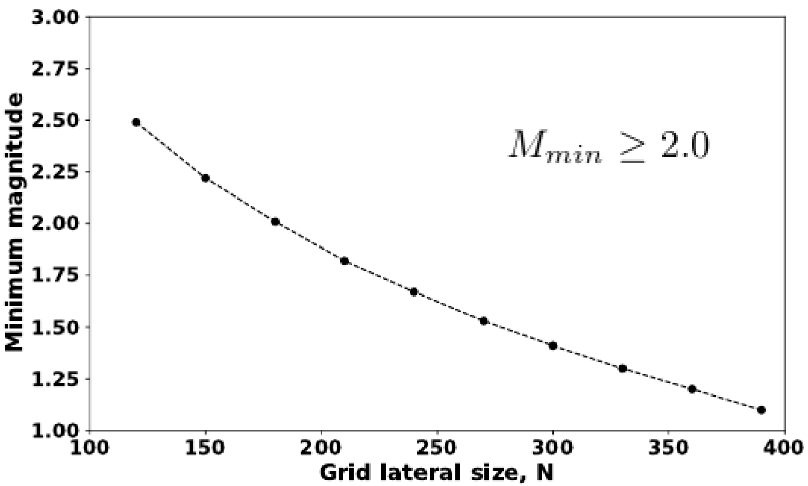
P = [0.0, 0.08, 0.16, 0.24]
π = [0.65, 0.75, 0.85, 0.9, 0.95]
N = [120,150,180,210,240,270,300,330,360,390]

Results

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Experiment 1: Grid size and minimum magnitude

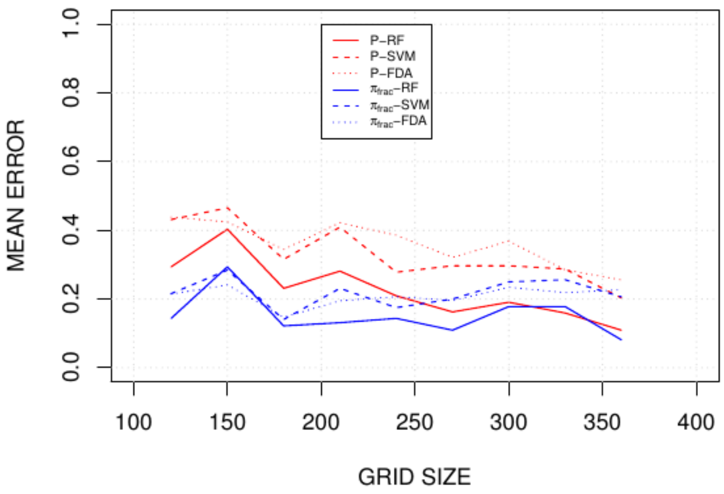




Larger N satisfies smaller minimum magnitudes, but larger grid size requires more computational hours to execute the simulation

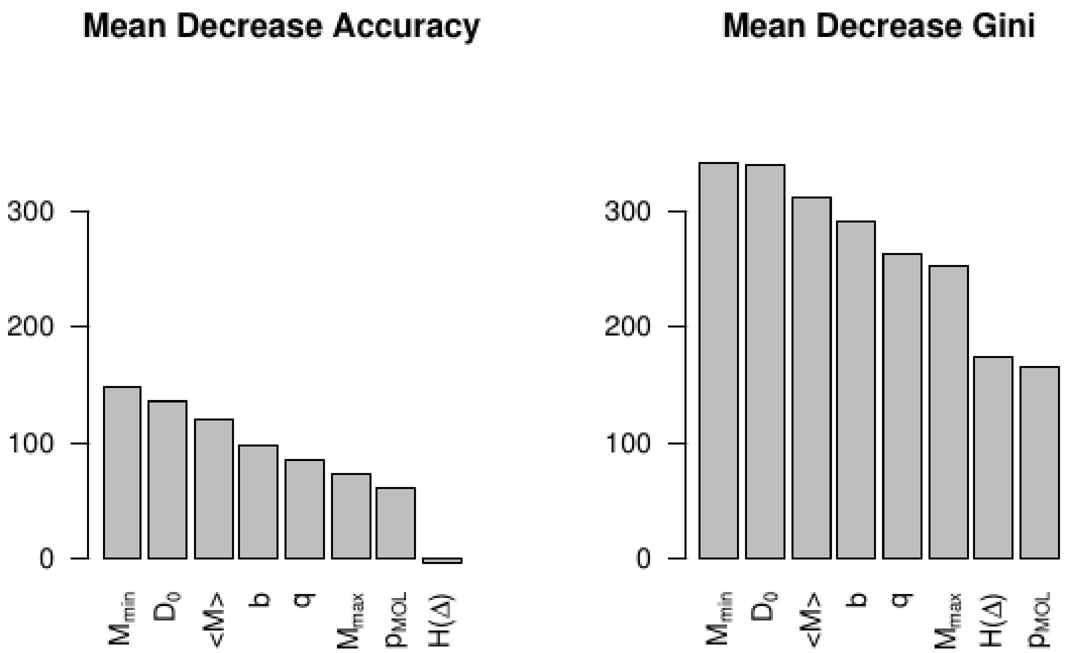
CLASSIFICATION CRITERIA

P: initial organization probability
π: transfer value



Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Experiment 2: Selecting most important aftershock statistical values.



Magnitude Features: M_{min} , < M >, b, q

Fractal Dimension: D_0

Experiment 3: Estimating optimal FBM parameters

- Used important features
- Trained with synthetic sequences
- Classification label (P , π_{frac} , and N)

Params. / Stat. Vals.	Aftershock Sequences		
	LND	*HM*	*NOR*
	$P=0$, $N=240$, $\pi_{frac}=0.95$	$P=0$, $N=240$, $\pi_{frac}=0.85$	$P=0$, $N=210$, $\pi_{frac}=0.85$
$<M>$	2.37 ± 0.01	2.32 ± 0.01	2.30 ± 0.01
D_0 (Eq. 1)	1.61 ± 0.01	1.61 ± 0.01	1.52 ± 0.01
M_{max}	5.87 ± 0.21	4.9 ± 0.48	5.49 ± 0.36
M_{min}	$2.06 \pm$ 1.21e-7	$2.07 \pm$ 1.14e-7	$2.06 \pm$ 1.21e-7
b (Eq. 3)	0.73 ± 0.06	1.07 ± 0.17	0.78 ± 0.10
q (Eq. 5)	1.61 ± 0.03	1.50 ± 0.05	1.57 ± 0.03
$H(\Delta)$ (Eq. 2)	0.52 ± 0.03	0.53 ± 0.03	0.52 ± 0.02
p_{MOL} (Eq. 4)	1.21 ± 0.58	1.12 ± 0.27	1.29 ± 0.46

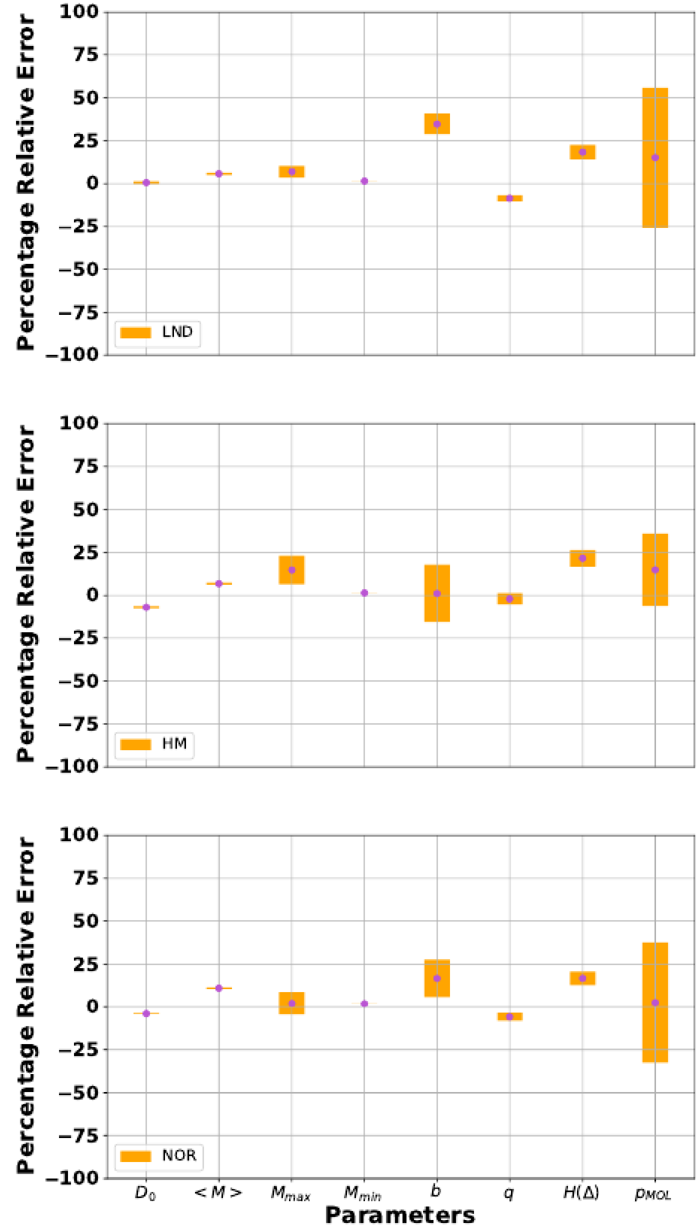
Statistical Measures	Aftershock Sequences		
	LND	*HM*	*NOR*
$<M>$	2.52	2.50	2.6
D_0 (Eq. 1)	1.61	1.51	1.46
M_{max}	6.3	5.8	5.6
M_c	2.1	2.1	2.1
b (Eq. 3)	1.0	1.03	0.94
q (Eq. 5)	1.49	1.47	1.49
$H(\Delta)$ (Eq. 2)	0.64	0.67	0.62
p_{MOL} (Eq. 4)	1.43	1.32	1.32

TABLE III

STATISTICAL MEASURES FOR THE REAL AFTERSHOCK SEQUENCES.

N > 210

Sufficiently large



Conclusions and future work

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

CONCLUSIONS

- ML is an efficient tool for parameter screening
- ML is a useful tool to study the properties of the FBM model.
- HPC and ML enables us to model highly realistic series of aftershocks, indistinguishable from real ones by the standard seismological measures
- opens the possibility of producing longer and most complex studies involving decades of observations and larger study areas

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

FUTURE WORK

- increase number of real aftershock sequences with the aim of generalizing our methodology.
- Artificial Neural Networks will be tested and compared to the algorithms used in the present work.
- use partially learned ML models to drive parameter exploration of simulation runs in order to reduce the number of simulations needed to approximate a mapping between FBM parameters and earthquake statistics.
- development of a software package that contains not only the simulator but also the optimal parameter screening

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

EXCELENCIA SEVERO OCHOA

Thank you

Barcelona
Supercomputing
Center
Centro Nacional de Supercomputación

EXCELENCIA
SEVERO
OCHOA