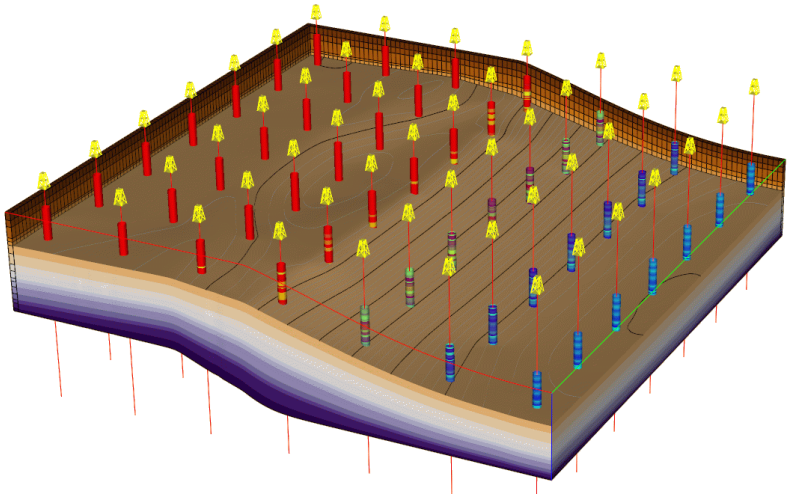
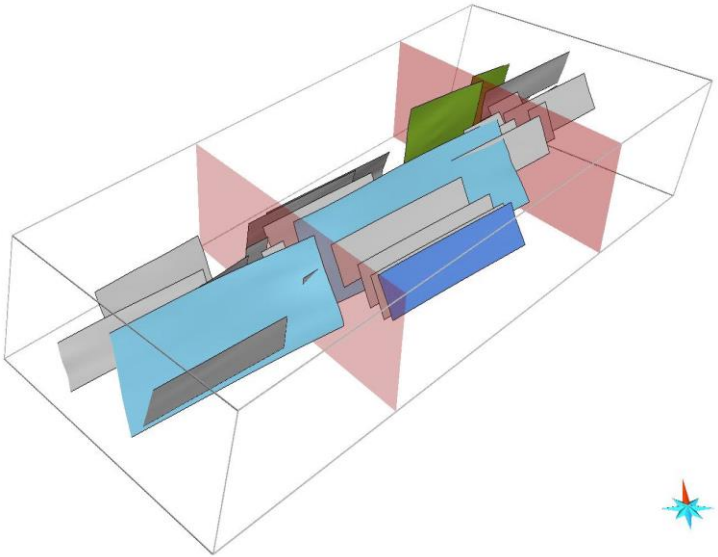
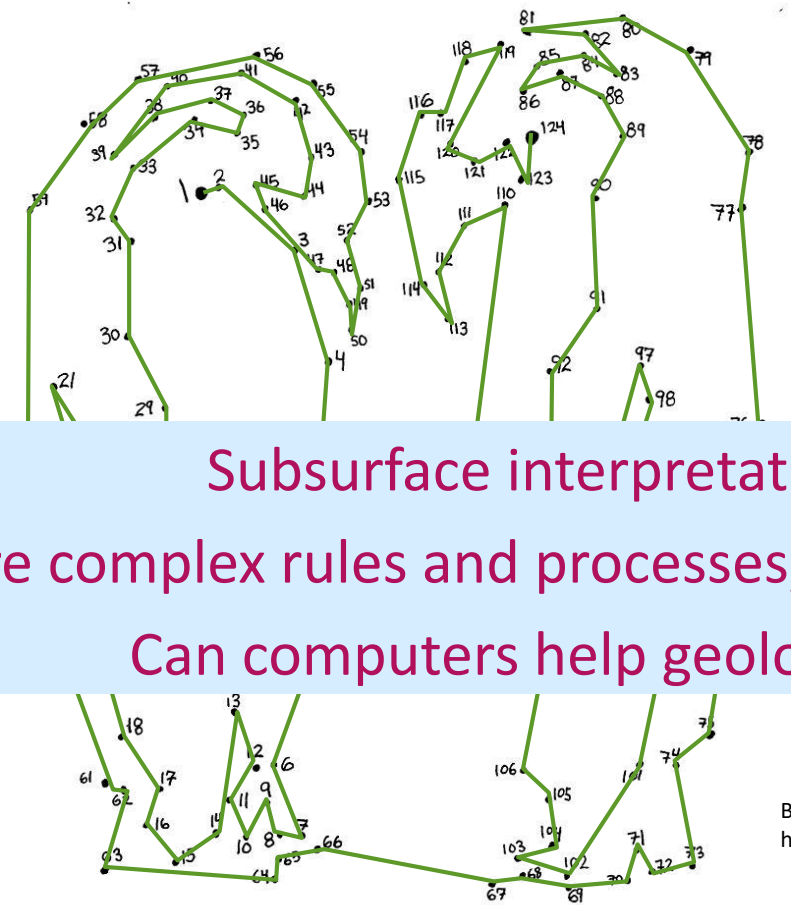
ASSOCIATION DE DONNÉES ÉPARSES : CORRELATION ET DE MODÉLISATION DES INCERTITUDES





Guillaume Caumon, F. Lallier, J. Edwards, G. Godefroy, P. Baville, C. Antoine, P. Marchal, C. Carpentier, M. Apel, S. Hoth, J. Borgomano, F. Fournier., S. Viseur

Interpretation…



Rule: increment number

- 124! itérations = 1.5^{207}

Strategy : search locally

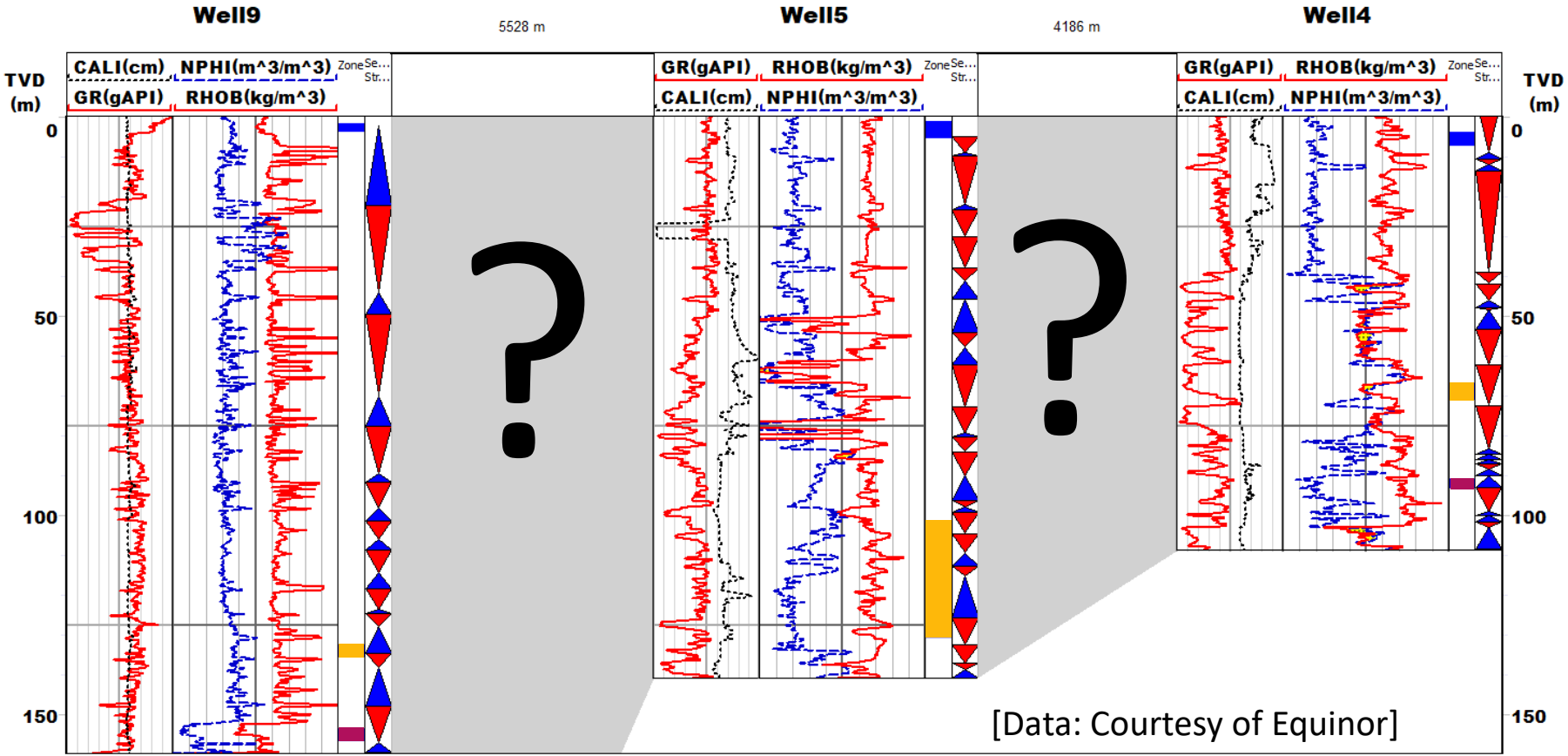
Subsurface interpretation:

More complex rules and processes, and reasoning.

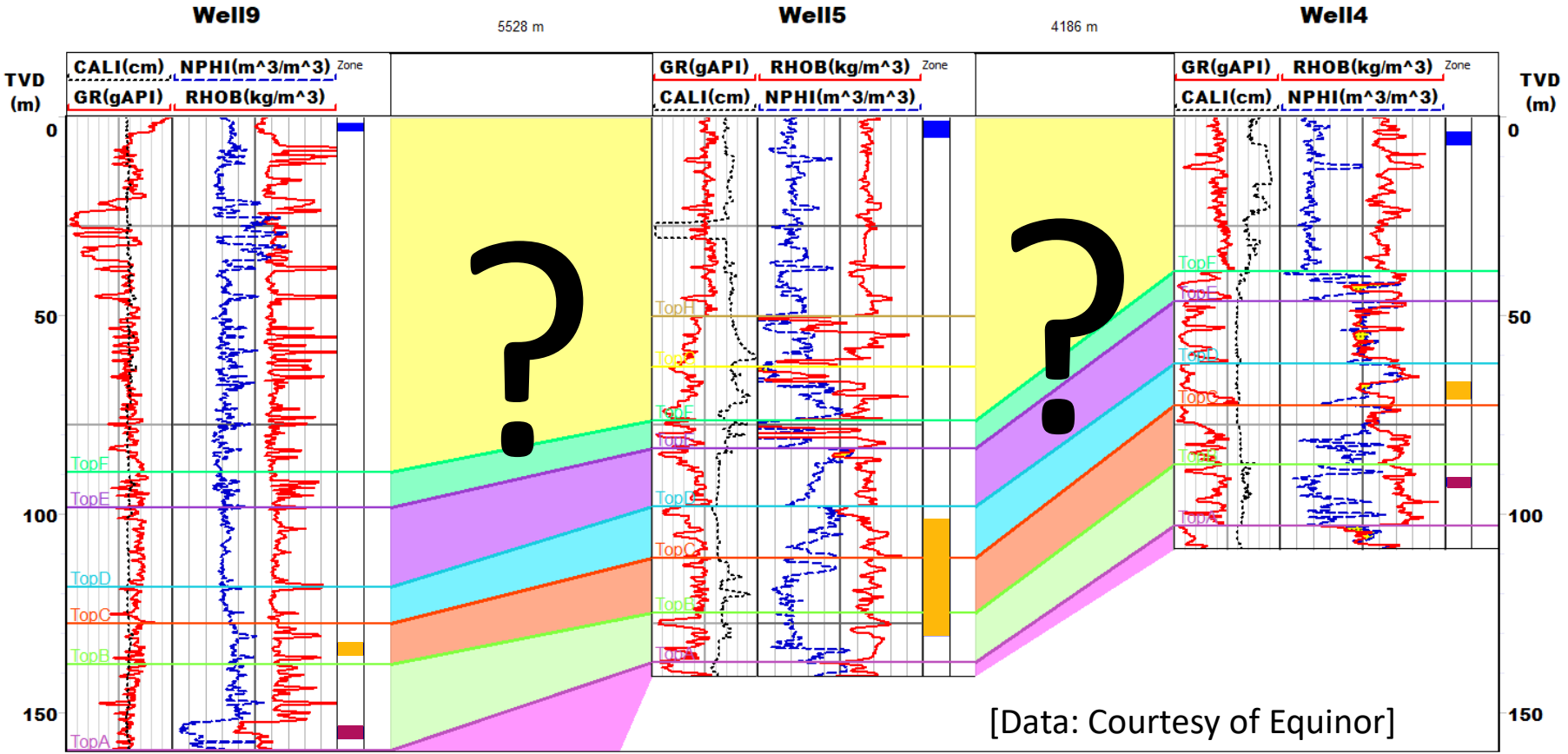
Can computers help geologists ?

By whitney waller - connect-the-dots, CC BY-SA 2.0, https://commons.wikimedia.org/w/index.php?curid=45762268

The well correlation problem



The well correlation problem



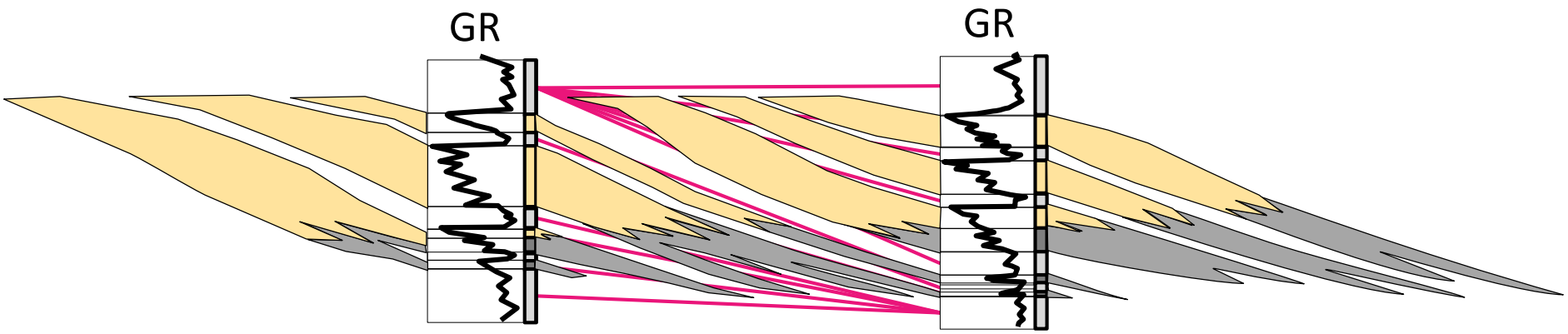
Motivation

“In developing the multiple hypotheses, the effort is to bring up into view every rational explanation of the phenomenon in hand […]

The chief danger that springs from affection is counteracted”

T.C. Chamberlin, *The method of Multiple working hypotheses, 1897*

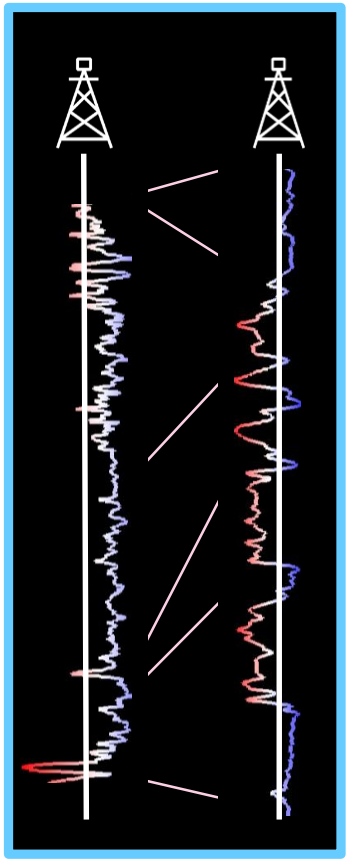
Formalizing the problem



[Modified from Ainsworth *et al.* 1999]

1. Selecting data and resolution → 1D samples [e.g. Ruiz & le Nir 1996, Perrier et al, RM 2021]
2. Associating samples = correlation – This talk
3. Determining geometry [Geomodeling software]

Research question (1): harnessing complexity



Very large number of possibilities

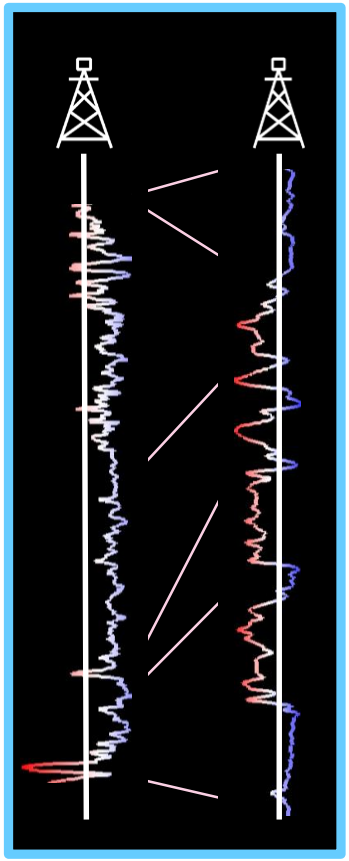
$$D_{n,m} = D_{n,m-1} + D_{n-1,m} + D_{n-1,m-1}$$ Delannoy number

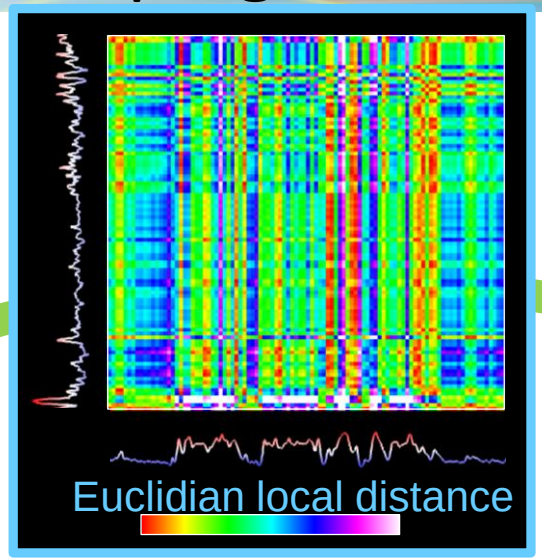
$$D_{10,10} = 1{,}462{,}563$$

[Lallier et al CR Geosci 2016]

Dynamic time warping finds the optimal solution

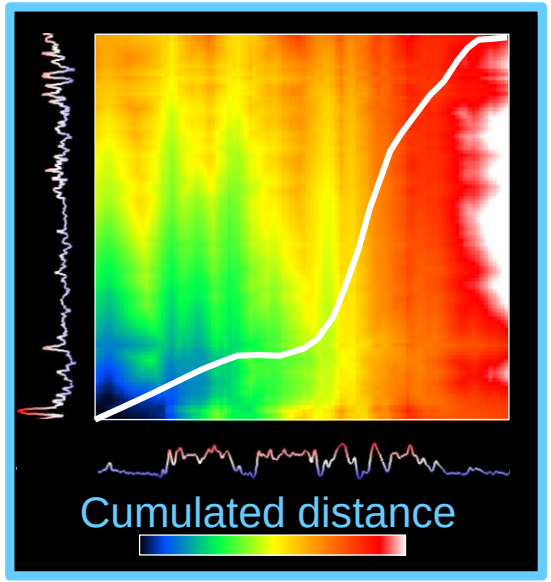
[Images: From Lallier, 2012]





$$d(i,j) = \sqrt{\left(Z(y_j) - Z(x_i)\right)^2}$$

[Sakoe & Chiba, 1978]
[Smith & Waterman, 1980]
[Waterman & Raymond 1987]
[Fang et al, 1992]
[Wheeler & Hale 2014]
[Lallier et al, 2012; 2015]



N wells?

HUGE number of possibilities

For 12 wells with 7 markers:

$$D_{7,7,7,7,7,7,7,7,7,7,7,7,} \simeq 10^{80}$$

[Lallier et al CR Geosci 2016]

→ Prohibitive RAM / CPU for N-dimensional DTW

[From Edwards, 2018]

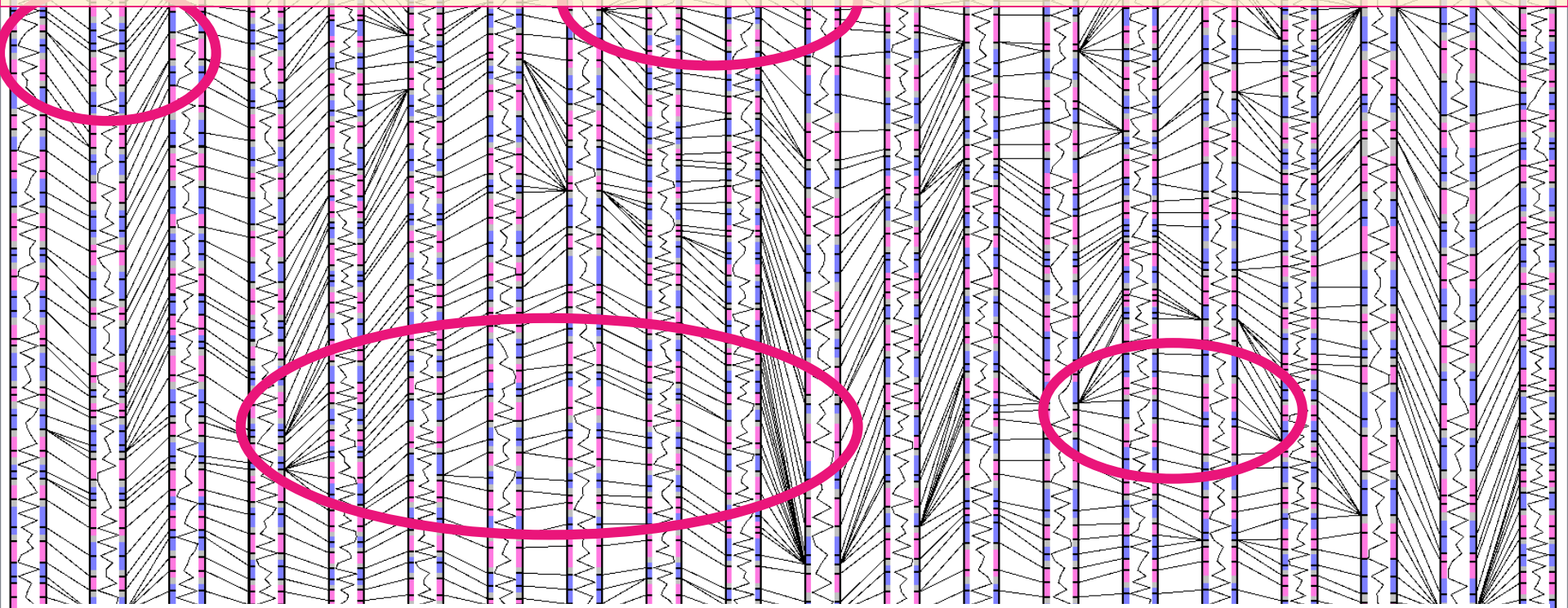
WeCo : a hierarchical multi-well correlation [Antoine & Caumon, RING Meeting 2018]

- Hierarchical correlation path
- Correlate sets of solutions

20 wells ~118 samples / well → 512 best solutions (>2 differences)

~15 minutes on a 4-core i7 machine (Intel Core i7-6700HQ)

Peak Memory usage ~30 GB



WeCo : a hierarchical multi-well correlation [Antoine & Caumon, RING Meeting 2018]

Research question (2): What concepts/rules?

- Logs, lithostratigraphy [Waterman & Raymond, MG 1986; Fang et al, AAPG Bull 1992; Olea, MG 1994; Lallier et al, GSL SP 2012]
- Pollens [Pels, P^3 1996]
- Magnetostratigraphy [Lallier et al, EPSL 2013]
- Paleo-slope [Borgomano et al, AAPG Bull 2008; Lallier et al, CR Geosci 2016]
- Seismic [Julio et al, Geostats Oslo 2012; Wu & Caumon, Geophys 2016]
- Training-based with FSM [Edwards et al, C&G 2018]

- Paul Baville's PhD : transport directions
  - Walther's law & distality [AAPG 2020, MPG 2021]
  - Dipmeter data and paleogeography [RINGMeeting 2021, IAMG2022]

Correlation impact: sedimentology & heterogeneity

Paleo-environments

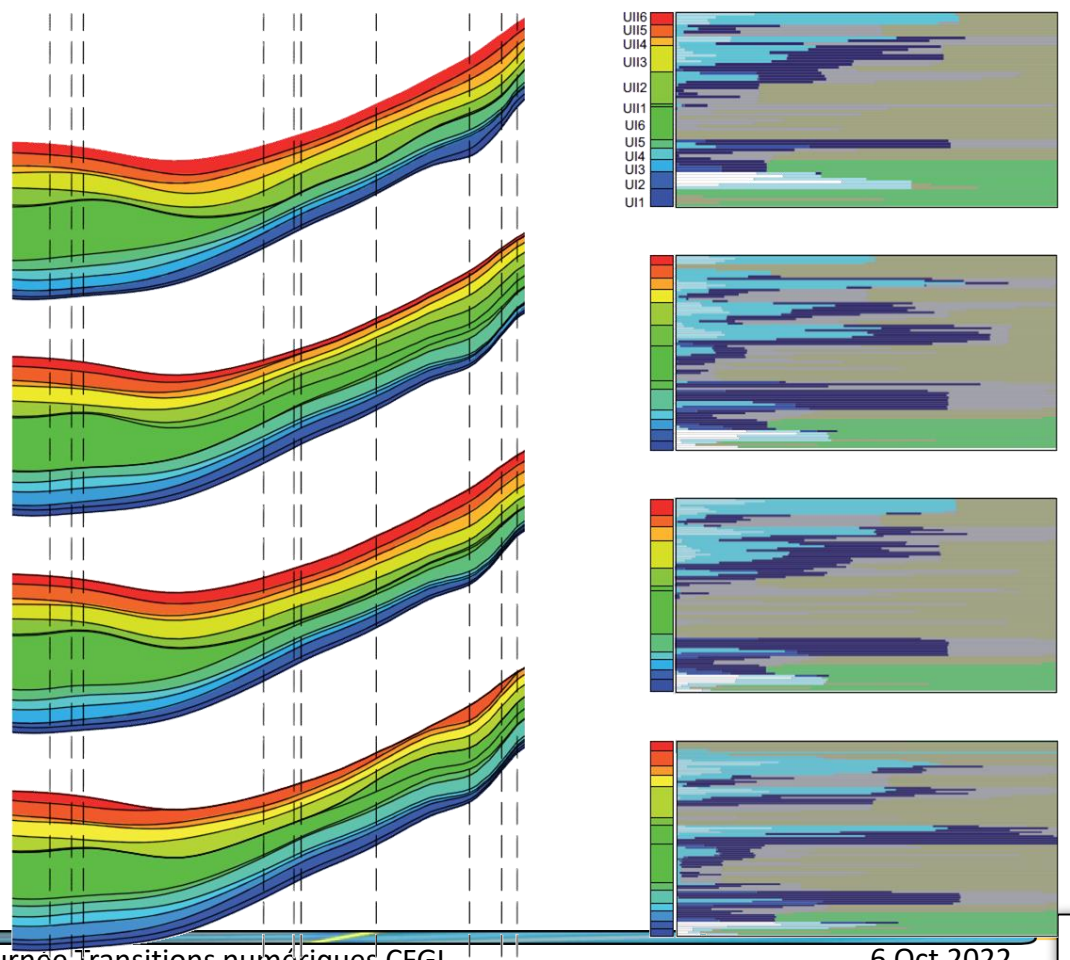
Stratigraphic architecture

Control parameters

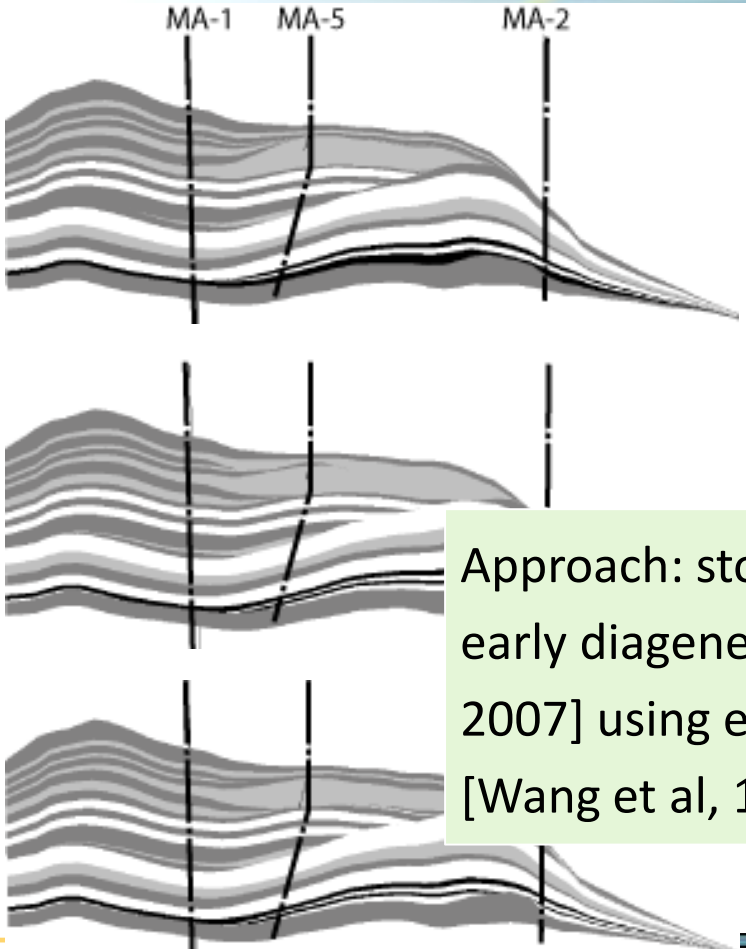
Vertical proportion curves

[Image: Lallier et al, CR Geosci 2016]

Approach: stochastic correlation using facies zonation and carbonate slope profiles.



Correlation impact – multiphase flow



Model 1

Model2

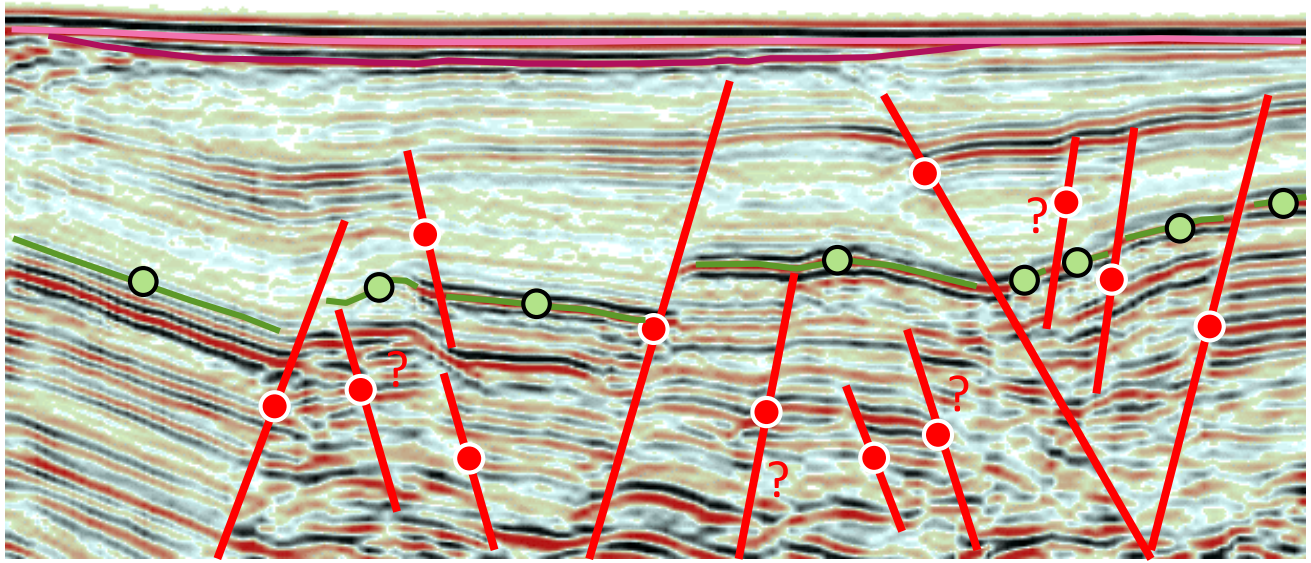
[Lallier et al, GSL SP 2012]

Water flooding models

Approach: stochastic correlation using of early diagenetic units [Fournier et al, 2007] using electrofacies signatures [Wang et al, 1992]

Part 2: Fault uncertainty

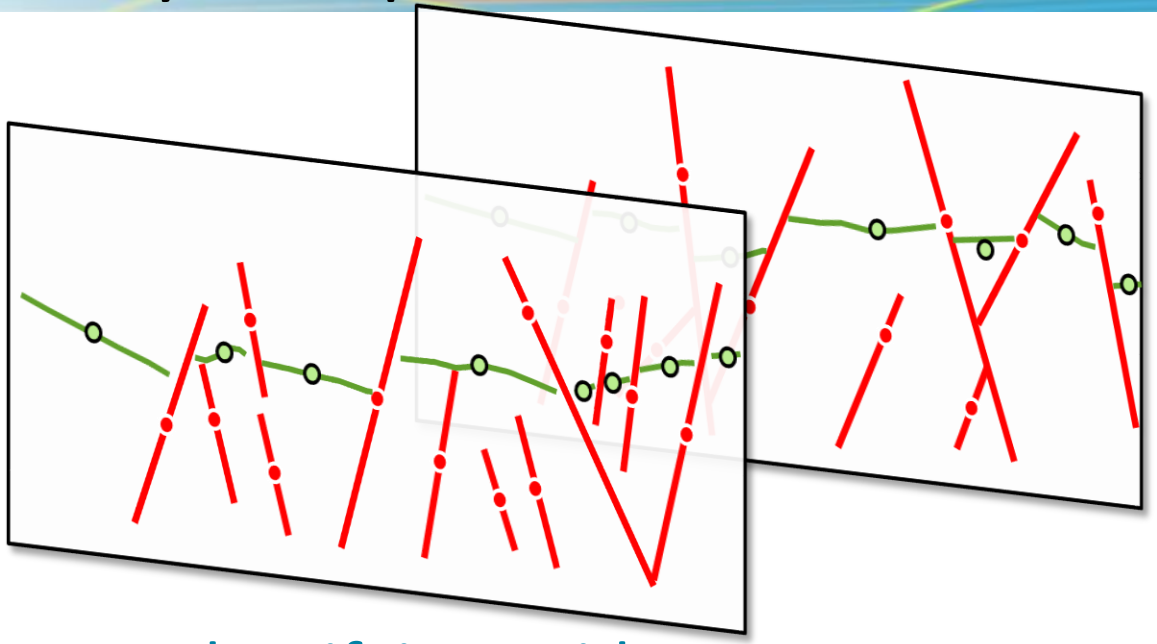
Fault uncertainty: components



[Data: Taylor et al, *GJI* 2010]

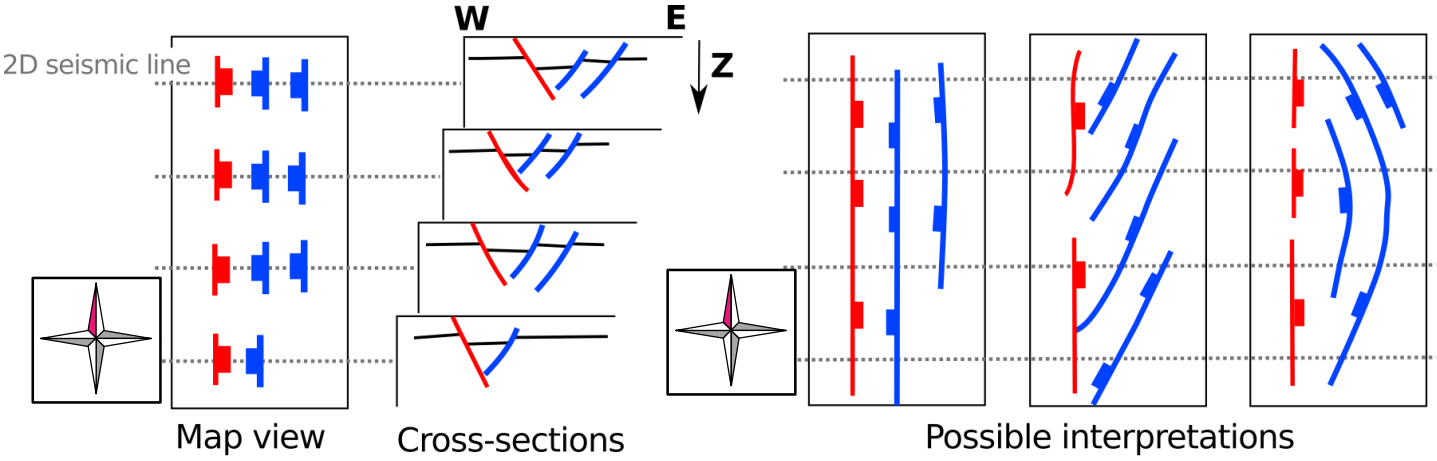
1. Identifying evidence

Fault uncertainty: components

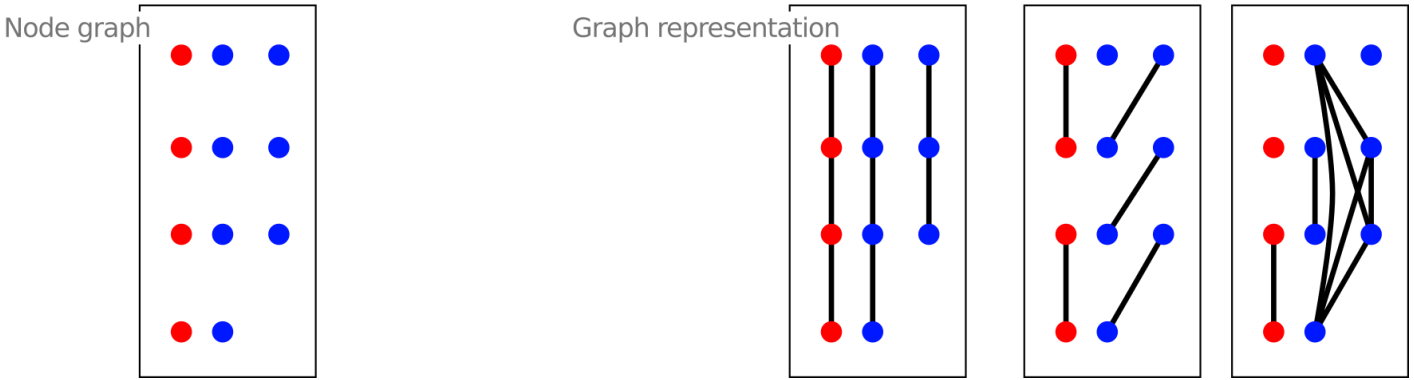


1. Identifying evidence
2. Associating evidence
3. Modeling & QC

Fault association as a graph creation problem



[Modified from **Freeman et al.**, *First Break*, 1990]



[Godefroy et al, Math Geosci, 2019]

Number of combinations

From **n** observations…

[Godefroy et al, Math Geosci, 2019]

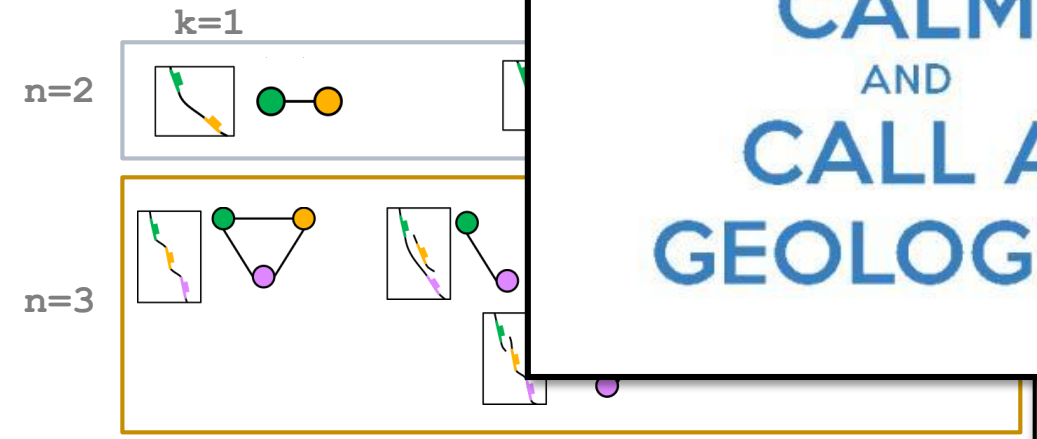
…to k faul … any number of faults

$S(n,k)$ Stirling … Bell number

k Number of …

n Number of …

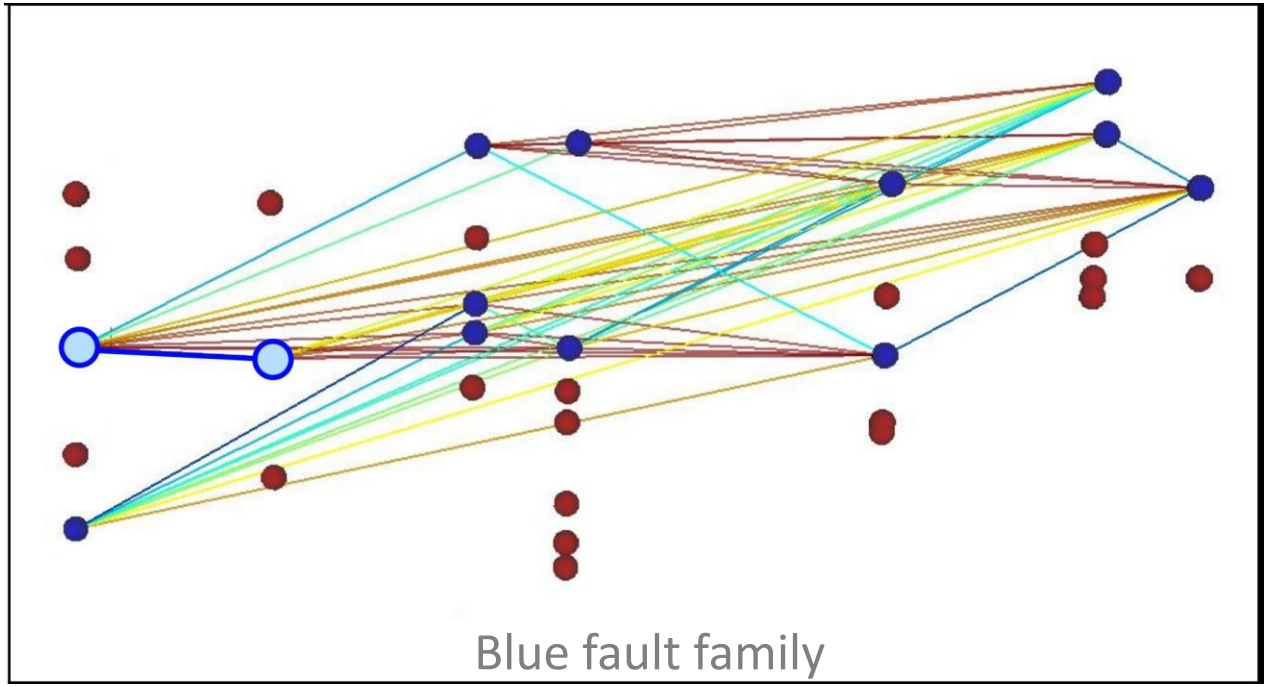
$= \sum_{k=1}^{n} S(n,k)$



2	3	4	13
2	5	15	2.8e7

Detecting possible structures: the possibility graph

[Godefroy et al, Math Geosci, 2019]



Blue fault family

Node

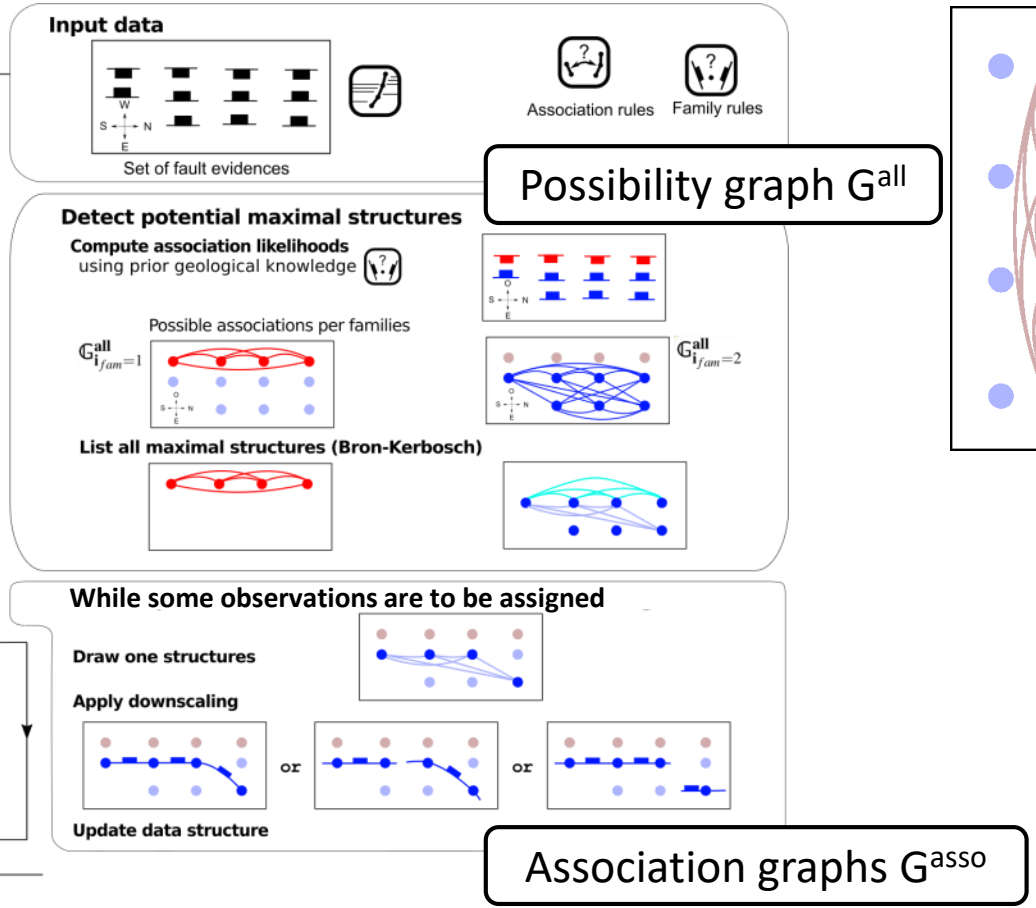
Fault evidence
(Point, line, surface)
+ information
(e.g., family
displacement,
probability of
existence)

Edge

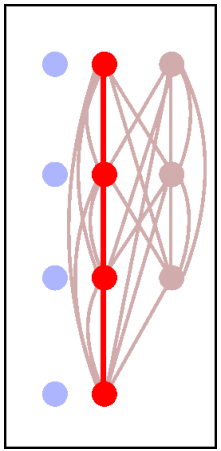
Association likelihood

Graph algorithm for structural uncertainties appraisal

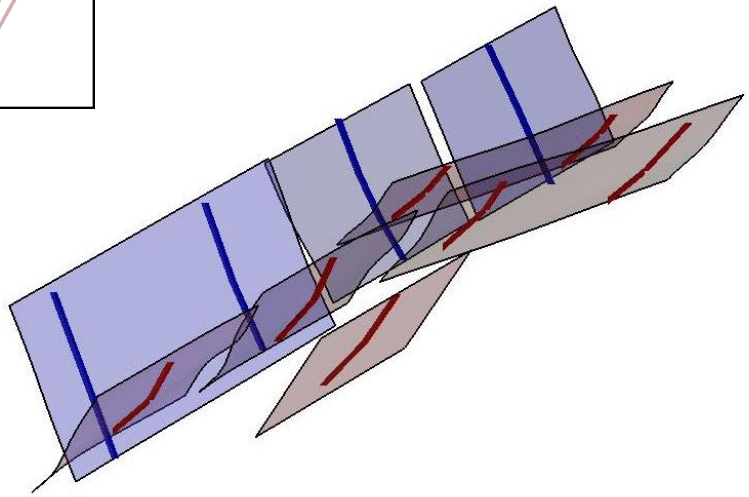
[Godefroy et al, JGR 2021]



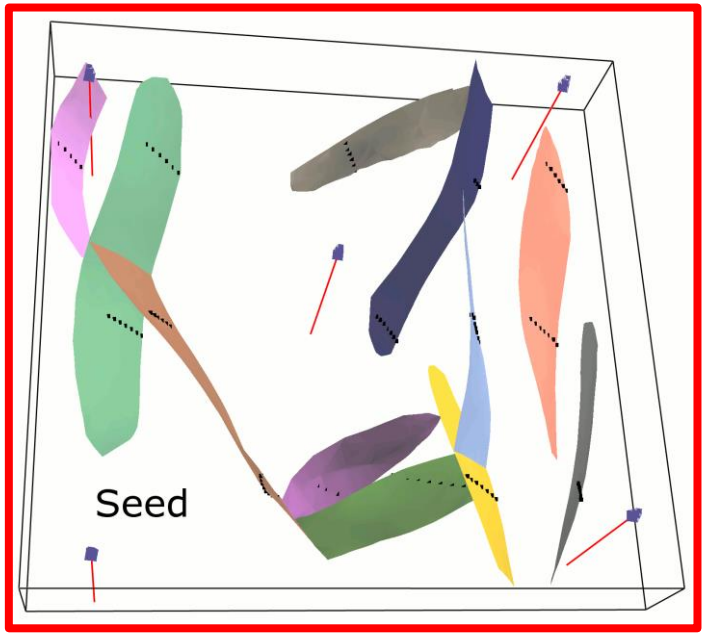
Possibility graph G^{all}

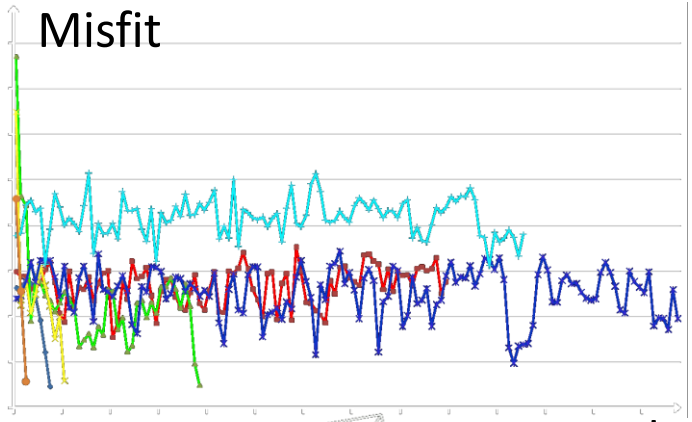


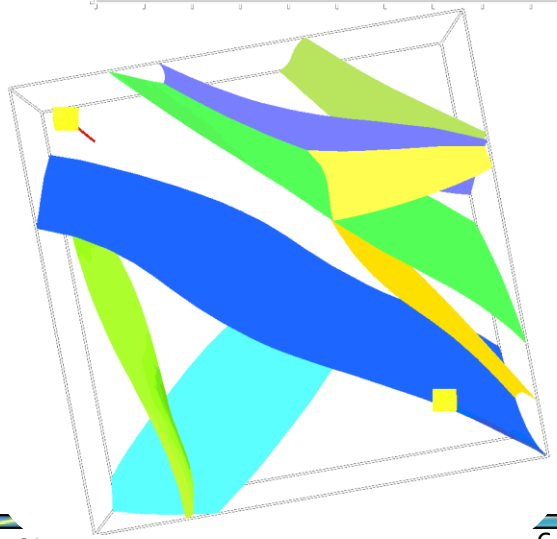
Association graphs G^{asso}



Reducing uncertainty : history matching







[Cherpeau et al, *Math Geosci* 2012]

Conclusions

- Topological uncertainties in Structural & Stratigraphic interpretation can be sampled
  - Unconformities, compartmentalization
- Graph framework + sampling algorithms
  - Abstraction and efficiency → model clustering, AI

    [Oumar et al, Fratani et al, RING Meeting 2022]
  - Generative methods, then interpolation / geometry
- Pending questions
  - More interpretation rules
  - Multiple-point interactions
  - Automation for uncertainty management

Thanks

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+ 111 universities and surveys

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