DATA DRIVEN SELECTION OF INDEPENDENT EDGES APPICATIONS TO LOAD PATH OPTIMISATION

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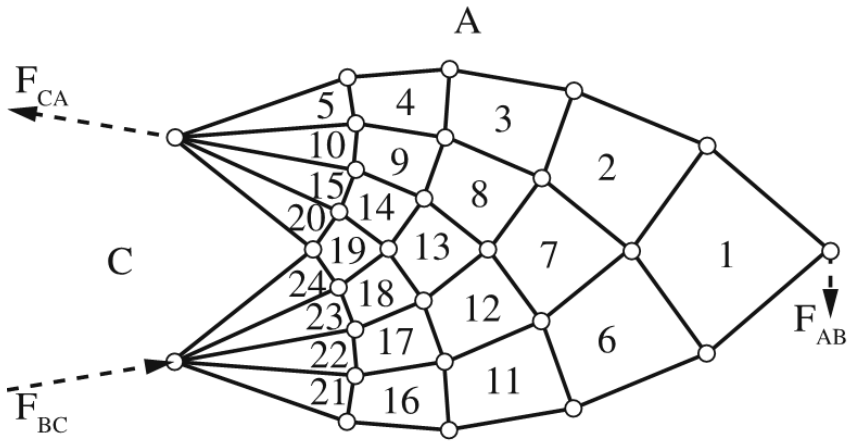
Introduction & Mathematical formulation

LVIII. ***The Limits of Economy of Material in Frame-structures.***
***By* A. G. M. Michell, *M.C.E., Melbourne**.**

Michell (1904)

$$\min \sum_i V_i = \min \sum_i A_i \, l_i = \min \frac{1}{\sigma} \sum_i |F_i| \, l_i \, ,$$



Michell Truss solution for Cantilever Problem.
Baker (2012)

Our Formulation in terms of force densities leads to:

$$\mathbf{q} = \mathbf{L}^{-1}\mathbf{f} \qquad f_i(r) = \mathbf{q}^T\mathbf{L}^T\mathbf{l}$$

Introducing the independent edges concept:

$$\mathbf{q} = \begin{bmatrix} \mathbf{q}_d \\ \mathbf{q}_{id} \end{bmatrix} = \begin{bmatrix} -\mathbf{A}_d^{-1}\mathbf{A}_{id} \\ \mathbf{I}_k \end{bmatrix} \mathbf{q}_{id} = \mathbf{K}\mathbf{q}_{id},$$

Van Mele (2014)

Load path function f written as function of qind:

$$f_i(\mathbf{q}_{id}) = \mathbf{q}^T\mathbf{l}^2$$

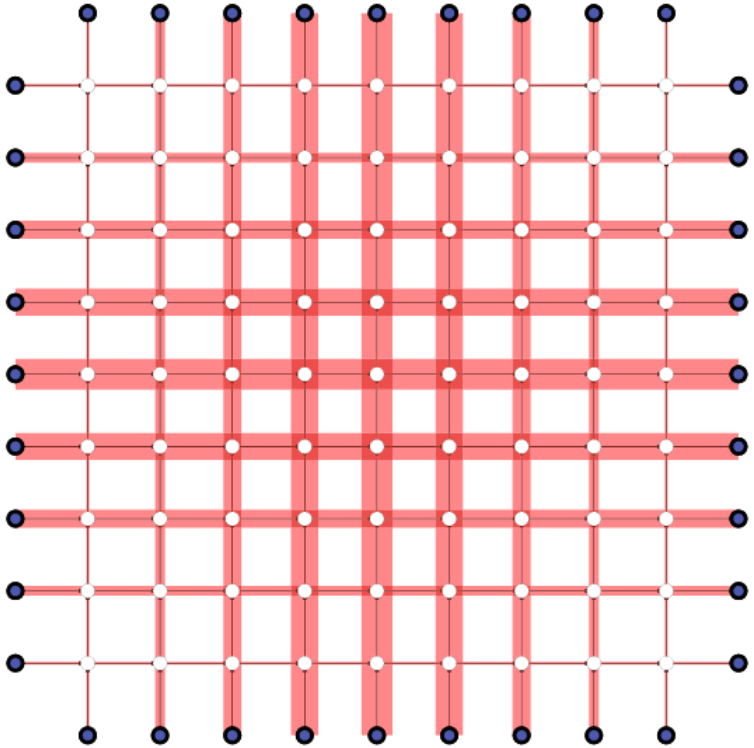
Objective function to minimize:

$$\min_{\mathbf{q}_{id}} \quad f(\mathbf{q}_{id}) \text{s.t.} \quad q_i \geq 0 \quad \forall \quad i \in \{1, 2, \ldots m\}$$

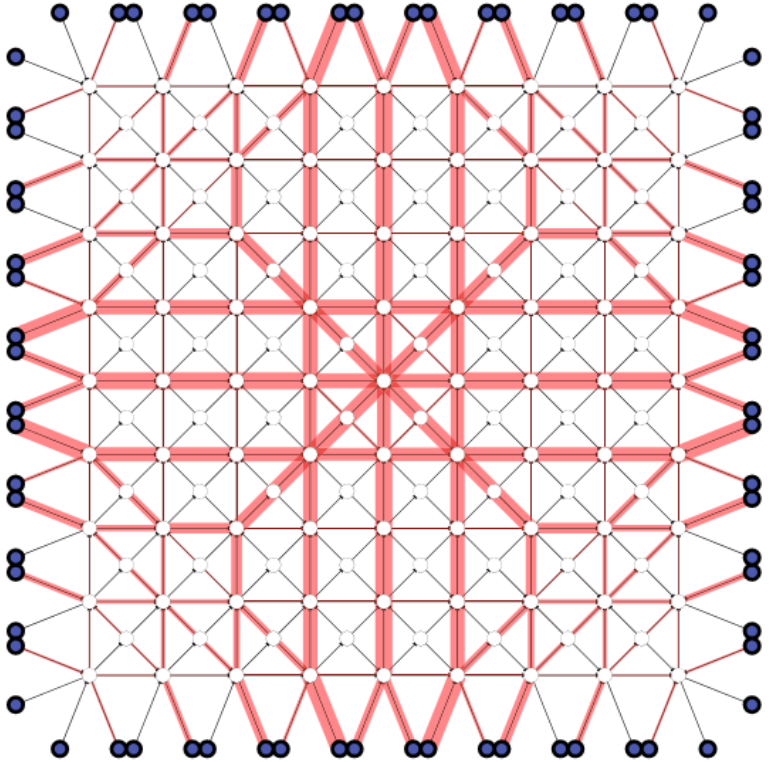
Solvers:

- Differential Evolution (Function Based)
- SLSQP (SciPy – Gradient Based)

Previous work in the group



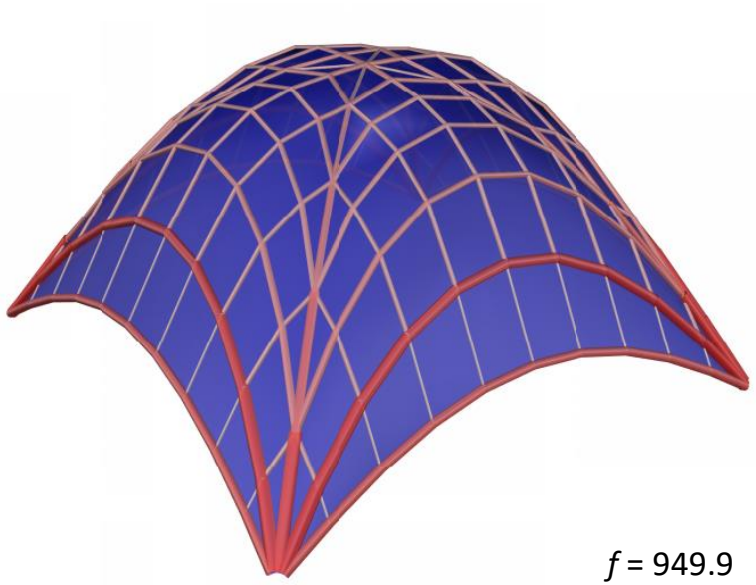
Optimizing material in orthogonal grid
f = 449.4



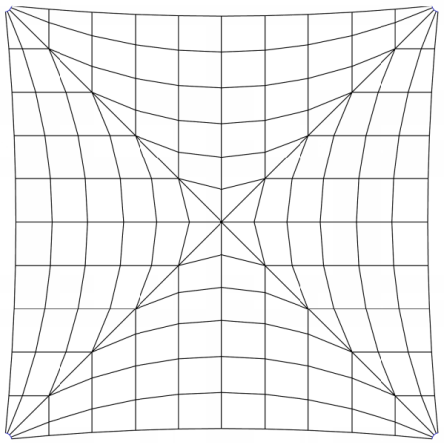
Optimizing pattern for given boundary condition
f = 440.5

Liew A. (2017)

Interest of the research



f = 949.9



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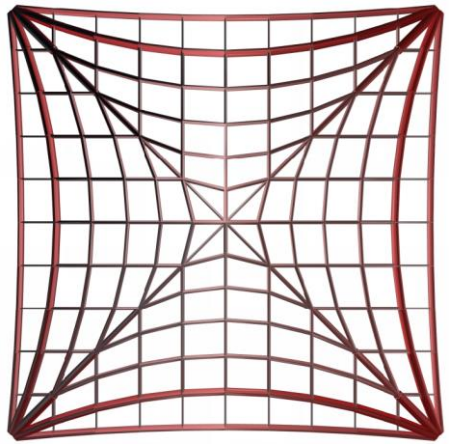

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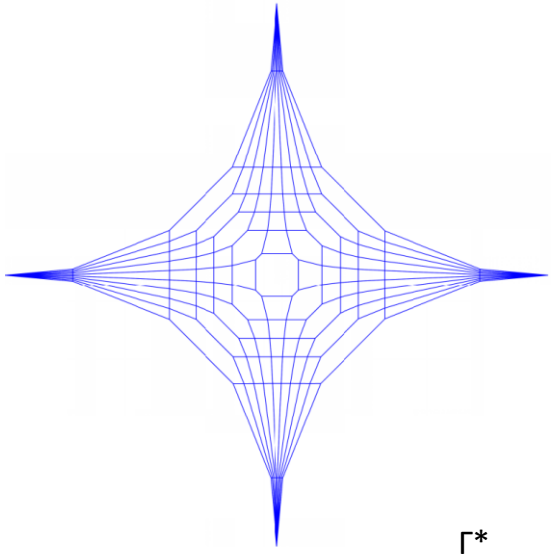

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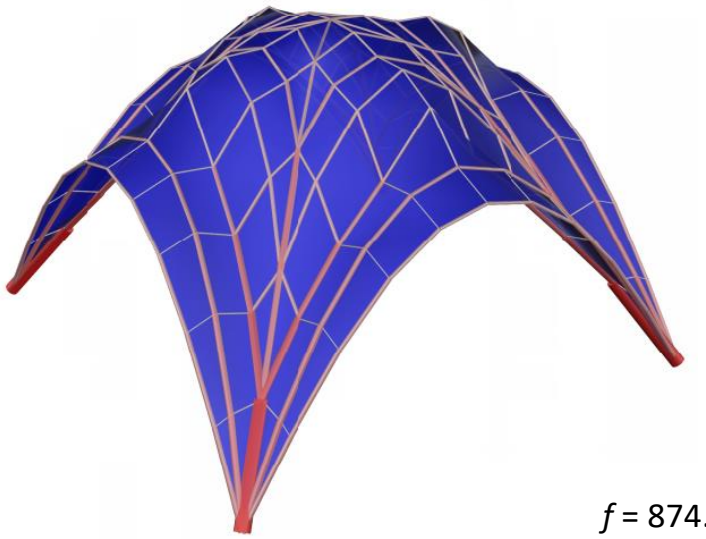
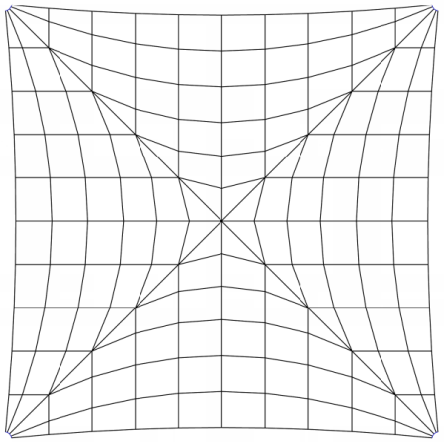


f = 874.2



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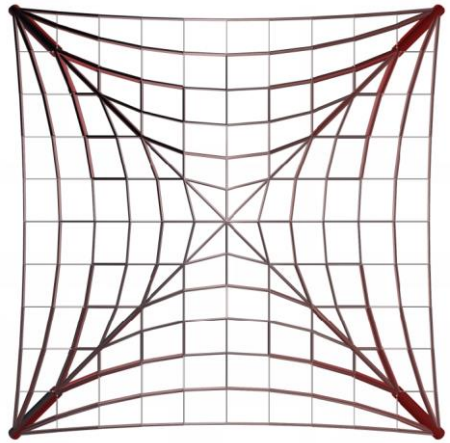

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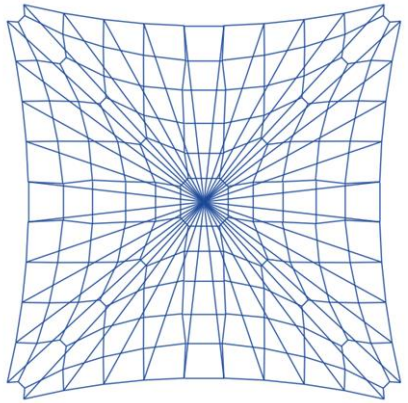
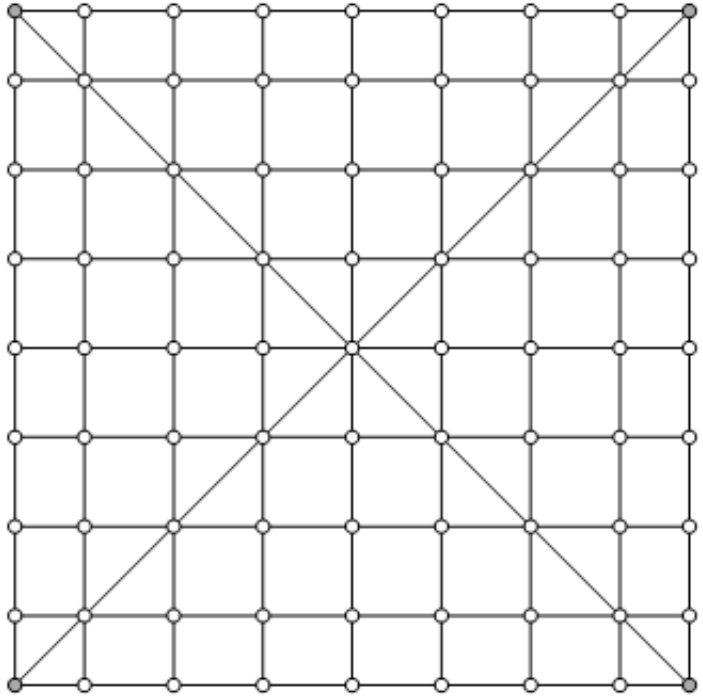
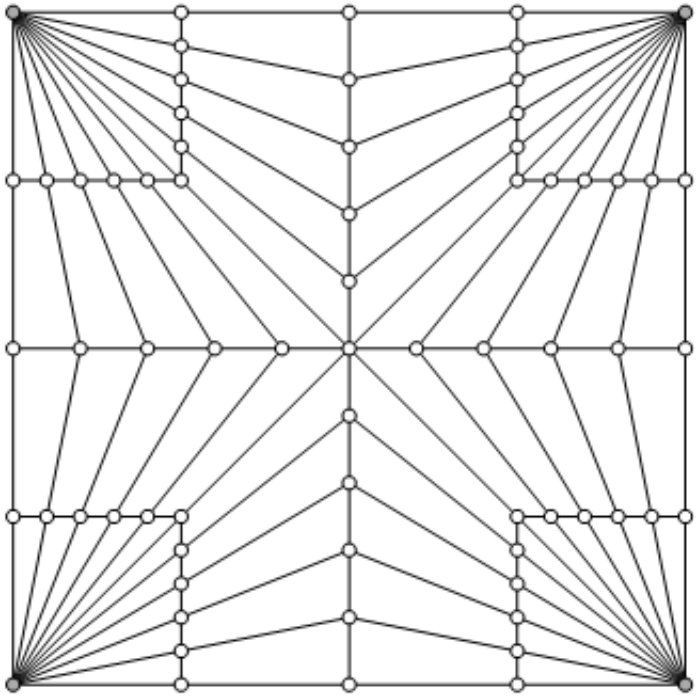


Γ*

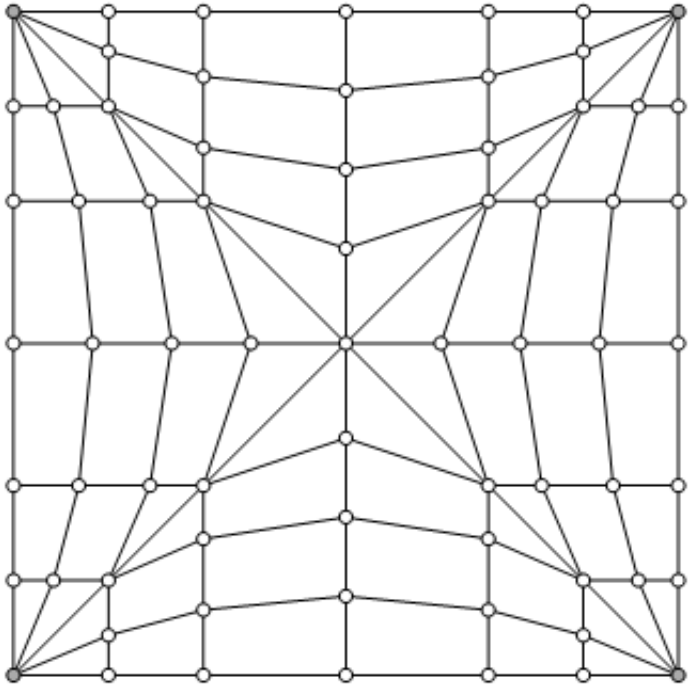
Analysis of Quadripartite Vaults



Simple Grid

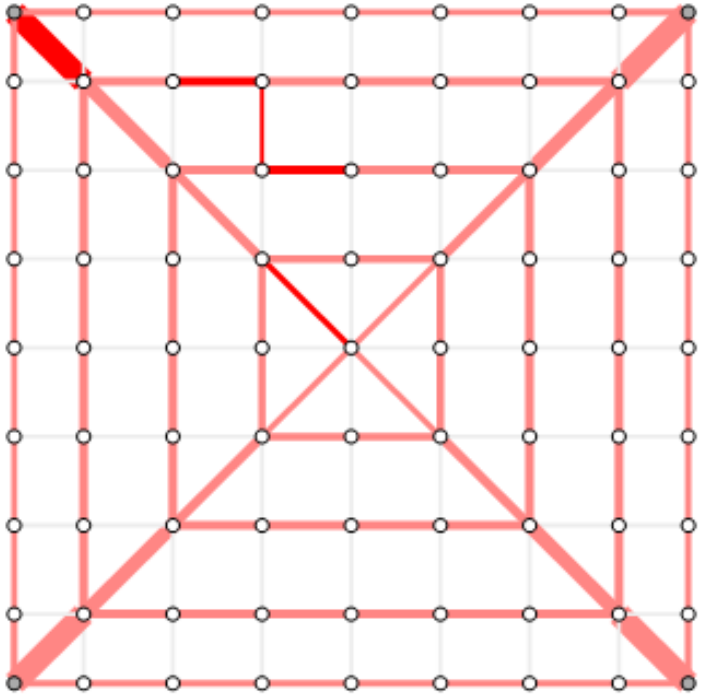


Fan Vaulting



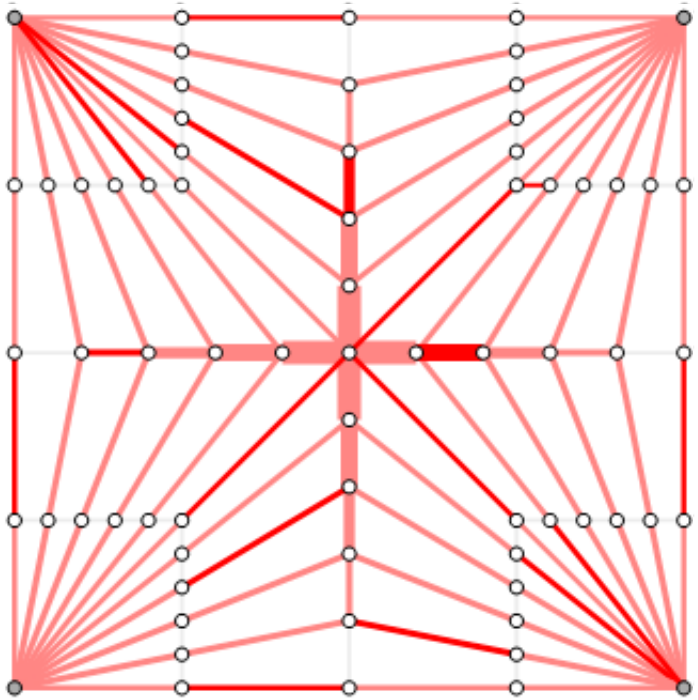
Arcs Pattern

Analysis of Quadripartite Vaults



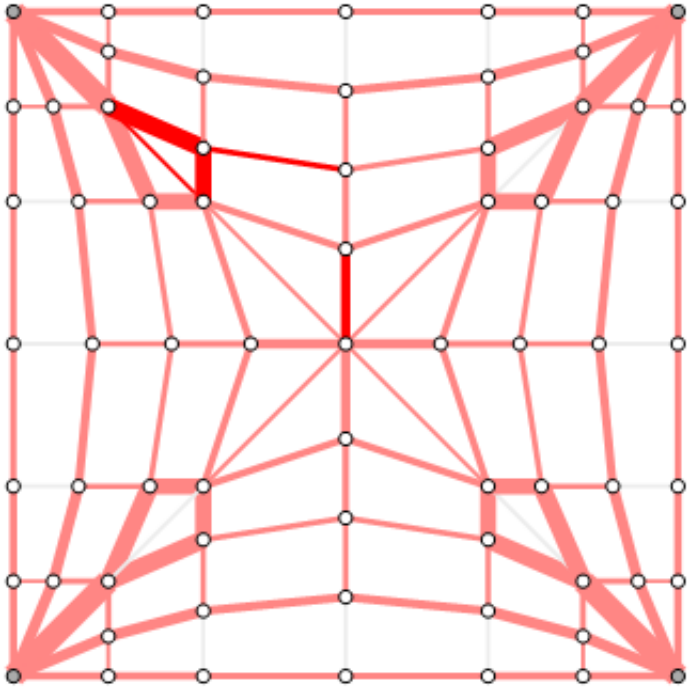
Simple Grid

f = 897.2



Fan Vaulting

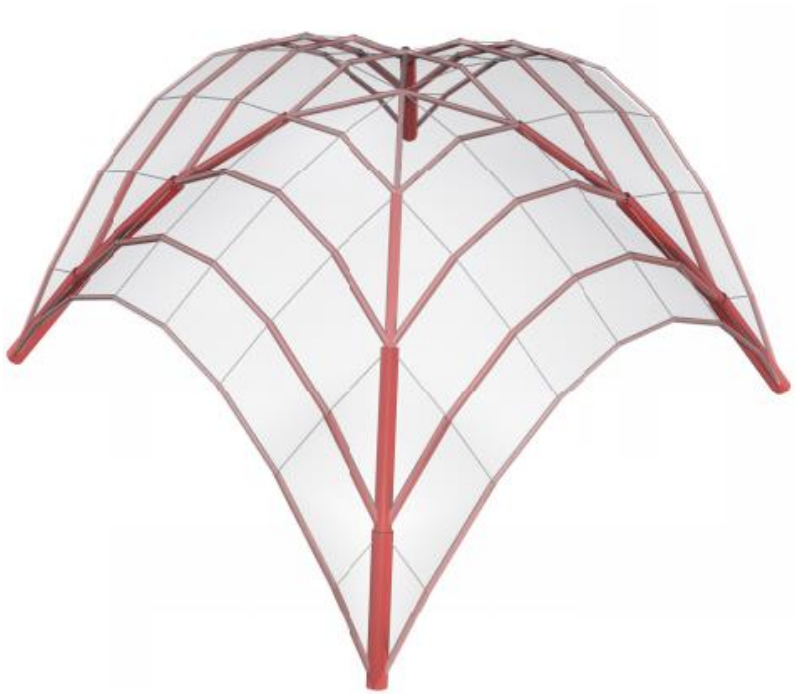
f = 885.3



Arcs Pattern

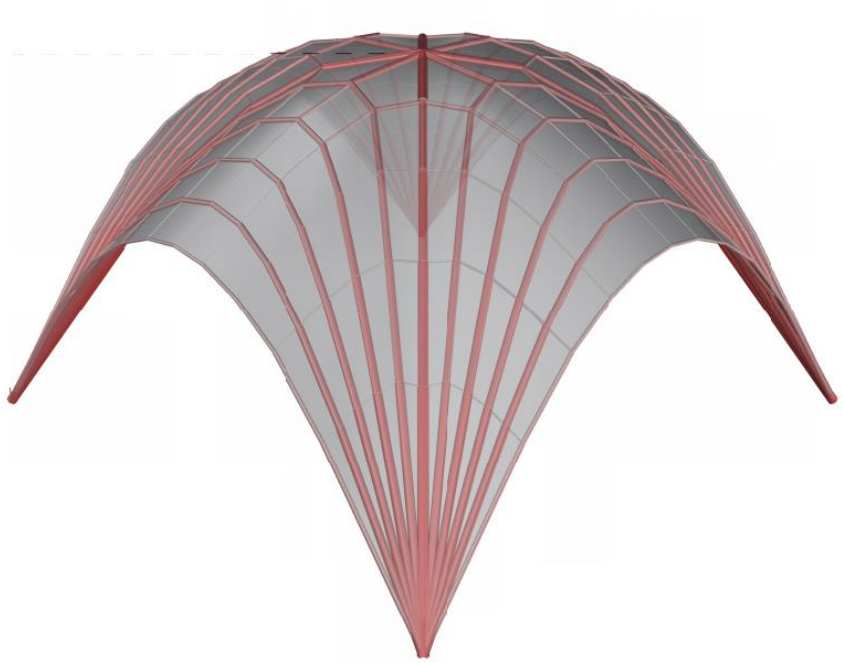
f = 851.5

Analysis of Quadripartite Vaults



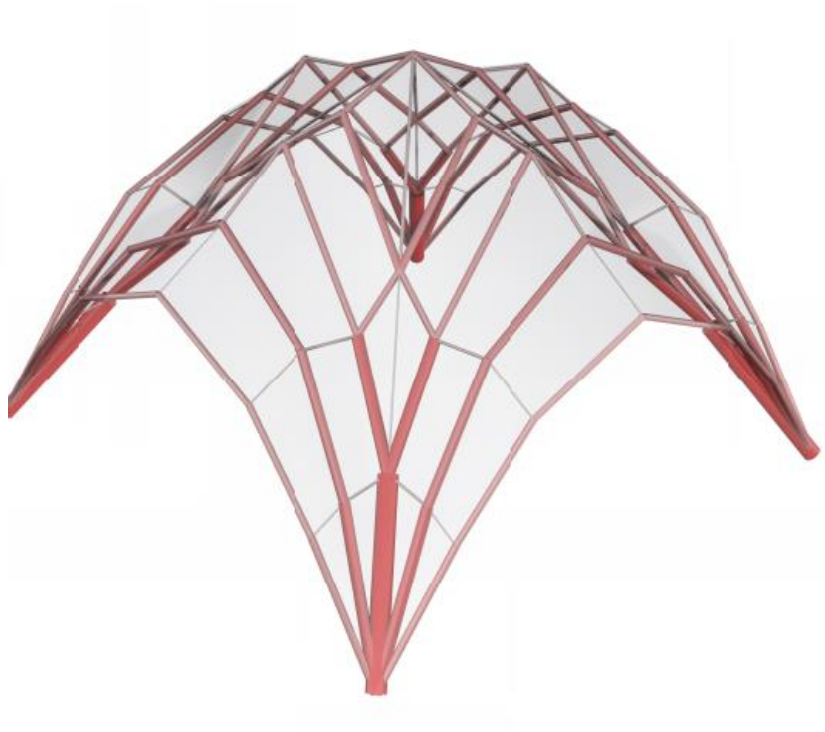
Simple Grid

f = 897.2



Fan Vaulting

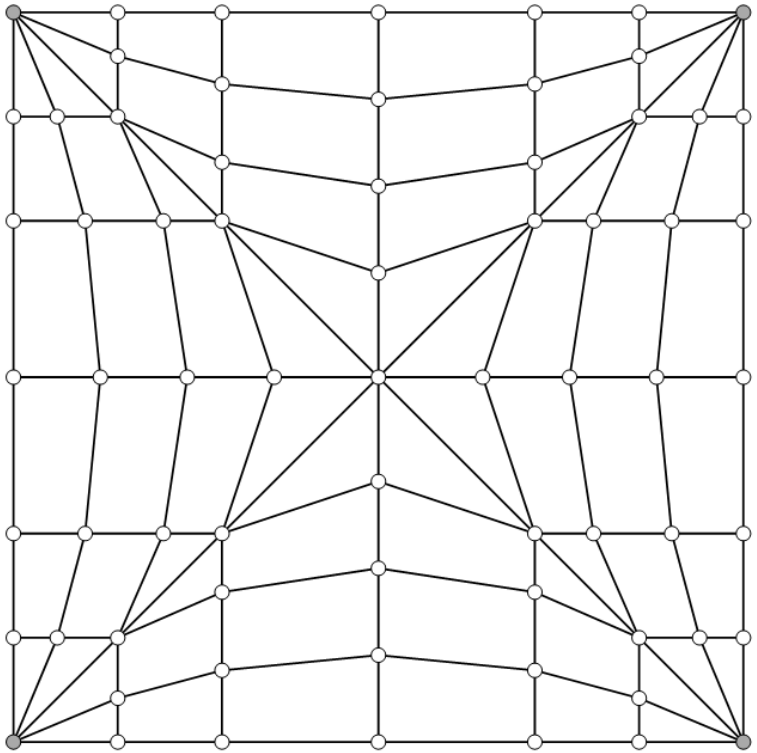
f = 885.3



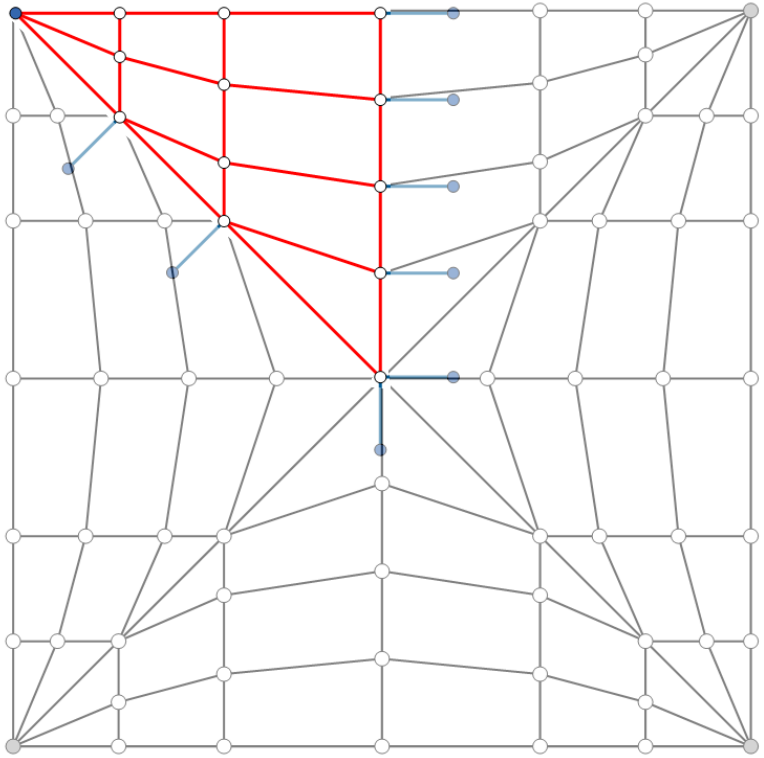
Arcs Pattern

f = 850.4

Large space to analyze



Original Network
M = 140 edges
K = 20 independent edges

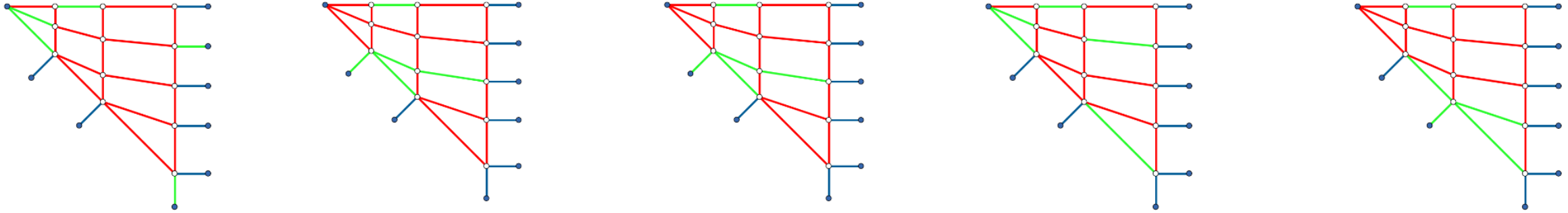


Symmetrical
M = 29 edges
K = 5 independent edges

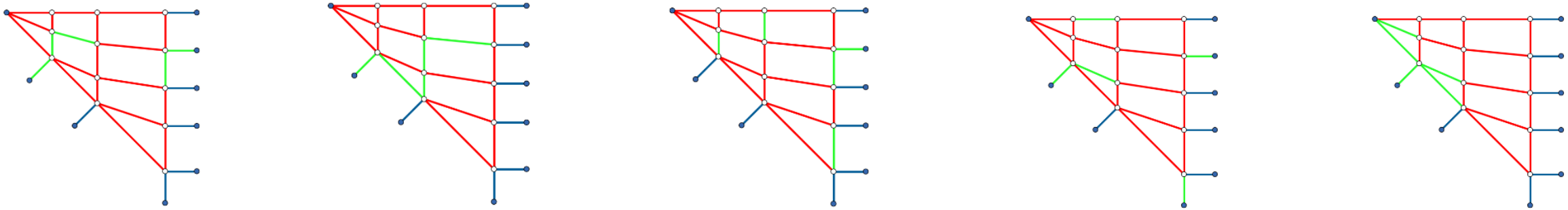
After the symmetry the problem presents:
118755 combinations of 5 different edges

Qualitative description of good/bad sets

5 “best” set of independents – led to good results



5 “worst” set of independents – led to bad results

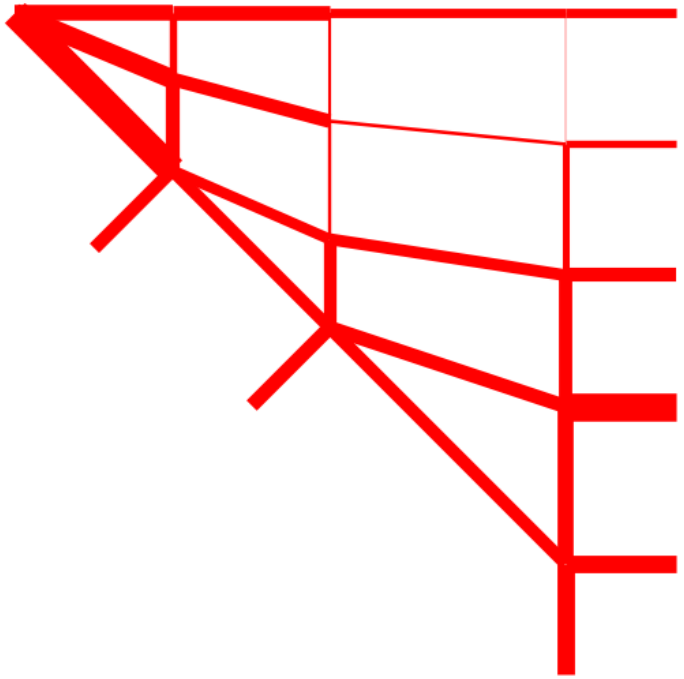


Independent edges Normal edges Symmetric edges

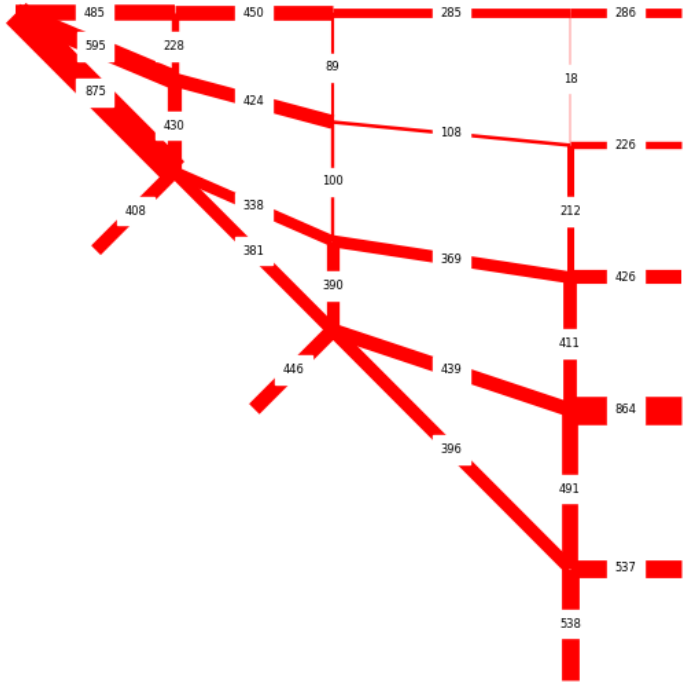
Not granted convergence

Heat-map of good/bad sets

Good Sets: Width represent the frequency they appeared in good sets



Bad Sets: Width represent the frequency they appeared in bad sets



Heat-map of good/bad sets

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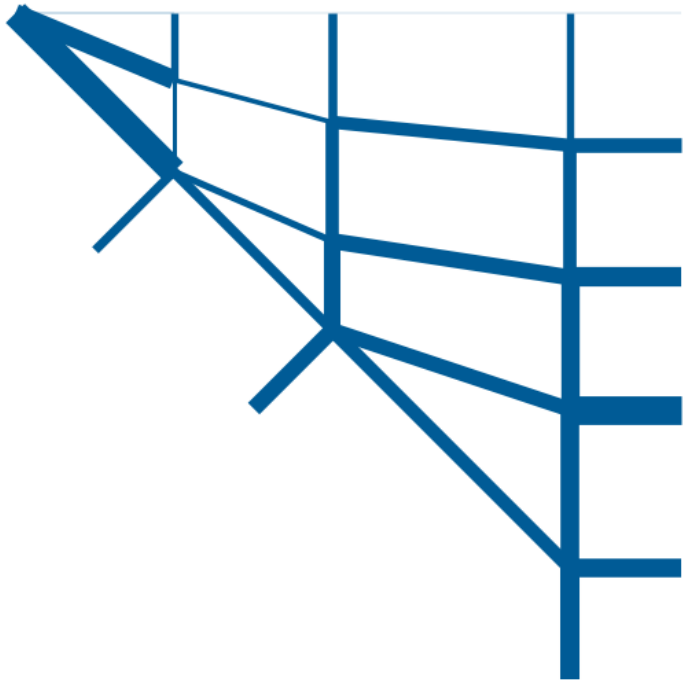
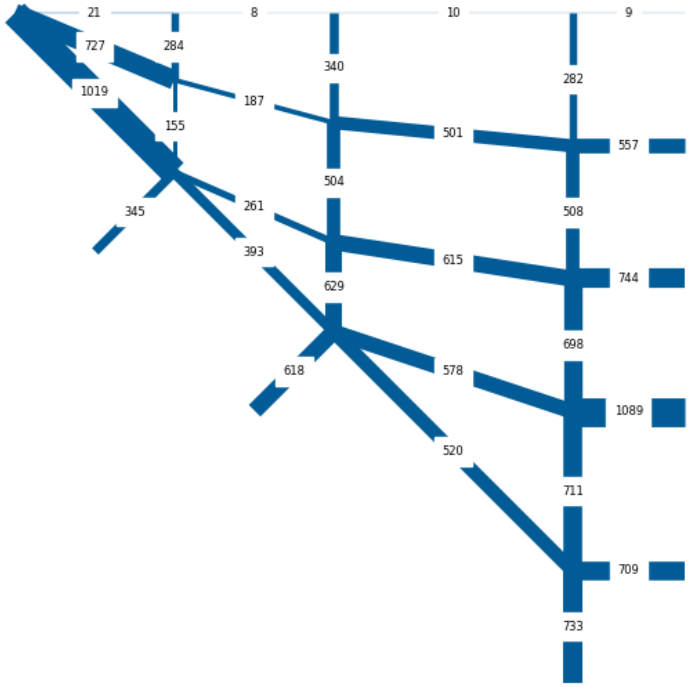


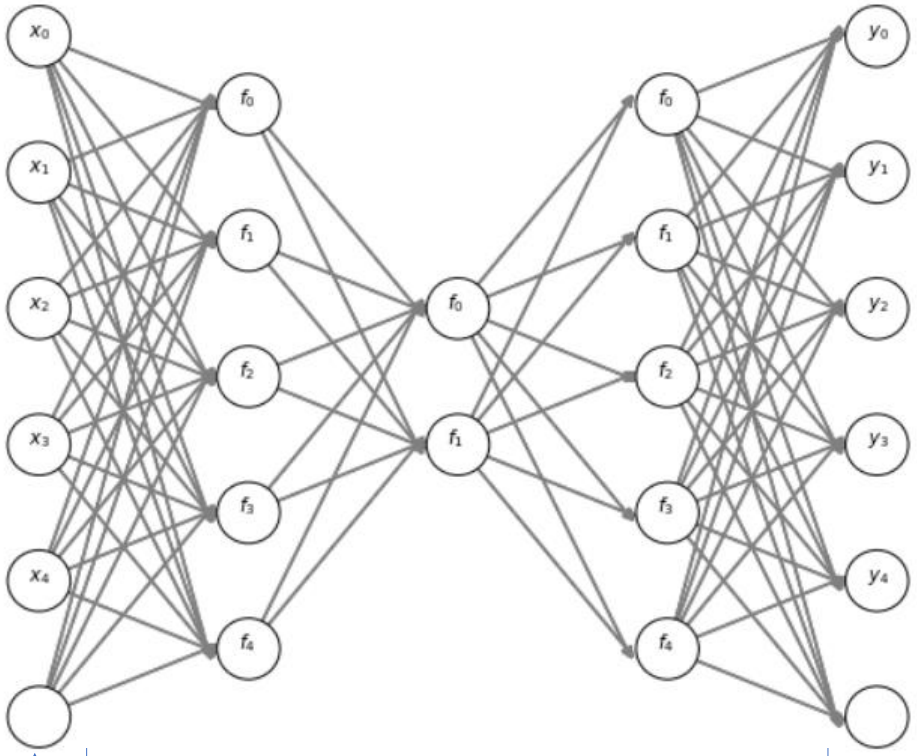
Bad Sets: Width represent the frequency they appeared in bad sets



Data driven based algorithm

Neural Networks

Moosavi (2018)

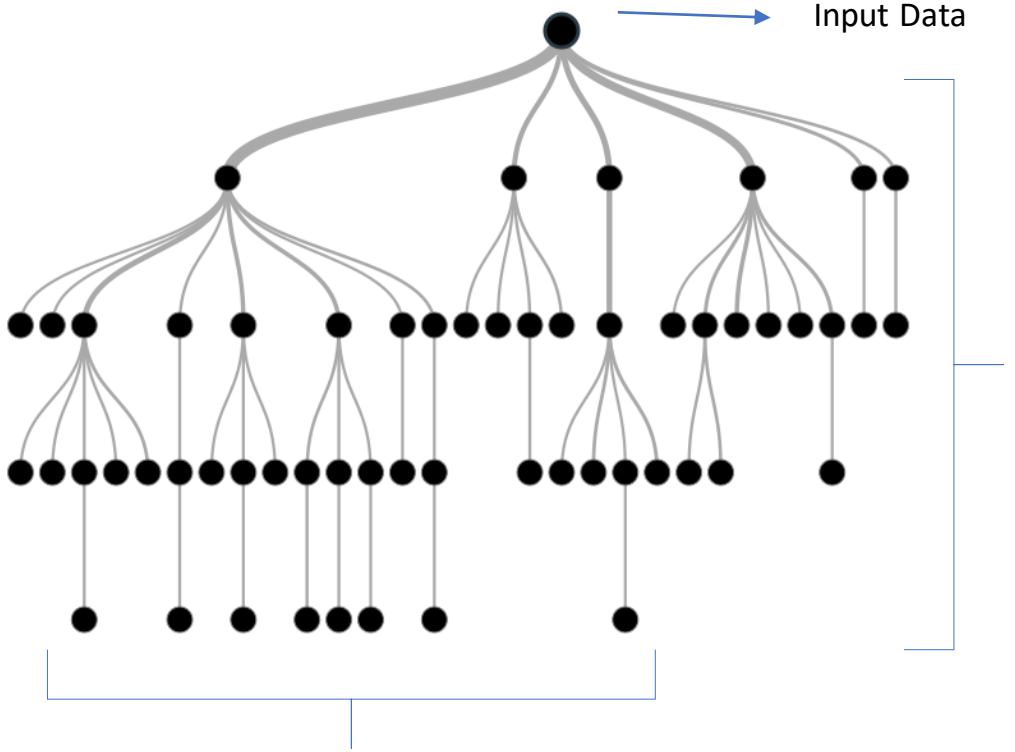


Depth of approximating functions
P = 20 layers

Input Data

Output Data

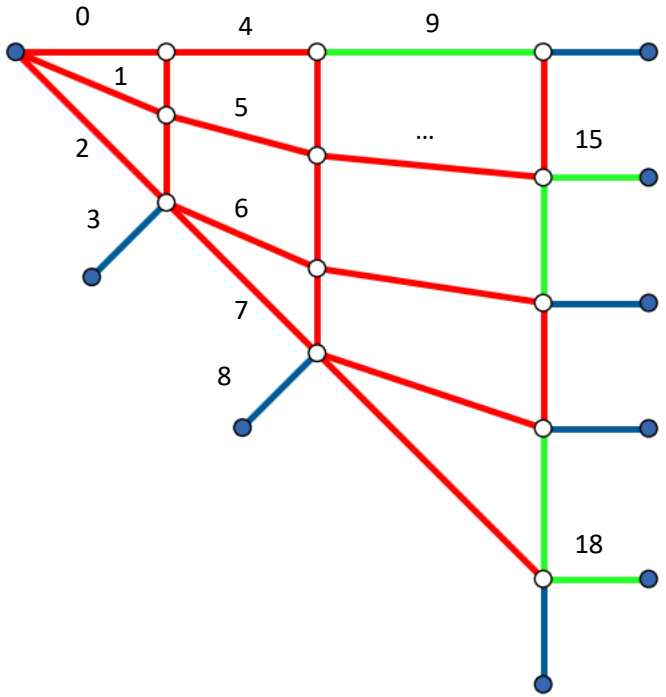
Random Forest



Analytics Vidhya (2016)

Number of estimators: 20
Max Depth: 10

Data driven based algorithm

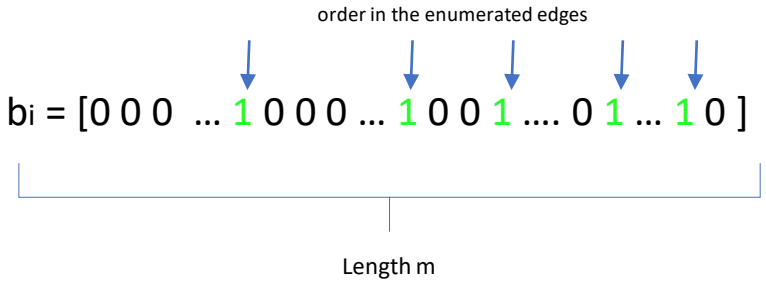


Independent edges

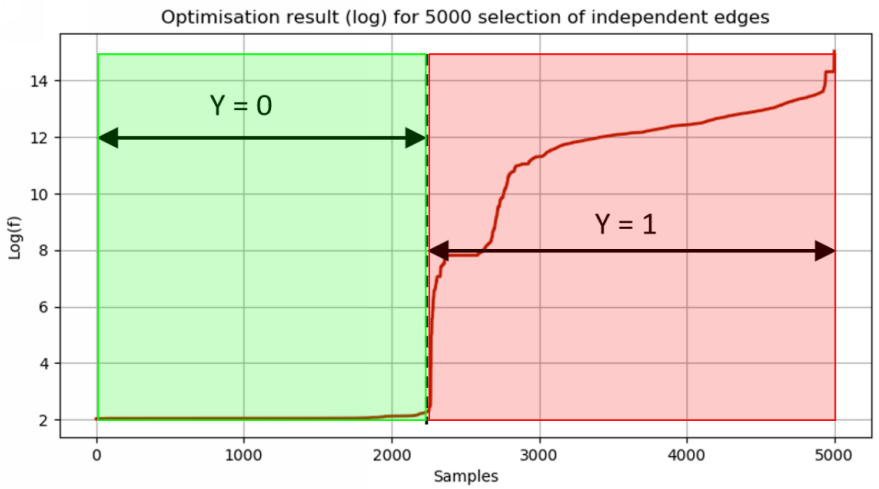
Normal edges

Symmetric edges

Feature:
Independent edges in a binary format

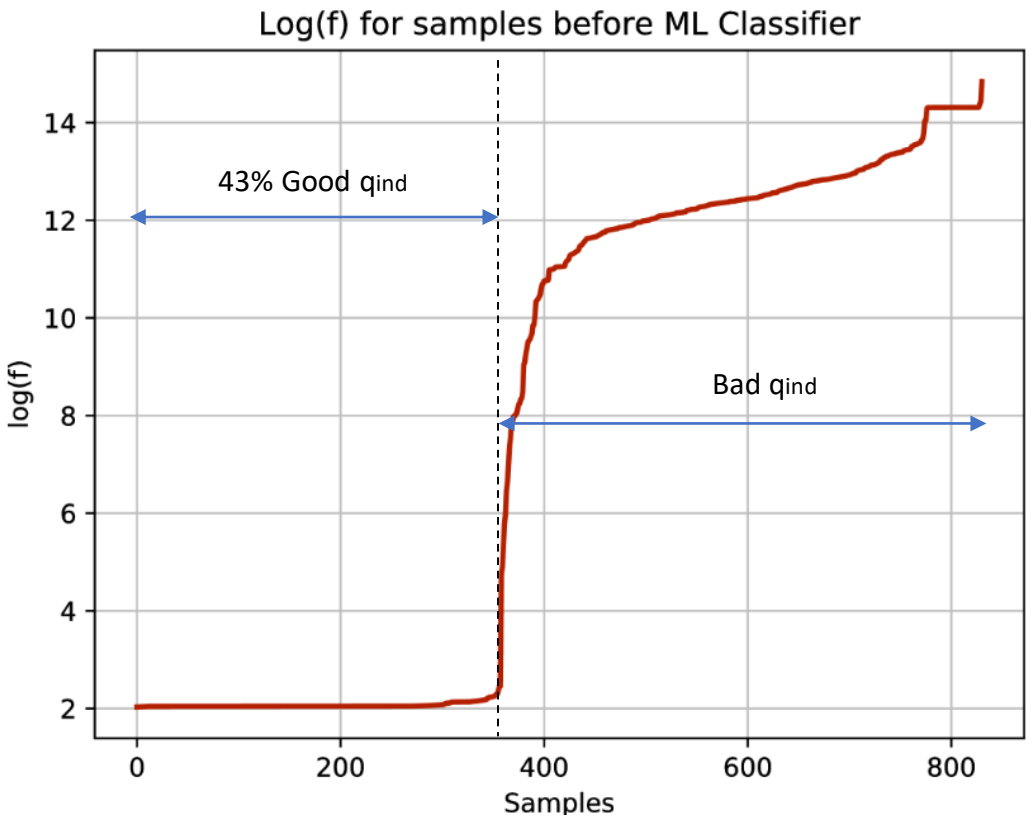


Label:
optimisation result: Load-path value simplified to 0/1 information meaning good or bad pattern

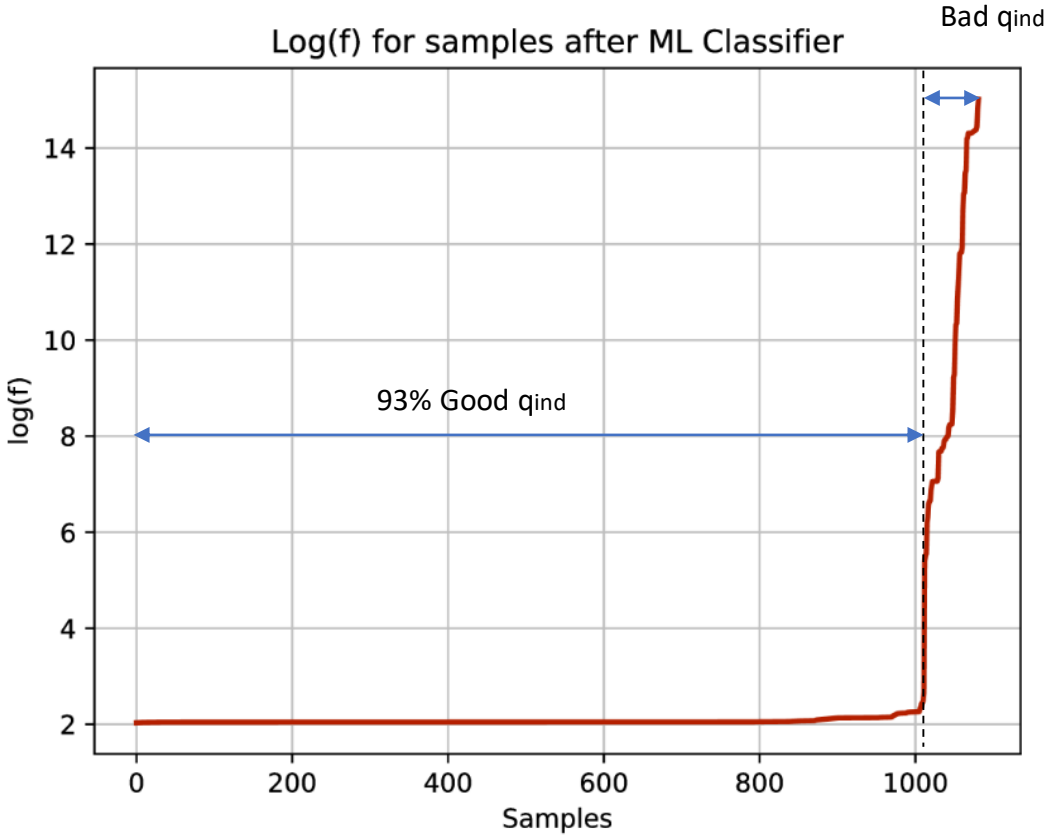


Data driven based algorithm

Learning process made with 831 randomized samples → **Learning** → **Calculation proceeded with samples accepted by the machine**

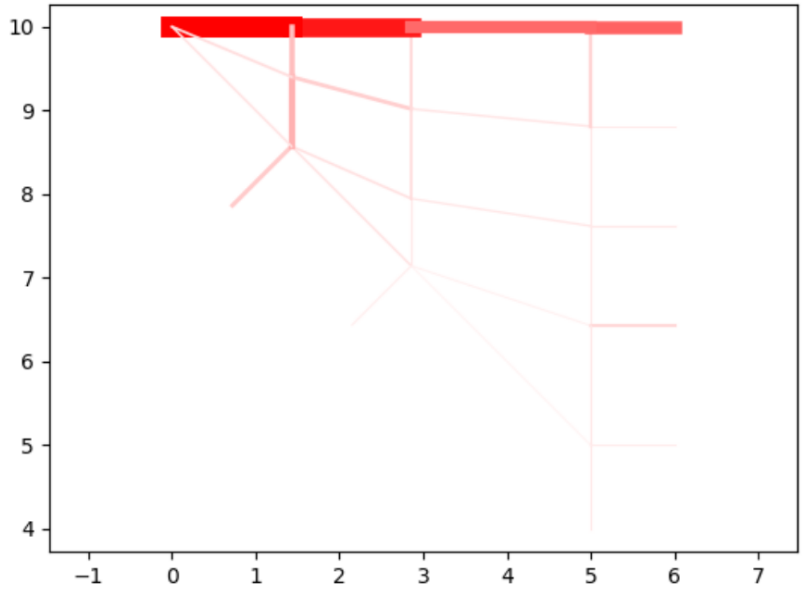


Randomised q_{ind} presented typically 43% of success "Good Samples"



The machine identifies "Good loking" q_{ind} and presents 97% of success

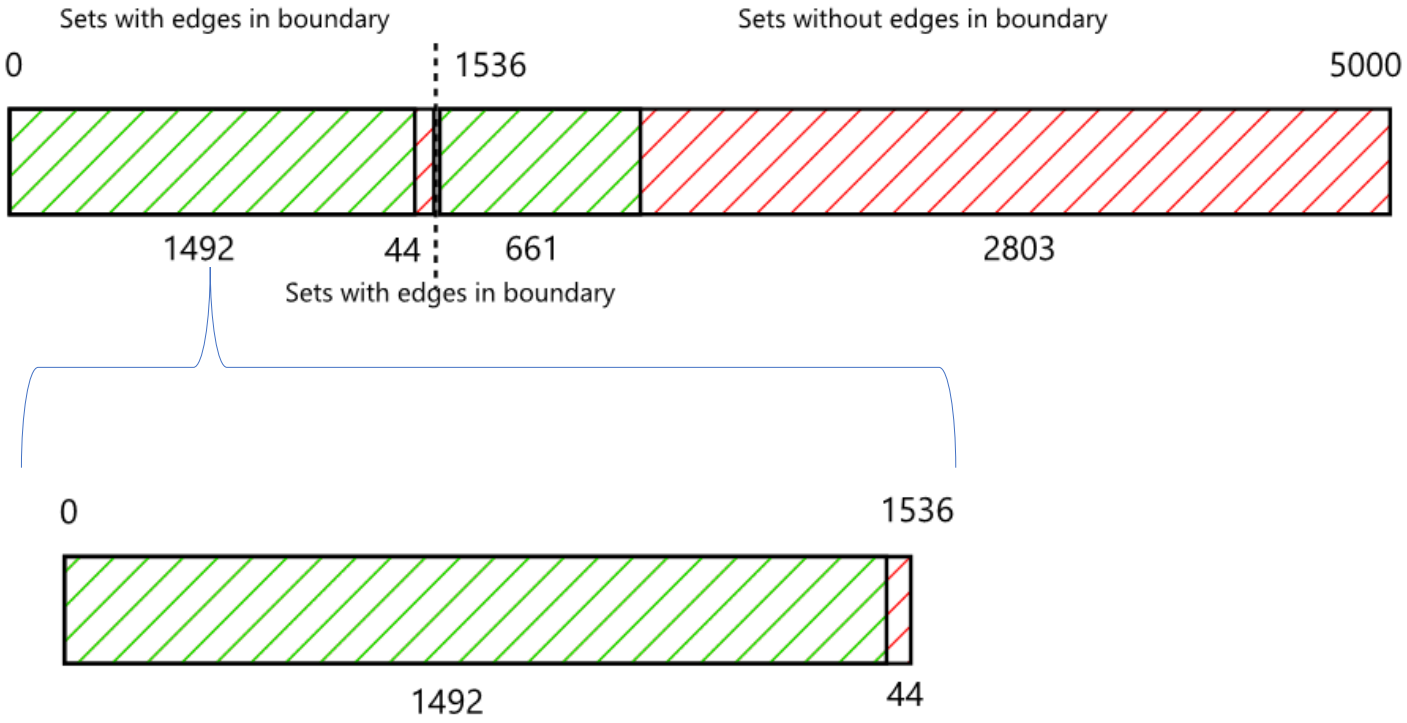
Importance of features on the process



Importance factors reveals the Importance of selecting or not the edges in the boundary of the pattern.

We use it as split point in our data

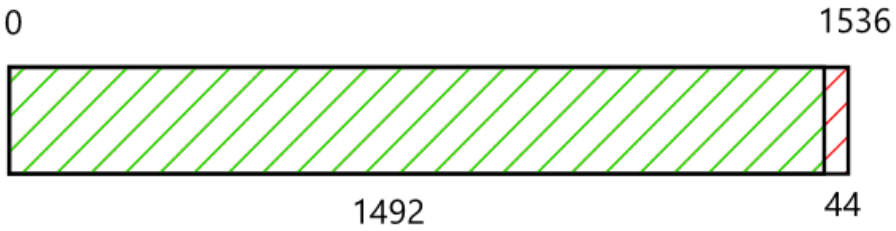
Importance of features on the process

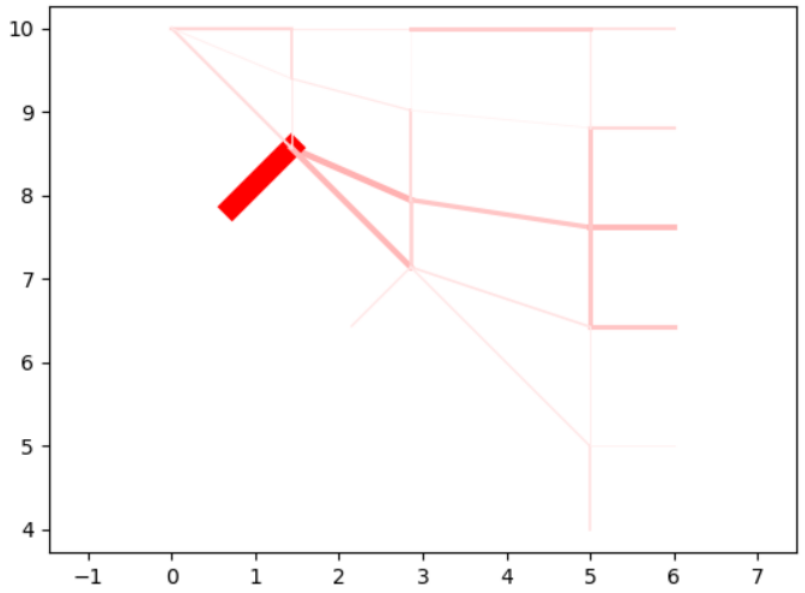


By selecting one of the edges present in the border (top edge) the samples present 97% of success

Importance of features on the process

Filtering the “good” data:

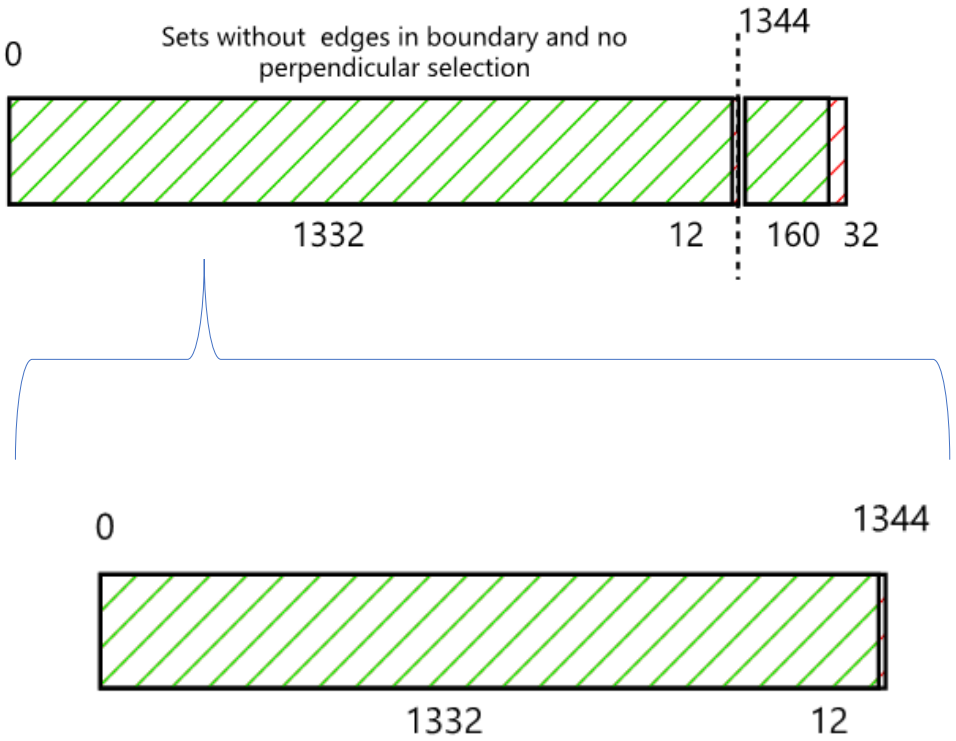




Importance factors reveals the Importance of selecting or not edge perpendicular to the main diagonal

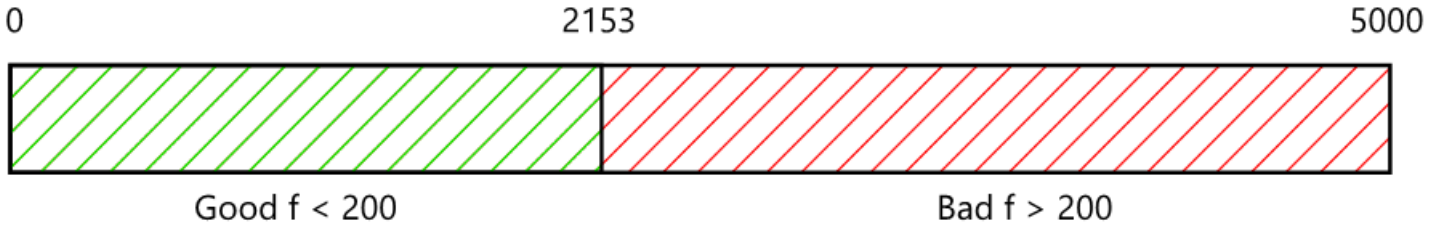
Importance of features on the process

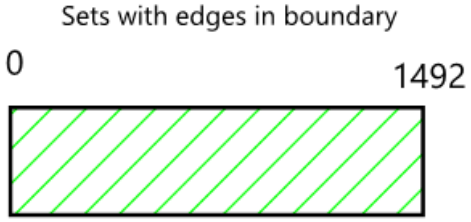
Filtering the “good” data:



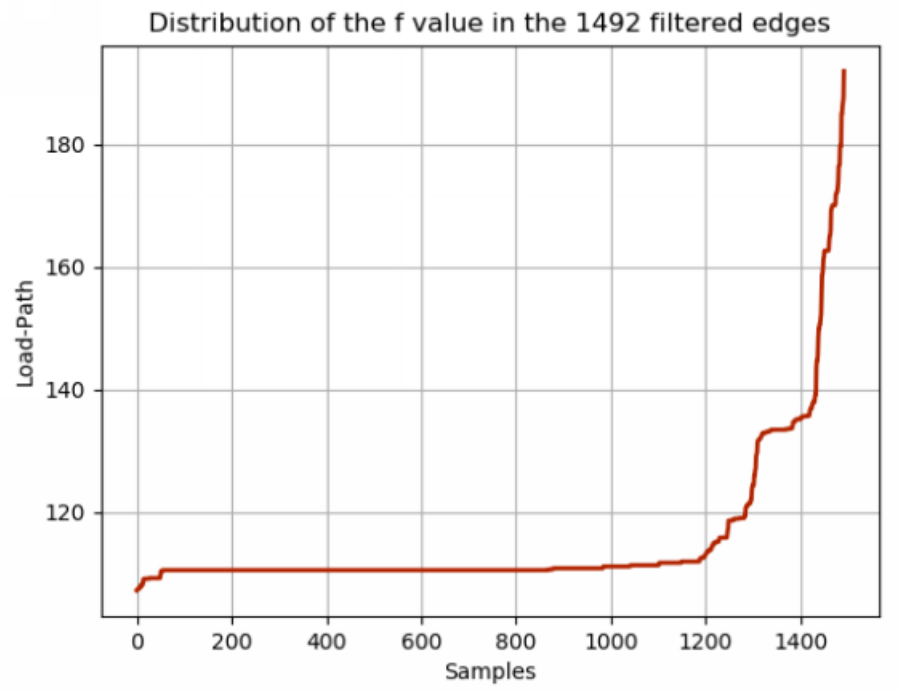
By selecting at least one in the top edge and not selecting the perpendicular to the diagonal the success is 99% (1332 in 1344)

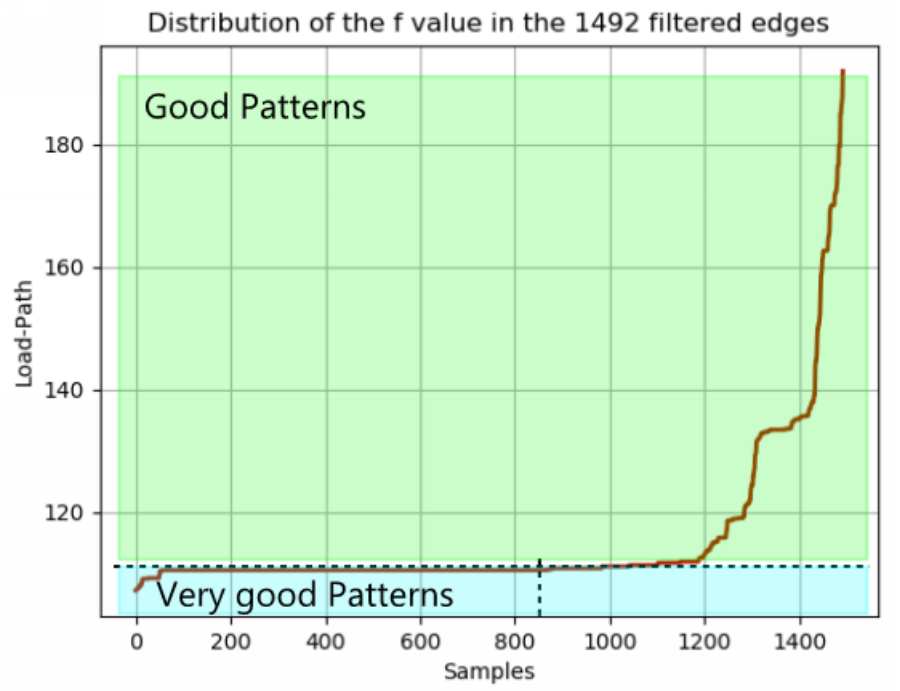
Importance of features on the process





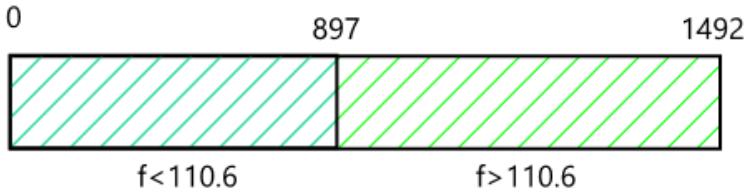
Analyzing only the good patterns f < 200
having an edge selected on the top.

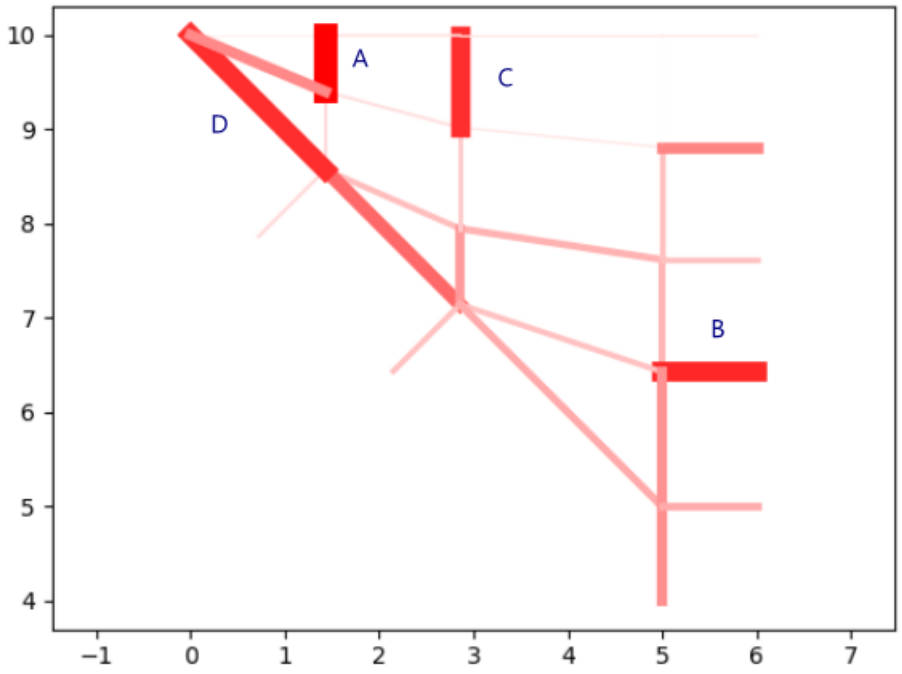




Importance of features on the process

Very good Patterns f < 110.6 / Good Patterns otherwise





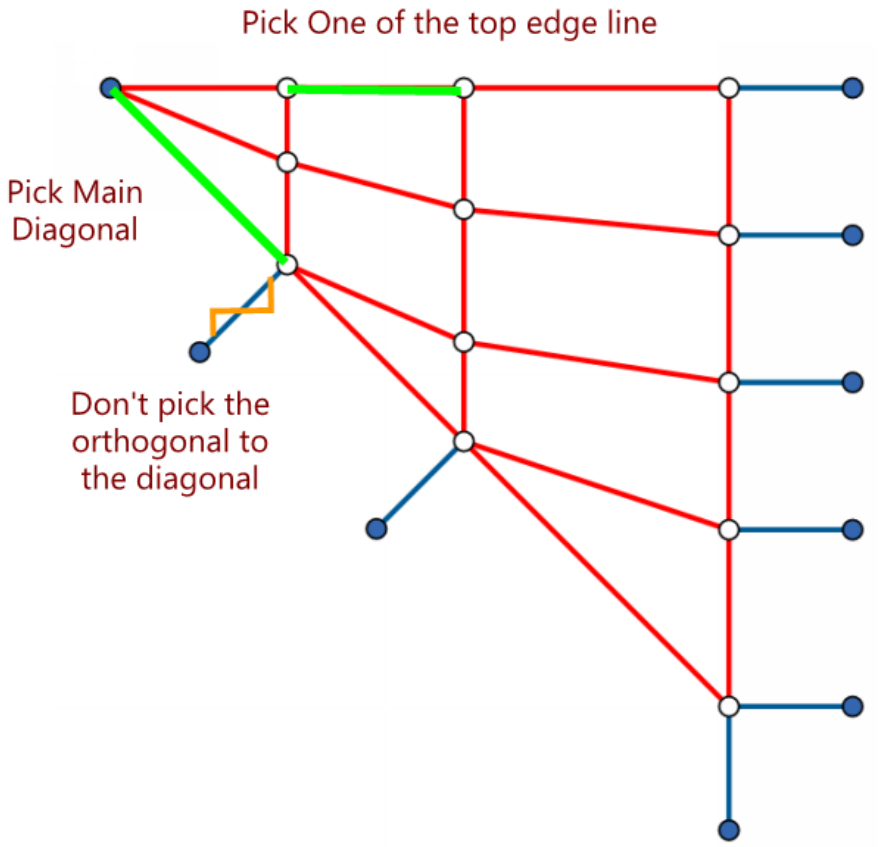
Presence or absence of these edges (ordered by greater importance)

Very Good "Success" rate		
Edge	With	Without
A	40%	62%
B	66%	56%
C	49%	61%
D	76%	50%

Importance of features on the process

Advices/rules for a selection of independent edges:

- Select at least One in the edge boundary.
- Select the Main Diagonal close to support
- Not Select the Edge perpendicular to main diagonal (symmetrical)

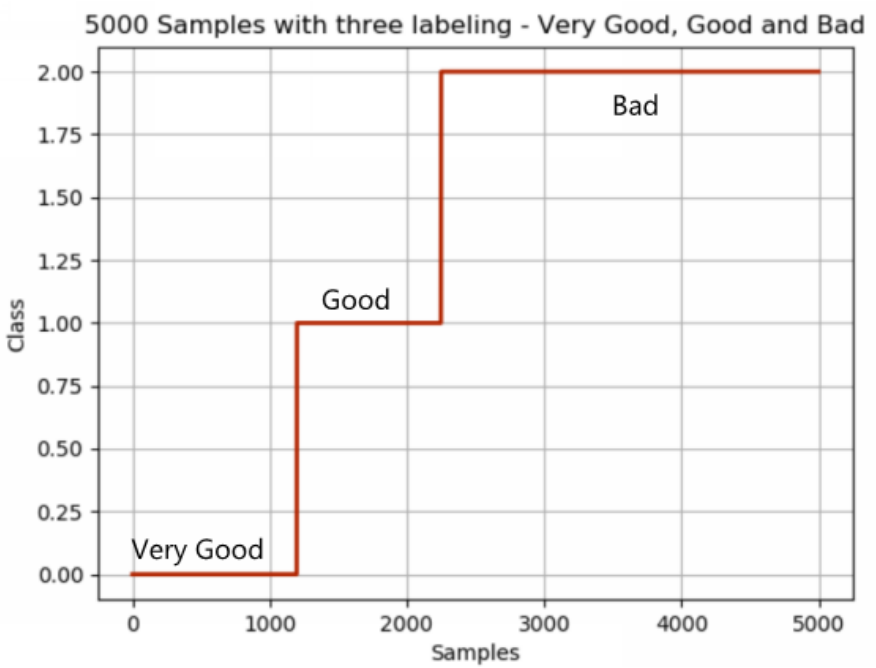


Importance of features on the process

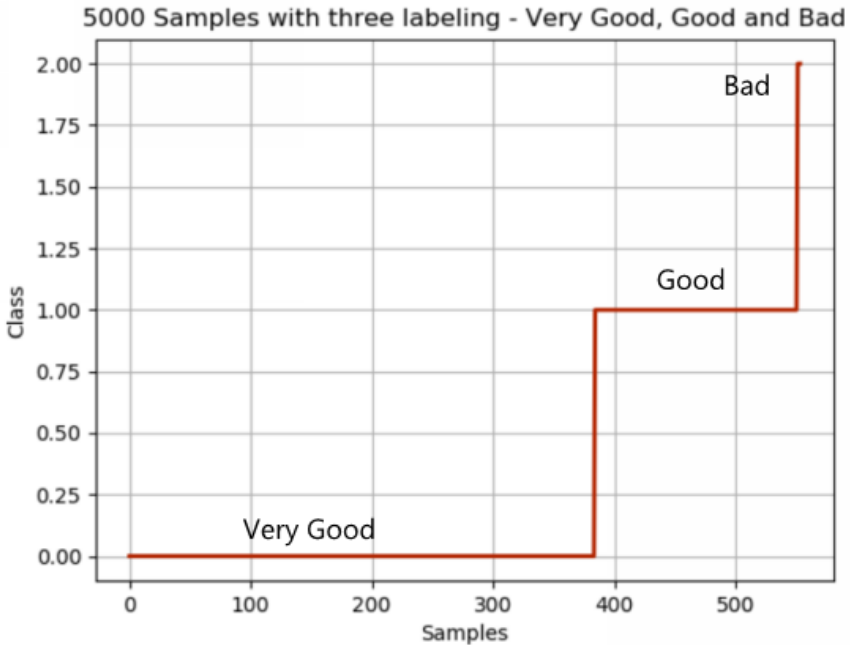
This data presents 554 Samples:

- 3 are bad (f > 200)
- 170 are at least good (99.5%)
- 384 are very good (f < 110.6) (69.4%)

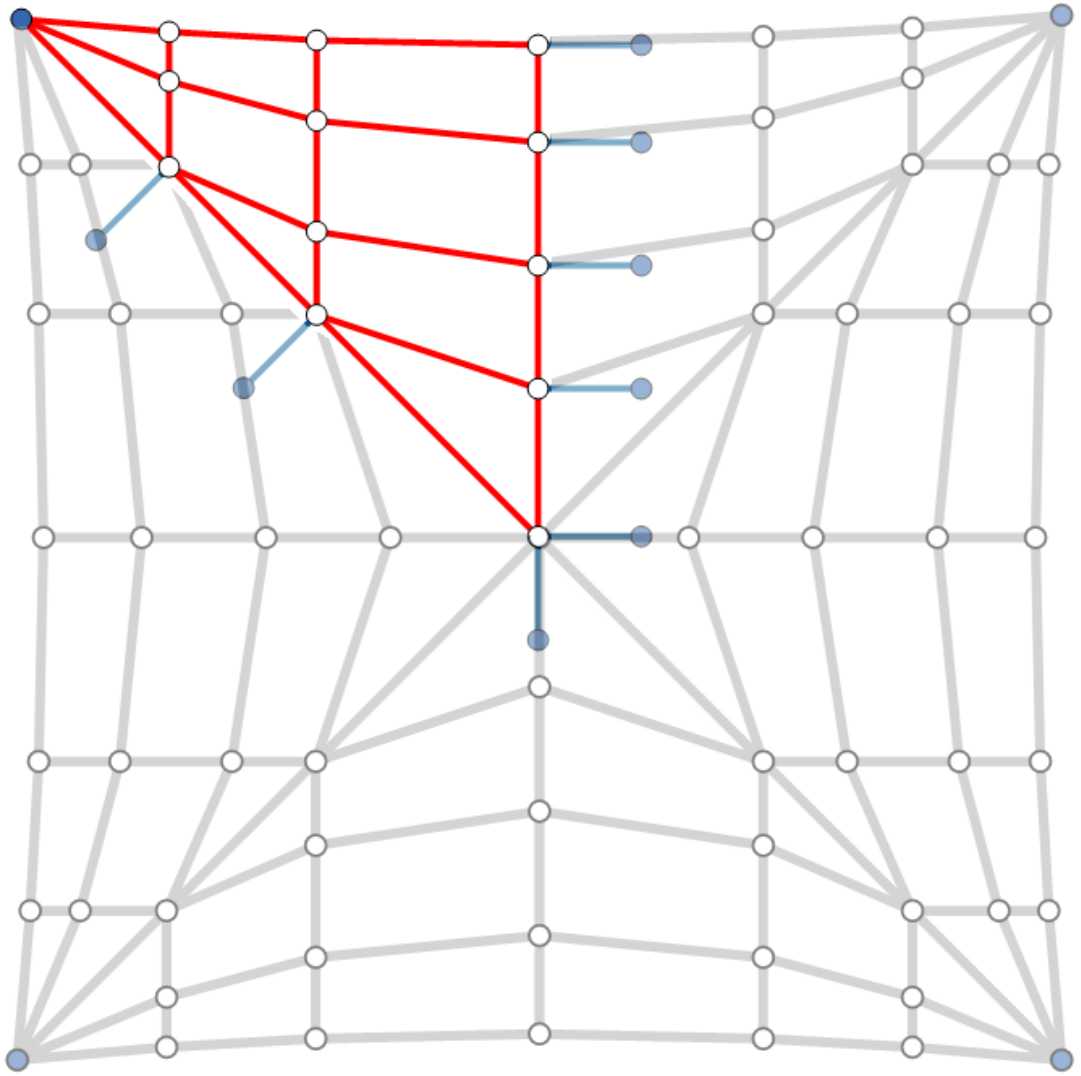
Before ML



After ML

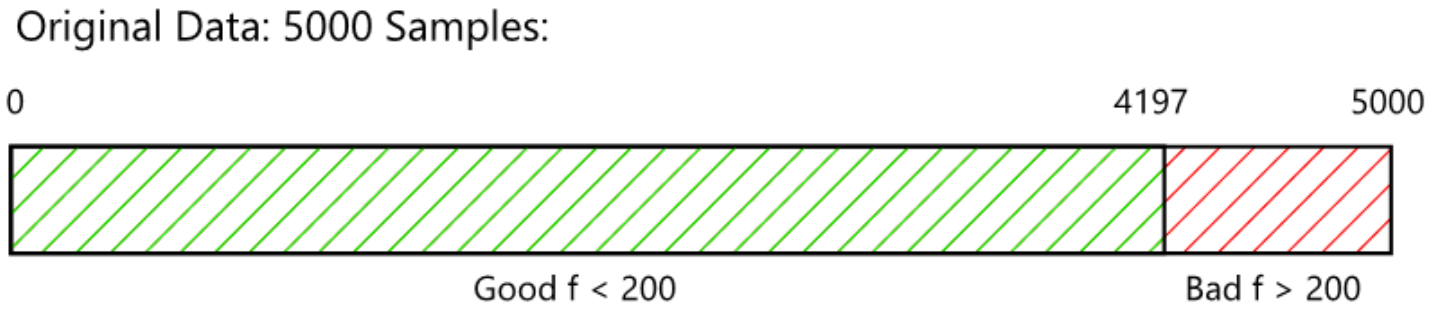


Improved input data

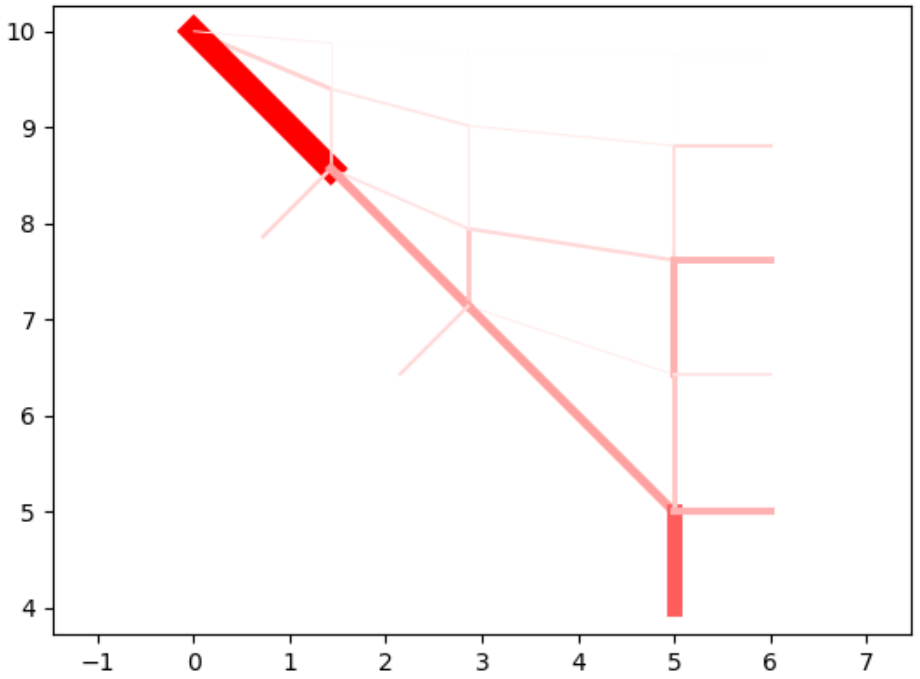


After the symmetry the problem presents:
118755 combinations of 5 different edges

Importance of features on the process



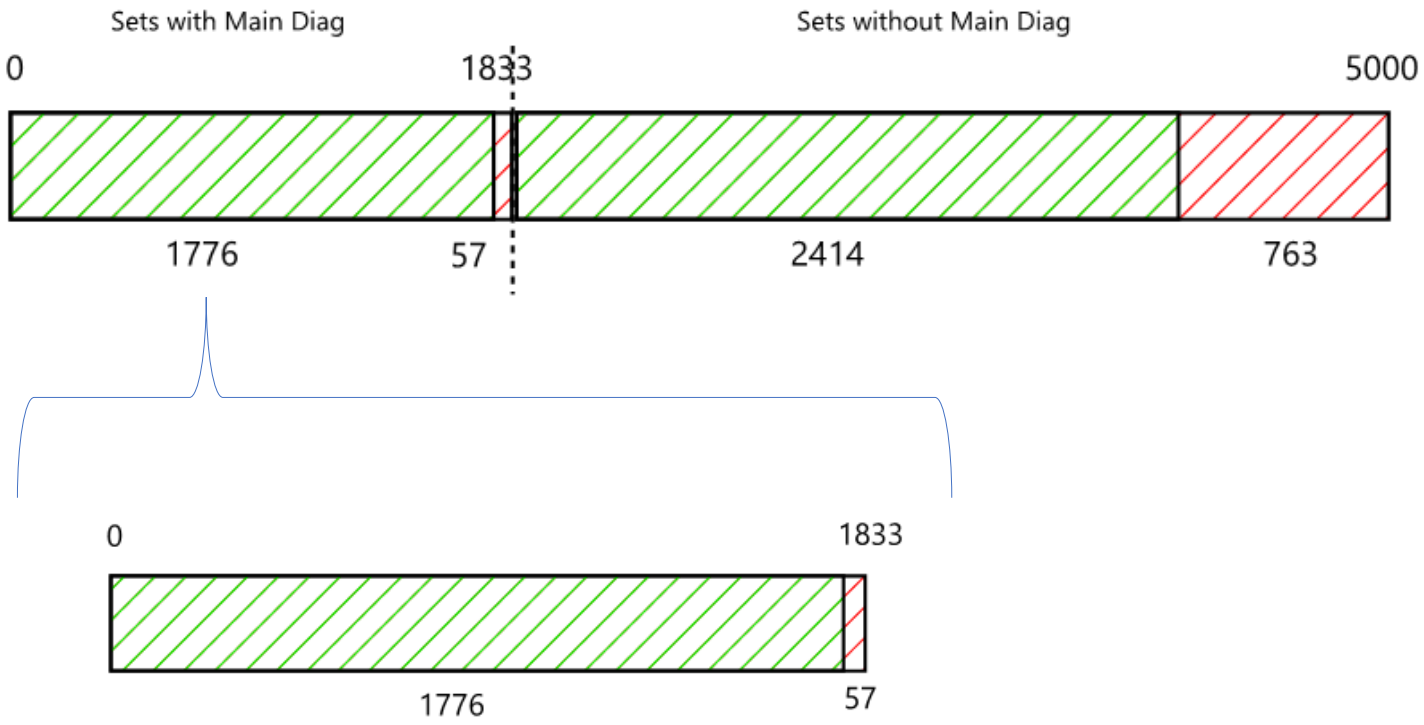
83% of Success with new pattern



Importance factors reveals the Importance of selecting or not the edges in the main diagonal close to the support.

We use it as split point in our data

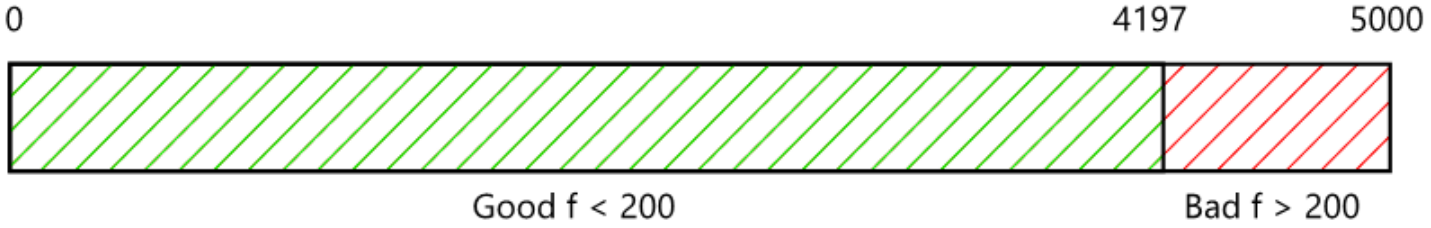
Importance of features on the process



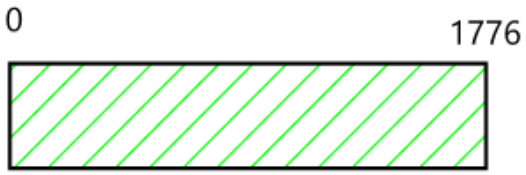
By selecting one of the edges present in the border (top edge) the samples present 97% of success

Importance of features on the process

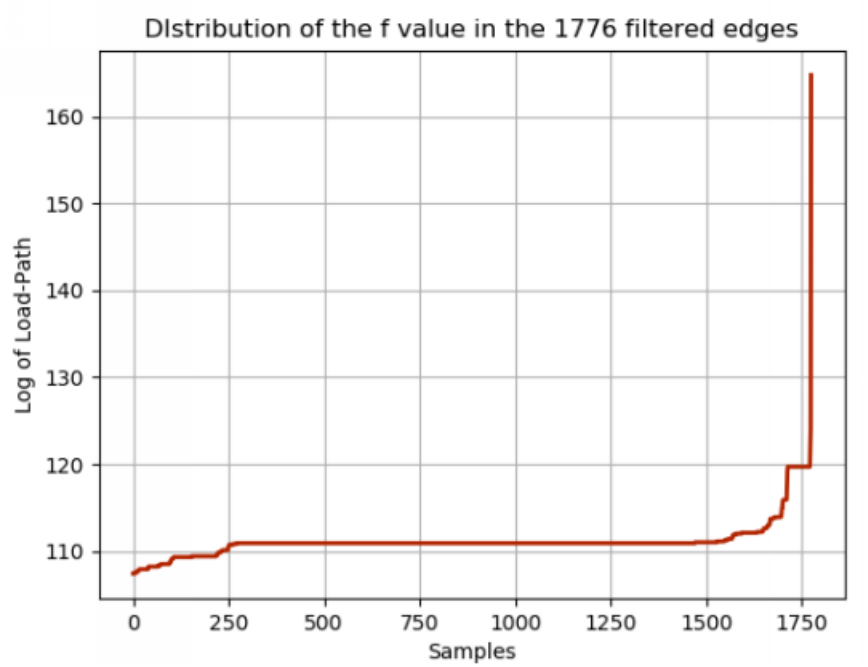
Original Data: 5000 Samples:

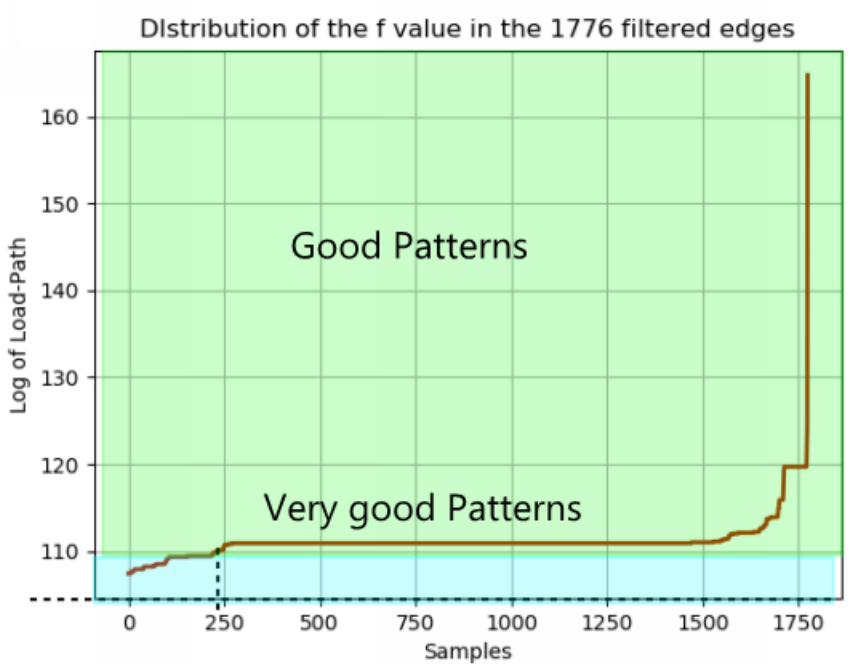


Sets with main diagonal selected



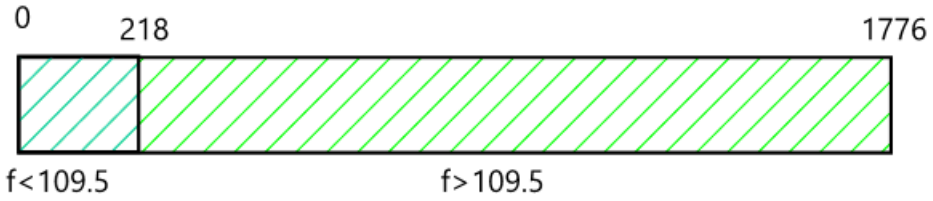
Analyzing only the good patterns f < 200 having an edge selected on the top.



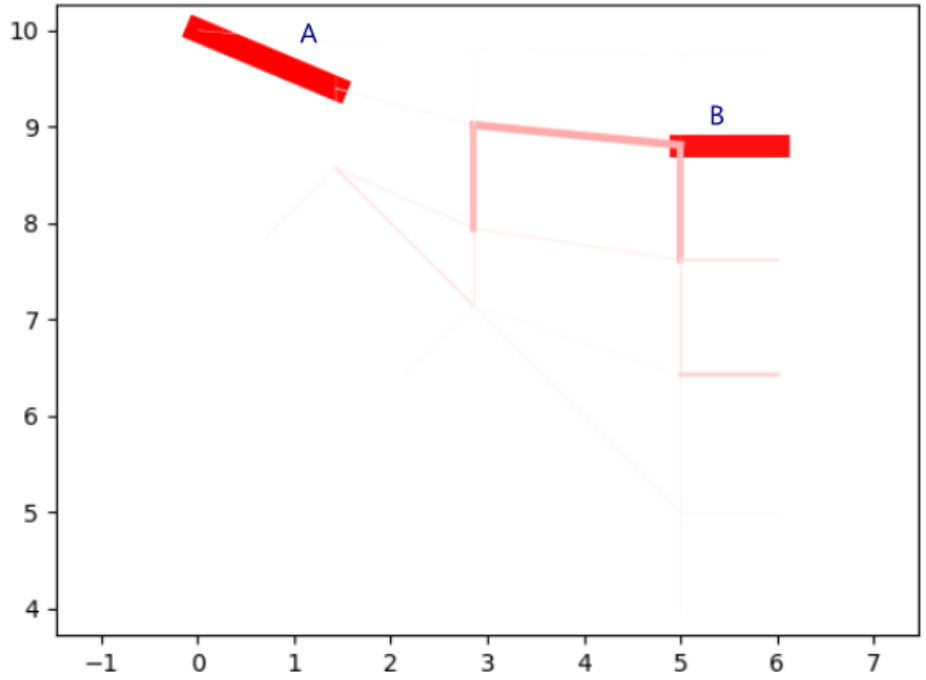


Importance of features on the process

Very good Patterns f < 109.5 / Good Patterns otherwise



Very Good Ratio: 218/1776 = 13%

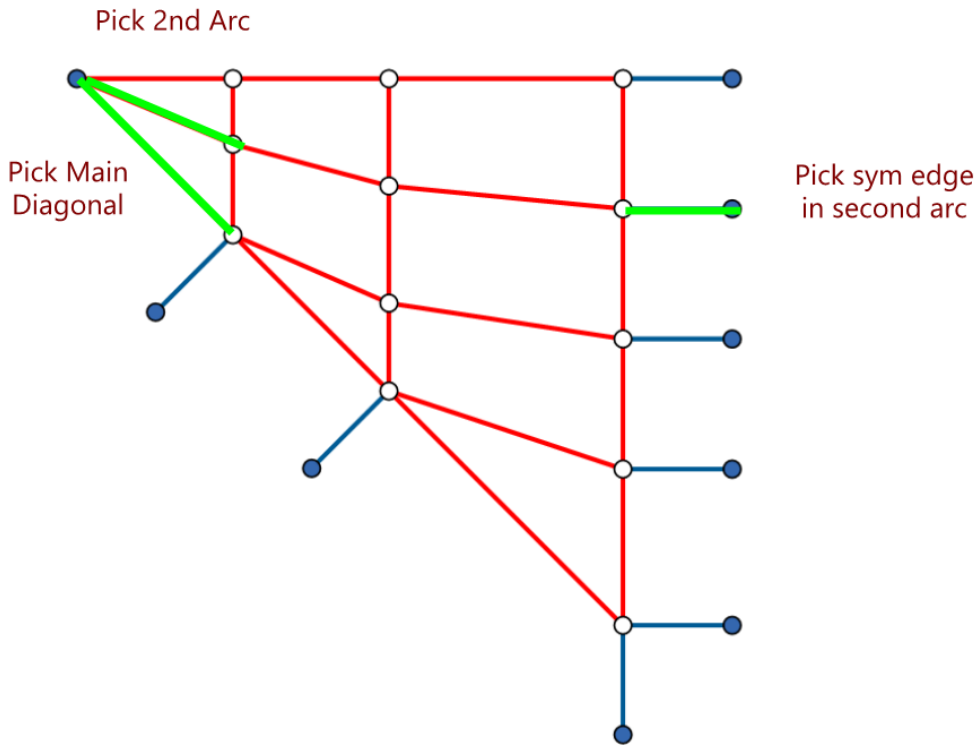


Very Good "Success" ratio		
Edge	With	Without
A	17%	4%
B	48%	7%
A + B	49%	61%

Importance of features on the process

Advices/rules for a selection of independent edges:

- Select the Main Diagonal close to support
- Select the second arc close to support at the same time as the Symmetrical edge present in the same arc

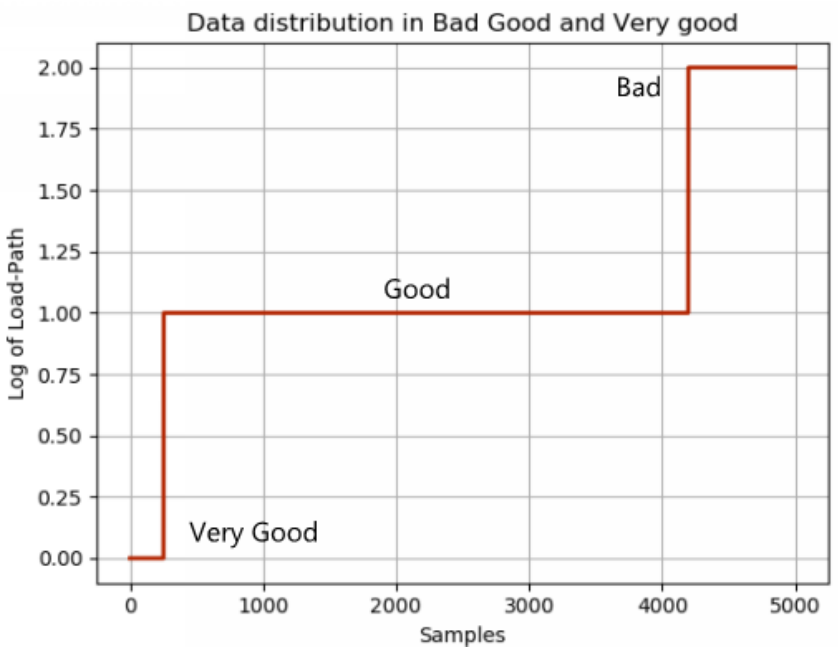


Importance of features on the process

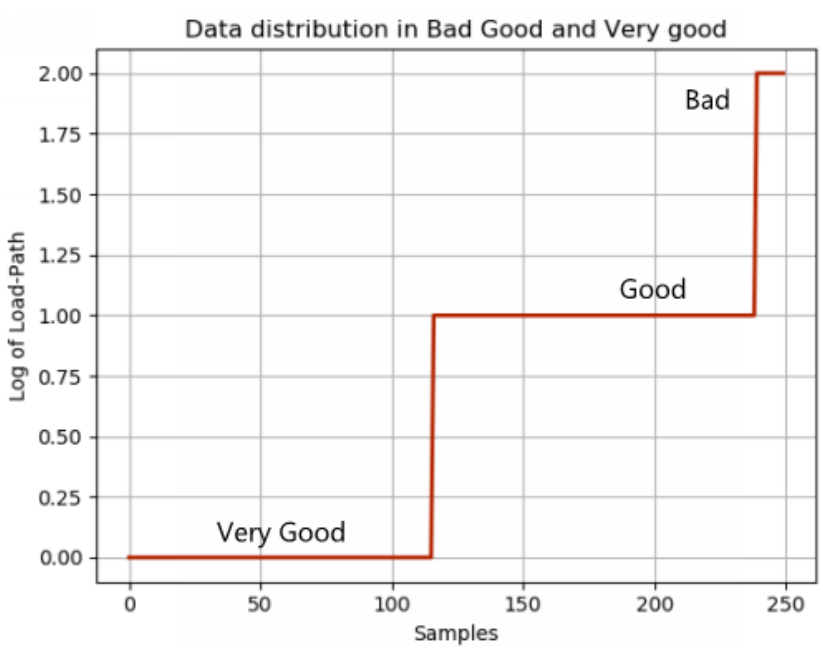
This data presents 250 Samples:

- 11 are bad (f > 200)
- 239 are at least good (96%)
- 116 are very good (f < 109.5) (46%)

Before ML



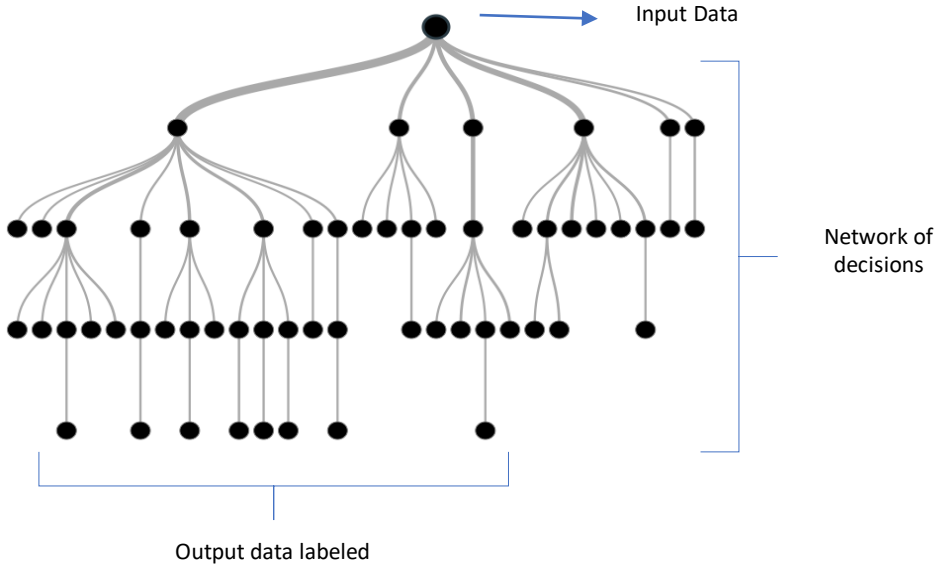
After ML



Change this image

Conclusions so far

Random Forest – Decision Tree



- Proved to be able to select a good set of independent edges for a given topology.
- It is able to speed up the optimization process specially for big and complex networks .
- It is able to give input to experts about good directions to follow.