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Using Delaunay tringles to build desire lines

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Abstract

Desire Lines is one of the most readily available tools for a modeller to understand OD matrices when getting acquainted with new data and/or new region. However, despite its easiness to use, they yield very poor maps for analysis when the number of filled cells in a matrix is too large, which is the case for our current transportation models with their many thousands of Traffic Analysis Zones (TAZs).

In order to circumvent the poor quality provided by these standard desire lines, this paper proposes an algorithm based on an all-or-assignment of the demand matrix onto a minimal network connecting all the centroids, instead of just generating straight lines from all origins to all destinations. Hence the automatic generation of these modified desire lines depends on the automatic generation of a minimal network in a consistent manner.

In this paper we implement this algorithm based on a novel interpretation of minimal networks, which are derived from Delaunay Triangles. This paper also discusses the impact of these new network properties in the analysis outcomes for testing cases for models available from Australia, Brazil and United States.

Further this paper also provides alternatives for construction of minimal networks and compare their assumptions and results with the baseline case of Delaunay Triangles.

Finally, the full algorithm and implementation are provided in an open source format in the form of an online repository.

1 Introduction

Desire lines are still one of the most used tools for quick analysis of transportation movements and to convey “big-picture” results about such movements, especially because desire lines are independent of the existing of an underlying network, which allows for their construction before simulation networks are prepared.

Despite its usefulness, desire lines yield very poor maps when the number of filled cells in a matrix is too large, which is the case for our current transportation models with their many thousands of Traffic Analysis Zones (TAZs), making it natural that transportation planners and modellers would make less use of such tools in practice as zoning systems grow more disaggregate.

Alternatives such showing only the largest flows and aggregating matrices are resources often used by transport planners to circumvent the visualisation issues caused by large and disperse matrices, but it those are resources that often consume considerable time, thus making the use of desire lines much less convenient than it was initially designed to be.

The next sections of this paper will present a very brief literature review, the proposed methodology, three case studies and an also brief conclusion. As this paper is focused on a practical, but yet very simple methodology in theoretical terms, most of the emphasis of this paper is put in case studies, particularly on the case of the US freight flows, which is one of the most complete freight model outputs freely available online.

As this paper is developed in the realm of Open Source software, the source code that implements this methodology is to be considered integral part of this work, and it is presented in the form of an online repository.

Lastly, this paper is the formalization of the initial work published by the author in his technical blog (Camargo 2016) and supersedes the initial publican both in technical rigor, software implementation and breadth of tests.

2 Literature review

Topics such as demand assignment to minimal networks and desire lines are not often described in the literature for different reasons. While the latter is simply too trivial to justify research in the realm of transportation planning, the former seems to not have sparked too much interest of researchers so far.

If in one hand the literature on desire lines is not substantial, in the other the literature on triangulation is considerably larger, spanning from the seminal work of (Delaunay 1934). In turn, Delaunay triangulation DT for a set of points N in a plane is a triangulation for which no point in N is enclosed by any triangulation in DT(N) such that the minimum angle of all the angles of the triangles in DT(N) is maximized.

Although initially developed in the realm of planar geometry, efficient algorithms for the construction of Delaunay Triangulations in spaces with an arbitrary number of dimensions are also available in the literature, such as (Cignoni et al. 1998), which is not particularly relevant in the realm of transportation planning.

The constrained variation of the general Delaunay Triangulation problem, however, remains extremely relevant to transportation planning and might provide a natural alternative for the furthering of this research, as the analysis of the case studies will demonstrate on section 4 of this document.

3 Methodology

As described in the introduction, the objective of this paper is to provide a consistent algorithm based on an All-or-Nothing (AoN) traffic assignment (where all flows are assigned to its shortest path) to a minimal network, which makes the choice of a minimal network the central part of the algorithm proposed.

In a nutshell, the proposed algorithm can be divided in 5 steps:

1. Compute the Delaunay triangulation for a set of network centroids
2. Interpret the edges of the Delaunay Triangles as bi-directional links
3. Build a graph based on the set of links generated
4. Performed an AoN assignment on the graph
5. Return the Delaunay Triangulation links with flows per direction to the user.

This procedure has two important characteristics: Yields unique and consistent results regardless of the implementation, and it uses procedures widely available in both proprietary and open-source software packages.

As the algorithm is extremely simple, further discussion of its properties are presented along with the case studies on section 4.

It is reasonable to admit, however, that a set of paths through a Delaunay Triangulation would generate flows through areas not exactly related to the direct connection between two nodes, as the detour between zones can be high. On this note, it is important to highlight that the shortest path between two nodes on a Delaunay Triangulation Network is known to be no longer than $\frac{4\pi}{3\sqrt{3}} \sim 2.42$, which is a reasonably small number. In any case, it is possible to compute the transportation production of the resulting loaded network and comparing it with what standard desire lines would generate in order to compute a general measure of *detour* for each case.

3.1 Implementation as an open source tool

Initially published in (Camargo 2016) as a laborious set of instructions using open source tools, the methodology presented in this paper was implemented inside AequilibraE (Camargo 2015), an open source Add-on for the free GIS software QGIS (QGIS-Authors 2016).

This implementation takes advantage of the Delaunay triangulation algorithm provided by the Python library Sci-Py and the traffic assignment library developed as part of AequilibraE, making it extremely efficient.

The permanent code repository for AequilibraE is https://github.com/AequilibraE/AequilibraE, while https://bitbucket.org/pedrocamargo/aequilibrae/ is the initial repository maintained for historical purposes only.

4 Case studies

In this section, three case studies are presented in order to illustrate the effectiveness of the proposed methodology. The first case study provided testing grounds for the initial testing of this methodology, and it involves freight movements in the United States, which is a well-known and used data source for freight modelling in the US.

The second case study involves the Brazilian National Freight Model currently under development, which consists of a zoning system much more detailed than the one used in the US case, allowing for the establishment of the performance of the proposed methodology for different levels of geographic resolution.

The third case study is the Australian highway freight movement with SA4s as transportation zones, which provides similar number of zones as the USA case study, but with a much higher degree of flow concentration.

For all these cases both traditional desire lines and those generated by the proposed algorithm will be presented in order to allow for the comparison of the techniques.

4.1 USA: Freight Analysis framework

The Freight Analysis Framework (FAF), currently in its fourth generation, is a comprehensive picture of freight movement between all US states and major metropolitan areas by all modes of transportation.

It is developed by the Oakridge National Laboratories (ORNL) for the US Federal Highway Administration (FHWA) and the US Bureau of Transport Statistics (BTS), and it integrates data from a large number of sources, including the national Commodity Flow Survey (CFS) and international trade data from the Census Bureau. It includes data from all economy sectors that a relevant from a freight transportation perspective, including agriculture, mineral extraction, manufacturing, construction, service, and other sectors.

The FAF data released to the public includes commodity flow matrices by mode of transport for all years between 2012 and 2015 and forecasts in 5 year increments for the interval 2020-2045, a national roadway network, and a zoning system composed by 123 zones corresponding to US states and metropolitan areas. FAF also publishes link flows for all forecast years, which are developed for a more detailed zoning system.

Of the 123 zones published by FAF, 120 are located in the contiguous portion of the continental US (48 contiguous states) which are going to be used as a test scenario, and those will be the zones used as example in this exercise. On the demand side, only truck flows will be considered, since coal rail flows would greatly distort the scale of the resulting maps.

The traditional desire lines generated for this problem are presented on Figure 1, which was simplified on Figure 2 by showing only the flows that sum up to 85% of the matrix total.

Figure 1: Desire lines for FAF

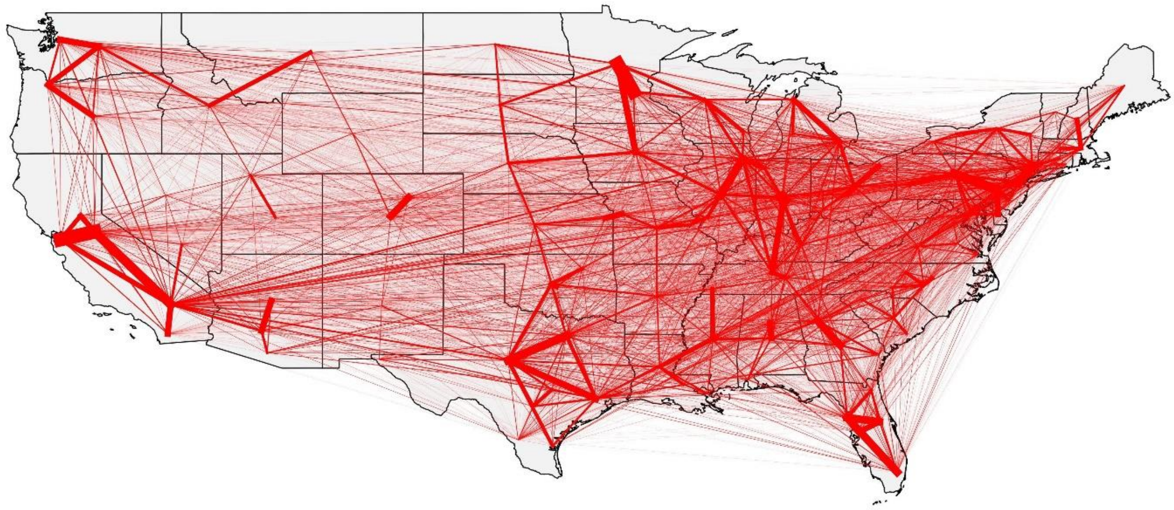
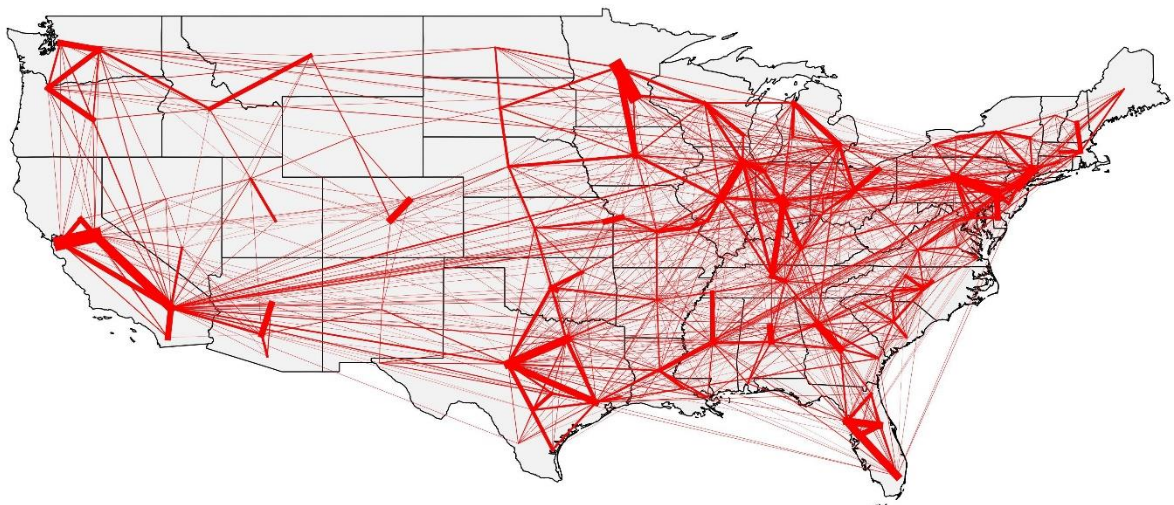


Figure 2: Desire lines for FAF with 85% of the flows

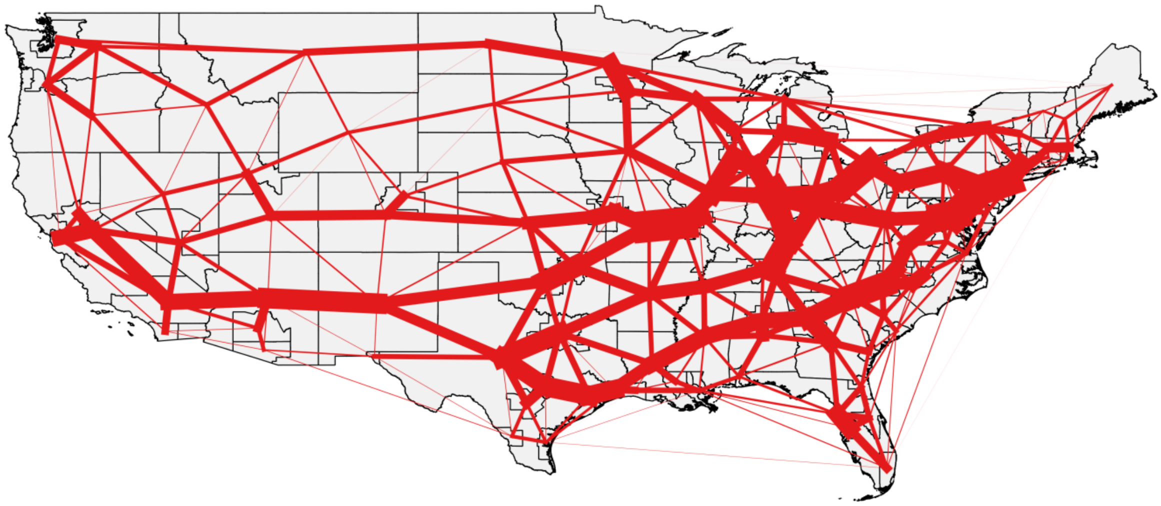


Although much improved, the results shown on Figure 2 are still not as good as expected, but it is the best that can be expected from the use of traditional desire lines.

When applying the proposed algorithm, the results become considerably clearer, as shown on Figure 3.

Additional to the fact that there is not a large of number overlapping lines, it is also easier to see some aggregate movements between the US regions, for example the movement between California and the Chicago region, and between the states in the South, or yet the movements between Chicago and the New York area.

Figure 3: Delaunay lines for FAF



It is true that it would be possible to just use the Interstate system network and perform an all or nothing assignment, but that is not possible in all cases (there isn't always a network that you can use before you develop your own) and that bias the results towards the network that already exists, which is not ideal when the objective it to analyse the demand alone, and not of the final result on the loaded network.

Finally, the transportation production difference between the two techniques resulted a factor of 1.094 (paths on Delaunay Network were 9.4% longer than direct paths on average).

4.2 Brazil: National Transportation and Logistics plan

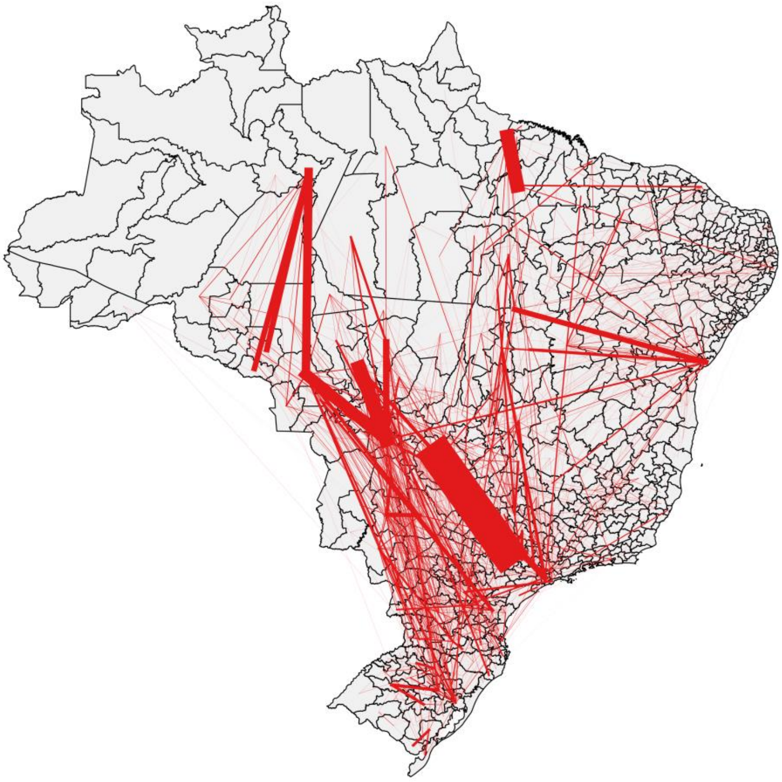
The latest national plan for transportation and logistics in Brazil (PNLT) is being finalized in 2016, and includes three demand scenarios (low, medium and high) forecasted for every five years until 2035 for both freight and passengers, and includes all motorized modes of transportation.

Although not particularly relevant as an aid to further develop state models, as it was the case with the US model, the PNLT is extremely detailed for a nationwide model, with over 500 zones defined by the Brazilian census with basis in socio-economic homogeneity.

The PNLT is the primary tool for defining national policy regarding regional transportation, and it is an important tool to identify the transportation infrastructures that can aide in regional development efforts.

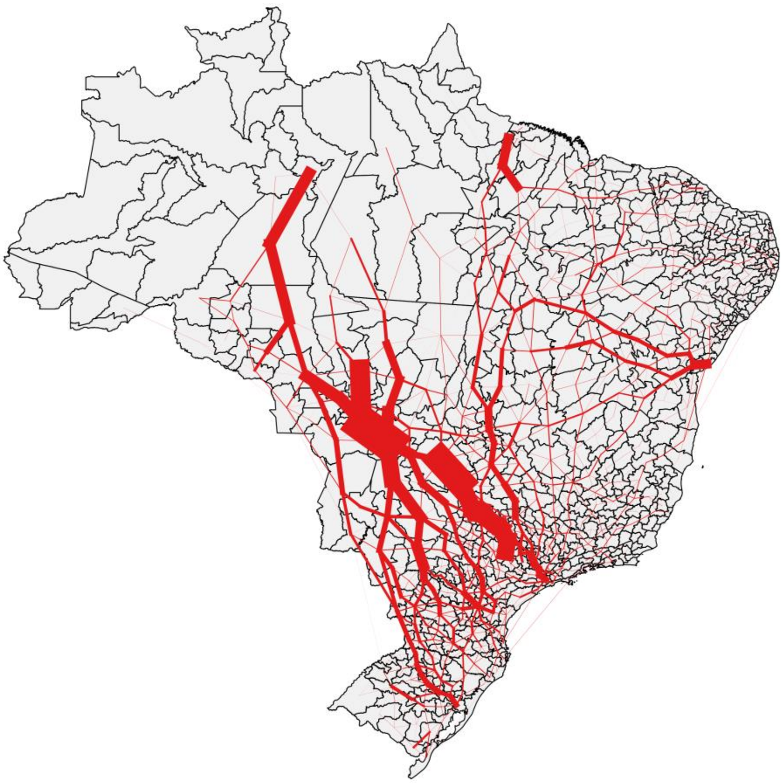
With a much larger number of zones, one would expect an unintelligible set of desire lines, since the number of possible lines is close to 20 times the number of that for the US. However, the Brazilian freight movements a considerably more concentrated than in the US, resulting in cleaner looking desire lines, as shown in Figure 4.

Figure 4: Desire lines for PNLT with 85% of the flows



Once again the Delaunay lines generated with the proposed procedure generates much cleaner output, as shown on Figure 5.

Figure 5: Delaunay lines for PNLT



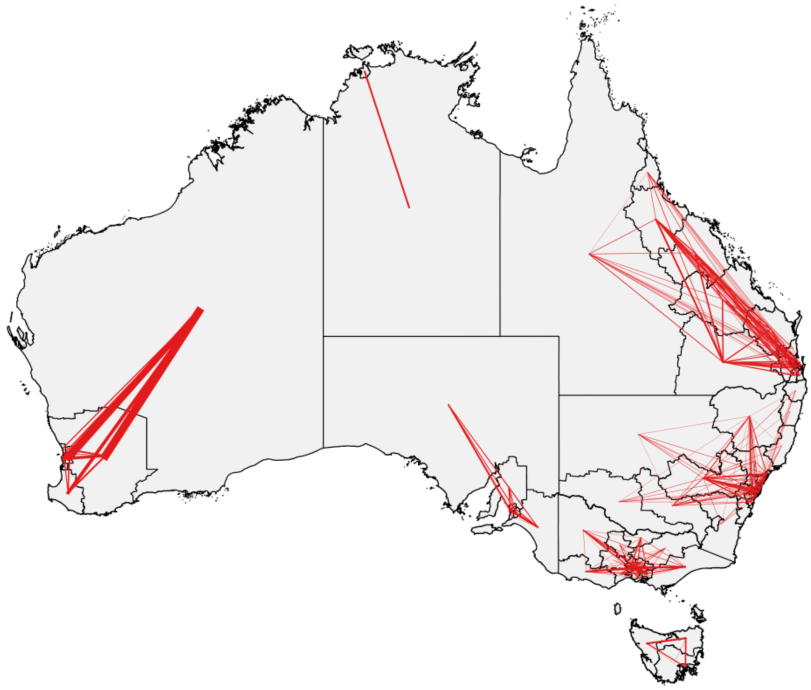
Finally, the transportation production difference between the two techniques resulted in a factor of merely 1.057, meaning that the Delaunay paths were only 5.7% longer than the straight lines on average. Just as a reference, the processing time for the Delaunay lines for this dataset was in the order of 1 second, making comparable to the generation of traditional desire lines.

4.3 Australia: Australia wide freight movements

Since there are no public datasets for transportation movements in Australia other than freight movements between the states, it was necessary to synthesize a matrix in order to have an Australian dataset for tests with the suggested procedure. This synthesized matrix, however, is not an attempt to properly estimate freight flows throughout Australia.

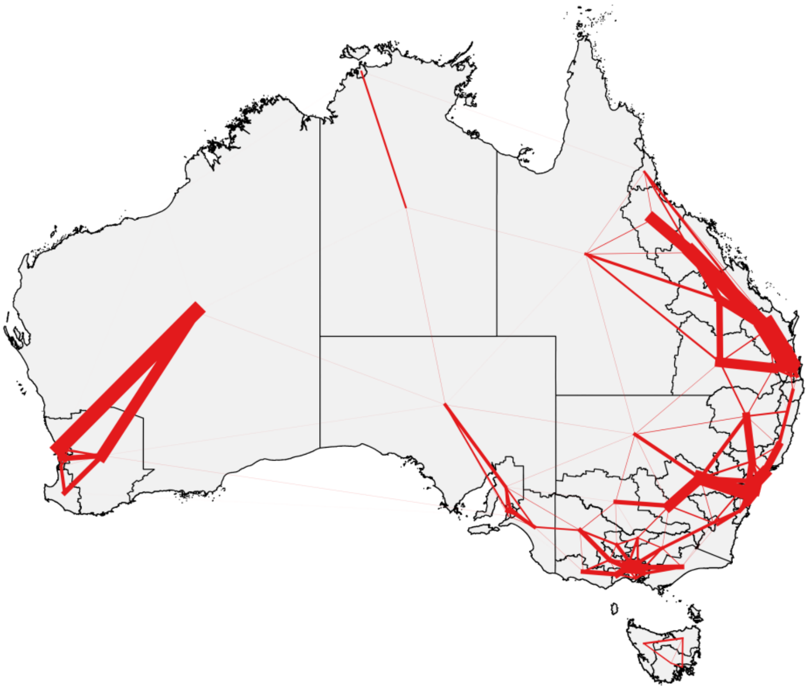
Observing Figure 6 it is possible to see that all largest freight flows, accounting for about 85% of the freight flows in Australia happen within the same state (for this particular version of a synthesized matrix), but it is still difficult to distinguish some of the individual flows, especially in Queensland.

Figure 6: Desire lines for the Australian freight movements



Once again the Delaunay lines generated with the proposed procedure generates much cleaner output, as shown on Figure 7, where flows directed to the Brisbane region are much more clear, as wells as the radial effect around Melbourne.

Figure 7: Delaunay lines for the Australian freight movements



Finally, the transportation production difference between the two techniques resulted a factor of 1.0135 (paths on Delaunay Network were only 1.35% longer than direct paths on average).

5 Conclusions

From the case studies presented, it can be concluded that the objective of having a fast and convenient alternative to Desire Lines with improved outputs has been achieved. Further, the realization that the paths were deviated by less than 10% for all cases presented gives a string indication that the movements shown are not too deformed when compared to the direct lines presented in desire lines, which is an excellent indication of the quality of the solution.

However, it is notable that in all the case studies there were occurrences of links than run virtually parallel to another set of links, raising the question if some of the resulting links could be eliminated in order to further improve the results of this algorithm, but these changes would only be geared towards further improving the visualization.

Lastly, exploring different types of minimal networks such as *Urquhart Graphs* and *Gabriel Graphs* might result in improved desire line visualizations, while more complex solutions such as exploring Constrained Delaunay Triangulation algorithms or developing heuristics to search and eliminate parallel paths in order to reduce the final network complexity are also viable alternatives to be explored in future research, although the last two cases would result in algorithms with parameters that might need to be *calibrated* by the user.

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