Scaling as a Design Principle for Cartography (updated)

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Scaling refers to the fact that there are far more small things than large ones in a map, or the fact that there are far more small geographic features than large ones in both natural and built environments. The notion of scaling is not just limited to geometric situations, but is widely applicable when considering topological and semantic properties. In the latter cases, the notion should be stated as far more less-connected (or unpopular) things than well-connected (or popular) ones in term of topology, and far more meaningless things than meaningful ones in terms of semantics. In this white paper, scaling possesses the same meaning as the term fractal, so the title could be rephrased as *Fractal as a Design Principle for Cartography*. Scaling is used because it is literally linked to scales that simply refer to sizes rather than the meaning of map scales, i.e., a series of scales ranging from the smallest to the largest form a scaling hierarchy with many smallest, a very few largest, and some in between the largest and the smallest.

Geographic features are fractal, and so are the maps that depict the geographic features. Geographic features are often represented using Euclidean geometry, but their essence is fractal. Euclidean and fractal geometry represent two different yet complementary world views. The former is an individual view, while the latter is holistic. If one considers a building plan or a small number of building plans as a whole, it is likely to be Euclidean; if one considers all or a large number of building plans as a whole, it is definitely fractal, because the whole involves far more small buildings than large ones. We therefore must adopt a large scope in order to observe fractals. Furthermore, perspective matters in seeing fractal. For a street network, if one takes the perspective of segments or junctions, it is likely to be Euclidean or Gaussian; if on the other hand one takes the perspective of streets (named or natural streets), it is definitely fractal. Bear it in mind that both scope and perspective matter in seeing fractal.

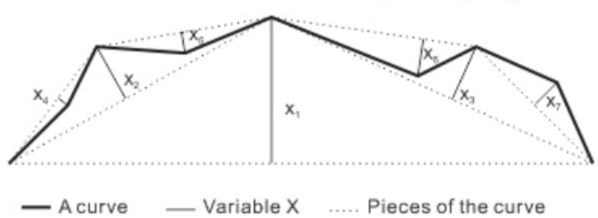

Figure 1: Illustration of a cartographic curve being fractal
(Note: The scaling pattern of far more small xi than large ones recurs twice, i.e., $x_1 + x_2 + x_3 > x_4 + x_5 + x_6 + x_7, and\ x_1 > x_2 + x_3.$)

Fractal can be intuitively seen from the two aspects: (1) far more small things than large ones, and (2) irregular shapes. There are far more small cities (or settlements broadly speaking) than large ones, commonly known as Zipf's law (Zipf 1949); statistically, the first largest city is twice as big as the second largest, three times as big as the third largest, and so on. Coastlines and mountains for example all have irregular shapes. This irregularity or roughness can also be interpreted as far more small things than large ones, i.e., far more small x_i than large ones (Figure 1). The notion of far more small things than large ones is what underlies the new definition of fractal: a set or pattern is fractal if the scaling pattern of far more small things than large ones recurs multiple times (Jiang 2015a). Under the new, relaxed definition, not only a coastline, but also a highway could be fractal; see Figure 1. This definition goes beyond the conventional definitions, e.g., relying fractal dimension to define a fractal (Mandelbrot 1982).

Mapping is not more than illustrating the fact of far more small things than large ones. In this regard, head/tail breaks - a classification scheme for data with a heavy-tailed distribution (Jiang 2013), is an effective means to illustrate scaling or fractals. In this approach, a whole is partitioned, around an average, into the head for those above the average and the tail for those below the average, and this partition continues recursively for the head or those greater than the average, until the notion of far more small things than large ones is violated. With the head/tail breaks, inherent hierarchy of data with a heavy-tailed distribution can be naturally and automatically derived. Figure 2 illustrates two mapping outcomes respectively based on the head/tail breaks and the natural breaks (Jenks 1967). Clearly, the left pattern based on the head/tail breaks reveals the underlying scaling, being more alive or informative than the right one (Jiang 2015b, Wu 2015). The head/tail breaks can also serve as an efficient and effective visualization tool for big data (Jiang 2015a). If we double or triple the number of cities in the same mapping space, the two patterns would become too crowded and look like hairballs. In this case, we can recursively drop out the tail, until the remaining head is clear enough, because the head is self-similar to the whole.

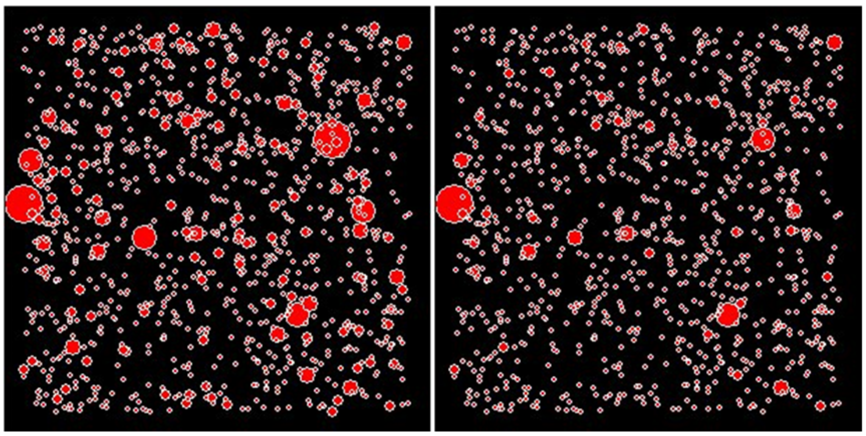

Figure 2: Scaling uncovered by head/tail breaks (left), yet covered by natural breaks (right)
(Note: What are mapped are 1024 cities that follow exactly Zipf's law; the first largest city is size 1, the second largest city is size 1/2, the third largest city is size 1/3, ... and the smallest city is size 1/1024.)

Scaling or maps that reveal scaling can evoke a sense of beauty in the human deep psyche (Jiang and Sui 2014). This kind of beauty exists, to some degree or other, in our surrounding things and spaces (Alexander 2002-2005), but those with a striking hierarchy tend to possess a high degree of beauty. This beauty differs essentially from beauty evoked by surface colors and harmonic design, which are subjective in nature. Traditionally, beauty is in the eye of the beholder, whereas the beauty, or objective beauty so to speak, lies in the scaling structure, and it is little to do with surface colors or harmony. Maps possess this kind of beauty, which deserves further research. I have claimed previously that scaling must be formulated as a law of cartography, and herewith I further claim scaling as a design principle for cartography. I used a design principle in the title, but what I really wanted to convey is that scaling must become a dominant principle, if not the principle, of cartographic design. All other principles must be subordinated to the major or dominant one.

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