Five General Properties of Resolution

Auriol Degbelo[1] and Werner Kuhn[2]

[1] Institute for Geoinformatics, University of Muenster, Germany
degbelo@uni-muenster.de

[2] Department of Geography, University of California, Santa Barbara, USA
kuhn@geog.ucsb.edu

Abstract. This paper presents five properties that are true of the resolution of (geographic) data, and discusses their implications for Geographic Information Science (GIScience). It argues that resolution is (i) always present in data, (ii) representation-dependent, (iii) positively correlated with accuracy, (iv) positively correlated with data volume, and (v) more specific than granularity. These statements are brought forward with the intent of stimulating discussions, and should be seen as provisional, not definitive, much less exhaustive regarding possible laws pertaining to resolution.

1 Introduction

Geographic Information Science (GIScience) is, by now, a field of research on its own, and existing work in the literature has attempted to identify its underlying principles. For example, Goodchild [15] describes six general properties of geographic information. These are: (i) position in the geographic frame are uncertain; (ii) spatial dependence is endemic in geographic information; (iii) geographic space is heterogeneous; (iv) the geographic world is dynamic; (v) much geographic information is derivative; and (vi) many geographic attributes are scale-specific. Another list of principles underlying GIScience was brought forward in [16][3]. It comprises: (i) *spatial dependence* (nearby related things are more related than distant things); (ii) *spatial heterogeneity* (results of any analysis depend explicitly on the bounds of the analysis); (iii) *the fractal principle* (all geographic phenomena reveal more detail with finer spatial resolution, at predictable rates); (iv) *the uncertainty principle* (it is impossible to measure location or to describe geographic phenomena exactly); and (v) *the first law of cognitive geography* (people think that closer things are more similar).

These early attempts are valuable, but a complete answer to the question "[w]hat do we know to be always true of geographic data" [18] needs more research efforts directed specifically towards the identification, where possible, of such principles. The field has now a tentative list of core concepts[4], and a

[3] Both lists overlap to a large extent. Novel in the list presented below is the 'first law of cognitive geography'.

[4] These are (see [25]): location, neighbourhood, field, object, network, event, granularity, accuracy, meaning, and value.

good point to start with is to look at these concepts, asking whether there are statements that are always true of them. This article focuses on *resolution*, and proposes a list of statements that are always valid for the resolution of geographic data[5]. The statements may appear trivial at first sight, but their consequences for geographic information science will explain their importance for the field. Resolution being an *information concept* (see [24]), its general properties are also pertinent to a comprehensive characterization of the geographic information universe. For the rest of the discussion, resolution is defined (in line with [7,8]) as the amount of detail in a data(set). It is distinct from accuracy (closeness of a measurement to the truth), precision (closeness of repeated measurements), coverage (sampling intensity in space or time), granularity (discussed later), discrimination (smallest change in a quantity being measured that causes a perceptible change in the corresponding observation value), and map scale (also called representative fraction).

2 Resolution is always there

Geographic reality is continuous, but a science of geographic information, has at its core *information* coming (or derived) from an observation of this geographic reality. Observation (also referred to as data collection) samples a geographic world too complex to be studied in its full detail (see [6,19,20] for early references to this fact). This has two consequences for GIScience: the first is that discrete models of space[6] (and time) might be more useful to GIScience than continuous ones, and the field should devote some attention to their (further) development. Couclelis [5] notes along these lines that "fitting discrete observations to continuous models and then rediscretizing the results for computational purposes is a less effective way of safeguarding the integrity of the data than when a discrete framework is used throughout". The second consequence is that (spatial) data analysis is always resolution-dependent. A simple example for this is the problem of determining the length of a coastline, lakeshore, or topographic contours. As summarized in [14], this length depends on the degree of generalization of the map[7], if the measurement is made from a map. If on the other hand, length is measured on the ground, resolution (or level of detail) is involved through the sampling interval inherent in the method of measurement. The fact that data analyses are invariably sensitive to resolution implies that data integration - be it manual, semi-automatic or automatic - always needs to be informed of the resolution of the combined datasets, on pain of producing meaningless results. The necessary presence of resolution in the analysis process also leads to the question "[w]hat is the optimum resolution or does an optimum really exist?" [26]. An early study [27] confirmed the validity of the concept of optimal spa-

[5] Section 5 explains why a discussion of resolution (not in [25]) is pertinent in this context.

[6] See for instance [11] for an example of theory of discrete space.

[7] And consequently of the amount of spatial detail in the map.

tial resolution in the field of remote sensing[8]. GIScience will benefit from more investigations about the concept of optimal resolution. More specifically, efforts should be directed toward the development of a fully worked-out theory of optimum spatial, temporal, and thematic resolution, taking into account both the specificities of the data production process (e.g. whether the data was produced by remote sensing or ground survey, human or technical sensors, derived from existing observations or not) and the task at hand (e.g. detection of geographic entities or understanding of global warming).

3 Resolution is representation-dependent

Data analysis, as the previous section discussed, is resolution-dependent. In turn, resolution is dependent upon the type of representation considered[9]. The definition of resolution as amount of detail in a representation makes the concept somewhat abstract. Yet, metrics of resolution are handy (when it comes to computation) and needed (for the comparison of different representations with respect to their resolution). The quest for a bridge between an abstract concept and useful metrics for the purposes of computation and comparison has given rise to various proxy measures for resolution. Several of such measures listed in [8] include: the instantaneous field of view of a satellite, the size of the minimum mapping unit, the precision of a measuring device, the spacing of a collection of samples, and the sampling intensity of a collection of samples. Additional examples of proxy measures for resolution are the spatial receptive field and the temporal receptive window of an observer (see [7] for details), and the location of the focus of measurement (see [30] for the formal treatment). In general, proxy measures for resolution are expected to vary according to the data consumer's purpose, and also from era to era[10]. The corollary of this fact is that, as far as resolution is concerned, semantic interoperability is only partly solvable. That is, it might be that some datasets can simply *not* be semantically integrated because the information communities which produced them use different and irreconcilable means of assessing their resolution. Following Scheider and Kuhn [29], the goal of semantic interoperability research is therefore to *articulate* heterogeneity regarding resolution (not to resolve, avoid or mitigate it) by developing methods which help machines to find out the types of proxy measures where semantic translation is possible, and the types where translation is not sensible.

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[8] The task considered in [27] was the detection and discrimination of coniferous classes in a temperate forest environment.

[9] 'Representation', as used in this paper, refers to what von Glasersfeld [13] calls *iconic representation* (as opposed to other meanings of the term such as *mental representation*, *substitution* or *denotation*).

[10] As Goodchild [17] pointed out, metrics of spatial resolution are strongly affected by the analog to digital transition.

4 Resolution is positively correlated with accuracy and data volume

Resolution is positively correlated with accuracy: the greater the amount of detail in a representation, the better the closeness of this representation to the 'truth' (or the perfect representation)[11]. Let geographic reality G be modelled as a set of n (n>1) infinitely small, discernible and structurally similar elements e: G = $\{e_1, ..., e_n\}$. Let R be a perfect representation of this geographic reality. R contains all elements of G, that is, R = $\{e_1, ..., e_n\}$. Let R_j and R_k be two imperfect representations of G: $R_j = \{e_1, ..., e_j\}$ and $R_k = \{e_1, ..., e_k\}$; j<n and k<n. The discrepancies (between R_j, R_k and R) associated with R_j and R_k are respectively: Discrepancy (R_j, R) = $\{e_{j+1}, ..., e_n\}$ and Discrepancy (R_k, R) = $\{e_{k+1}, ..., e_n\}$. Let NElements (s) be the number of elements in a set s, Error (r) be the error associated with a given representation r, and Resolution (r) be the resolution of a representation r.

$$\begin{aligned} Error(R_{\mathrm{j}}) < Error(R_{\mathrm{k}}) &\iff \\ NElements(Discrepancy(R_{\mathrm{j}}, R)) < NElements(Discrepancy(R_{\mathrm{k}}, R)) &\iff \\ NElements(\{e_{\mathrm{j}+1}, ..., e_{\mathrm{n}}\}) < NElements(\{e_{\mathrm{k}+1}, ..., e_{\mathrm{n}}\}) &\iff \\ j+1 > k+1 &\iff \\ NElements(\{e_1, ..., e_{\mathrm{j}}\}) > NElements(\{e_1, ..., e_{\mathrm{k}}\}) &\iff \\ Resolution(R_{\mathrm{j}}) > Resolution(R_{\mathrm{k}}) & \end{aligned}$$

Resolution and error are inversely correlated, therefore resolution is positively correlated with accuracy[12]. Resolution is also positively correlated with data volume: the more detail to store, the more data volume required[13]. The usefulness of these two statements for GIScience is at least twofold: (i) development of consistency tests for spatial databases; and (ii) the assessment of the *value* of geographic information. Accuracy, resolution and data volume are critical parameters of geographic information, and knowledge about their dependencies is a necessary basis for the bigger undertaking (mentioned in [24,25]) of assessing the valuation of geographic information as a good in society. GIScience would

[11] Veregin (cited in [8]) argues that one would expect accuracy and resolution to be inversely related so that a higher level of accuracy is achieved when the specification is less demanding. His argument is valid for the relationship between 'accuracy of a representation' and 'resolution of the specification used to assess the representation's accuracy'. This work discusses another relationship, namely the one between 'accuracy of a representation' and 'resolution of the same representation', when the representation is generated by a (technical) sensor.

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[12] For an early finding in line with this statement, see [12]. Gao [12] observed that the root mean square error of a gridded digital elevation model (DEM) increases linearly when the spatial resolution of the DEM is reduced (i.e. the DEM's accuracy becomes lower and lower as its resolution decreases).

[13] For example, Gao [12] states: "The representation of a terrain by a gridded DEM requires a large volume of data that increases with the square of the resolution".

thus benefit from the development of mathematical models which make explicit, where possible, the correlation-coefficients between these parameters.

5 Resolution is more specific than granularity

What is the difference between resolution and granularity? Hornsby (cited in [9]) suggests a simple answer to the question, namely: "Resolution refers to the amount of detail in a representation, while granularity refers to the cognitive aspects involved in selection of features". Degbelo and Kuhn [8] set forth that resolution refers to the amount of detail in a dataset, while granularity denotes the amount of detail in a conceptual model. Evidence supporting this view is that existing GIScience theories of resolution all center upon *data and sensors*, while GIScience theories of granularity revolve around *partitions*[14] *and foreground of attention*. Examples of key notions appearing in previous theories of resolution and granularity in GIScience reviewed are provided in Table 1. The table shows that indiscernibility (the more discernible elements, the more amount of detail) is a notion that is common to both types of theories. The table also illustrates that theories of granularity cover broader (and also less understood) aspects than those covered by theories of resolution. The notion of granular partition (see for example [2]) includes not only maps (i.e. data), but also *categorizations* (which go beyond measurement and observation, and enter the realm of conceptual modelling).

As discussed in [10], resolution appears in datasets because of the intrinsic perceptive limitations of sensory apparatuses. Regarding granularity, Hobbs [21] indicates that it relates to the efficient selection of the aspects of our environment that are most likely to be *relevant* to our interests. Along similar lines, Tenbrink and Winter [33] point out that humans "typically manage to present information in an integrated and coherent way, switching flexibly and smoothly between levels of granularity according to the expected relevance for the information seeker". That is, at least two factors induce granularity: (i) intrinsic limitations of humans' cognitive abilities ("cognition is not omniscient" [4]); and (ii) the intentional choice of forgetting, for a moment, some aspects of the environment that are deemed irrelevant. Granularity pervades conceptual models, whether these take the form of *visual* (e.g. a picture in [22] showing a geo-ontology design pattern for semantic trajectories) or *narrative* summaries (e.g. a description such as [23] aiming at providing an explanation about working principles of observation processes).

That resolution is more specific than granularity - resolution is a more specialized aspect of granularity referring to data - implies that theories of resolution and granularity can learn from each other. It is to be expected that certain laws of resolution no longer hold for granularity and vice-versa. For example, that "granularity is always there" is valid for conceptual models. However (and contrary to

[14] Partitions are defined in [4] as cognitive devices designed by human beings, and which have the built-in capability to recognize objects, reflect certain features and ignore other features of these objects.

Table 1. Examples of key notions appearing in previous theories of resolution and granularity in GIScience

	Examples of key notions	References
Theories of resolution	data/observation, sensor, support, indiscernibility, spatial receptive field, temporal receptive window	[7,10,32,34]
Theories of granularity	foreground, background, indiscernibility, context, judgment, projection, partition	[1,2,3,4,31]

the arguments exposed in Section 4) granularity and accuracy are independent. Consider for example the question "where were you yesterday morning?" and the following possible answers[15]: "back in the States", "in California", "in L.A.", "in Topanga", "at home", "at my desk", "at the computer". Although the answers exhibit different levels of granularity, all are correct (or 100% accurate in that they 'tell the truth').

6 Conclusion

The paper has proposed five statements as candidate laws pertaining to the resolution of geographic data, and briefly discussed their implications for GIScience. The article pointed out the need for further investigations regarding (i) the concept of optimal resolution; (ii) semantic translation as regards proxy measures for resolution, (iii) mathematical models specifying correlation-coefficients between resolution and accuracy, as well as resolution and data volume; and (iv) the (cognitive) processes inducing granularity.

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References

1. Bittner, T.: Granularity in reference to spatio-temporal location and relations. In: Haller, S., Simmons, G. (eds.) Proceedings of the 15th International FLAIRS (Florida Artificial Intelligence Research Society) Conference. pp. 466–470. AAAI Press, Pensacola Beach, Florida, USA (2002)
2. Bittner, T., Smith, B.: A taxonomy of granular partitions. In: Montello, D.R. (ed.) Spatial Information Theory - Foundations of Geographic Information Science. pp. 28–43. Springer-Verlag Berlin Heidelberg, Morro Bay, California, USA (2001)
3. Bittner, T., Smith, B.: A unified theory of granularity, vagueness and approximation. In: Proceedings of the COSIT01 Workshop on Spatial Vagueness, Uncertainty, and Granularity. Morro Bay, California, USA (2001)

[15] The example is slightly modified from [28].

4. Bittner, T., Smith, B.: A theory of granular partitions. In: Duckham, M., Goodchild, M.F., Worboys, M.F. (eds.) Foundations of geographic information science, chap. 7, pp. 117–149. Taylor and Francis, New York (2003)
5. Couclelis, H.: Ontologies of geographic information. International Journal of Geographical Information Science 24(12), 1785–1809 (2010)
6. Degbelo, A.: Estimating the spatial resolution of observation data in vector format. In: Schwering, A., Kray, C. (eds.) Conference on Spatial Information Theory: COSIT'11 - Proceedings of the Doctoral Colloquium. Belfast, Maine, USA (2011)
7. Degbelo, A.: Modelling the spatial and temporal resolution of a sensor observation. In: Jekel, T., Car, A., Strobl, J., Griesebner, G. (eds.) GI_Forum 2013 - Creating the GISociety. pp. 71–80. Herbert Wichmann Verlag, Salzburg, Austria (2013)
8. Degbelo, A., Kuhn, W.: A conceptual analysis of resolution. In: Bogorny, V., Namikawa, L. (eds.) XIII Brazilian Symposium on Geoinformatics. pp. 11–22. Campos do Jordão, Brazil (2012)
9. Fonseca, F., Egenhofer, M., Davis, C., Câmara, G.: Semantic granularity in ontology-driven geographic information systems. Annals of Mathematics and Artificial Intelligence 36(1), 121–151 (2002)
10. Frank, A.: Why is scale an effective descriptor for data quality? The physical and ontological rationale for imprecision and level of detail. In: Navratil, G. (ed.) Research Trends in Geographic Information Science, pp. 39–61. Springer Berlin Heidelberg (2009)
11. Galton, A.: The Mereotopology of discrete space. In: Freksa, C., Mark, D.M. (eds.) Spatial Information Theory - Cognitive and Computational Foundations of Geographic Information Science (COSIT'99). pp. 251–266. Springer-Verlag Berlin Heidelberg, Stade, Germany (1999)
12. Gao, J.: Resolution and accuracy of terrain representation by grid DEMs at a micro-scale. International Journal of Geographical Information Science 11(2), 199–212 (1997)
13. von Glasersfeld, E.: Preliminaries to any theory of representation. In: Janvier, C. (ed.) Problems of representation in the teaching and learning of mathematics, pp. 215–225. Lawrence Erlbaum Associates (1987)
14. Goodchild, M.F.: Fractals and the accuracy of geographical measures. Mathematical Geology 12(2), 85–98 (1980)
15. Goodchild, M.F.: A geographer looks at spatial information theory. In: Montello, D.R. (ed.) Spatial Information Theory - Foundations of Geographic Information Science, pp. 1–13. Springer-Verlag Berlin Heidelberg, Morro Bay, California, USA (2001)
16. Goodchild, M.F.: GIScience, geography, form, and process. Annals of the Association of American Geographers 94(4), 709–714 (2004)
17. Goodchild, M.F.: Scales of cybergeography. In: Sheppard, E., McMaster, R. (eds.) Scale and geographic inquiry: nature, society, and method, chap. 7, pp. 154–169. Blackwell Publishing Ltd, Malden, MA (2004)
18. Goodchild, M.F.: The validity and usefulness of laws in geographic information science and geography. Annals of the Association of American Geographers 94(2), 300–303 (2004)
19. Goodchild, M.F.: Scale in GIS: an overview. Geomorphology 130(1-2), 5–9 (2011)
20. Goodchild, M.F., Proctor, J.: Scale in a digital geographic world. Geographical and environmental modelling 1(1), 5–23 (1997)
21. Hobbs, J.R.: Granularity. In: Joshi, A. (ed.) In Proceedings of the Ninth International Joint Conference on Artificial Intelligence. pp. 432–435. Morgan Kaufmann Publishers, Los Angeles, California, USA (1985)

22. Hu, Y., Janowicz, K., Carral, D., Scheider, S., Kuhn, W., Berg-Cross, G., Hitzler, P., Dean, M., Kolas, D.: A geo-ontology design pattern for semantic trajectories. In: Tenbrink, T., Stell, J., Galton, A., Wood, Z. (eds.) Spatial Information Theory - 11th International Conference (COSIT 2013). pp. 438–456. Springer International Publishing, Scarborough, UK (2013)
23. Kuhn, W.: A functional ontology of observation and measurement. In: Janowicz, K., Raubal, M., Levashkin, S. (eds.) GeoSpatial Semantics: Third International Conference. pp. 26–43. Springer Berlin Heidelberg, Mexico City, Mexico (2009)
24. Kuhn, W.: Core concepts of spatial information: a first selection. In: Vinhas, L., Davis Jr., C. (eds.) XII Brazilian Symposium on Geoinformatics. pp. 13–26. Campos do Jordão, Brazil (2011)
25. Kuhn, W.: Core concepts of spatial information for transdisciplinary research. International Journal of Geographical Information Science 26(12), 2267–2276 (2012)
26. Lam, N.S.N., Quattrochi, D.A.: On the issues of scale, resolution, and fractal analysis in the mapping sciences*. The Professional Geographer 44(1), 88–98 (1992)
27. Marceau, D.J., Gratton, D.J., Fournier, R.A., Fortin, J.P.: Remote sensing and the measurement of geographical entities in a forested environment. 2. The optimal spatial resolution. Remote Sensing of Environment 49(2), 105–117 (1994)
28. Schegloff, E.: On granularity. Annual Review of Sociology 26, 715–720 (2000)
29. Scheider, S., Kuhn, W.: How to talk to each other via computers - Semantic interoperability as conceptual imitation (2014), forthcoming.
30. Scheider, S., Stasch, C.: The semantics of sensor observations based on attention (2014), forthcoming.
31. Stell, J.: Granulation for graphs. In: Freksa, C., Mark, D.M. (eds.) Spatial Information Theory - Cognitive and Computational Foundations of Geographic Information Science (COSIT'99). pp. 417–432. Springer-Verlag Berlin Heidelberg, Stade, Germany (1999)
32. Stell, J., Worboys, M.: Stratified map spaces: a formal basis for multi-resolution spatial databases. In: Poiker, T., Chrisman, N. (eds.) SDH'98 - Proceedings 8th International Symposium on Spatial Data Handling. pp. 180–189. Vancouver, British Columbia, Canada (1998)
33. Tenbrink, T., Winter, S.: Presenting spatial information: Granularity, relevance, and integration. Journal of Spatial Information Science (1), 49–51 (2010)
34. Worboys, M.: Imprecision in finite resolution spatial data. GeoInformatica 2(3), 257–279 (1998)