DIVERSITY: TOWARDS AN UNIFYING CONCEPT JOINING THEORETICAL AND PRACTICAL VIEWS OF ECOLOGY AND GEOGRAPHY UNDER A SPATIAL AND STATISTICAL FRAMEWORK

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Abstract. The 1992 United Nations Convention on Biodiversity brought to the attention of scientists the concept of diversity. Its definition allowed for including new elements, developing new concepts and refining the existing theories. Geographers developed their own interpretation, resulting into the concept of geodiversity. Particular concepts were defined for the human society, soils and other components of the physical realm. This paper attempts to integrate all concepts and developments into a unitary perspective, and apply this theoretical framework to analyze the diversity of an entire country in a measurable way. The results indicate the need for merging the variety of diversities into a unitary approach.

Keywords: ecodiversity, biodiversity, geodiversity, pedodiversity, territorial diversity.

Rezumat. Diversitatea: către un concept unitar ce îmbină perspectivele teoretice şi practice ale ecologiei şi geografiei în accepţie spaţială şi statistică. Convenţia Naţiunilor Unite din 1992 privind Diversitatea Biologică a adus în atenţia specialiştilor conceptul de diversitate. Definiţia sa permite includerea de noi elemente, elaborarea unor noi concepte şi rafinarea teoriilor existente. Geografii au dezvoltat propriile interpretări, conducând la apariţia conceptului de geodiversitate. Noţiuni particulare au fost definite cu referire la societatea umană, soluri şi alte componente ale lumii fizice. Lucrarea îşi propune să integreze aceste concepte şi abordări într-un cadru unitar şi să îl aplice pentru a analiza cantitativ diversitatea unei ţări întregi. Rezultatele susţin necesitatea de a integra varietatea de diversităţi într-o abordare unitară.

Cuvinte cheie: ecodiversitate, biodiversitate, geodiversitate, pedodiversitate, diversitate teritorială.

THE CONCEPT OF DIVERSITY

According to the most common understanding, diversity refers to dissimilarities between objects of the same class, making them distinguishable one from another, while preserving the common features of the class, even though there are many definitions, measurements and indices associated with it (MOR BARACK, 1999; MC DONALD & DIMMICK, 2003; WINEBERG & OPPACHER, 2003). It is also called variability or heterogeneity. Apart from this very general understanding, the diversity of physical realm has been interpreted in numerous ways by disciplines concerned with its study; components ranging from molecules to ecosystems (HUBER et al., 2005) have been joined and separated in concepts like biodiversity, ecodiversity, geodiversity, pedodiversity, territorial diversity, etc.

ECODIVERSITY, BIODIVERSITY, GEODIVERSITY, PEDODIVERSITY

For ecologists, the 1992 United Nations Convention on Biodiversity established a conceptual model which overlaps diversity (biological or ecological) to the structure and functions of ecological systems, seen as life-support systems or ecological foundation (VĂDINEANU, 1998). The simplest rationale is that the most common measurement of diversity (species richness) is also a simple descriptor of the structure of ecosystems (PIMM & RAVEN, 2000). Consequently, the conservation of diversity is identical to the protection of environment. Ecologists believe that a greater diversity gives the system better chances of adapting to the fluctuations of command factors; the range of fluctuations is diminished in terms of effects, resulting into a higher stability (WASHINGTON, 1984; VĂDINEANU, 1998; MC CANN, 2000; IVES & CARPENTER, 2007). Ecologists believed initially that diversity and stability are proportional, but later found out that there is a diversity threshold. If diversity exceeds this value, the system becomes unstable. The threshold is given by the number of species connected through stable relations (TOMESCU & SAVU, 2002; MOUGI & KONDOH, 2012).

Two concepts of diversity, *i.e.*, biodiversity and ecodiversity, are used to describe the structure – including relationships between structural elements – and functions of ecological systems (PETRIŞOR, 2008b; VĂDINEANU, 1998; 2007). Starting from this dichotomy, biodiversity and ecodiversity are defined in two perspectives. The first refers to the structure of the ecological systems and will be called "structural biodiversity", and the other to their functions, namely 'functional biodiversity' (NOSS, 1990; KAENNEL, 1998; DANOVARO et al., 2008). According to VĂDINEANU (1998, pp. 116-117), structural biodiversity includes: (1) diversity of ecological systems; embeds the diversity of supra-species biological systems integrated in the biological organizational hierarchy – biocoenosis, biome, biosphere, and the diversity of hydro-geomorphologic units, including habitats; this side is called ecodiversity in its strict sense; (2) diversity of species and levels of the taxonomic hierarchy (ω or phylogenetic diversity) – biodiversity in its strict sense; (3) genetic diversity of populations, species, genetic resources, including the human species, and (4) ethno-cultural diversity of socio-economic systems. The first three components reflect the natural capital, and the latest, the created capital. Functional biodiversity is reflected by the variety of food niches and trophic subunits of the biocoenosis: trophic dynamic modules, guilds, trophic levels, etc. (MARTINEZ, 1996; PETCHEY & GASTON, 2006; POPESCU, 2009).

Geodiversity is disputed by three disciplines. In geography, geodiversity is the heterogeneity of "*geological features (rocks, minerals, fossils, and structures), geomorphologic features (landforms and processes) and soil features, including their assemblages, relationships, properties, interpretations and systems*" (GRAY, 2004, pp. 8). In geology, geodiversity is an expression of the "*geology of a region, including rocks, minerals, fossils and geological structures open by natural or anthropic means*" (POPA, 2007). For ecologists, geodiversity is "*a measure of environmental resource availability, which includes climate, topography, soils and geology*" (PARKS & MULLIGAN, 2010). Similar definitions or understandings are found in LESER & SCHAUB, 1995; BARTHLOTT et al., 1996; JAČKOVÁ & ROMPORTL, 2008 and PĂTRU-STUPARIU et al., 2011.

These two perspectives indicate a proprietary understanding of diversity based on discipline. In fact, ecology and geography describe the same territorial reality, and use a systemic approach to describe it, making correspondences possible based on spatial scale (PETRIŞOR, 2012), as showed in Table 1. For this reason, several authors believe that geodiversity and biodiversity overlap conceptually (MUSILA et al., 2005; SANTUCCI, 2005), while others argue that geodiversity includes biodiversity (HAKALA, 2005) and some claim the opposite (VĂDINEANU, 1998, pp. 116-117).

PETRIŞOR & SÂRBU (2010) consider that the confusion is etymological, since "biodiversity" is built upon the Greek ßίος (bios) – living, as in the Rio Convention on biological diversity: "*variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems*" (United Nations, 1992). Provided that the Rio definition of biodiversity embeds the diversity of ecosystems, which include "*not only the organism-complex, but also the whole complex of physical factors*" (TANSLEY, 1935), it can be extended to include non-living (abiotic) components. The resulting diversity (of living and non-living components of ecological systems), seen as a component of biodiversity, was called ecodiversity, and constructed etymologically around the concept of ecosystem. PETRIŞOR & SÂRBU (2010) believe that the inclusion of ecodiversity in the already consecrated concept of biodiversity, as an extension, was preferred despite on their inverse logical and semantic relationship, even though erroneous, and concluded that, if understood correctly, ecodiversity overlaps with geodiversity, and represents the diversity of natural and anthropic sub-systems, including biodiversity (Fig. 1). Landscape ecologists also use "landscape ecology" as a synonym for ecodiversity (LESER et al., 1995; BARTHLOTT et al., 1996; JEDICKE, 2001; DEGÓRSKI, 2006; WALZ, 2011; PĂTRU-STUPARIU et al., 2011).

Table 1. Correspondence of the hierarchies of systems in geography, ecology and spatial planning and spatial diversity (PETRIŞOR, 2012).

Hierarchy of ecological systems	**Hierarchy of geographic systems**	**Hierarchy of territorial systems**	**Spatial diversity**
Structural and functional sub-units of ecosystems	Nano- and micro-structures, house/ block, company/ unit/ section, street/ street segment	-	α, ω
Ecosystem	Geosystem, geofacies, geotope, local system	NUTS V (LAU II)	α, ω
Regional complex of ecosystems	Natural region, geographical region, regional system	NUTS III	ß, γ, ω
Macro-regional complex of ecosystems	Domain, zone, national/ supra-national, continental system	NUTS II, NUTS I national territory, continent	γ, δ, ε, ω
Ecosphere	Geosphere, planetary system	Globe	ω

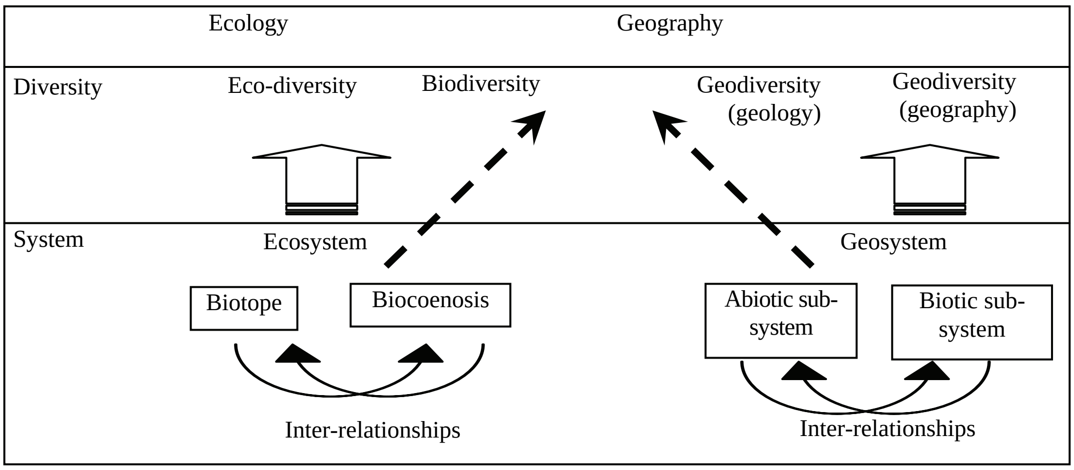

Figure 1. Relationships between biodiversity, ecodiversity and geodiversity correlated to the hierarchy of systems in ecology and geography (PETRIŞOR & SÂRBU, 2010).

The relationship between the two concepts was also discussed by PETRIŞOR & SÂRBU (2010) based on the concept of eco-energy, measuring the degree of anthropization (IANOŞ, 2000). The anthropization process is joined by impacts including pollution (BRAGHINĂ et al., 2010, 2011; PEPTENATU et al., 2010, 2011, 2012; CORNEANU et al., 2012) or the so-called "global changes", term introduce to coin land cover and use changes, climate changes and alterations of the energy flow and their connections (DALE, 1997; DALE et al., 2009, 2011; CHEVAL et al., 2009), determining the simplification and fragmentation of natural habitats and loss of biodiversity, which results in a reduced biodiversity of man-dominated systems, as it can be seen along the urbanization gradients (VĂDINEANU, 1998; SAVARD et al., 2000; HABERL et al., 2009; ŠUSTEK, 2011, 2012). Concomitantly, urbanization results into the emergence of new structures, specific to the socio-economic systems, leading to an increased complexity of territorial systems, translated into increased geodiversity (SÂRBU, 1999; IANOŞ et al., 2011). If natural resources are managed in an environmental-friendly manner (IANOŞ et al., 2009), biodiversity is "amplified" through the human contribution (VĂDINEANU, 2004), and geodiversity increases (VĂDINEANU, 1998).

Given the very particular view on soil systems (pedosystems), seen as an interface between the living and non-living realms, IBÁÑEZ et al. (2012) consider that pedodiversity, defined as "*inventory of the various discrete pedological entities (e.g. soil taxa) and the analysis of their spatial and temporal patterns*", differs from biodiversity, but can be used as its surrogate indicator. On a similar note, FLOREA et al. (2013) consider that pedodiversity is a synthetic and ingrate expression of the variety and differences between the soils of a given territory from genetic and spatial viewpoints, distinguishing between genetic pedodiversity (defined similarly to species richness, based on soil taxonomy) and spatial pedodiversity, related to the pattern and spatial distribution of soils, composing a pedo-landscape (FLOREA, 2002; PETRIŞOR, 2012).

STATISTICAL INTERPRETATION AND MEASUREMENT OF DIVERSITY

Diversity is understood in statistics **quantitatively** as scatter around a central trend (DRAGOMIRESCU, 1998, pp. 37) and **qualitatively** as different number of constituents and their different weights, *i.e*., evenness of distribution (DRAGOMIRESCU, 1998, pp. 88; DRAGOMIRESCU & PETRIŞOR, 2009, pp. 110; MAGURRAN, 1998, pp. 7). The first view, commonly named "variability", applies to biological and ecological "metrics" – size, weight, and other measurable characteristics of individuals, and has the potential for distinguishing between species or taxonomic subdivisions of species. For example, consider a distribution of lengths of lake fishes belonging to different species; in this case, for each species lengths have a Normal distribution, as most individuals have lengths close to the average value, and only few are abnormally long or short (Fig. 2, bottom row). Each peak indicated by the average length corresponds to a species, and experts are able to distinguish, for instance, the peak of large Gibel carp *Carassius auratus gibelio* (Bloch, 1782), average bleak *Alburnus alburnus* (Linnaeus, 1758) or small bitterling *Rhodeus sericeus amarus* (Bloch, 1782). In the second view, "diversity' (*sensu stricto*) or heterogeneity produces a "diversity of diversities" (MAGURRAN, 1998) measured by many indices, such as the simple species richness or complex models (McArthur, Shannon, Motomura, etc.), including unifying indices (HILL, 1973), all based at least on the number of species, and eventually the number of individuals from each species. Even though these indices were traditionally used in ecology, different authors used them for measuring pedo-diversity (FLOREA et al., 2013) or ethno-cultural diversity (PETRIŞOR & IANOŞ, 2012).

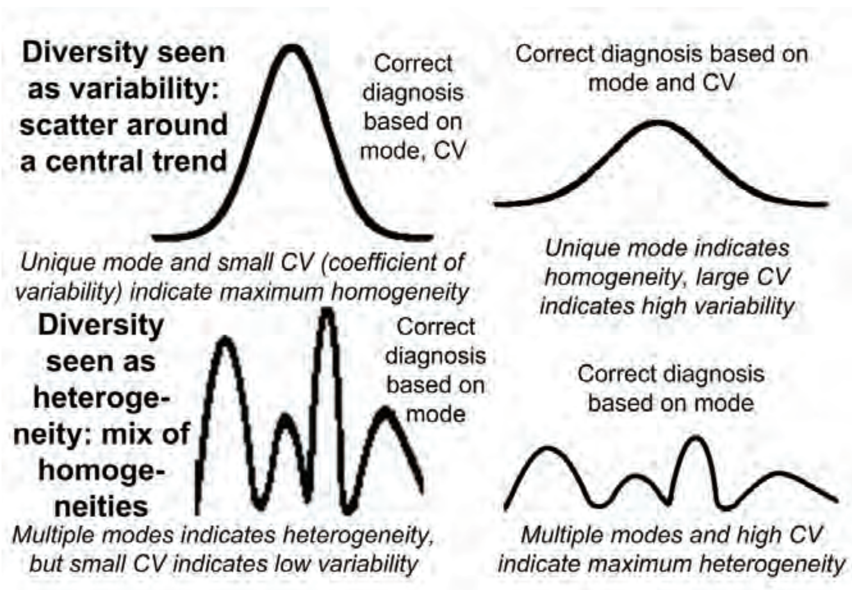

Figure 2. Statistical interpretation and indicators of diversity based on metrics (PETRIŞOR, 2012).

The distinction between variability and heterogeneity is fine-tuned; the number of modes indicates the number of homogenous distributions, as each unimodal (single-mode) distribution is homogeneous from this standpoint (see the example with the fish length distribution above; each unimodal distribution corresponds to a species). If there are several modes, they can indicate variability or heterogeneity: sexual dimorphism producing two modes when looking at the metrics is an example of variability, but the discrimination of species based on modes seen in the metrics distribution indicates heterogeneity (DRAGOMIRESCU, 1998). The coefficient of variability (CV) indicates only variability; sometimes, the two indicators might give contradictory messages, but it has to be recalled that the CV makes sense only when the mode is singular (Fig. 2).

A SPATIAL PERSPECTIVE ON DIVERSITY

The importance of temporal and spatial scales to ecology has been underlined by numerous studies (WEGENER et al., 1986; WIENS, 1989; SAVARD et al., 2000; FISHER et al., 2009). The spatial approach is particularly important to pinpointing "hotspots" defined as areas with high biodiversity or concentrated risks for the loss of biodiversity (MYERS et al., 2000). However, spatial and temporal data on species richness can hardly assess long term environmental changes due to sparseness (CIUBUC, 2004; ZINEVICI et al., 2010) resulting from financial constraints, change of priorities, or lack of taxonomists covering some groups.

Different authors (MAGURRAN, 1998, pp. 58; PETRIŞOR, 2008a, 2009a, b; PUSCEDDU, 2008, pp. 6-7) believe that diversity has different levels, corresponding to the spatial scale, namely: (1) α diversity – diversity of an ecosystem, (2) ß diversity – diversity of a micro-regional complex of ecosystems, (3) γ diversity – diversity of a regional complex of ecosystems, such as ecological regions or European biogeographical regions, (4) δ diversity – diversity of a macro-regional complex of ecosystems, such as global biogeographical regions, (5) ε diversity – diversity of life environments (oceanic, terrestrial), and (6) ω diversity – global phylogenetic diversity (included in the same categories, even though the approach refers more to structural diversity). Given the correspondence presented in Table 1, these levels can be extended to geographical systems. Furthermore, there is a correspondence with temporality, meaning that smaller systems change faster and more frequently (WIENS, 1989).

The diversity of socio-spatial systems (dominated by the human species) is analysed through the ethno-cultural component of diversity (DIETZ, 2007), consisting of the presence of more cultures belonging to different ethnic or religious groups and the linguistic diversity (PETRIŞOR, 2008b; PETRIŞOR & IANOŞ, 2012).

This spatial perspective is particularly useful in determining concrete way to assessing diversity. Since socio-ecological complexes correspond administratively and spatially to the levels of the Nomenclature of Territorial Units for Statistics (NUTS) hierarchy, a correspondence can be made between NUTS levels and geo-, bio- and ecodiversity. Table 2 lists several classifications that reflect units of different sizes with known structure and overall diversity. Some of the most important classifications are:

- Global diversity of continental systems is reflected by global biogeographical regions (PIELOU, 1979).
- Within each continent, macro-regional diversity is reflected by biogeographical regions; there are eleven European biogeographical regions: Arctic, Boreal, Continental, Atlantic, Macaronesian, Mediterranean, Alpine, Pannonian, Steppic, Black Sea (Pontic), and Anatolian (PINBORG & LARSSON, 2002).
- The diversity of regional ecological complexes of ecosystems is described at the macro-regional level by the ecological regions.
- Regional diversity is reflected by habitats. The classification of the European natural and man-dominated ecological habitats is the European Nature Information System (EUNIS) classification, developed between 1996 and 2001 by the European Environment Agency, successor to the CORINE (CoORdination INformation Environment) Biotopes Habitat Classification developed in 1991 (DAVIES et al., 2004).
- Local diversity is reflected by land cover and use. According to JENSEN (2000, pp. 413), "*land cover*" indicates what lays on the ground surface from a biophysical viewpoint, while "*land use*" indicates its use by human communities. However, the second definition is perfectly valid for man-dominated systems only; in natural systems, land use reflects only a more detailed classification (PETRIŞOR et al., 2010). The United States use Anderson's classification (ANDERSON et al., 1976), with two levels; the first shows land cover, and the second land use. Europe utilizes CORINE classification with three levels (DE LIMA, 2005); the first one shows land cover, and the last two land use, in more or less details (PETRIŞOR et al., 2010).

Table 2. Spatial approach to diversity based on the Nomenclature of Territorial Units for Statistics (PETRIŞOR, 2008a).

Diversity	**NUTS levels**			
	I	**II**	**III**	**IV-V/ LAU I-II**
Hydro-geomorphologic units (relief)	x	x	x (by case)	
Biogeographical regions	x	x		
Ecological regions	x	x	x (by case)	
Types of ecosystems and/or habitats – land cover and use	CORINE I Anderson 1	CORINE I/II Anderson 1	CORINE II Anderson 2	CORINE III Anderson 2

x – indicates that diversity can be described by a given classification at a certain spatial scale.

A UNIFYING CONCEPT OF DIVERSITY

As it has been stated in the beginning, different disciplines interpreted in particular ways the diversity of the same physical realm, producing overlapping or even identical concepts. These were a result of multiple dichotomous separations: natural vs. man-dominated, living vs. non-living, functional vs. structural, qualitative vs. quantitative. The purpose of this research was to develop a unifying concept. Fig. 3 is a graphic representation of what can be called "diversity", a multifarious concepts with sides and sub-units dictated by the dichotomous classifications and disciplines concerned with developing a particular view.

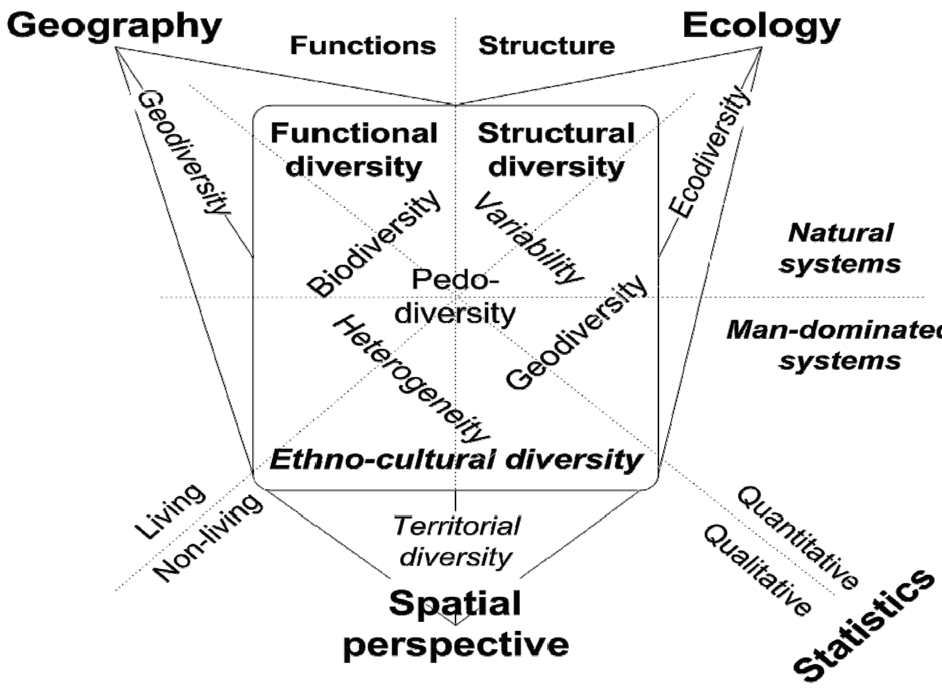

Figure 3. Towards a unifying concept of diversity (original).

ROMANIA AS A CASE STUDY

This paper proposed a unified approach for analysing the components of diversity under geographical, ecological, statistical, and spatial frameworks, addressing both natural and man-dominated systems. In order to apply this conceptual framework to describing the diversity of Romania, in all aspects (abiotic and biotic components, at several spatial scale), it is sufficient to list the constituents:

- Five types of relief – floodplain, field, hill or plateau and mountain (CAZAN et al., 2004; MÂRA, 2007)
- 900 species of Carpathian minerals (PAPP & SZAKÁLL, 1996)
- 10 classes and 39 types of soil (Ministry of the Environment and Sustainable Development, 2008)
- Five of the eleven European biogeographical regions – alpine, Pontic (Black Sea), continental, Pannonian and steppic (PETRIŞOR, 2008a)
- 22 level 1 and 57 level 2 ecological regions (COGĂLNICEANU & STANCIU, 2001)
- Over 3700 superior plant species and 33802 animal species (VĂDINEANU et al., 2003)
- 783 types of habitats identified and characterized in 261 areas spread over the national territory, analysed in the CORINE (Co-ordinated Environmental Information in the European Community) Biotopes program (Ministry of the Environment and Sustainable Development, 2007)
- Ethno-cultural diversity: 20 ethnic (National Institute of Statistics, 2008a) and 18 religious (National Institute of Statistics, 2008b) groups at the 2002 census.

CONCLUSION

The different elements of the same physical realm led to the development of a variety of diversity concepts, disputed by the disciplines concerned with their study. Even though numerous classifications are used and can be proposed, the analysis demonstrates the need for their integration in a unitary concept. Especially when the analysis is carried out from a spatial perspective, it makes little, if any sense to divide the same physical reality into different units, when each classification uses different criteria. In such situations, it seems to be more important to see the whole rather than its parts.

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