Structuring GIS information with types of granularity: a case study

Estructuración de información SIG con tipos de granularidad: un estudio de caso

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1. Scope and Problems
   - Motivation
   - Problem analysis
2. Foundations of granularity
   - Types of granularity
   - Lean theory of granularity
3. Problems revisited
4. Conclusions

Setting

- Granularity is a essential dimension in the subject domains of GISs
- Long-term goal is to manage in one system the granulated instance data, type-level information and knowledge, scale-based granularity and non-scale-based granularity
- Such a system has to be usable, *reusable*, *interoperable*, and *scalable*

Related works on granularity

- Data-centric focus (e.g., Bittner, Rigaux, Stell, Zhou [3, 11, 12, 13, 14]), OGC, GML
- Minor adornments in conceptual data modelling languages (Oracle Cartridge, MADS [9], DISTIL [10], MultiDimER [8]); ‘semantic granularity’ noted but not widely investigated
- Reduction in resolution and ‘hiding’ attributes or whole objects, set theory and mereology, ‘horizontal and ‘vertical’ components [3, 4, 11, 12]
- Known problems with choosing the wrong level of granularity; e.g., spatial-temporal niche partitioning of grassland ants [1]

Example

USDA ecological units vs. Köppen: mixing types and instances, area-based vs. *combination of properties* independent of a particular area and time:

Köppen		**USDA's "Ecoregion equivalents"**
Warm temperate climate (C)	$\equiv$	Humid Temperate Domain (200)
$\uparrow$		$\uparrow$
Warm temperate climate, dry summer (Cs)	$\equiv$	Mediterranean Division (260)
$\uparrow$		$\uparrow$
no equivalent given in [2] (Warm temperate climate, (dry, hot summer (Csa) [7])	$\not\equiv$	California coastal steppe, Mixed forest, and Redwood forest Province (263)

Problems

- Implementation-focus makes it difficult to reuse in a similar setting
- There is little, and lack of consensus, on representing and using granularity at the semantic layer
- Cumbersome to compute granular levels, not as ‘first-class citizen’ available for modelling and operation
- There is no systematic approach to and mechanism to devise perspectives / views / contexts other than that there are granulation hierarchies
- Interplay between quantitative and qualitative aspects of granularity, linking levels, hierarchies

Foundational semantics of granularity

- Extract ‘patterns’ of granulation, i.e, types of granulation hierarchies and ways how levels are identified
- Thus, identifying **mechanisms of granulation**
- Each mechanism is *subject domain-independent* and *implementation-independent* because the focus is on foundational semantics, hence, reusable and facilitating interoperability

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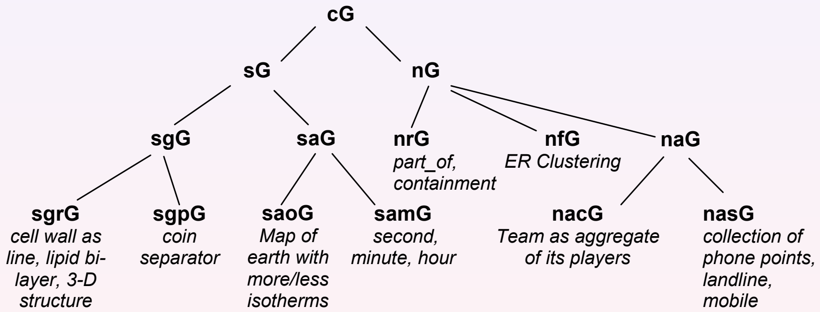

Basic TOG

- Fragment of the TOG [6] that is a logical theory in FOL with model-theoretic semantics
- Advantages of the ontological motivations for the definitions, derivations of constraints, yet smaller so that it may be easier to implement in real systems
- With the features—such as level, perspective, criterion of granulation, relation between levels, perspectives, and linkage to types of granularity—we can address the problems outlined and demonstrate the modelling approach

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Excerpt (definitions)

Definition 1 (Granular perspective)

$\forall x \exists ! w, y, z, \phi$ such that $GP(x)$ is a concept $CN(x)$, has a definition $DF(x, y)$, relates to its criterion $C(z)$ through the relation $RC(x, z)$, has_granulation type $TG(\phi)$ and is contained in $D^f(w)$.

$$\forall x (GP(x) \triangleq \exists w, y, z, \phi (DF(x, y) \wedge RC(x, z) \wedge C(z) \wedge RE(x, w) \wedge has\_granulation(x, \phi))) \quad (1)$$

DEFINITION 2 (Granular level)

*$\forall x \exists! v, w, y, z \exists p$ such that $GL(x)$ is a concept $CN(x)$, has a definition $DF(x, y)$, is related to $GP(w)$ with $RE(x, w)$ and uses criterion $C(z)$ with $RC(w, z)$ and has_value(z, v) where the value is in region $V(v)$ for any $GL(x)$ that adheres_to **sG**, $GL^s(x)$, and z's label for any $GL(x)$ that adheres_to type **nG**, $GL^n(x)$. Entities residing in $GL^s(x)$ are similar to each other with respect to (the value z of) $V(v)$, entities residing in $GL^n(x)$ are similar to each other with respect to (the label of the universal of) Prop(p) of $C(z)$, and both are φ-indistinguishable with respect to its adjacent coarser-grained level.*

$$\forall x(GL(x) \triangleq \exists! v, w, y, z(DF(x, y) \wedge GP(w) \wedge RE(x, w) \wedge C(z) \wedge RC(w, z) \wedge R(v) \wedge has\_value(z, v))) \quad (2)$$

Excerpt (constraints)

- Part-whole relations for *RE*, *RL*, and *GR*.
- Why some entity (/type) resides in a level, with similarity, indistinguishability, and equivalence [5], resulting in:

THEOREM 1 (3.2)

A granular perspective GP must contain at least two granular levels GL: $\forall x(GP(x) \rightarrow \exists^{\geq 2} y(RE^{-}(x,y) \wedge GL(y)))$

THEOREM 2 (3.1)

The combination of some $C(y)$ *with a* $TG(\phi)$ *determines uniqueness of each* $GP(x)$.

more theorems

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Toward implementations

- Need for three principal components:
  - the types of granularity that link to the basic TOG
  - an instantiation (model) of this theory for a specific subject domain
  - a data source to be granulated
- E.g., perspective Biogeography (π_i) with level Biotope (λ_i) and at least one other level (e.g., Bioregion, λ_j), criterion scale-delimited biogeography (υ_i), and granulation type samG (θ_i)

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Sample granular perspectives

Spatial data representation		Conditional perspectives		
Shape (π_1)	**Raster (π_2)** (Size in m)	**Admin (π_3)**		**Hydro (π_4)** (river with flow $\geq$)
Point	1000	Country	$\Leftrightarrow$	100 000 litres/min
$\uparrow$	$\uparrow$	$\uparrow$		$\uparrow$
Line	100	Province	$\Leftrightarrow$	10 000 litres/min
$\uparrow$	$\uparrow$	$\uparrow$		$\uparrow$
Polygon	10	Region	$\Leftrightarrow$	2500 litres/min
$\uparrow$	$\uparrow$	$\uparrow$		$\uparrow$
Polyhedron	1	Municipality	$\Leftrightarrow$	1000 litres/min
		$\uparrow$		$\uparrow$
		Municipality district	$\Leftrightarrow$	250 litres/min

Π	Θ	Υ criterion	Γ gran.rel.	**Comments**
π_1	θ_1 = sgrG	υ_1 = GIS vector-based spatial data representation	γ_1 = *has_ppart*	relation to the granulated entity, relation to resolution and how to convert between these resolutions
π_2	θ_2 = saoG	υ_2 = GIS raster-based spatial data representation	γ_2 = *ppart_of*	additional conversion function to aggregate the squares into the next coarser level, relation to the granulated entity
π_3	θ_3 = nrG	υ_3 = Administrative region	γ_3 = *contained_in*	
π_4	θ_4 = sgpG	υ_4 = River water throughput	–	
π_5	θ_5 = saoG	υ_5 = July isotherm, average		optional aggregation function to move from finer-to coarser-grained level, linked to an administrative region entity
π_6	θ_6 = saoG	υ_6 = Yearly precipitation, average		optional aggregation function to move from finer-to coarser-grained level, linked to an administrative region entity

Conditional selections

- "*if one makes a map with granularity at the Province-level then only rivers with a flow* $\geq$ *10 000 litres/min should be included in the map*"
- With $\mathcal{G}$ and two functions to select a level (*selectL* : $\mathcal{L} \mapsto \mathcal{L}$, with $\mathcal{L}$ the set of all levels $\lambda_1 ... \lambda_n$) and retrieve the contents of a level (*getC* : $\mathcal{L} \mapsto \mathcal{E}$, and $\mathcal{E}$ the collection of universals or particulars residing in a level λ_i), we can generalise this into a constraint pattern for conditional selection and retrieval (where $i \neq j$):
- ***if*** *selectL*(λ_i) ***and*** *getC*(λ_i) ***where*** $r_e(\lambda_i, \pi_i)$***, then*** *selectL*(λ_j) ***and*** *getC*(λ_j)***, where*** $r_e(\lambda_j, \pi_j)$***, as well***

Reassessing extant hierarchies

Table: Varying scales at different levels of regions as well as within-scale variations (values populating the levels are taken from maps in the Dutch “Grote Bos Atlas”).

	Avg. July temperature (π_5) (°C)	**Avg. Yearly Precipitation (π_6)** (in mm)
λ_1 World	0 – 10 – 20 – 30	$<$250 – 250-500 – 500-1000 – 1000-2000 – $\geq$2000
	↑	↑
λ_2 Europe (EU)	$<$10 – 10-15 – 15-17.5 – 17.5-20 – 20-25 – $\geq$25	$<$200 – 200-400 – 400-600 – 600-800 – 800-1200 – 1200-2000 – $\geq$2000
	↑	↑
λ_3 Netherlands (country)	16 – 16.5 – 17 – 17.5	$<$750 – 750-800 – 800-850 – 850-900 – $\geq$900

Conclusions and current work

- Types of granularity and a basic framework for modelling granularity
- Lifting it up to a higher level of abstraction independent of design and implementation $\longrightarrow$ declaring explicitly the levels, perspectives, criteria for granulation, mechanism of granulation
- Illustrated the simplifications for modelling granulation hierarchies in GIS and GIS-enabled ecology transparently, consistently, and in a reusable manner
- Thus facilitating flexibility, reusability, transparency, interoperability of implementations

Thank you for your attention

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Foundational semantics of granularity

Table: Distinguishing characteristics at the branching points in the taxonomy of types of granularity.

Branching point	**Distinguishing feature**
sG – nG	scale – non-scale (or, roughly: quantitative – qualitative)
sgG – saG	grain size – aggregation (or: scale *on* entity – scale *of* entity)
sgrG – sgpG	resolution – size of the entity
saoG – samG	overlay aggregated – entities aggregated according to scale
naG – nrG – nfG	semantic aggregation – one type of relation between entities in different levels – different type of relation between entities in levels and relations among entities in level
nacG – nasG	parent-child not taxonomic and relative independence of contents of higher/lower level – parent-child with taxonomic inheritance

Excerpt (constraints)

THEOREM 3 (3.5)

RL is of the same type, s_ppart_of, not only within some particular instance of GP, but it is of the same type between granular levels in all granular perspectives.

THEOREM 4 (3.6)

The multiplicity (cardinality) of RL and RL^- is 1:1, i.e. $\forall x \exists! y (RL(x, y))$ *and* $\forall x \exists! y (RL^-(x, y))$.

Excerpt (constraints)

LEMMA 1 (3.19)

Two levels in different perspectives can overcross:
$\forall x, y(overcross(x, y) \wedge GL(x) \wedge GL(y) \wedge \neg(x = y) \rightarrow$
$\exists v, w(R_E(x, v) \wedge R_E(y, w) \wedge \neg(v = w)))$.

THEOREM 5 (3.7)

If two levels in different perspectives overcross, then their perspectives overcross:
$\forall x_1, x_2, y_1, y_2(overcross(x_1, x_2) \wedge GL(x_1) \wedge GL(x_2) \wedge GP(y_1) \wedge$
$GP(y_2) \wedge R_E(x_1, y_1) \wedge R_E(x_2, y_2) \rightarrow overcross(y_1, y_2))$.

back to main