An Ontology Design Pattern for Cartographic Map Scaling*

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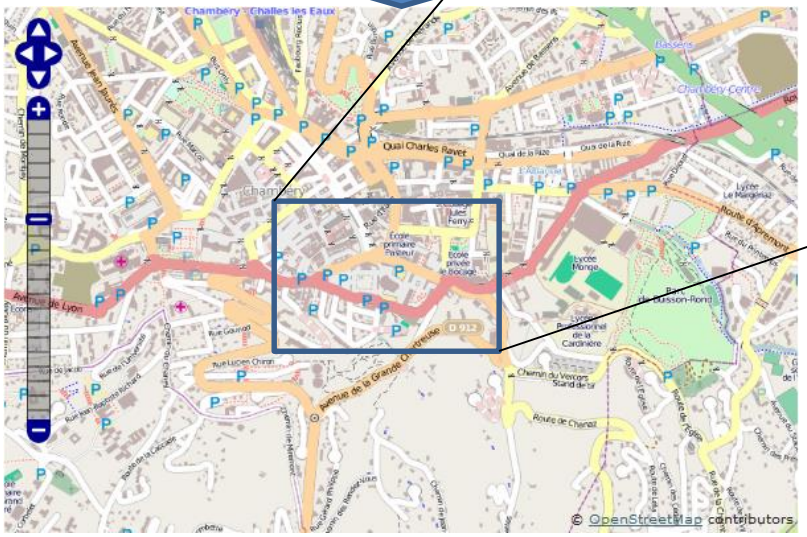
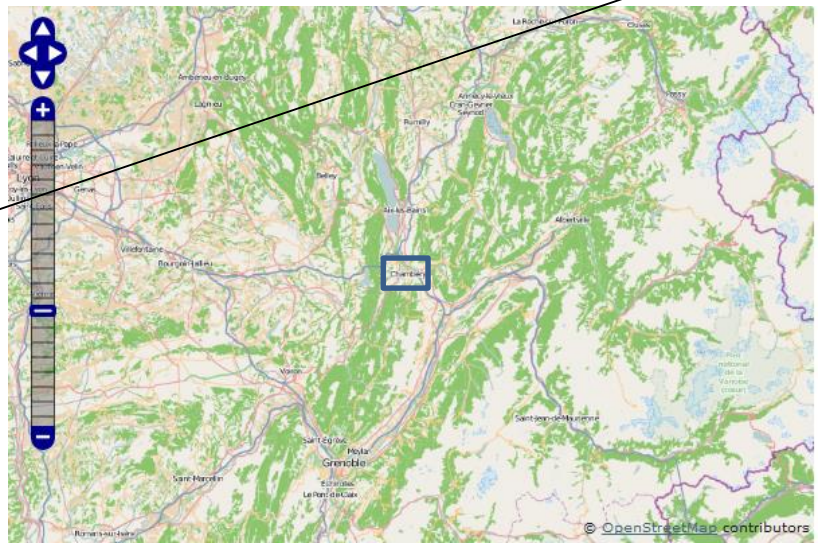
The need for scale and levels of detail

- Digital representations (of space) come with a level of detail (LoD), i.e., a scale level
- The level of detail is crucial knowledge which allows **assessing compatibility** across linked spatial data
- What is the LoD of spatial LOD?
- Our scaling ontology allows to **query and link** data according to its scale level and to **describe and check the consistency** of scaling applications

Zooming out in OSM



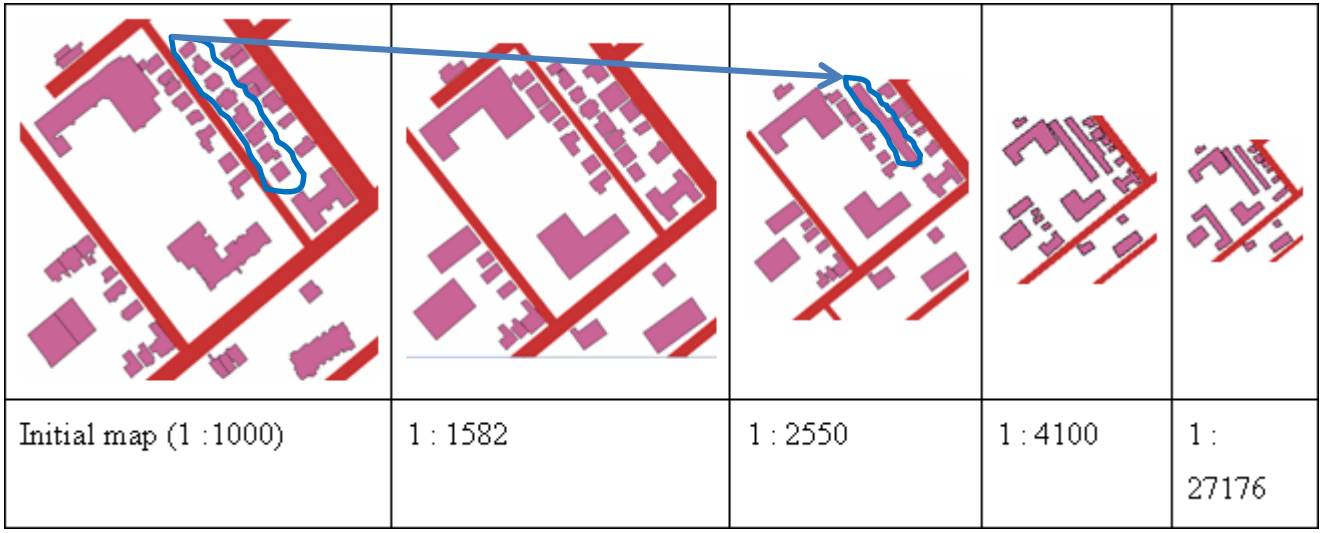


The need for scale and levels of detail

If one ``scales'' maps across zoom levels, then:

- Things disappear/appear (e.g. restaurants)
- Classes disappear/appear (e.g. forest landcover)
- Things are modified (e.g. road geometry is simplified)

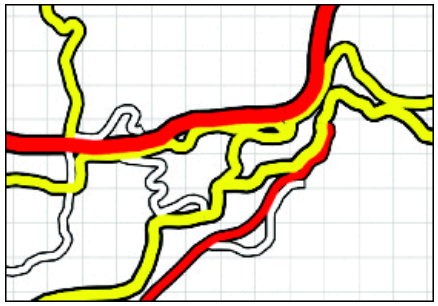
Automated map generalization

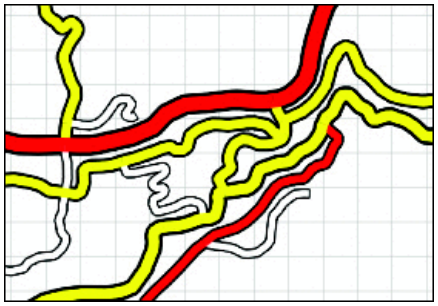


Initial map (1 :1000)	1 : 1582	1 : 2550	1 : 4100	1 : 27176

Merge and simplification

Source: Mamane Nouri SABO, Yvan BÉDARD, Bernard MOULIN, Eveline BERNIER 2007

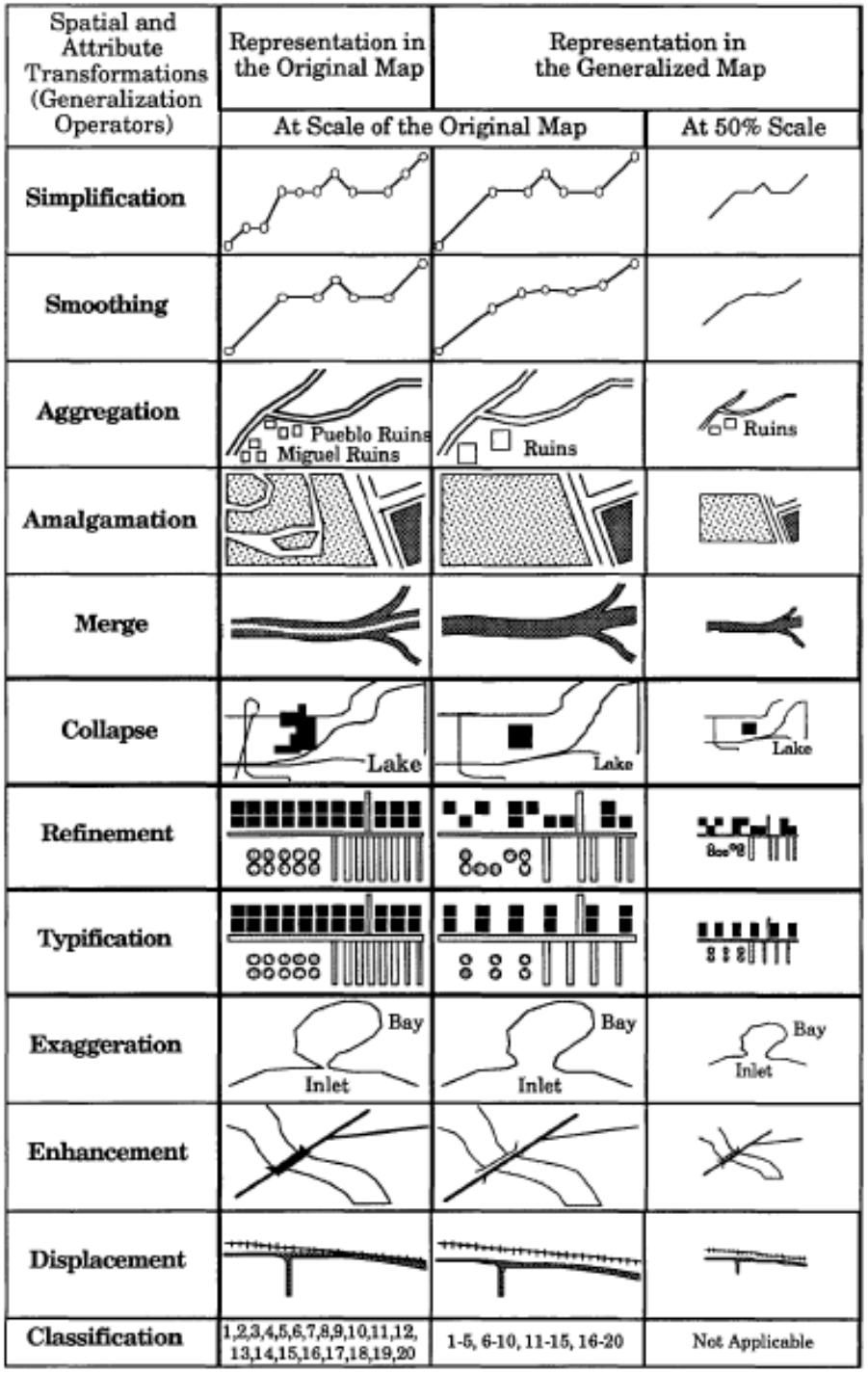




displacement

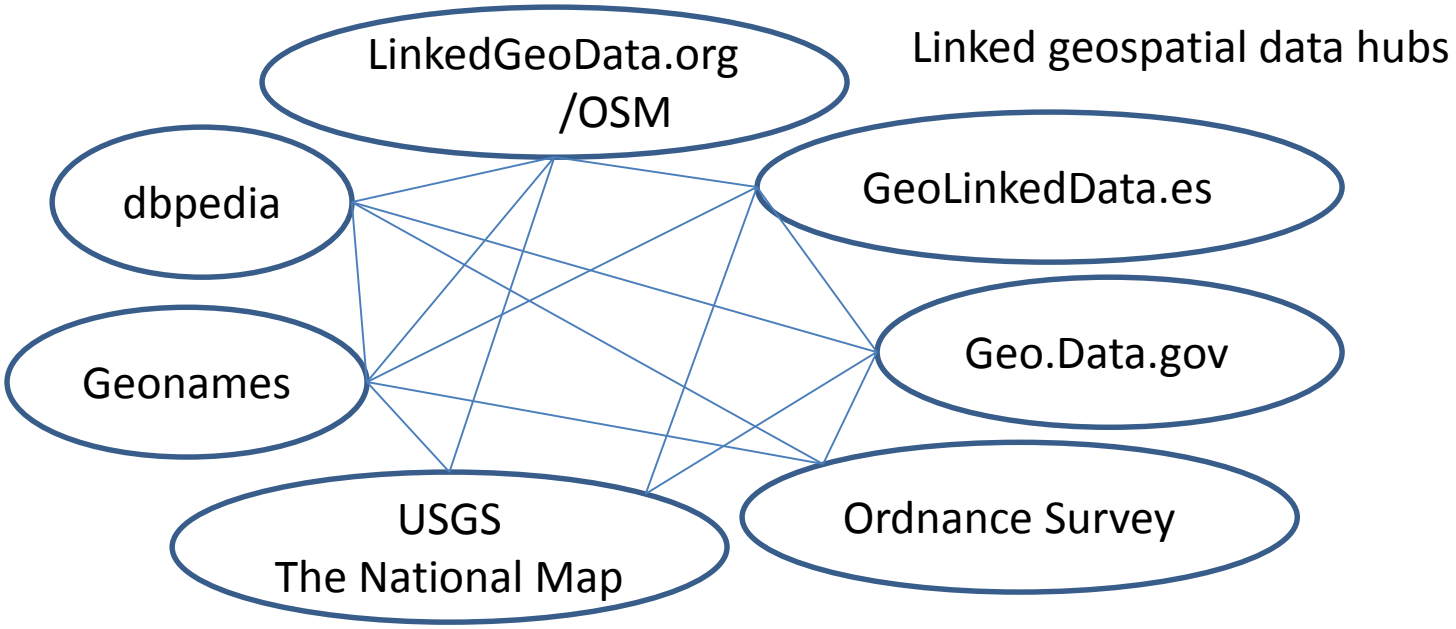
Overview of map generalization techniques

Source:
Shea, McMaster
1989



What is the level of detail (LoD) of linked open data (LOD)?

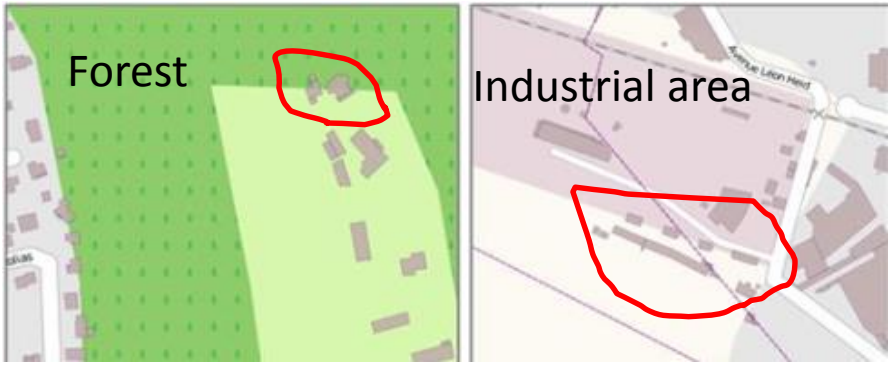
How to *link spatial data*
on the appropriate *level of detail* ?



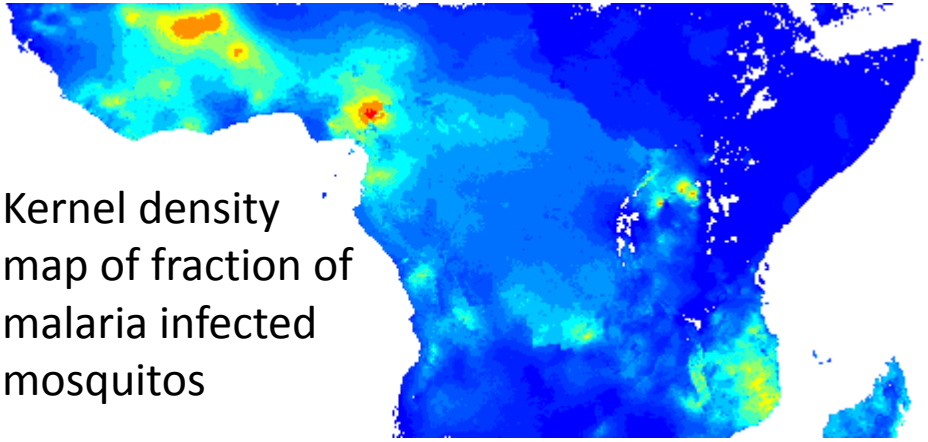
→Would help prevent **meaningless map comparisons**

What is the level of detail (LoD) of linked open data (LOD)?

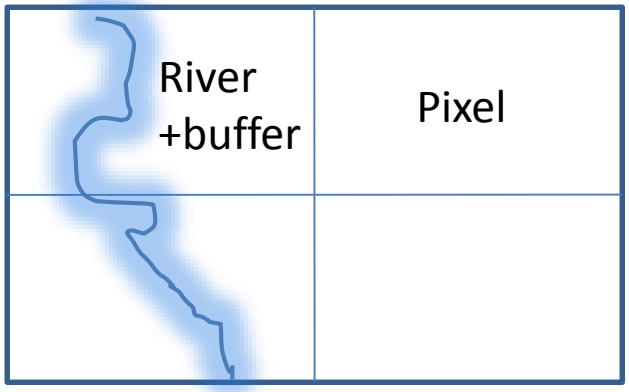
- Meaningless artefacts: Forest/industrial areas and buildings overlap only due to different LoD



- Meaningless analysis: Malaria density pixels and river data

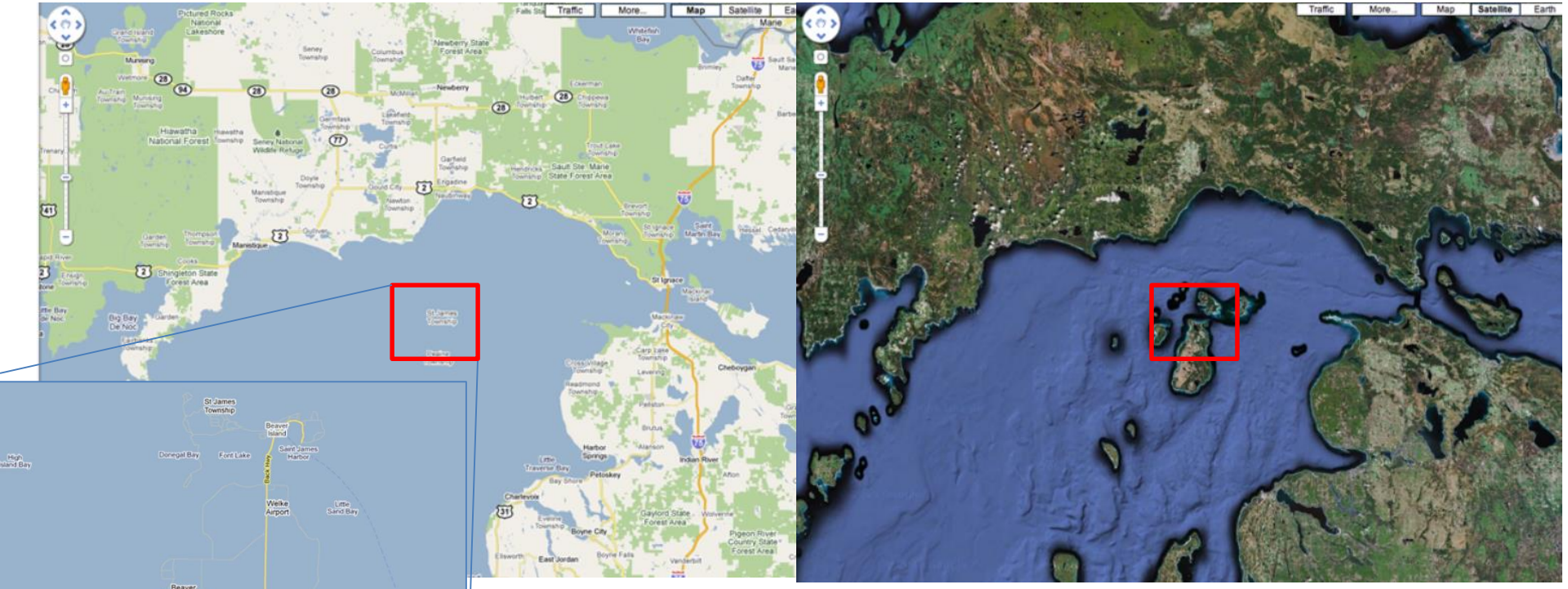


Kernel density map of fraction of malaria infected mosquitos



What is the level of detail (LoD) of linked open data (LOD)?

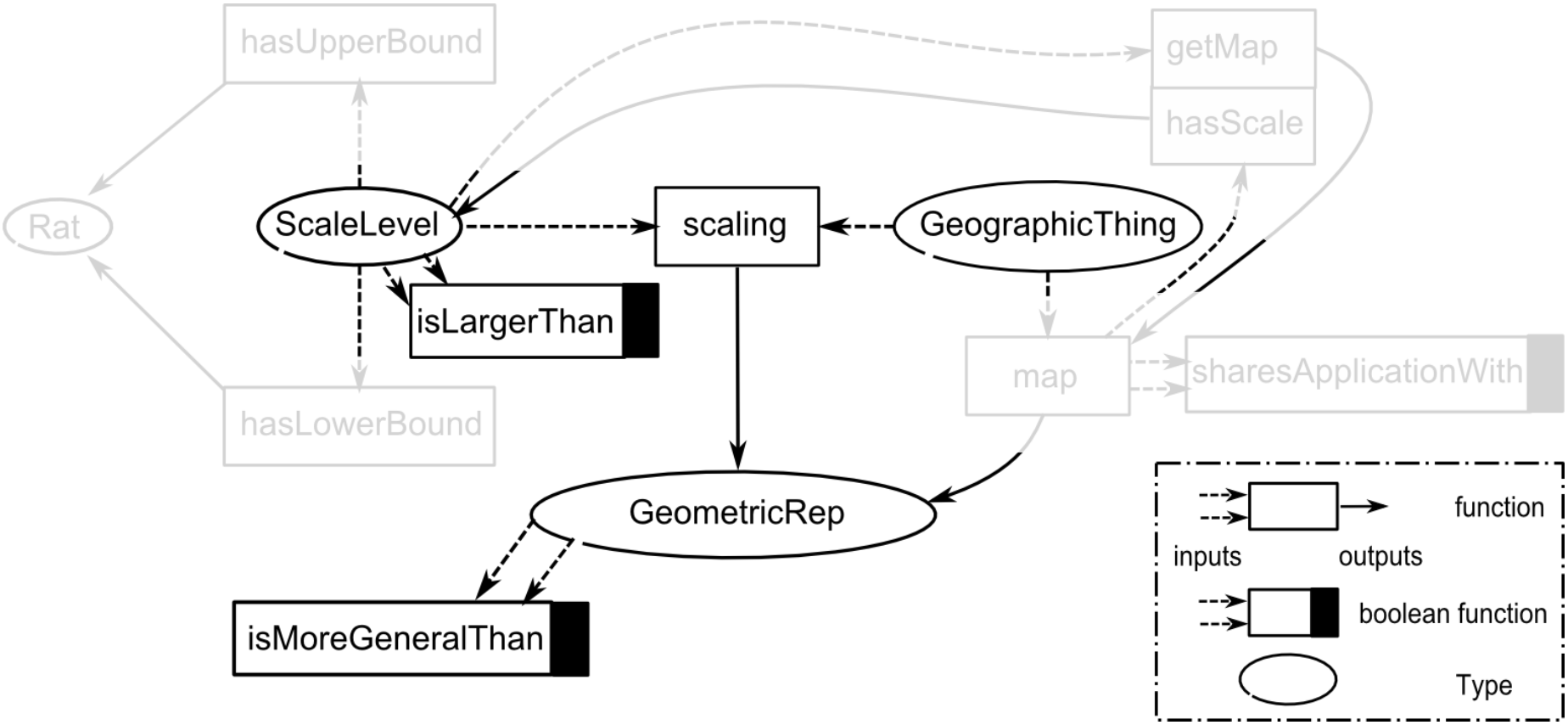
``Roads on the water'' and ``missing land'' in Google Maps:
Beaver island, Lake Michigan



Source: Daniel Huffman
http://cartastrophe.wordpress.com/tag/bad-generalization/

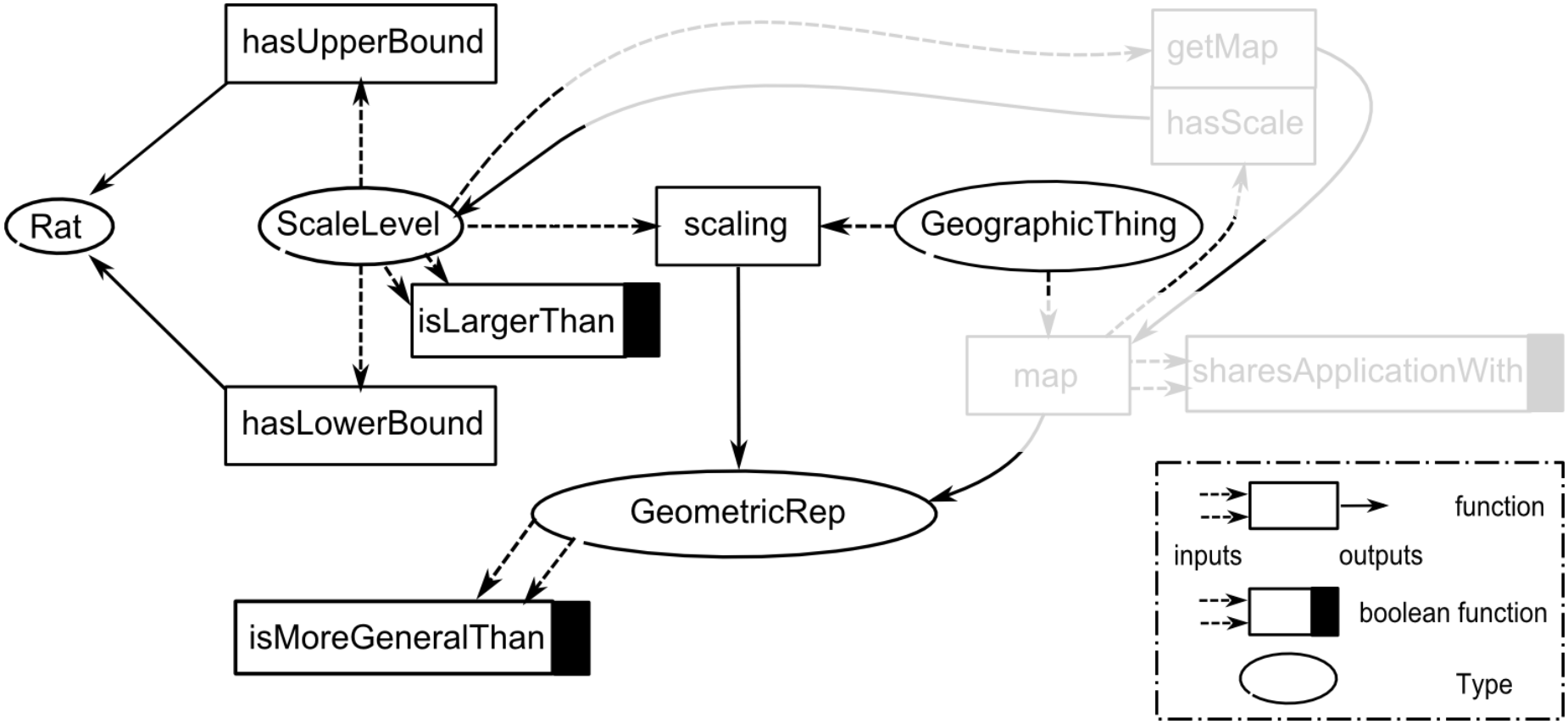
Map scaling in a nutshell

1) **Map scaling** can be described as a binary function from things and scale levels to geometric representations. The latter two are partially ordered:



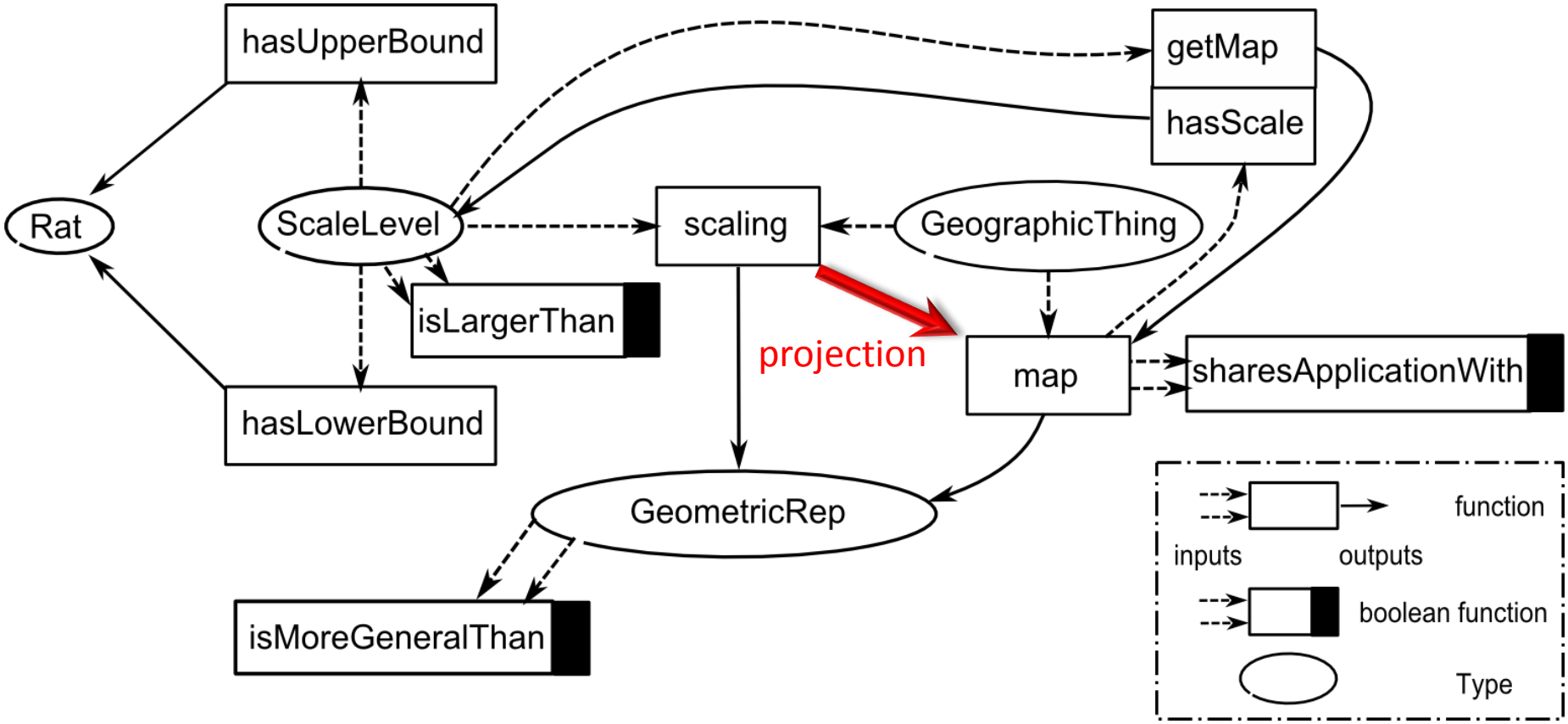
Map scaling in a nutshell

2) **Scale levels** have lower and upper bounds



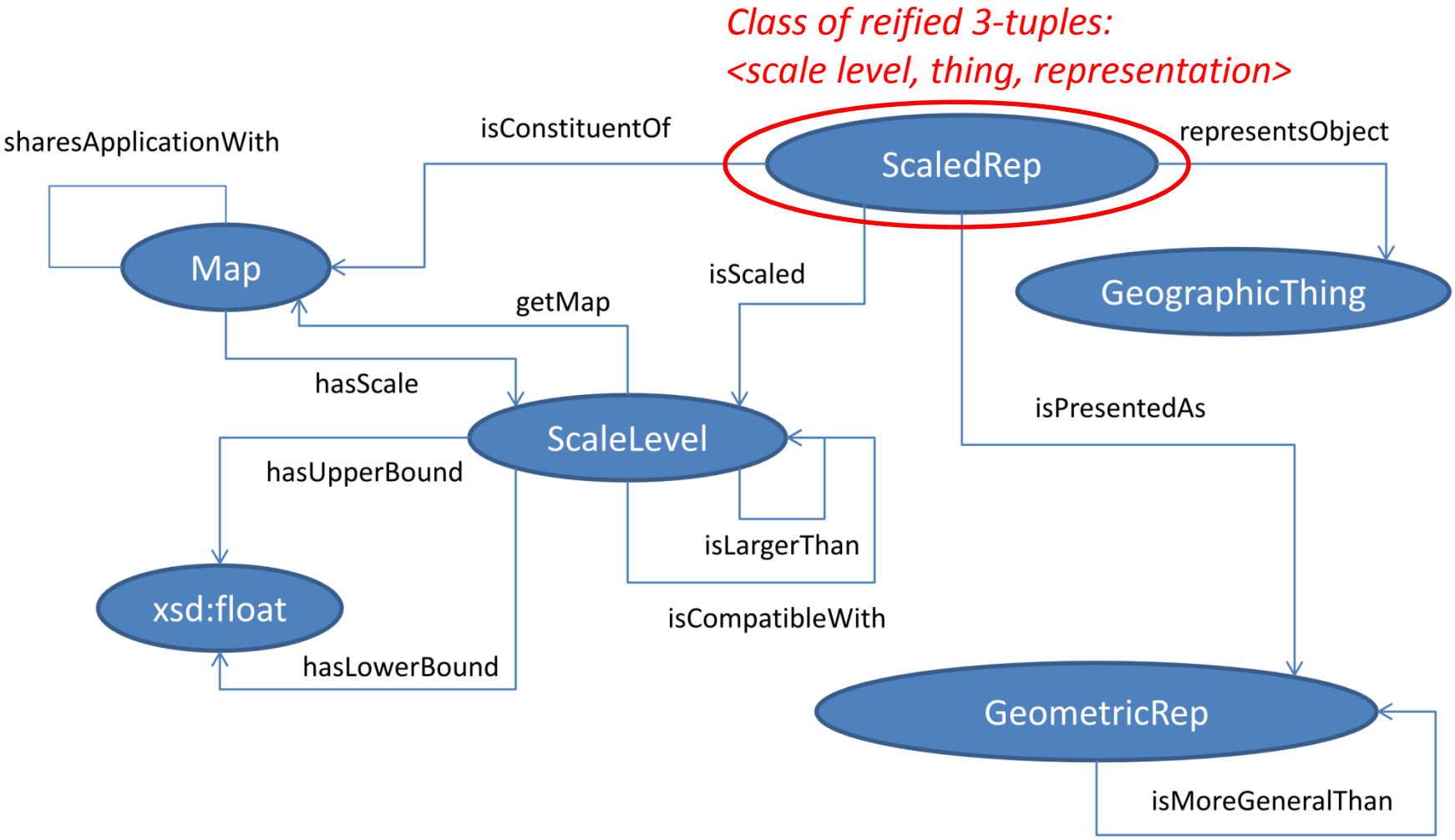
Map scaling in a nutshell

3) **Maps** can be treated as projections of scaling functions to fixed scale levels. Maps form scaling applications.



Ontology Design Pattern for Map Scaling:

Classes and Properties



$DLP_{\exists}$

$$C \sqsubseteq D \qquad R \sqsubseteq S$$

$$C \sqcap E \sqsubseteq D \qquad R^{-} \sqsubseteq S$$

$$C \sqsubseteq \exists S.D \qquad R \circ V \sqsubseteq S$$

$$\exists R.C \sqsubseteq D \qquad R \sqcap V \sqsubseteq S$$

$$C \sqsubseteq \exists S.\text{Self}$$

$$\exists R.\text{Self} \sqsubseteq C \qquad D(a)$$

$$C \sqsubseteq \leq 1 S.D \qquad S(a, b$$

where $C, D, E \in N_C \cup \{\top, \bot\}$, $R, S, V \in N_R$, and $a, b \in N_I$

Fig. 1. $DLP_{\exists}$ Normal Form

$DLP_{\exists}$

$$ScaledRep \sqsubseteq \exists isPresentedAs.GeometricRep$$

$$ScaledRep \sqsubseteq \exists isScaled.ScaleLevel$$

$$ScaledRep \sqsubseteq \exists representsObject.GeographicThing$$

$DLP_{\exists}$

$$ScaledRep \sqsubseteq \exists isPresentedAs.GeometricRep$$

$$ScaledRep \sqsubseteq \exists isScaled.ScaleLevel$$

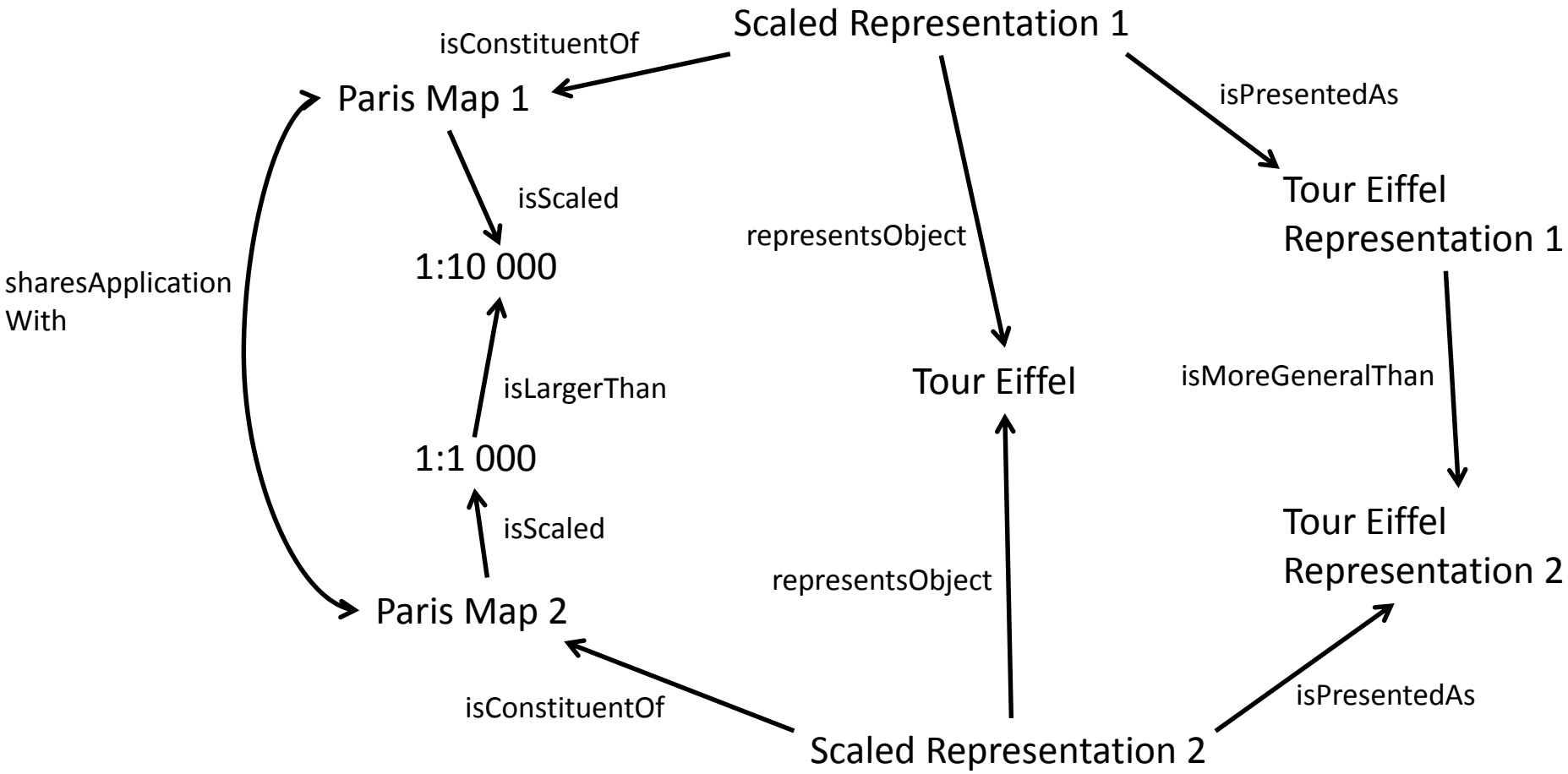
$$ScaledRep \sqsubseteq \exists representsObject.GeographicThing$$

ScaledRep: disjoint with GeometricRep, ScaleLevel, and GeographicThing

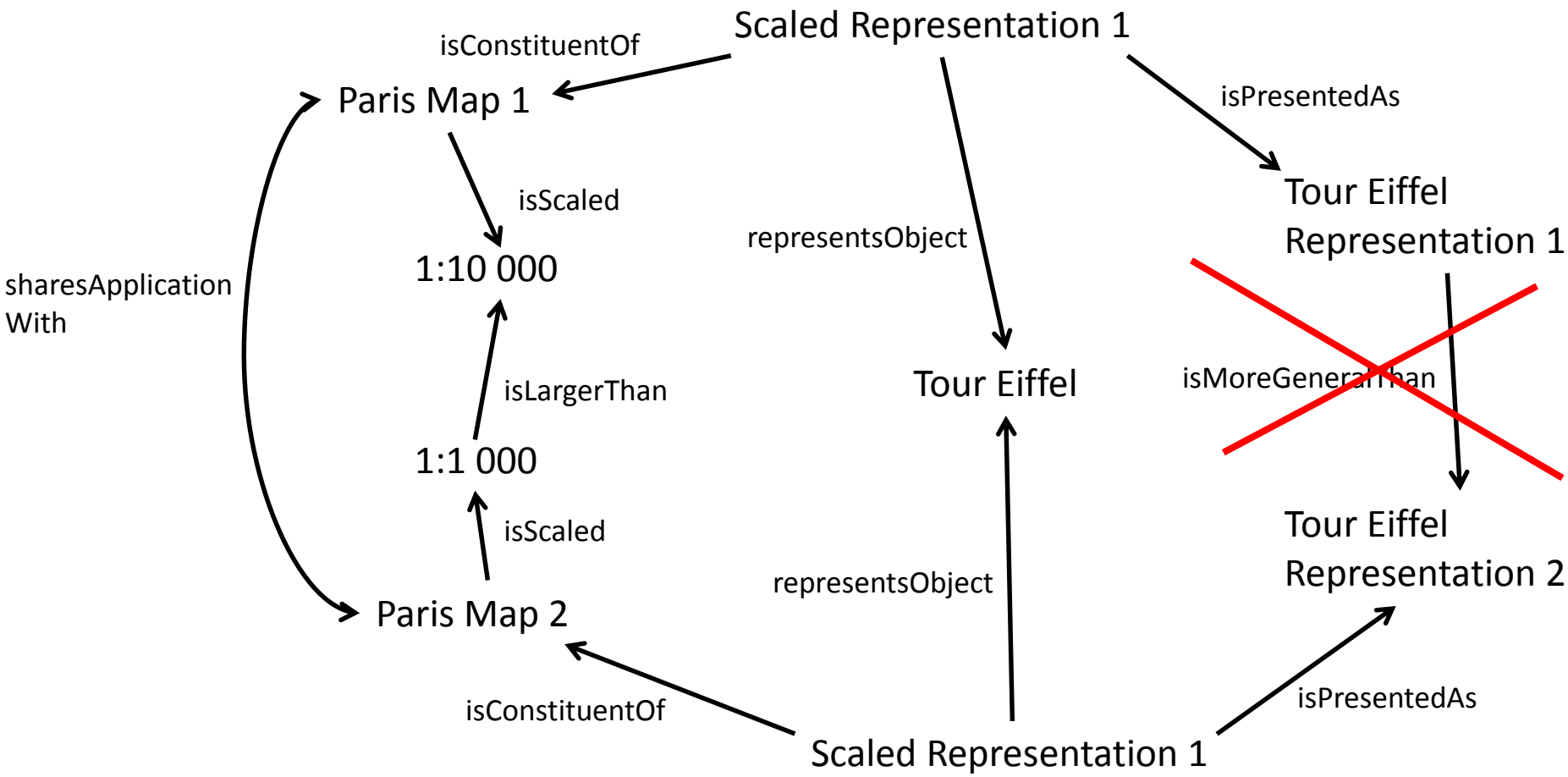
Constraints

- Functional Properties: hasScale, isPresentedAs, isScaled, representsObject.
- Transitive Properties: sharesApplicationWith, isLargerThan, isMoreGeneralThan.
- Symmetric Properties: sharesApplicationWith.
- Role chains, existential restrictions, range and domain, disjoint classes…

Monotonicity of Scaling



Monotonicity of Scaling



Monotonicity of Scaling

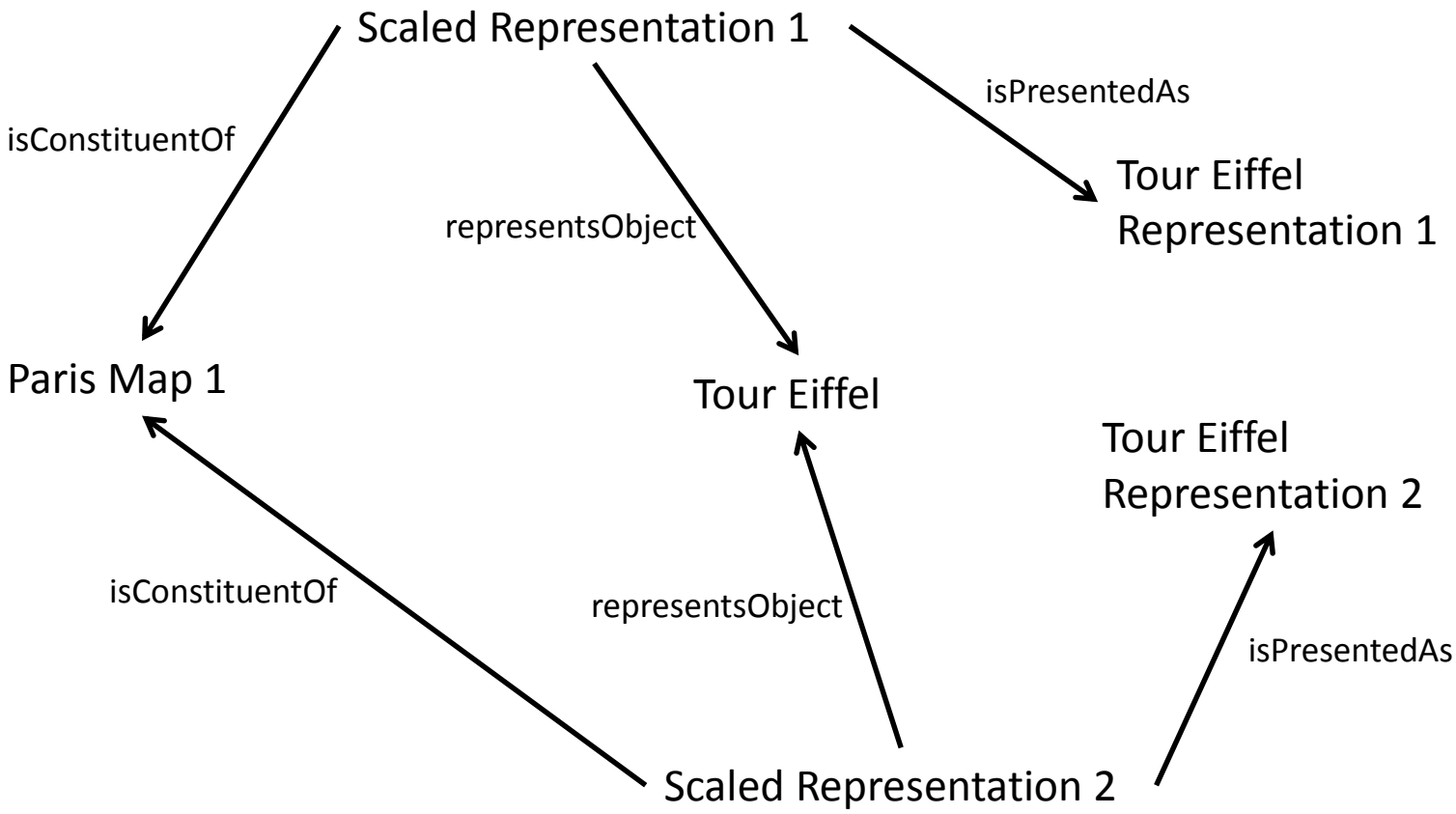
$$sharesApplicationWith(m_x, m_y) \wedge hasScale(s_y, m_y) \wedge hasScale(s_x, m_x)$$
$$\wedge isLargerThan(s_x, s_y) \wedge$$
$$isConstituentOf(m_x, sr_x) \wedge isConstituentOf(m_y, sr_y) \wedge$$
$$representsObject(sr_x, g) \wedge representsObject(sr_y, g) \wedge$$
$$isPresentedAs(sr_x, grr_x) \wedge isPresentedAs(sr_y, grr_y) \wedge$$
$$isMoreGeneralThan(grr_x, grr_y) \rightarrow \perp(m_x)$$

Monotonicity of Scaling

$$sharesApplicationWith(m_x, m_y) \wedge hasScale(s_y, m_y) \wedge hasScale(s_x, m_x)$$
$$\wedge\, isLargerThan(s_x, s_y) \wedge$$
$$isConstituentOf(m_x, sr_x) \wedge isConstituentOf(m_y, sr_y) \wedge$$
$$representsObject(sr_x, g) \wedge representsObject(sr_y, g) \wedge$$
$$isPresentedAs(sr_x, grr_x) \wedge isPresentedAs(sr_y, grr_y) \wedge$$
$$isMoreGeneralThan(grr_x, grr_y) \rightarrow \bot(m_x)$$

$$hasScale^{-} \circ sharesApplicationWith \circ hasScale \sqsubseteq R_1$$
$$R_1 \sqcap isLargerThan \sqsubseteq R_2$$
$$isScaled \circ R_2 \circ isScaled \sqsubseteq R_3$$
$$isPresentedAs \circ isMoreGeneralThan^{-} \circ isPresentedAs^{-} \sqsubseteq R_4$$
$$representsObject \circ representsObject^{-} \sqsubseteq R_5$$
$$R_3 \sqcap R_4 \sqcap R_5 \sqsubseteq R_{\bot}$$
$$\exists R_{\bot}.\top \sqsubseteq \bot$$

Functionality of Scaling



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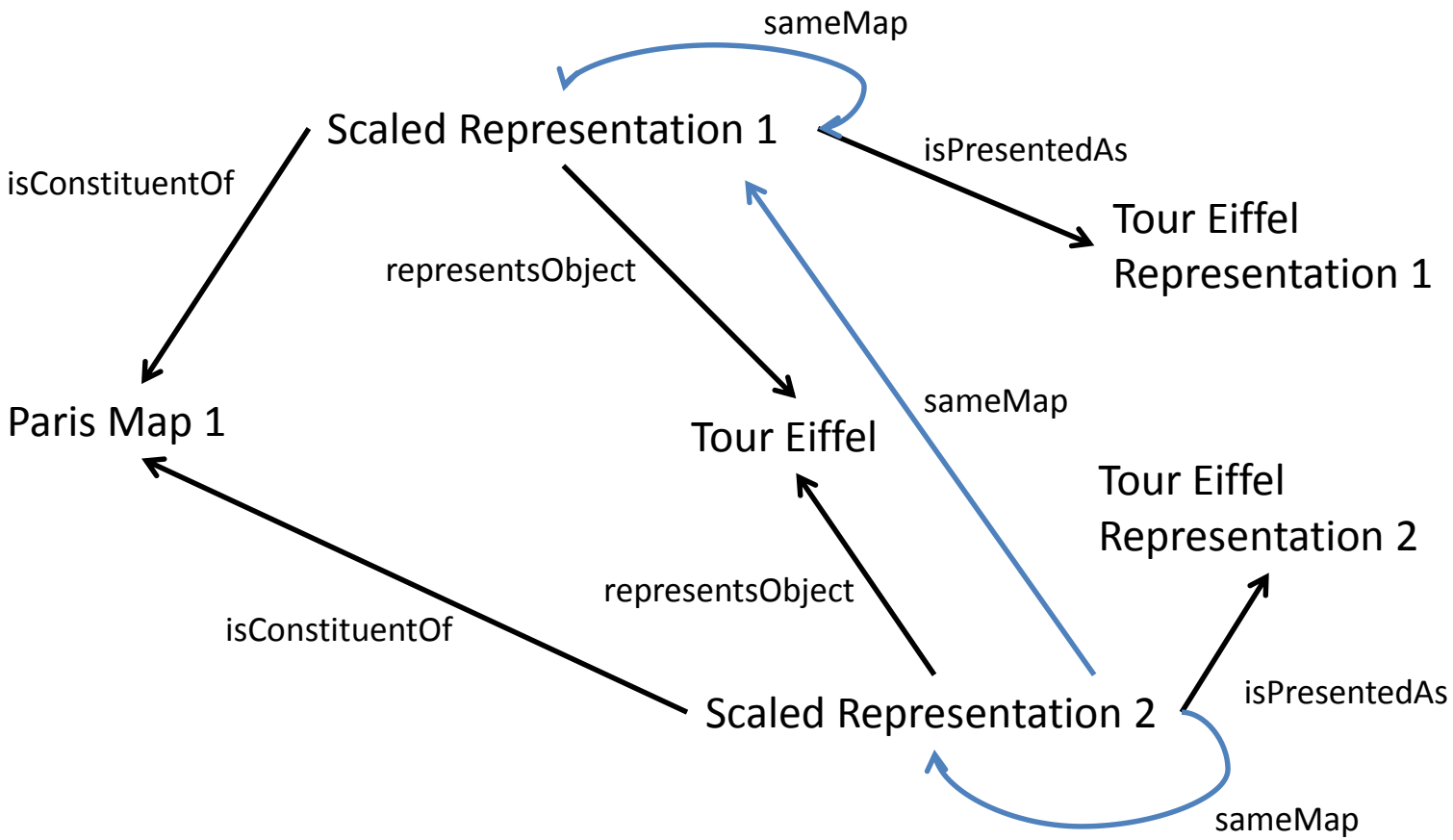
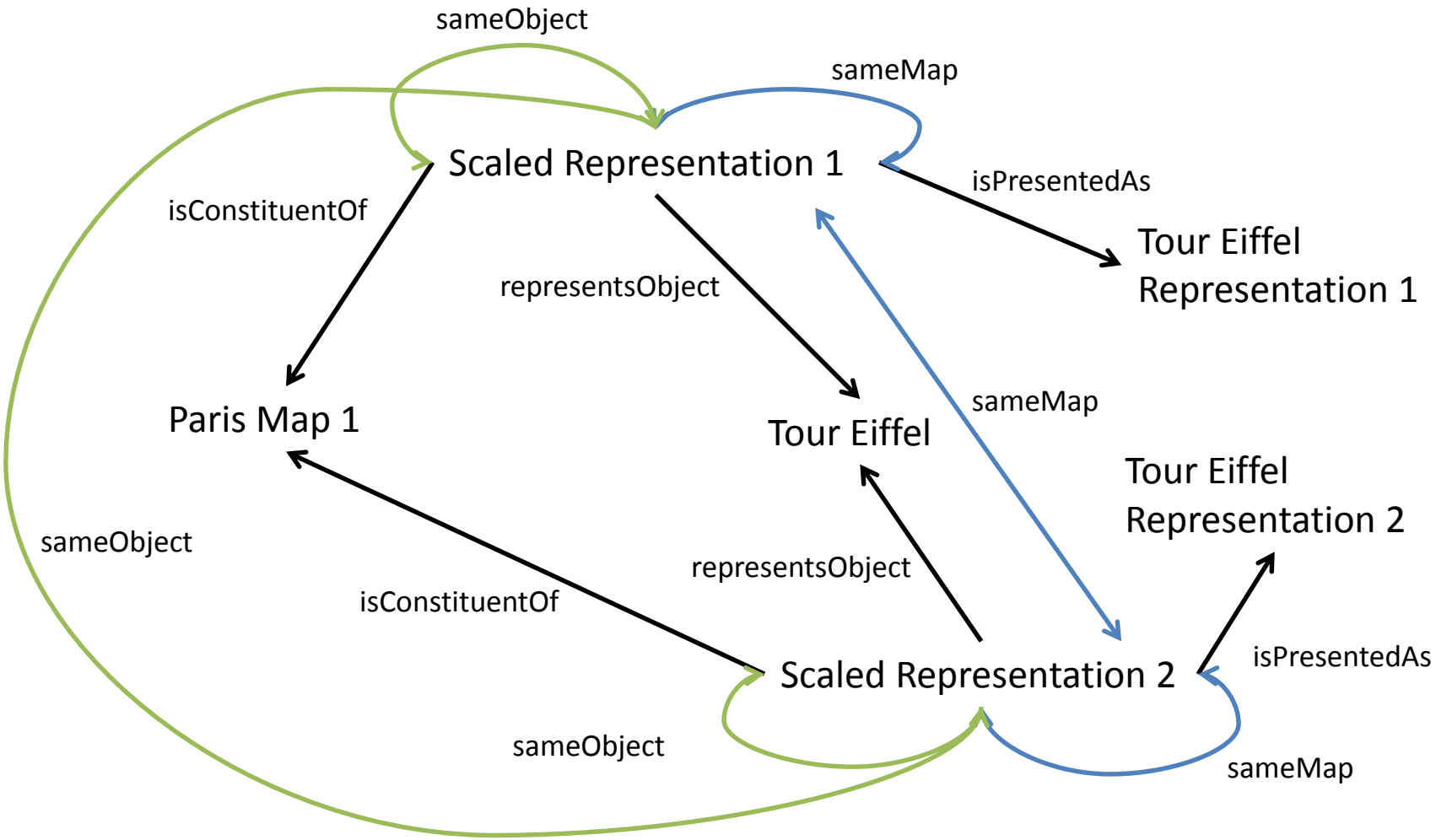


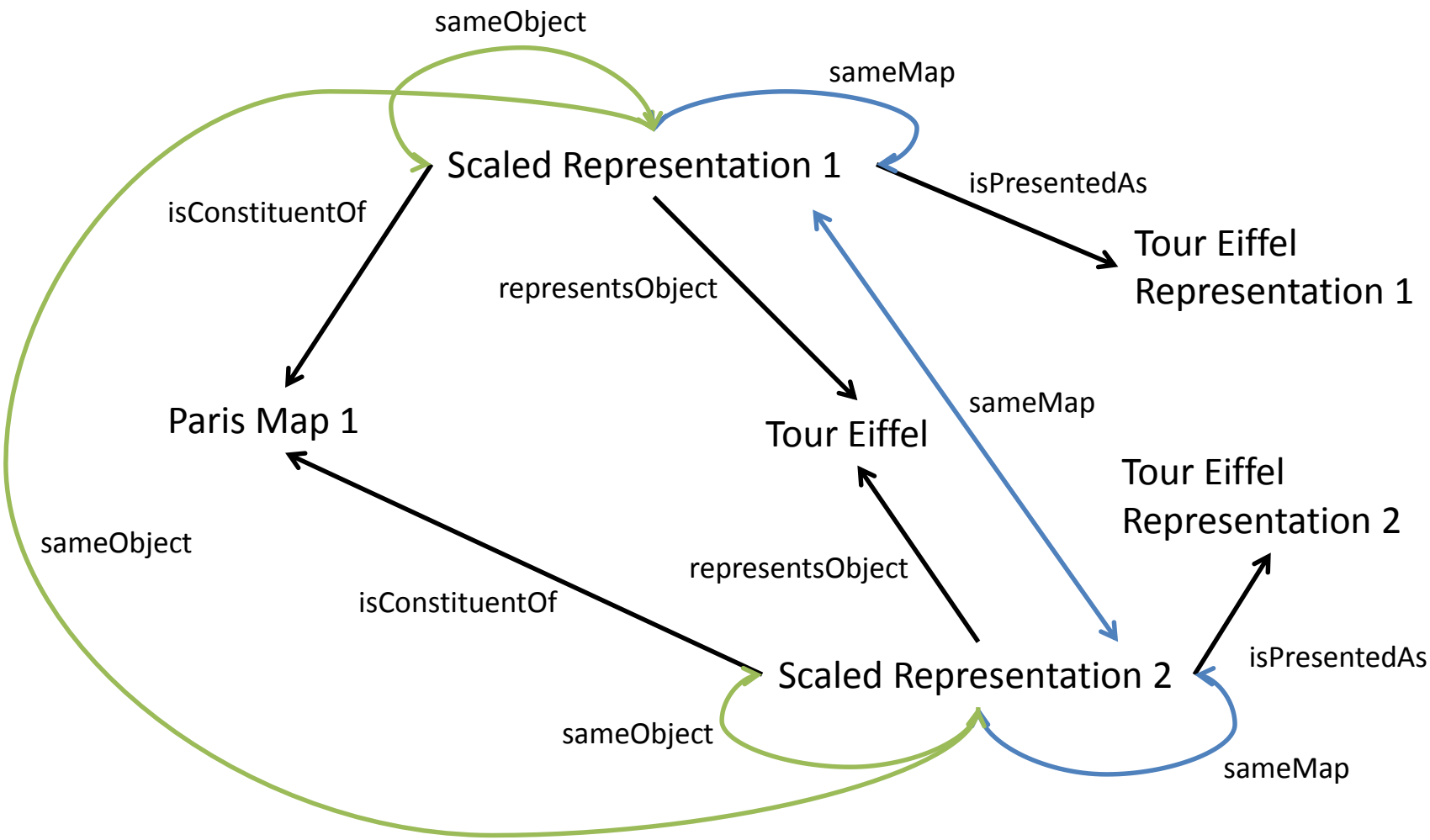
$$isConstituentOf \circ isConstituentOf^{-} \sqsubseteq sameMap$$

Functionality of Scaling



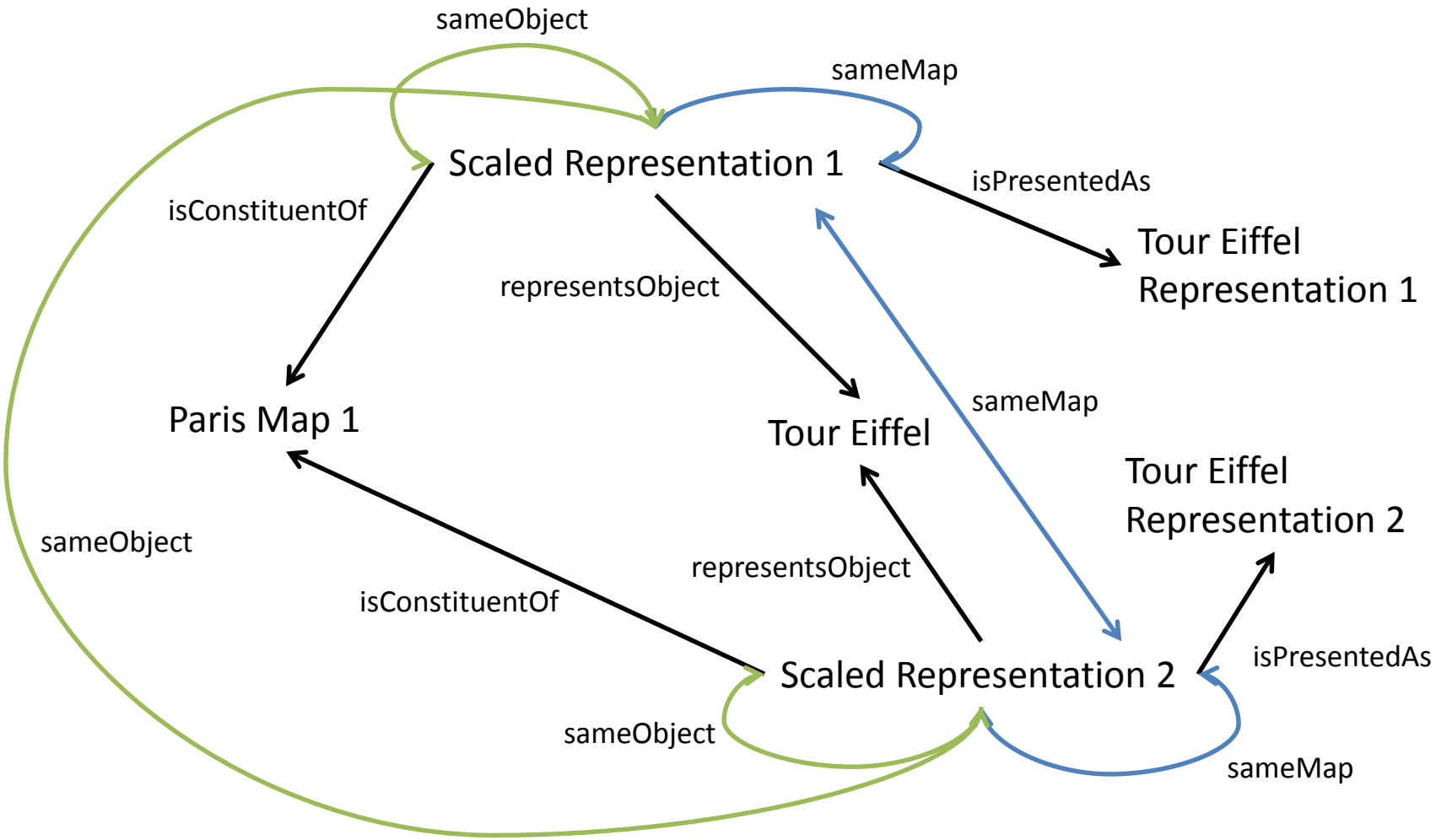
$$representsObject \circ representsObject^{-} \sqsubseteq sameObject$$

Functionality of Scaling



$$\top \sqsubseteq \leq 1(sameObject \sqcap sameMap).\top$$

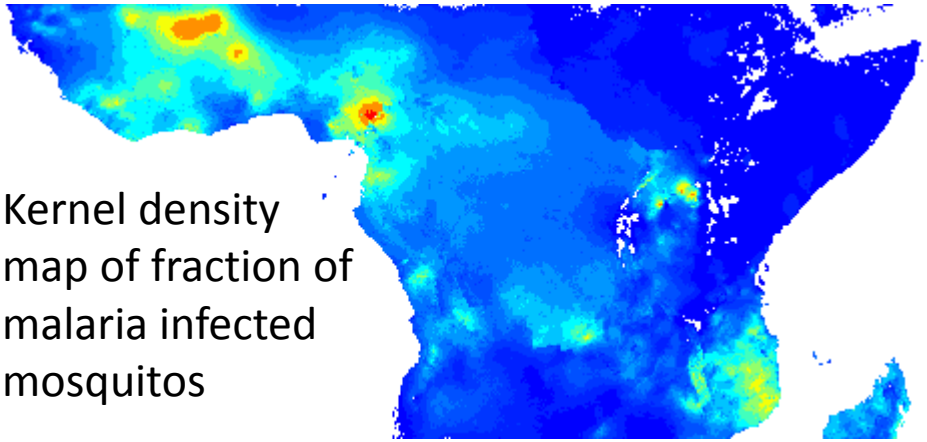
Functionality of Scaling



isPresentedAs is declared functional

Applying the pattern

1) **Querying maps across applications:** Finding all villages which are on a compatible scale with Malaria infection degree raster



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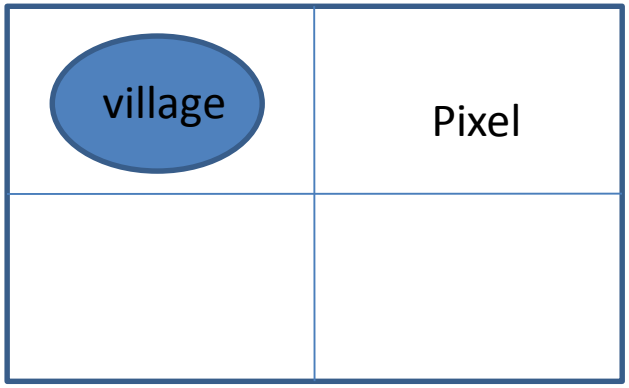

Are certain villages more affected than others?

2) **Check logical consistency** of scaling applications, e.g., OSM, Google Maps, ...

Conclusion and outlook

- The Semantic Web lacks information about scale
- Map scaling can be described in terms of binary functions
- Our scaling pattern in $DLP_{\exists}$ allows to express functional constraints and is still tractable (w.r.t. the query problem)
- Outlook 1: Tailor a Datalog engine to **reason** over $DLP_{\exists}$
- Outlook 2: Populate a **map scaling triple store** using the pattern and combine map resources