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Towards a Framework for Functional Representation of Spatial Relations

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Abstract. Although human perception is geometrically constrained, not all geometric relations are equally prominent and not all geometric relations are used in everyday settings in human perception. Further, some geometric relations are systematically transformed. In this study we describe a robust geometric framework expressing spatial relations but including some strong and systematic non-geometric extensions that operate in human perception. We generally adopt the view that spatial cognition centers on qualitative spatial relations, including geometrical and topological but also functional ones (Coventry and Garrod, 2004, Gärdenfors, 2014, Mani and Pustejovsky, 2012). The topological and geometrical principles of qualitative spatial reasoning have been formalized using the framework of the Region Connection Calculus (RCC; Cohn et al., 1997), complemented with convexity and distance and orientation primitives. In work in progress, we extend this framework to include functional relations (Coventry and Garrod, 2004, Vandeloise, 1991). The central functional relations are identified as locational control and support, as they enable us to characterize a wide range of further relations, including interlocking, containment, functional enclosure and telicity.

Keywords: functional relations, locational control, support, qualitative spatial relations, extensions of RCC.

1. Introduction

Research on representation of spatial relations and their expression in natural languages has a large background of diverse approaches that can be broadly conceived as either arguing that geometry drives human spatial cognition and is necessary (and sometimes sufficient) to express core spatial relations (Herskovits, 1986; Landau and Jackendoff, 1993) or that patterns of interaction constrain or even replace geometric relations in spatial cognition (Coventry, 1998, Coventry and Garrod, 2004, Coventry et al., 1994, Vandeloise, 1991). In our study, we argue that instead of replacing geometry or minimizing interactional impacts, spatial cognition and its representation in language involves a set of geometric relations that are complemented with functional relations that are derived from everyday spatial interaction and typical object knowledge (for compatible perspectives see, e.g., Hafri et al., 2023, Landau, 2020, Zwarts 2017).

Our approach aims to provide an intuitive formal background but it has also experimental support that is explained elsewhere (Žilinskaitė-Šinkūnienė et al., 2019a, 2019b, Šķilters et al., 2020, Žilinskaitė-Šinkūnienė et al., 2020).

2. Theoretical background

Spatial relations as encoded in natural languages are always applied to at least two objects: one is called figure (F) (object or region to be located); the other is called ground (G), i.e., object or region enabling the localization of the figure. Figure is the functionally prominent central object, whereas ground offers a single or complex reference object (cp., e.g., Talmy, 1988). We thus work with pairs

$$(F, G)$$

where F and G are objects or regions.

We assume that *regions* are any spatially extended 2-dimensional areas. An intuitive clarification of an object is less straightforward. We assume that *objects* might be

a. ***spatial*** (in this definition of objects we also include regions)

$$(F^S, G^S)$$

Example:
A cup (F) is on the table (G).

b. ***temporal***

$$(F^T, G^T)$$

Example:
The concert (F) took place on the anniversary of the Latvian independence (G).

c. spatial and temporal objects can be combined

$$(F^S, G^T)$$

Example:
Peter (F) is in a concert (G).

The difference between both types of objects is that temporal objects lack clear topological properties (that to some degree underlie all spatial relations). In all cases, the relations between figure and ground objects are asymmetric – when substituting figure and ground objects the overall meaning of the sentence is either intuitively not plausible or semantically unacceptable. E.g., we cannot plausibly say 'the table is below the cup' although the opposite - 'a cup is on the table' - is intuitive and corresponds to our default use of language; in both cases the description refers to the same spatial configuration.

To proceed, we will describe some simple topological, geometric, and functional principles for formal representation of spatial relations. We start with a robust topological formalism known as the RCC (the Region Connection Calculus; Cohn et al., 1997) which allows for the expression of convexity relations. We then addi two sets of geometrical primitives expressing distance and orientation, and, finally, we move to a version of the RCC that is equipped with crucial functional relations (RCC+F) such as support and locational control.

2.1 RCC

What are geometric and topological relations between figure and ground objects? According to RCC (Cohn et al., 1997; Galton, 2000, 82f.), we can define core relations based on the relational primitive *C* (connectedness) which we understand in a topological sense indicating that connected regions or objects are touching one another.

If *x*, *y*, *z* are regions or objects fulfilling the role of F or G:

1. Connectedness (C)

C(x,y): *x* connects to *y;*

Connectedness is reflexive and symmetric, i.e., $\forall x[C(x,x)]$ and$\forall x \forall y[C(x,y) \to C(y,x)]$;

If *C(x,y)* then (a) *x* and *y* have at least one shared point and (b) their closures have a shared point (see also Dong, 2008, 321, Cohn and Varzi, 2003).

2. Disconectedness (DC):

$$DC(x,y) \equiv_{def} \neg C(x,y)$$

3. Part (P):

$$P(x,y) \equiv_{def} \forall z[C(z,x) \to C(z,y)]$$

Parthood is reflexive and transitive, i.e., $\forall x[P(x,x)]$ and $\forall x \forall y[P(x,y) \wedge P(y,z) \to P(x,z)]$.

4. Proper part (PP):

$$PP(x,y) \equiv_{def} P(x,y) \wedge \neg P(y,x)$$

5. Overlap (O):

$$O(x,y) \equiv_{def} \exists z[P(z,x) \wedge P(z,y)]$$

6. External connectedness (EC):

$$EC(x,y) \equiv_{def} C(x,y) \wedge \neg O(x,y)$$

7. Partial overlap (PO):

$$PO(x,y) \equiv_{def} O(x,y) \wedge \neg P(x,y) \wedge \neg P(y,x)$$

8. Equality (EQ):

$$EQ(x,y) \equiv_{def} P(x,y) \wedge P(y,x)$$

9. Discreteness (DR):

$$DR(x,y) \equiv_{def} \neg O(x,y)$$
$$DR(x,y) \equiv_{def} EC(x,y) \vee DC(x,y)$$

10. Tangential proper part (TPP):

$$TPP(x,y) \equiv_{def} PP(x,y) \wedge \exists z[EC(z,x) \wedge EC(z,y)]$$

11. Non-tangential proper part (NTPP):

$$NTPP(x,y) \equiv_{def} PP(x,y) \wedge \neg\exists z[EC(z,x) \wedge EC(z,y)]$$

C, DC, DR, O, PO, EC, EQ are symmetric whereas P, PP, TPP, NTPP are not symmetric and can have an inverse interpretation (see also Galton, 2009, 179).

RCC is typically extended with an additional frequently used geometric relation applying to a variety of everyday situations where containment is used in a way that does not fit into a topological containment. By introducing an additional primitive one-place function *conv(x)* 'the convex hull of region x', a more expressive calculus may be produced (Cohn et al., 1994, Cohn et al., 1997). Cohn et al. (1998, 8) argue that "A convex region can be defined as one having such a shape that a straight line joining any two points within the region does not go outside it. The *convex hull* of an arbitrary region is then the smallest convex region that contains it[.]" (Cohn et al., 1997,287ff., Cohn, 1995, Cohn et al., 1998, 8)

12. *conv(x)* 'the convex hull of region x': the smallest convex region of which x is a part

12.1. $(x) \equiv_{def} EQ(x, conv(x))$: a region is convex if it is equal to its own convex hull
12.2. $\forall x[conv(conv(x)) = conv(x)]$,
12.3. $\forall x[TPP(x, conv(x))]$
12.4. $\forall x \forall y[P(x,y) \rightarrow P(conv(x), conv(y))]$
12.5. $\forall x \forall y[conv(x) = conv(y) \rightarrow C(x,y)]$

Conv(x) enables to define regions that are entirely/partly inside (*p_inside)* or outside the convex hull but not overlapping (Cohnet al., 1997, 288, Randell et al., 1992):

12.6. $inside(x,y) \equiv_{def} DR(x,y) \wedge P(x, conv(y))$
12.7. $p\_inside(x,y) \equiv_{def} DR(x,y) \wedge PO(x, conv(y))$
12.8. $outside(x,y) \equiv_{def} DR(x, conv(y))$

Also inverse relations of convexity can be formulated. Convexity works in the case of geometric (*geo_inside*) but not topological (*top_inside*) insidedness.

12.9. $top\_inside(x,y) \equiv_{def} inside(x,y) \wedge \forall z[[conv(z) \wedge C(z,x) \wedge$

$$C(z, outside(y)] \rightarrow O(z, y)]$$

12.10. $geo\_inside(x, y) \equiv_{def} inside(x, y) \wedge \neg top\_inside(x, y)$

Relations that are mentioned before are topological or geometric (convexity). To make the formalism more flexible two relational geometric partially functional primitives are added (cp. also Mani and Pustejovsky, 2012) – Orientation (ORIENT) and Distance (DIST).

13. Orientation (*ORIENT)*

$$ORIENT(F, G)$$

ORIENT = {UNDER, OVER, TO_THE_RIGHT_OF (TO_THE_LEFT_OF), IN_FRONT_OF (BEHIND_OF), NEXT_TO}. These are *main orientational primitives* (Mani and Pustejovsky, 2012, 32) that are to some extent compatible with qualitative spatial reasoning approach (Galton, 2000, 174-176) and linguistics (Jackendoff, 1983, 173).

Further, orientation is not just a relation between figure and ground objects but involves also the frame of reference (Cohn and Renz, 2008, 566, Hernandez, 1994, 39).

These primitives are necessary but not sufficient to explain orientation in a natural language communication. E.g., IN_FRONT_OF can be used in a variety of different ways and modulated by other operators (e.g., distance). Then, some orientation operators are also interdependent on the distance (e.g, NEXT_TO).

14. Distance *(DIST)*

$$DIST(F, G)$$

DIST = {NEAR, FAR}

The main intuition here is that the distance applies to all cases where there is no connectedness relation between regions. Distance can be defined not only in relational way as in the current approach but also in a metric space by adding a distance function which is typically the case for point-set geometries. In our approach we are making a simple (point-less) topology relationally sensitive by adding distance (and orientation) operators but without adding a metric space.

Conv(x) and *C(x,y)* are both spatial primitives in the initially extended RCC (all other relations such as Orientation or Distance are not elaborated within the initial RCC). Both Orientation and Distance are relational primitives and to some degree based on spatial interactional patterns. Orientation is primarily linked to the egocentric frame of reference – once the observer or speaker changes her location the meaning of orientation changes as well. In the case of distance – allocentric frame of reference (determining the relations based on object features) is involved and sometimes complemented with egocentric as well.

2.2. RCC+F

We argue that RCC extended with *convexity, orientation, and distance operators,* is a necessary but not sufficient set of conditions for representing real-life spatial relations. We do not perceive the world strictly geometrically or topologically; rather, we supplement geometric and topological relations with functional ones. Phenomenologically we live in a world of functional dependencies (and not only geometric or topological ones). Topological or geometrical relations are frequently functionally constrained and some geometrical and topological relations are not used in the context of everyday situations at all.

This explains why natural languages usually do not straightforwardly reflect exact geometric relations. Only sometimes are there even somewhat imperfect mappings between geometric (and topological) relations and natural languages. More frequently spatial relations in natural languages are significant modifications of geometric and topological ones.

Several recent studies emphasize that spatial relations in natural languages are functionally constrained rather than directly represented (Coventry and Garrod, 2004, Gärdenfors, 2014, Mani and Pustejovsky, 2012). These are the main motivations for developing the formalism RCC+F that enables the representation of spatial relations in a topologically robust but at the same time functionally sensitive way.

The most significant and determining relation in the RCC+F is ***support*** reflecting the principles of force and gravity and the relationship between figure and ground objects in the way that figure has a downward and ground and upward force-dynamic effect:

$$EC^{S}(F^{S\rightarrow}, G^{\rightarrow S})$$

Support is asymmetric.

<u>Example</u>
Book (F) is on the table (G).

Based on the support relation a variety of different other relations can be defined. All cases of support use the principle of ***locational control***: once the ground is moved, the figure is moved as well.

<u>Example</u>
Flowers (F) are in the vase (G).

Locational control typically assumes external connectedness and support. It adds that if the ground is moved, the figure is moved as well. As we will see later some cases without external connectedness are also possible.

In the cases of locational control the relationship of containment (not directly geometric or topological) is frequently perceived, e.g., although most parts of flowers are outside of the vase, we still describe the relationship as a figure object (flowers) contained *in* the ground object (vase). By varying convexity we might increase or decrease the effect of containment (see Feist and Gentner, 2003).

Locational control also enables us to perceive the cases of *extended location* (Zwarts, 2017): relation between figure and ground is perceived even if it is intervened by a third object. For example, a cup is still perceived *on* the table even if a book mediates both. Therefore, locational control is an asymmetric but weakly transitive relation that depends on the object configuration (cp. Coventry and Garrod, 2004, 88): if the objects are movable we can come to a transitive relation whereas if one of the objects is relatively stationary we cannot derive a transitive relation (e.g., it makes less sense to speak about transitivity in case of floor, table, and book). However, the perception of extended location can be weakened by adding more mediating objects between the figure and ground objects (e.g., if several books are placed between the cup and table, the cup can be less plausibly perceived as being 'on' the table).

In order to define locational control a primitive of relational determination $R^{\Rrightarrow}(G,F)$ has to be introduced with the meaning that *G determines the location of F*. Relational determination is asymmetric and weakly transitive.

Locational control works when relational determination between Figure and Ground operates in the way that once G is moved, F is moved as well. Locational control applies both in situations where F and G are connected by EC (such as ‘flowers in a vase’) and also in situations where objects are not externally connected (such as ‘a person standing in a cue in a supermarket’). In both kinds of situations relational determination of locational control applies:

$$LocC(F,G) \equiv_{def} R^{\Rrightarrow}(G,F) \wedge [EC^{S}(F^{S\rightarrow}, G^{\rightarrow S}) \,\acute{\vee}\, DC(F,G)]$$

This includes, first, canonical cases of locational control $LocC^{EC}(F,G)$ where there is *EC* relation of support between the *F* and *G:*

$$LocC^{EC}(F,G) \equiv_{def} R^{\Rrightarrow}(G,F) \wedge EC^{S}(F^{S\rightarrow}, G^{\rightarrow S})$$

<u>Examples:</u>
Flowers (F) are in vase (G).
The coat (F) is on (G).

Second, a less frequent case of locational control is also possible where there is no external connection between F and G. This type of locational control is called ‘scattered inside’ (Galton, 2000), i.e., perceived containment occurs without physical connectedness:

$$LocC^{SI}(F,G) \equiv_{def} R^{\Rrightarrow}(G,F) \wedge DC(F,G)$$

<u>Examples:</u>
An island (F) in the archipelago (G).
Man (F) standing in the cue (G).

Cases of 'scattered inside' are also possible where a physical connectedness occurs but that is not crucial for the relation itself.

Other functionally derived relations

Based on locational control relations of different strength can be distinguished varying from the strongest – interlocking – to different cases of functional containment where in the weakest case – functional containment by 'scattered inside' – external connectedness is not even applied.

Interlocking
The strongest possibility of locational control is the relation of interlocking: F and G cannot be removed without damaging the whole:

$$EC^{IL}(F,G)$$

Examples
A screw (F) is in a board (G).
A key (F) in a lock (G).

There are cases that can be disambiguated by distinguishing the dominant relation – interlocking or support. Disambiguation of ‘the screw is in the bard’: one reading refers to interlocking ($EC^{IL}(F,G)$), whereas another to support ($EC^{S}(F^{S\rightarrow},G^{\rightarrow S})$), but in both cases *EC* (Galton, 2000).

Functional enclosure / partial occlusion
We can now define a notion of *functional enclosure*, requiring at least some of the following relations have to be present: partial overlap, external connectedness by interlocking, external connectedness by support, locational control or convexity.

$$FE(F,G) \equiv_{def} PO(F,G) \vee EC^{IL}(F,G) \vee EC^{S}(F^{\rightarrow S},G^{S\rightarrow}) \vee LocC(F,G) \vee Conv(F,G)$$

Examples
A flower (F) in a vase (G).
A spoon (F) in a cup (G).

Of course, although practically rare, it is also possible that all mentioned relations are present. Due to the disjunction, the expression will have a true reading in cases all disjuncts are true or just some (or just one) of it.

Containment
In contrast to other approaches we assume that containment is a relationship derived from locational control and can be weaker or stronger depending on how many additional factors are involved. E.g., if support, convexity and enclosure are used then containment is perceived to a stronger degree than just by locational control alone.

A definition of functional containment that works in most cases is as follows:

$$Fctm(F,G) \equiv_{def} LocC(F,G) \vee conv(F,G) \vee FE(F,G)$$

Examples
Drink (F) in a glass (G).
An apple (F) in a bow (G).

Due to the fact that locational control can be interpreted in two ways, functional containment can be also interpreted in two broad ways. In the strict way we interpret locational control as binding externally connected objects ($LocC^{EC}(F, G)$), whereas in the weak sense locational control is interpreted without external connectedness (i.e., $LocC^{SI}(F, G)$). In both cases we perceive containment but only in the former we have the relation of externally connected objects. Although the factors mentioned before impact the strength of perceived containment, it seems to be context-dependent and sensitive to orientation (see also Strickland and Scholl, 2015, Žilinskaitė-Šinkūnienė, 2109a). In the cases where Figure and Ground objects are aligned horizontally the relation of containment seems to operate to a lesser degree than where both objects are aligned vertically.

Examples
A bus (F) in a tunnel (G).
A cigarette (F) in mouth (G).

Telicity
The situations of interaction where spatial co-location is just one and not the primary aspect is represented by the relation of telicity:

$$tel(F, G)$$

Examples:
John (F) is on the computer (G).
John (F) is next to a computer (G).

Although both examples refer to a similar spatial area in terms of distance between both objects, the first example presupposes interaction between them:

$$tel(F, G) \equiv_{def} LocC(F, G) \wedge NEAR(F, G)$$

Frequently geometric factors are also emphasizing functional effects. E.g., containment is perceived better in conditions of convexity (*conv*; see before: page 5) or proximity (*DIST*; see before: page 6). Both convexity and proximity are geometric factors. Also object orientation (*ORIENT*; see before: page 6), shape, and size are basically geometric features that support functional factors (e.g., containment). Our model includes all mentioned components except object shape and size which is a future research desideratum.

2.3. Hierarchy of functional relations

The functional relations are systematically linked to one another. *EC* by support seems to determine the majority of other functional relations (e.g., locational control) in spatial cognition. Therefore, some possible patterns of impact between dependencies can be distinguished:

a. The strongest and most straightforward determining relationship between dependencies seems to be:

$$EC^{S}(F^{S\rightarrow}, G^{\rightarrow S})\ determines \Rightarrow LocC(F, G)\ determines \Rightarrow Fctm(F, G)$$

where support determines locational control which, in turn, determines the perceived containment.

b. Although support enables locational control, there is a strong direct (such that inverse is also possible) relationship between locational control and interlocking:

$$LocC(F,G)\ determines \Rightarrow EC^{IL}(F,G)$$

c. Finally locational control operates in the case without a direct contact (scattered inside)

$$LocC(F,G)\ determines \Rightarrow Fctm(F,G) \wedge DC(F,G)$$

In this case we can apply locational control in the sense of ‘scattered inside’:

$$LocC^{SI}(F,G)$$

Additional geometric relations emphasizing the effects of containment are (1) partial occlusion/enclosure, and additional geometrical factors (2) proximity, (3) object size, (4) convexity.

Partial geometric containment is interpreted as a clear case of containment due to the underlying functional constraints.

Examples
Pen (F) is on the hand (G).
Pen (F) is in the hand (G).

Although in both cases external connectedness applies, there are a variety of situations where functional containment in the second (‘Pen is in the hand’) is perceived due to the additional mentioned functional and geometric factors (e.g., convexity of the palm which is holding the pen).

Also partial geometric containment such as the following examples is characterized as clear cases of containment due to the additional emphasizing factors.

Examples
Flowers (F) in a vase (G).
Bird (F) in the tree (G).

Some situations of containment seem to operate due to convexity only.

Example
An island (F) in the archipelago (G).

Additional interesting example of functional containment is drawn from the Latvian locative, where the locative is applied in a reverse way in cases of clothes and body-parts.

Examples:
Coat (F) in back (G) (*Mētelis (F) mugurā (G)*).
Cap (F) in the head (G) (*Cepure (F) galvā (G)*).

We argue that the inverse locative operates due to locational control complemented by partial occlusion, proximity, and convexity.

Finally, according to our results (Žilinskaitė-Šinkūnienė et al., 2019a, 2019b, Šķilters et al., 2020, Žilinskaitė-Šinkūnienė et al., 2020), topological and geometric relations are complemented but not replaced by functional ones.

To sum up, in general the following structure of non-functional and functional core relations can be formulated:

1. $C(A, B)$ non-functional, topological
2. $EC(A, B)$ non-functional, topological
3. $EC(F, G)$ functional
4. $EC^S(F^{S\rightarrow}, G^{\rightarrow S})$ functional

From $EC^S(F^{S\rightarrow}, G^{\rightarrow S})$ another functional core relation can be derived:

5. $LocC(F, G)$ functional

From $LocC(F, G)$ interpretations of locational control having external connectedness and non-connected version (scattered inside) can be derived; i.e.,

5.1. $LocC^{EC}(F, G)$ functional

The relation of interlocing – the strongest version of functional control – can be derived from $LocC^{EC}(F, G)$:

5.1.1. $EC^{IL}(F, G)$ functional

5.2. $LocC^{SI}(F, G)$ functional

A weaker case of $LocC(F, G)$ is telicity:

5.3. $tel(F, G)$ functional

Locational control is a necessary relation for functional containment $Fctm(F, G)$ (both external connectedness and scattered inside cases corresponding to $LocC^{EC}(F, G)$ and $LocC^{SI}(F, G)$). However, containment can be perceived to a different degree and is increased by convexity $conv(F, G)$, orientation (*ORIENT(F,G)*; in particular vertical alignment), and distance *(DIST(F,G)*; in particular, near distance) (convexity, distance, and orientation are per se geometric). Additionally, functional enclosure (partial occlusion) $FE(F, G)$ between objects increase the effect of functional containment.

Discussion

The underlying idea of our approach was to generate a formal Qualitative Reasoning framework that is consistent with empirical evidence from spatial perception and cognition. At the same time we also argue that there is a potential for further formal development (e.g., Forbus, 2019). An advantage of the current framework is its simplicity – we are starting with (a) a simple logical formalism RCC for *topological* relations, then adding (b) convexity and relational distance and orientation operators (operating on a simple *geometry*), and, finally, adding two core (c) *functional* operators of support and locational control.

We assume that this framework is plausible for natural language representation (e.g., Mani and Pustejovsky, 2012).

We also note some complexity features of our framework. As a first order theory, the axioms of RCC are recursive, and its theorems recursively enumerable. This is a good start, though it is well-known that mere recursive enumerability does not lead to feasible computability. A significant body of research explores how to implement RCC-based notions in more feasible ways (see Cohn et al., 1997). Outside of formal measures of complexity, our framework identifies a highly limited range of operators involved in spatial cognition, each describing a specific relation in the topological, geometric, or force-dynamic domains, such as connectedness or support.

The main idea of the current framework is that the relation of connectedness is foundational in spatial perception. Different types of connectedness are distinguished and different core features (e.g., support, locational control) are described by arguing that they modulate the strength of functional relations where the strongest case of functional relation is the interlocking and the weakest is 'scattered inside' (where the locational control is perceived without *EC* at all). The idea that varieties of connectedness underly spatial perception is also confirmed by experimental work: in the research on perception there is a prominent tradition (Palmer and Rock, 1994, Chen, 2005) arguing that connectedness is among the primary principles of perceptual organization Although research on perception primarily focuses on topological and geometric features of connectedness, we argue that the typology of connectedness in functional cases is much more complex and includes external connectedness that is functionally constrained by the relation of gravitational support that enables locational control. Locational control, further, allows different types of containment both with external connectedness between figure and ground objects and without (which is the case of 'scattered inside' relation). Functionally constrained external connectedness operates also in the relations of interlocking, partial occlusion, and telicity (where cases without physical connectedness are also possible).

The current approach can be extended both formally and experimentally. We note that preliminary experimental evidence supports the current idea (Šķilters et al., 2020, Zariņa et al, 2023, Žilinskaitė-Šinkūnienė et al., 2019a and 2019b, Žilinskaitė-Šinkūnienė et al., 2020). There are, however, several areas where a future work would be important: (1) an in-depth analysis of the relations between the current formalism and the conception of the Naive Physics (e.g., programmatically: Hayes, 1985, and experimentally, Firestone and Scholl, 2017); (2) an extension of the current approach with a Model Theory (for an attempt to equip RCC with a model theory see Li and Ying, 2003); (3) context might affect how we express spatial relations, so work on pragmatics in the settings of spatial cognition would be important; (4) information on object shape and size is not included in the current work but would be an important geometric extension; (5) most of the current approach refers to space as provided in visual perception, yet there are interesting differences once RCC (and its extensions) are applied to other perceptual domains such as haptics (see Zarina et al., 2023).

Abbreviations

F – Figure object
G – Ground object
RCC – Region Connection Calculus
RCC+F – RCC that is equipped with crucial functional relations

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