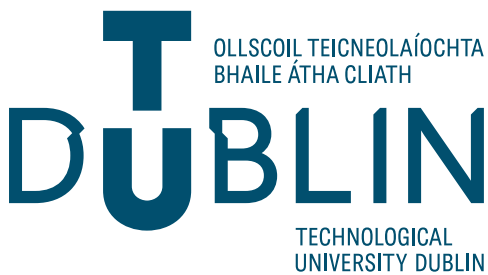
Language and Space

John D. Kelleher

Language, Action, and Perception
31 European Summer School in Logic,
Language and Information
$12^{th} - 16^{th}$ August 2019, Riga Latvia



Outline

Why is the relationship between space and language important?

Why is the relationship between space and language important?

Understanding how language and space connects can help us to:

- understand spatial cognition (spatial language can act as a window into cognition)
- build useful technologies (talking robots)

Why is the relationship between space and language important?

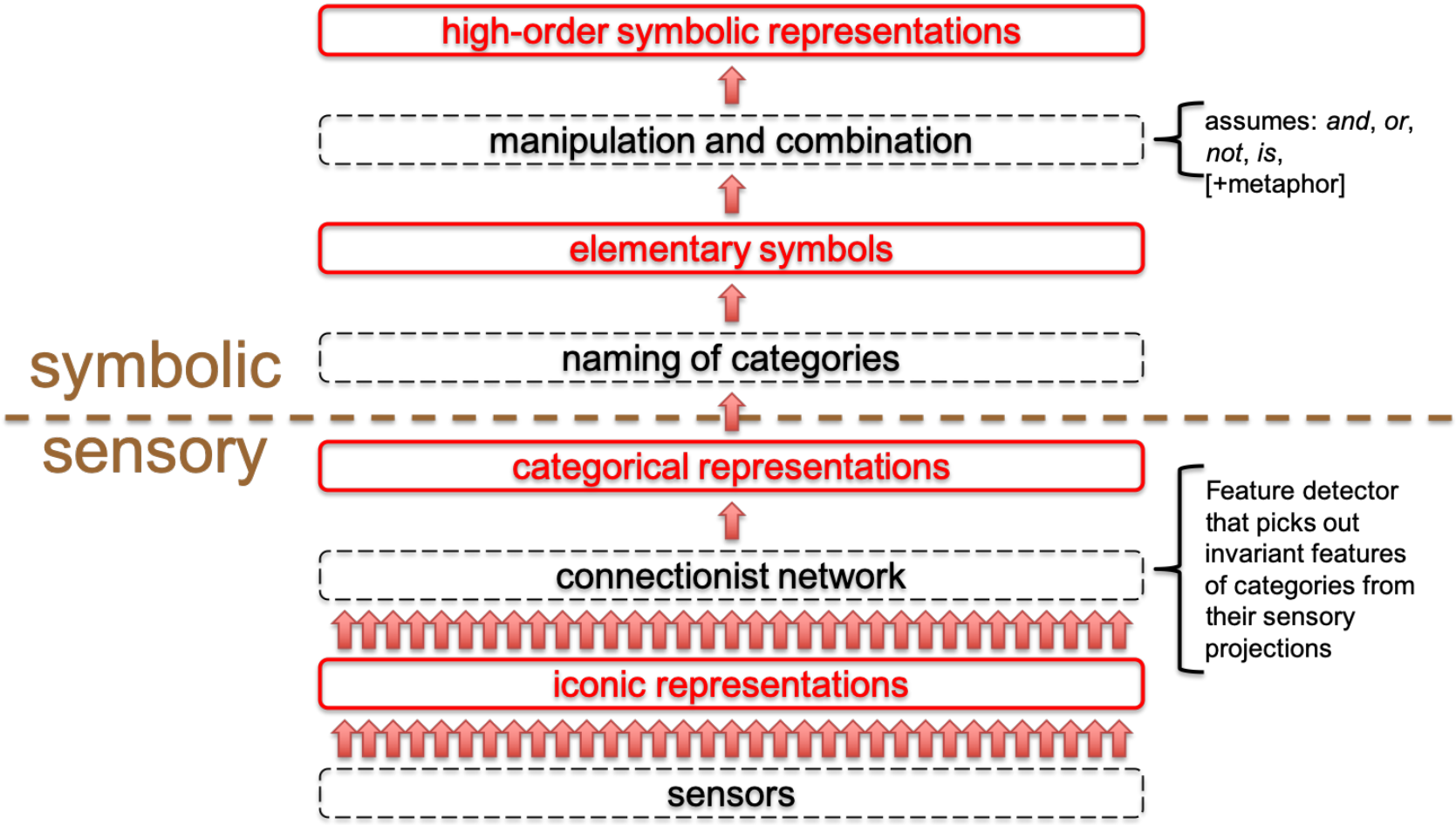


Figure: Schematic of Harnad (1990) model, image from Kelleher (2010)

Why is the relationship between space and language important?

- Spatial language provides an interesting case study for grounding - because it focuses on the grounding of relations between objects.
- We percieve a spatial relation in a different way to how we see an object. (?)
  - Spatial prepositions are not pre-attentively available Logan (1994, 1995)

Why is the relationship between space and language important?

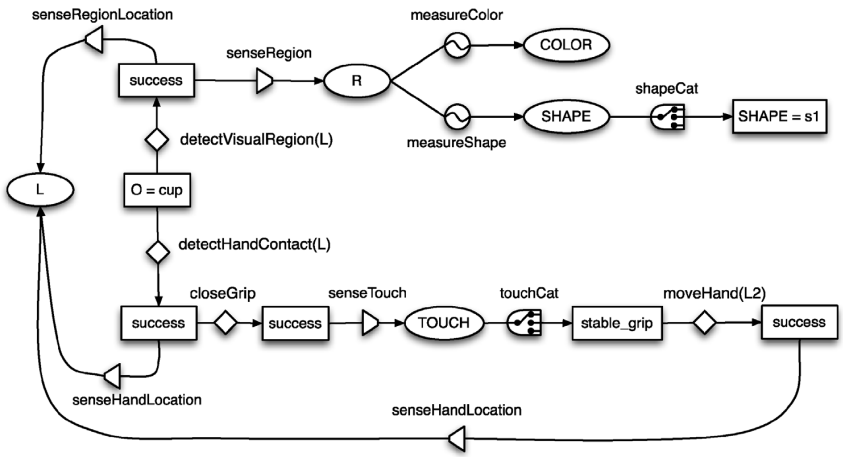


Figure: Schema for a tangible object (touchable, graspable, moveable, visible) such as a cup.

Figures from Roy (2005)

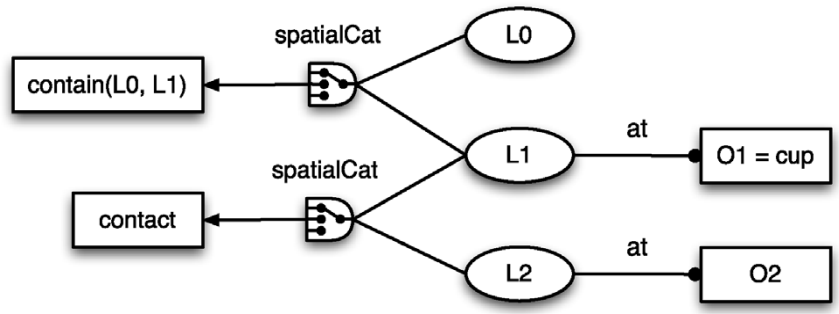


Figure: Schema for the situation: *There is a cup here, something is touching the cup*.

How does language represent space?

How does language represent space?

- Language does not exhibit spatial structure (it is symbolic rather than iconic; cf. maps, pictures and so on) (Bierwisch, 1996)
- At the same time we use language to talk about space[1]:
  - conveying information about where important things are located (food, water, safety, enemies, and so on)
  - and how to get from place to place

[1] Examples from (Peterson et al., 1996)

How does language represent space?

- Syntax and morphology do not directly encode spatial information (Bierwisch, 1996)
  1. Identical syntactic structures can express spatial and non-spatial information:
     - We entered Saint Peter's Cathedral
     - We admired Saint Peter's Cathedral
  2. Location v. Direction in German
     - Er schwamm unter dem Steg. (dative→location)
     - Er schwamm unter den Sten. (accusative→directional)

How does language represent space?

- In English most major word classes have members that have spatial readings, including nouns, adjectives, verbs and prepositions (Landau, 1996)
  - nouns: e.g. *top*, *bottom*
  - adjectives: e.g. *long*, *wide*
  - verbs: e.g. *enter*, *stand*, *stack*
  - prepositions: e.g. *at*, *on*, *in*
- Note also, that most words that have a spatial interpretation carry a non-spatial reading under some conditions (Bierwisch, 1996)
  - He entered the church (as in he became a Priest)

How does language represent space?

- Most of the literature on spatial cognition and language has focused on spatial prepositions
- They are a relatively small class of words (around 80) where their spatial meaning is often primary and as such provide a useful basis for studying how language encodes space

How does language represent space?

at	in	on	near
up	down	over	under
above	below	along	around
between	amongst	amidst	throughout
		Compounds	
on top of	in between	to the right of	to the left of
in front of	in back of	parallel to	perpendicular to

Table: A Sample of English Spatial Prepositions sourced from (Landau, 1996, pg. 322)

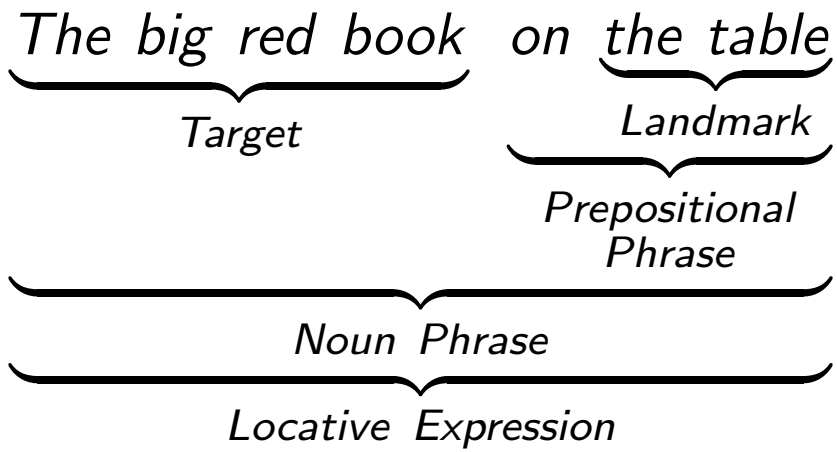
How does language represent space?

- In English most prepositions are two place predicates (although some take more arguments, e.g. *between*)
- Note: there is variability between languages in how the encode spatial relationships:
  - some languages collapse several English distinctions into broader categories; e.g. Spanish *en* $\approx$ English *in* and *on*
  - some language split English distinctions into finder categories; e.g. English *on* $\approx$ German *auf* and *an* (vertical versus horizontal attachment)

Locative Expressions & Categories of Prepositions

Locative Expression

- In its simplest form a locative expression is a noun phrase that is modified by a prepositional phrase that has an adjectival role and locates the object.



A variety of terms is used in the literature to refer to the objects included in a locative expression: the *target* is also sometimes called the *located object*, the *figure*, or the *trajector*; and the *landmark* object is sometimes referred to as the *reference object*, *relatum* or the *ground*.

Locative Expressions

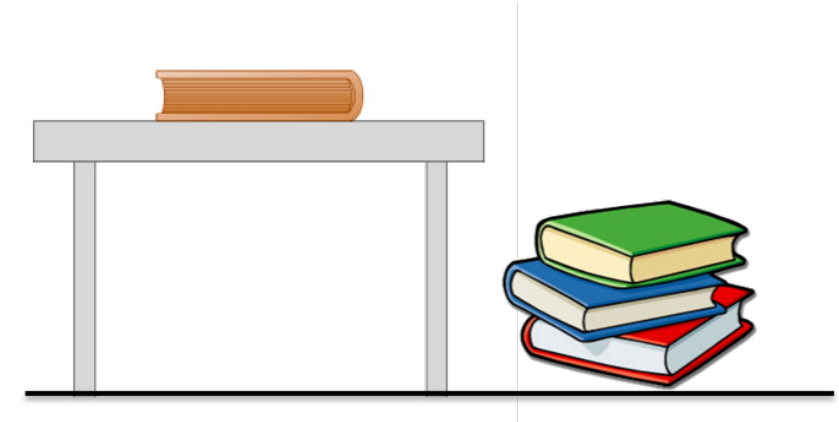
The English linguistic conception of space is fundamentally relativistic the location of the target object is specified relative to the landmark whose location is usually assumed to be known by the hearer (Kelleher, 2003, pg. 26)

Locative Expressions

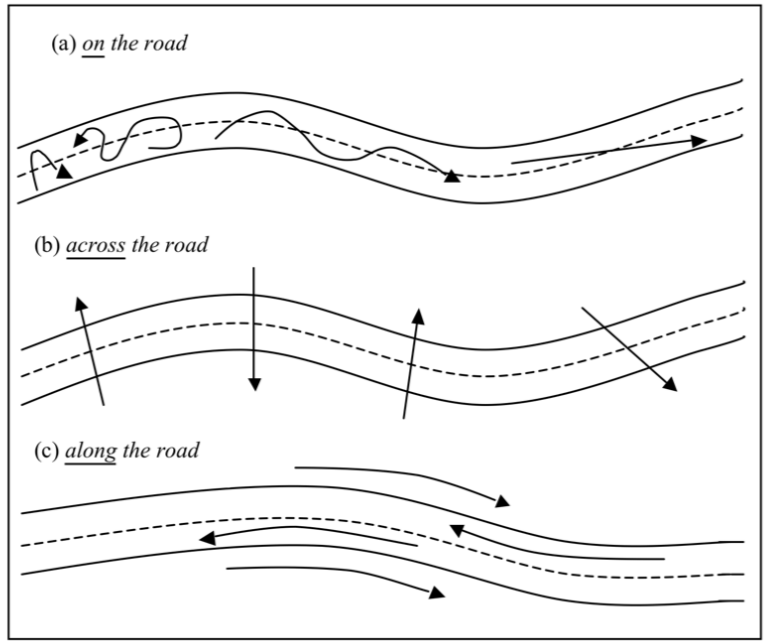
A locative expression can express different types of spatial relationships between the target and the landmark:

1. static versus dynamic
2. topological versus projective

Static versus Dynamic

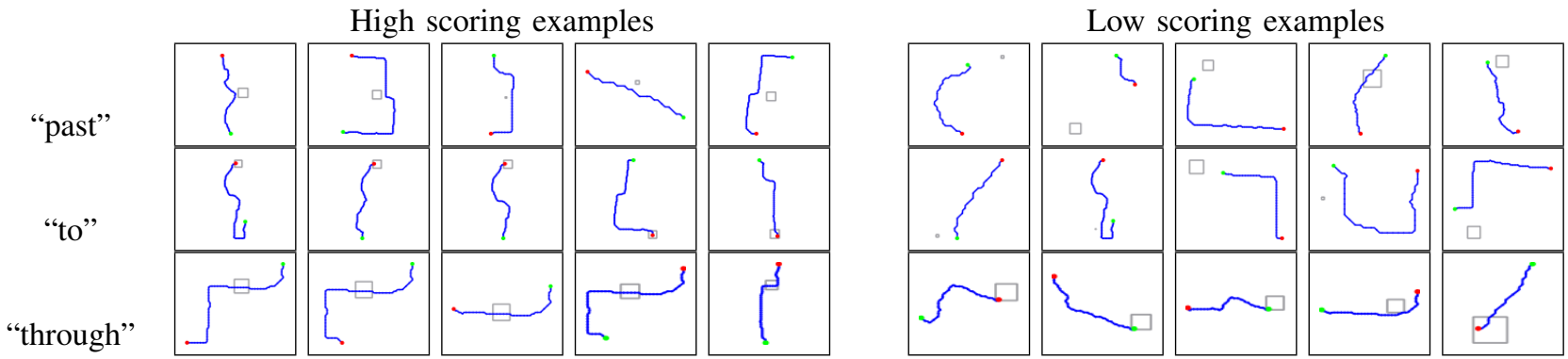


The book on the table.



- a static preposition describes the location of a stationary target
- a dynamic (or motion) preposition describes the direction of the path of the target

Static versus Dynamic



- Today we will focus on static prepositions but see Kollar et al. (2010) for work on modelling dynamic prepositions.

Topological versus Projective

- Topological prepositions distinguish different topological relationships between the target and the landmark.
- Examples: *at*, *on*, *in*

Topological versus Projective

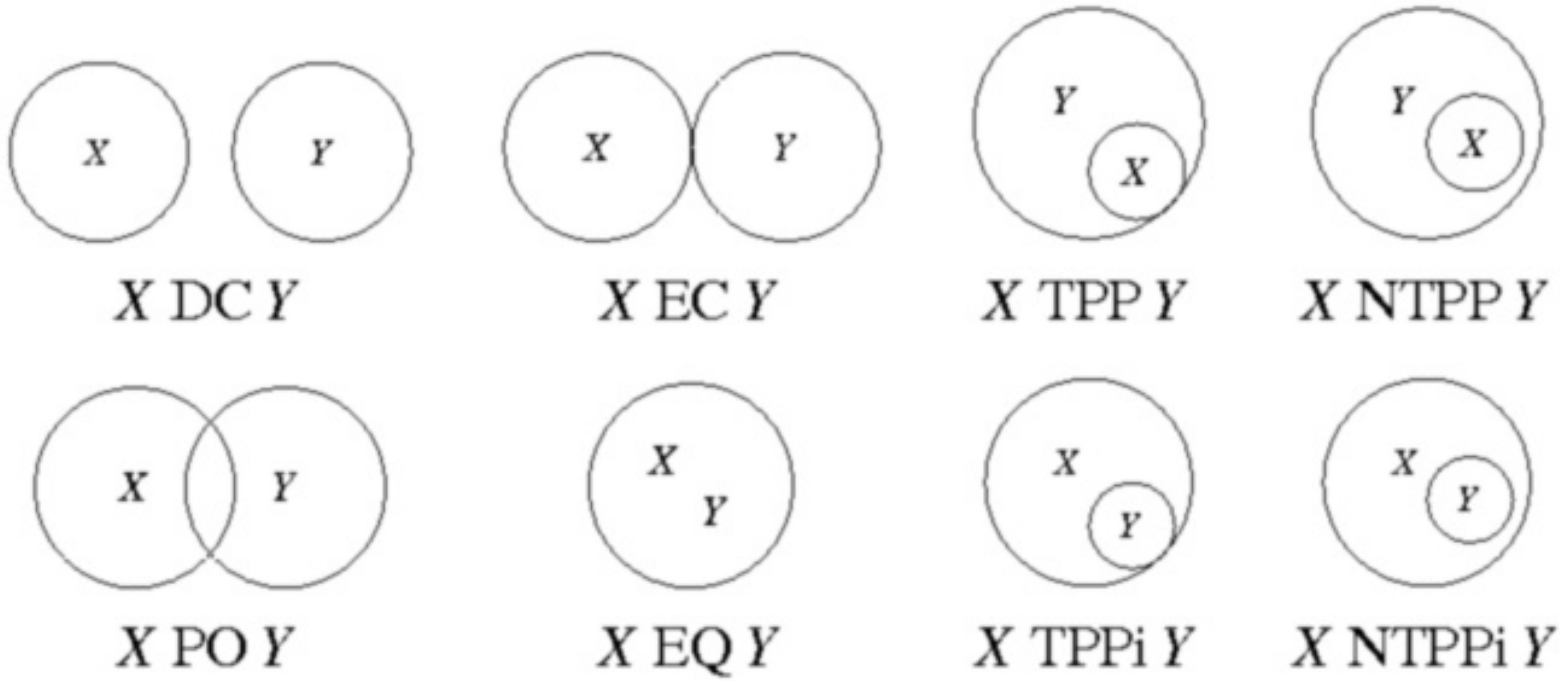
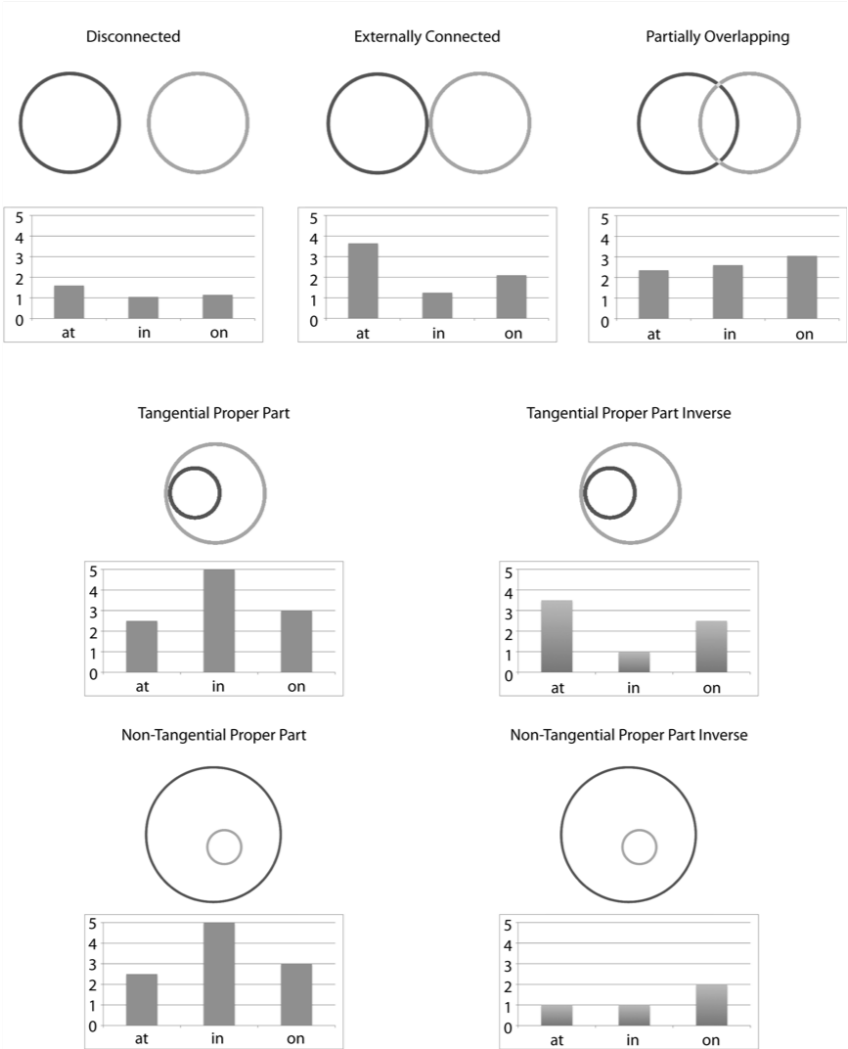


Figure: Region connection calculus 8 (RCC-8): DC disconnected; PO partially overlapping; EC externally connected; TPP tangential proper part; nontangential proper part; EQ equal; i inverse.

- See (Cohn et al., 1997) for more on RCC-8.

Image sourced from Wikipedia:
https://en.wikipedia.org/wiki/Region_connection_calculus

Topological versus Projective



Results from Kelleher et al. (2009)

- A preference for at emerges in all of those cases in which objects appear to connect, suggesting that connection is an integral part of people's understanding of the preposition *at*.
- TPP and NTPP a strong preference for in is expressed in all of these cases.

Topological versus Projective

- Projective relations describe a region in a particular direction relative to the landmark.
- Examples: *above*, *behind*,
- We often include composite spatial terms in this category: *to the right of*, *in front of*, *in back of* and so on.

Topological versus Projective

- Composite spatial terms, such as *at the right of*, *on the right of*, *at the left of*, *on the left of* are interesting because they blend a topological semantics (*at*, *on*) with a projective relation (*left*, *right*)

Topological versus Projective

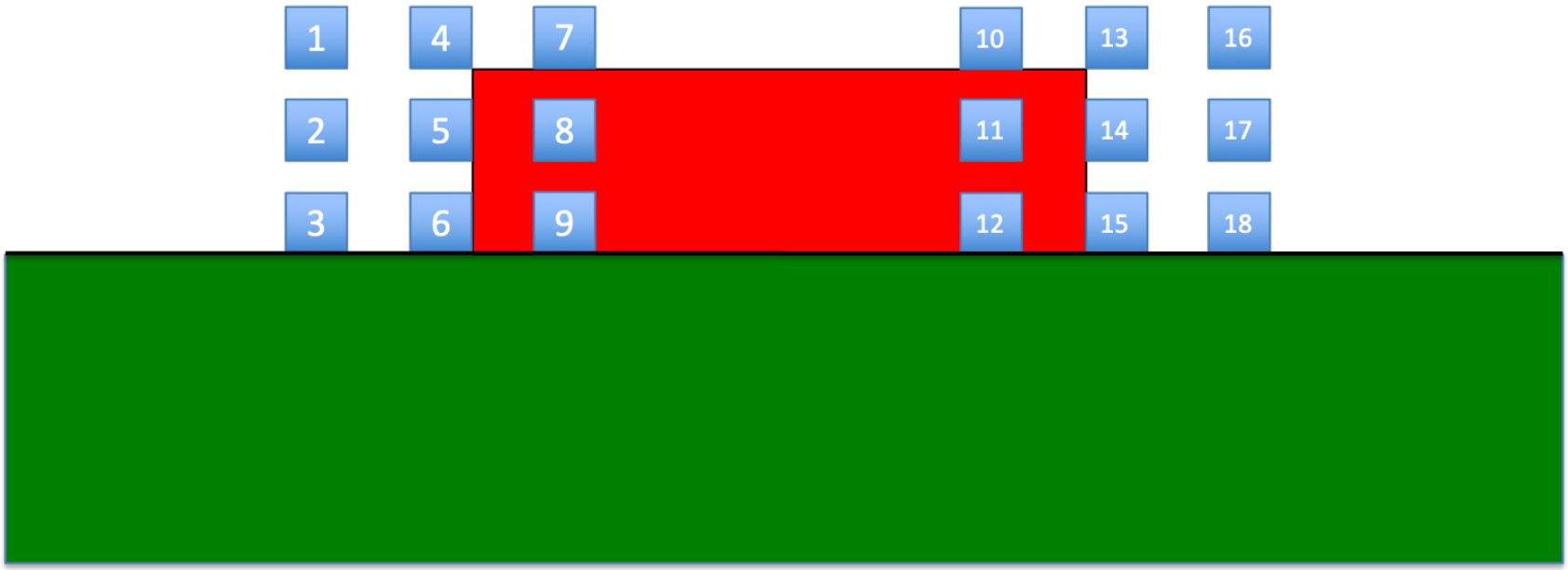


Figure: The positions of the 18 locations where the target object (small blue box) appeared relative to the landmark object (large red box). Figure from: (Kelleher and Ross, 2010)

Topological versus Projective

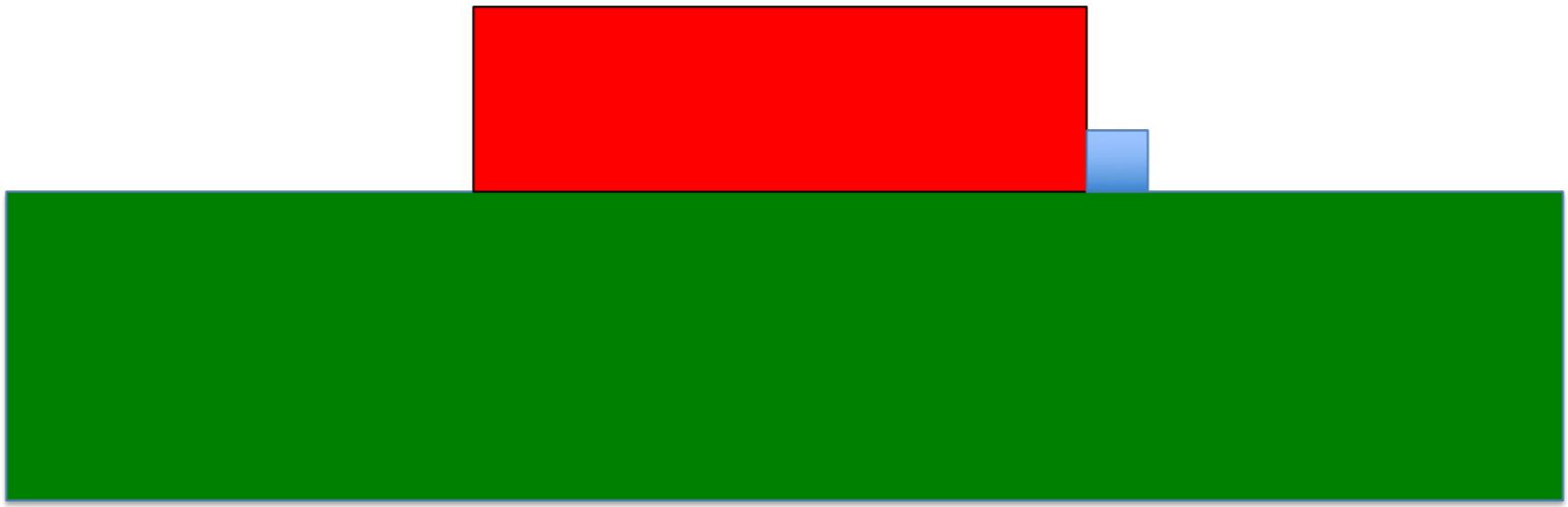


Figure: The blue box is X the Y the red box.

- X is replaced by one of: *at*, *on*, *in*, *to*
- Y is replaced by either *left of* or *right of*

Topological versus Projective

Results from (Kelleher and Ross, 2010):

- *in* is sensitive to inclusion: high acceptability in positions 8, 9, 11, and 12
- *at* is sensitive to contact: high acceptability 4-7 and 10-15
- *to*, while not traditionally treated as a topological preposition, does demonstrate topological features in that it is sensitive to landmark boundary; (similar to *at*) its acceptability increases notably once the target is no longer contained within the landmark

Topological versus Projective

Results from (Kelleher and Ross, 2010):

- in this context *on* deviates from its purely topological meaning:
  - locations 7 and 10 (directly above and touching the landmark) are rated poorly
  - a likely cause is that *on the right of* can be interpreted as having an idomatic meaning similar to *to the right of*

Frames of References

Frames of Reference

- For the purposes of this course a frame of reference is a 3D coordinate system with an origin at the landmark.
- In English the axes of the coordinate system are usually labelled: *front*, *back*, *right*, *left*, *up*, *down*

Frames of Reference

- In English[2] three different classes of frames of reference are distinguished:
  1. intrinsic
  2. relative
  3. absolute

[2] Although the use of a tripartite system is common in European languages, this is not a universal with many languages taking different approaches here. Levinson (1996) describes the Tzeltal language from Mexico, which uses only an intrinsic and absolute frame, both of which are variant from their European counterparts. Other examples are given in Levelt (1996) where speakers of Guugu Yimithirr are reported as exclusive users of an absolute perspective system while Mopan speakers are attributed to be exclusive users of an intrinsic system.

Frames of Reference

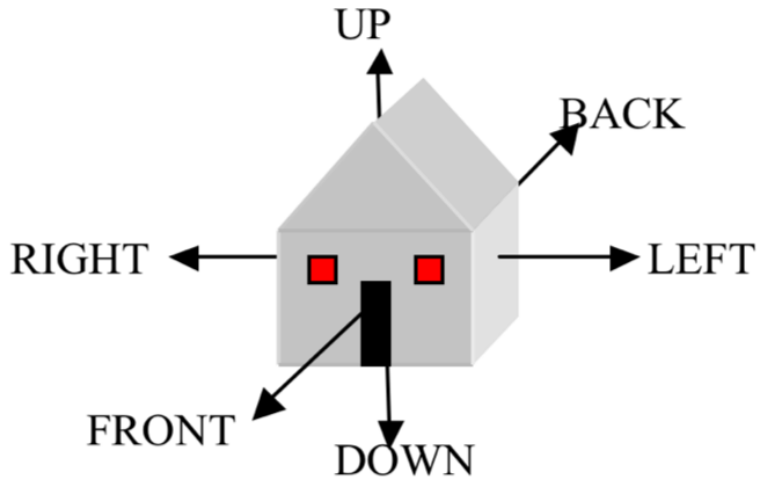


Figure: Intrinsic frame (object-centred, landmark-based): the axes of the coordinate system are oriented around the landmark based on its canonical position (i.e., how we normally encounter it).

Frames of Reference

> *"The question of whether an object is considered to have an intrinsic top is relatively straightforward; it depends on whether it has a characteristic orientation to the vertical"*

(Miller and Johnson-Laird, 1976, pg. 400)

Frames of Reference

Fillmore (1997) describes 2 possible process through which a front can be defined for an animate being:

> *"For animate beings having a certain degree of complexity, the front is that portion of it which contains its main organs of perception and which arrives first whenever it moves in its most characteristic manner of movement ... [but] the location of the main organs of perception outweighs the direction of movement criterion" (Fillmore, 1997, pg. 33)*

Frames of Reference

Fillmore (1997) describes 4 possible process through which a front can be defined for an inanimate object:

- Analogy: If an object has some surface similarity to a front-back oriented animal, the portion of the object designated as its front is so designated on analogy with the model.
- Motion: Objects which have a fixed orientation when they are in motion have that part which arrives earlier designated as the front.
- Function: The part of an object that is oriented towards a user when they are using the object in its usual manner may be designated as the front.
- Access: The part of an object which a user typically, or symbolically, has access to, may be designated as its front.

Frames of Reference

> *"If an object has both an intrinsic top and bottom, and an intrinsic front and back, the remaining two sides are intrinsically left and right"*

(Miller and Johnson-Laird, 1976, pg. 401)

- However, the alignment of an object's left and right with respect to the front-back axis is not fixed, but is dependent on its characteristic use Levelt (1996).

Frames of Reference

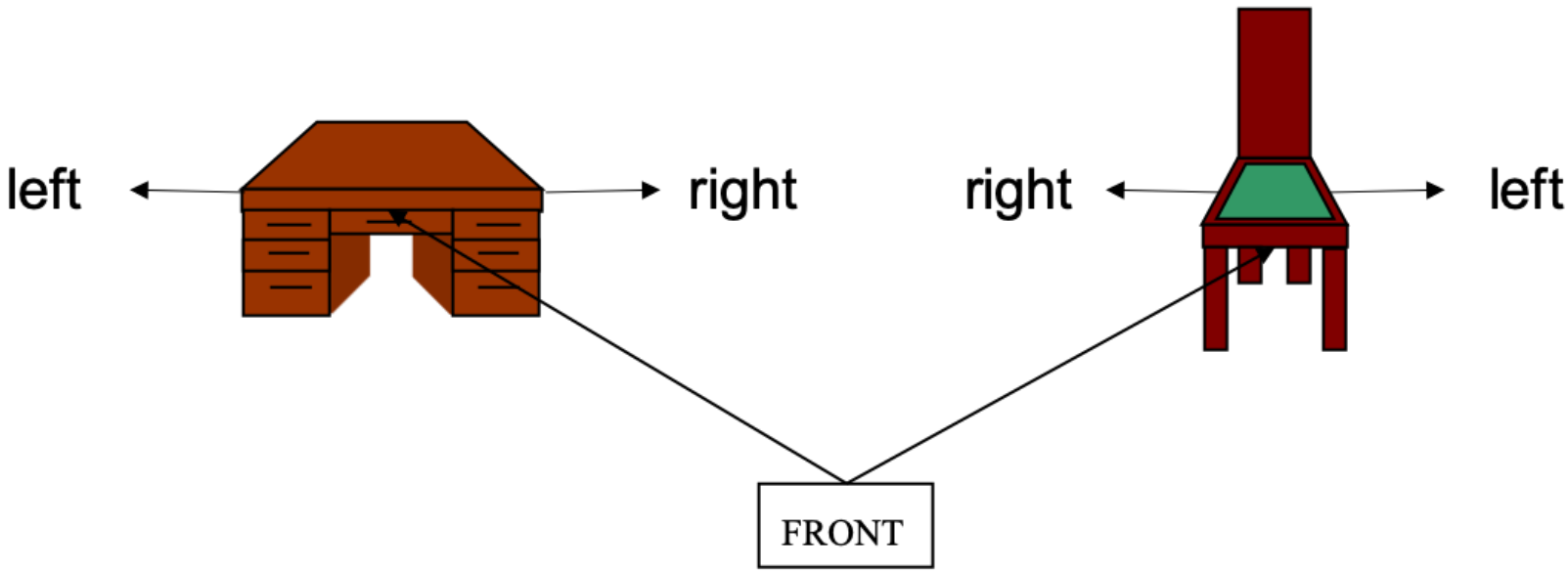


Figure: In this figure, although the front-back axes of the chair and desk's intrinic orientation are parallel, the right-left axes are reversed.

Frames of Reference

One explantation for this phenomenon, proposed by (Miller and Johnson-Laird, 1976, pg. 401), is to distinguish between two kinds of characteristic use:

- inside: if the characteristic use of an object involves the user being inside the object car, chair, clothing, etc. the part of the object adjacent to their right hand will become the object?s intrinsic right side through analogy with the body.
- outside: if during the characteristic use of an object a user is positioned outside the object, the part of the object adjacent to their right hand will become the object?s intrinsic right side.

Frames of Reference

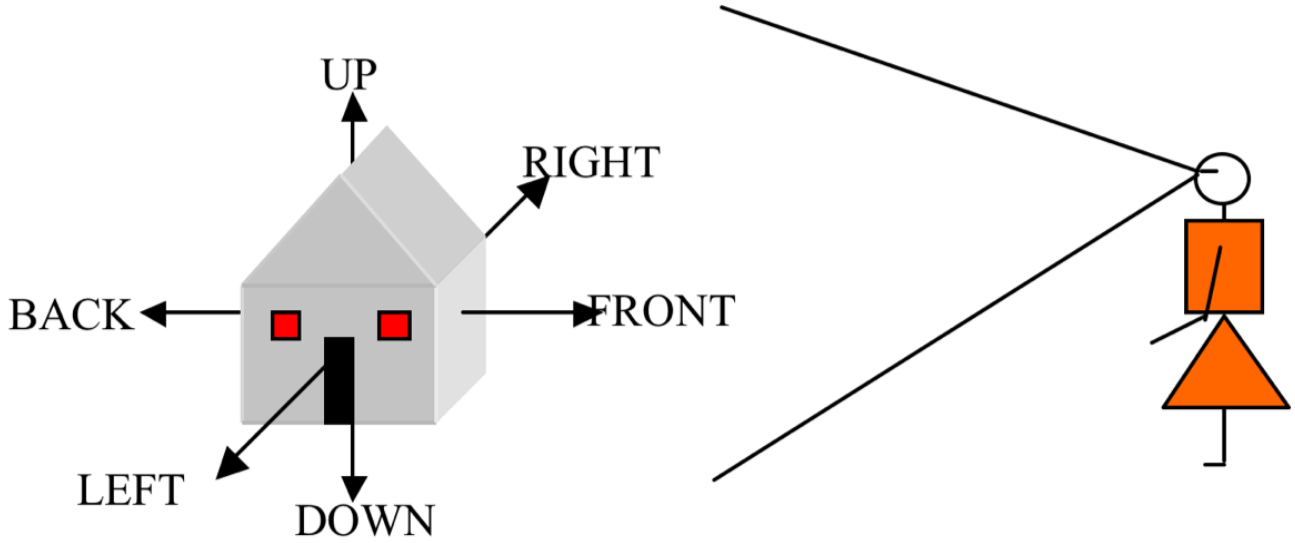


Figure: Viewer-centred frame (ego-centric, relative, deictic): the axes of the coordinate system are oriented based on the perspective the viewer has on the landmark.

Frames of Reference

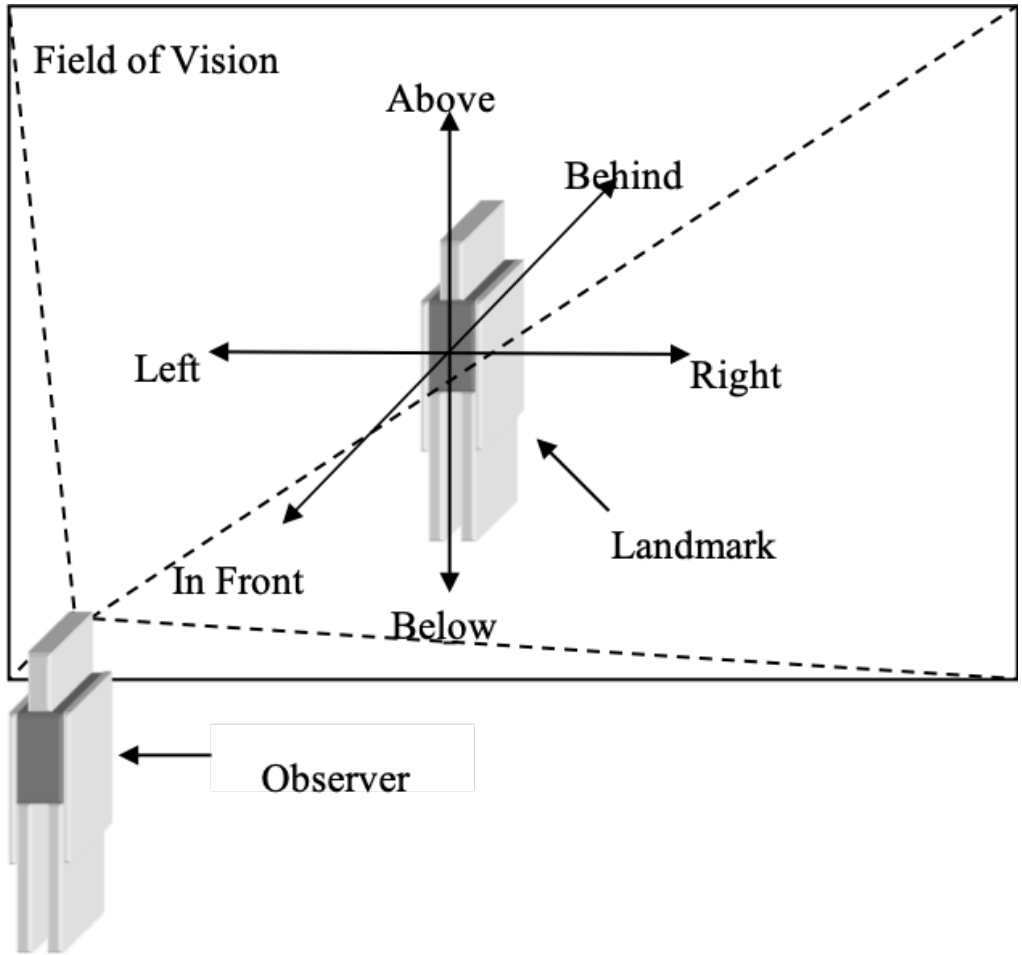


Figure: The strategy for labelling the axis around the landmark in this figure is based on the rules of a canonical encounter. The labelling of the axis is done from the observer's point of view – demonstrating a viewer-centred frame of reference.

Frames of Reference

(Hill, 1982) notes that:

- In European languages the standard strategy for labelling the axes in the canonical encounter is to follow a *mirror imagery strategy*: the axes of the speaker are translated to the landmark and then the front back axes is rotated.
- However, this is not universal; speakers of the West African language Hausa, among others, use an *in-tandem strategy*; using this strategy the sentence *the lion in front of the tree* in Hausa descibes a situation which an English speaker would characterise as *the lion behind the tree*.

Frames of Reference

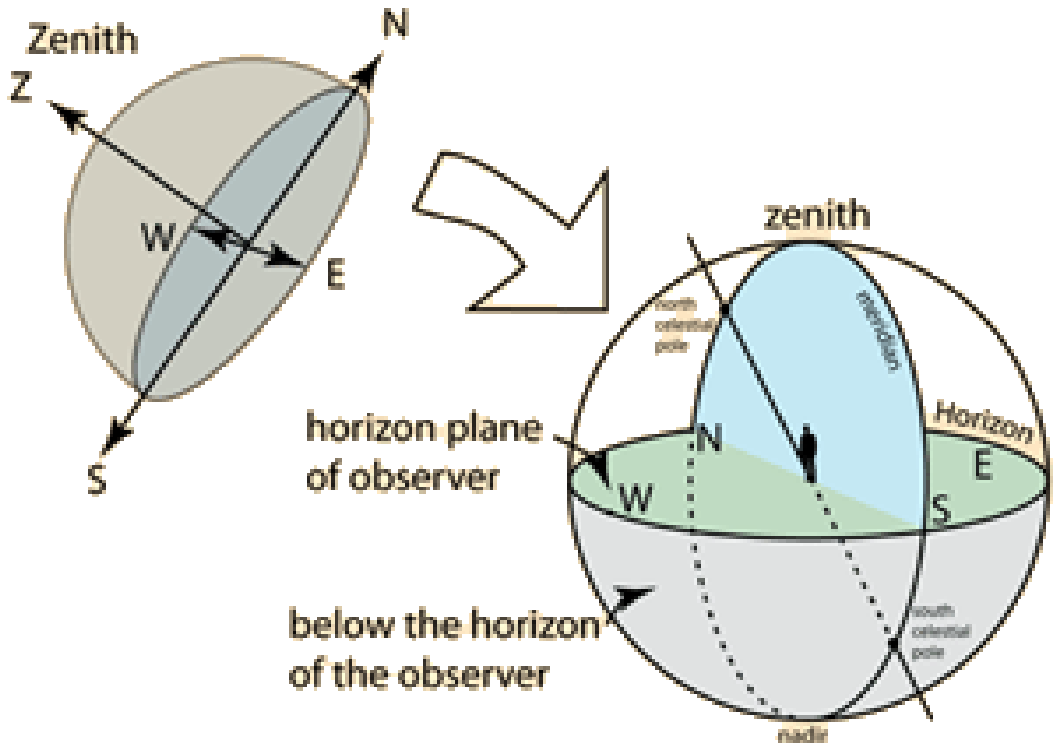


Figure: Absolute frame (extrinsic, environmental, world-based): the labelling of the landmark axes if dependent on salient environment features; e.g., gravity, magnetic poles, map orientation, etc.

Image sourced from: http://hyperphysics.phy-astr.gsu.edu/hbase/Astro/Obscoord.html

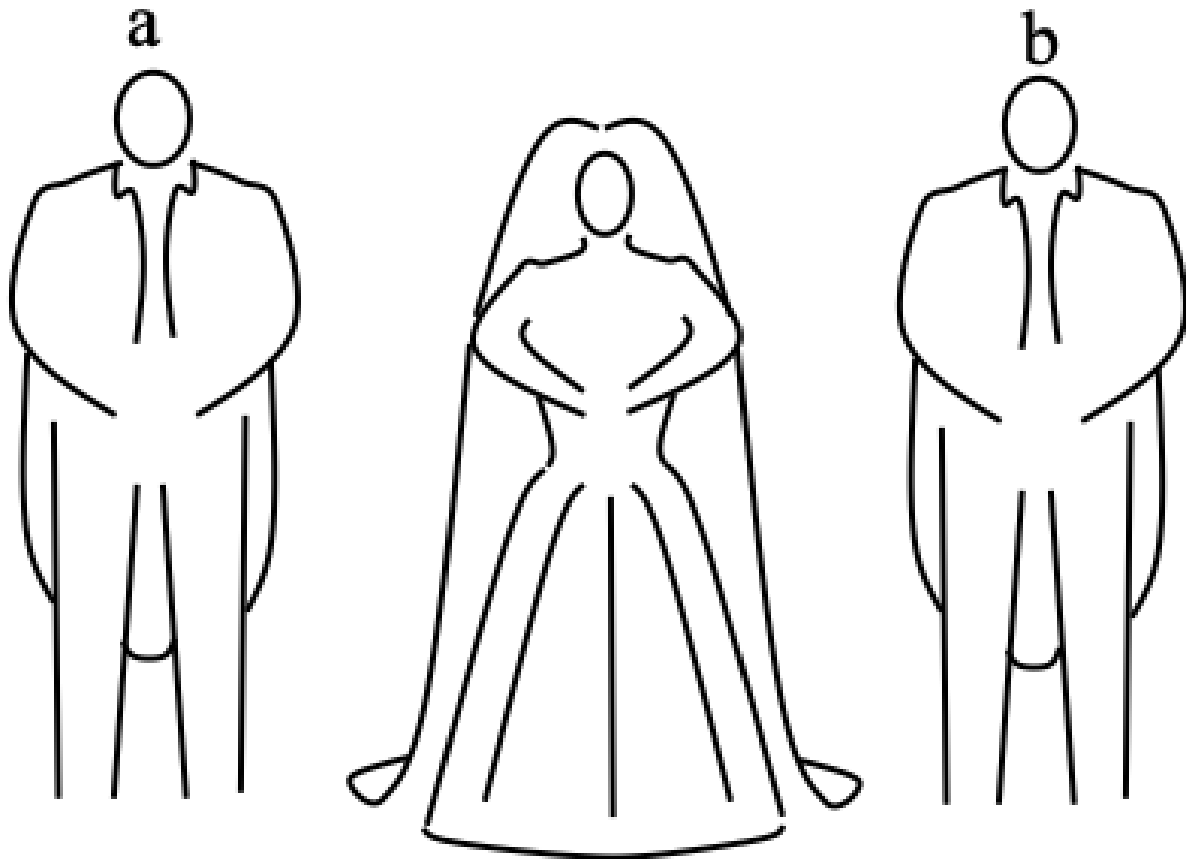
Frames of Reference

- In order to define the area described by a projective locative description a hearer must understand which frame of reference a speaker intended.
- However, the intended frame of reference is usually left implicit in an utterance (although not always)

Frames of Reference

- A speaker may explicitly mark the intended frame of reference
- For example in English the use of a genitive form of the landmark indicates that its intrinsic frame of reference is intended.

Frames of Reference



- *the man to the bride's right* → a
- *the man to the right of the bride* → a or b?

Frames of Reference

- Landau and Munnich (1998) note that the use of the determiner *the* in the noun phrase which describes a spatial region implies an intrinsic frame of reference.
  - *on top of X* could imply any of the frames of reference
  - *on the top of X* indicates the intrinsic frame of reference is indicated

Frames of Reference

Dobnik et al. (2015) and Dobnik et al. (2016) report experiments that explored how subjects align FoR within a dialog.

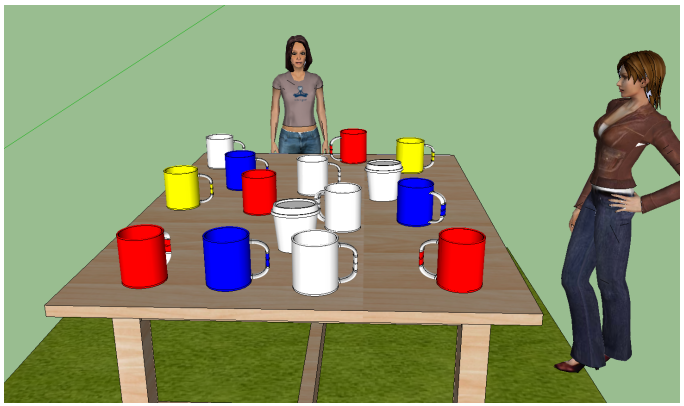


Figure: Scene was designed to provide mulitiple FoRs: the partner was represented by an avatar facing the subject, another perspective was introduced by having a 2^{nd} avatar, named Katie, looking on from the side.

- Subjects worked in pairs; each participant had a different view on a shared scene and interacted with their partner through teletype.
- The shared scene was a table top with cups on it
- Each participant's view was missing some cups that were present in their partners view
- The task was to work together to identify the cups missing from each person's view.

Frames of Reference

P2: 123: ok, so i see a red mug directly behind the red one **on your left**
P2: 124: probably next to the white with "funny top" that i cant see
P1: 125: it is just behind that and to **my left/your right**
P1: 126 : **behind from my perspective**
P2: 127 : and the red i can't see is it to the left of the yellow?
P1: 128 : yes, **as you se it its left**
P2: 129 : ok, i mark it, and you mark the other red
P1: 130 : yup
P1: 131 : and the blue ones are one on the second row **from you, to the right from you**
P1: 132 : one slightly **to my left**
P1: 133 : and one **in front of katie** in the first row
P2: 134 : yes, that's the same
P1: 135 : and the yellow are on between us to **your far right**
P1: 136 : and one quite close to the corner **on your left and katies right**?

Frames of Reference

Based on the data gathered Dobnik et al. (2015) and Dobnik et al. (2016) conclude that:

- Participants use different task strategies (and hence engage in different dialogue games) and FoR alignment is dependent on the strategy/game
- Alignment is local (i.e., participants generally do not adopt a default FoR throughout the dialog)
- Alignment requires interaction.

Frames of Reference

- In normal dialog explicit linguistic cues are relatively rare
- Consequently there can often be ambiguity with respect to the intended frame of reference
- We will return to this topic later

Spatial Language Frameworks

Schematization

- Many researchers have conjectured that objects are cognitively characterised as simple geometric shapes when locating them with a preposition.
- The term *schematisation* is used to describe the cognitive process that reduces a detailed scene to a sparse schematic content:

  "schematisation – a process that involves the systematic selection of certain aspects of a referent to represent the whole, while disregarding the remaining aspects"

(Talmy, 1983, pg. 225)

Schematization

- The concept of schematization is based on the restrictions on the types of objects that may complement certain prepositions

  "Prepositions contain certain presuppositions about their point of reference – e.g. whether it is one-, two-, or three dimensional" (Clark, 1973, pg. 40)

  "The preposition 'at' is said to ascribe no particular dimensionality to the referent of its associated noun, the preposition 'on' is said to ascribe to the referent of its complement the property of being a line or a surface, and the preposition 'in' is said to ascribe to the referent of its complement the notion of a bounded two-dimensional or three-dimensional space."(Fillmore, 1997, pp. 28-29)

Schematization

- *The man stood* **in** *the yard.*
- *The man stood* **on** *the yard.**

Schematization

- Although schematization (or the abstraction from details of objects to simple geometric forms) has been adopted in many models of spatial term semantics it has also been criticised.
- For example, Claude Vandeloise argues for a functional approach to spatial language and argues that:

  > *"the dimensionality of the object is often only a superficial consequence of the preposition itself, and not an essential characterisation of the use of the prepositions"* (*Vandeloise, 1991, pg. 7*)

- We will return to the question of the functional aspects of spatial semantics later.

Neat versus Scruffy

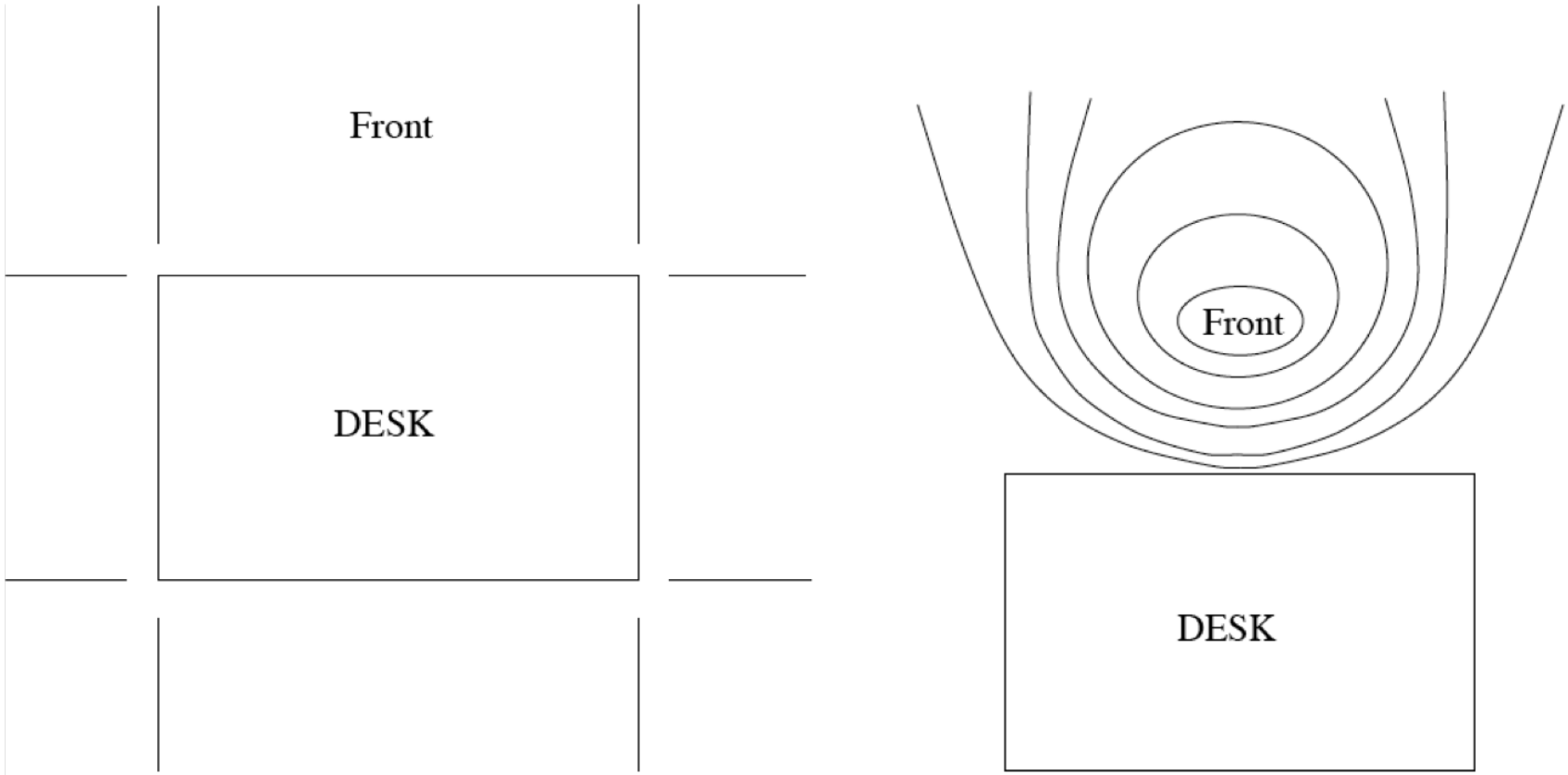


Figure: Mukerjee (1998) characterises spatial frameworks based on their discretisation of space as: neat or scuffy.

Neat versus Scuffy

- The defining characteristic of a neat framework is the proposal of definitions for spatial prepositions that may be expressed in first-order logic.
- For example, the meaning of *in* might be defined as:
  - "x in y: x is located internal to y with the constraint that x is smaller than y" (Cooper, 1968)
  - "x in y: x is enclosed or contained either in a two-dimensional or in a three-dimensional place y"(Leech, 1970)
- The problem for neat models is that counter examples are easy to find for any strict definition.

Neat versus Scruffy

Figure: Illustration of the range of meanings of *in* from (Kelleher, 2003)

Neat versus Scruffy

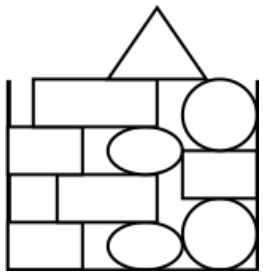


Figure: Neat constraints, such as *enclosure*, can be difficult to define: *the triangle is in the box*

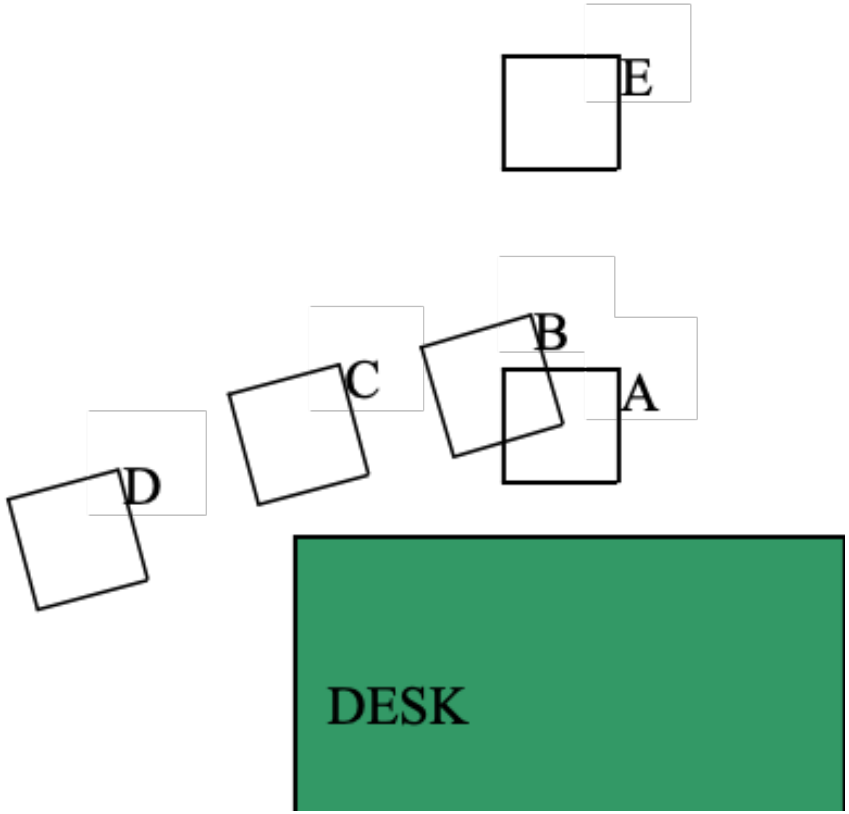


Figure: Spatial terms have graded meanings: chair A is more in front of the desk than char E; based on an example in (Mukerjee, 1998)

Neat versus Scruffy

- Building on the idea of schematization Herskovits (1987) proposes a semantic approach to spatial language that is based on the notions of an ideal and deviation from the ideal.
- In a sense Herskovits' framework can be understood as an attempt to propose a neat model that has the flexibility to handle the variation of linguistic use.
- Word meanings have an ideal from from which uses types can be obtained via transformations:
  - sense shifts: dropping or adding a condition, generalisation to higher dimensional (schematized) objects, ...
  - tolerance

Neat versus Scruffy

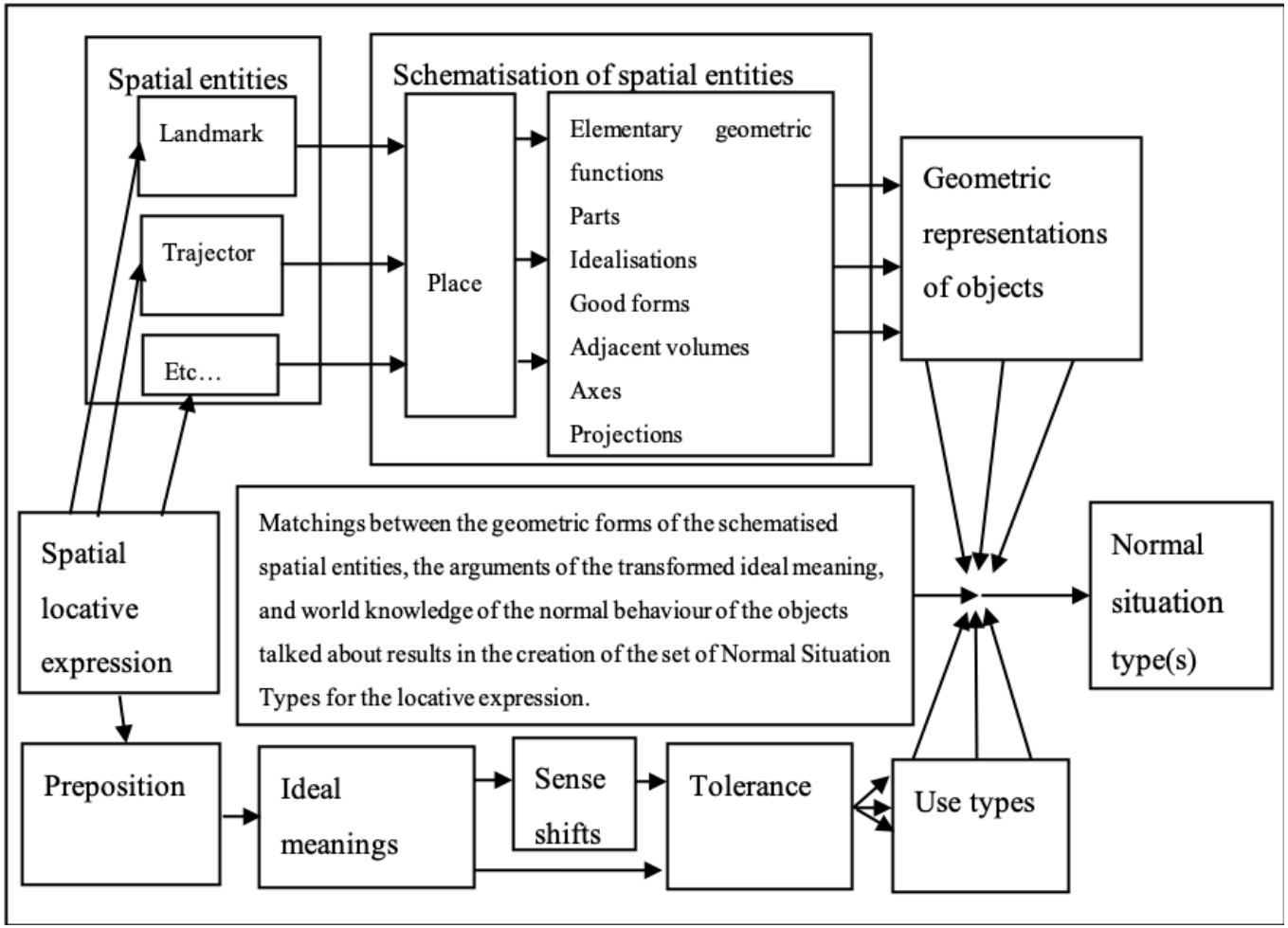


Figure: Schematic representation of the steps involved in Herskovits (1987) framework to generate the set of normal situation types for a given locative expression; schematic taken from Kelleher (2003)

Neat versus Scruffy

- Where neat models are characterised by logical definitions, scruffy models often focus on modelling geometry.
- A fundamental concept underpinning many scruffy models is the **spatial template**

Spatial Templates

- Logan and Sadler (1996) propose the concept of a spatial template as the basic meaning of a spatial preposition
- The term spatial template denotes regions of acceptability associated with a preposition
- Logan and Sadler (1996) proposed a method to discover the spatial template of a spatial preposition which involves presenting a visual stimulus to a subject and asking them to rank on a Likert scale the acceptability of a spatial description relative to the visual stimulus.

Spatial Templates

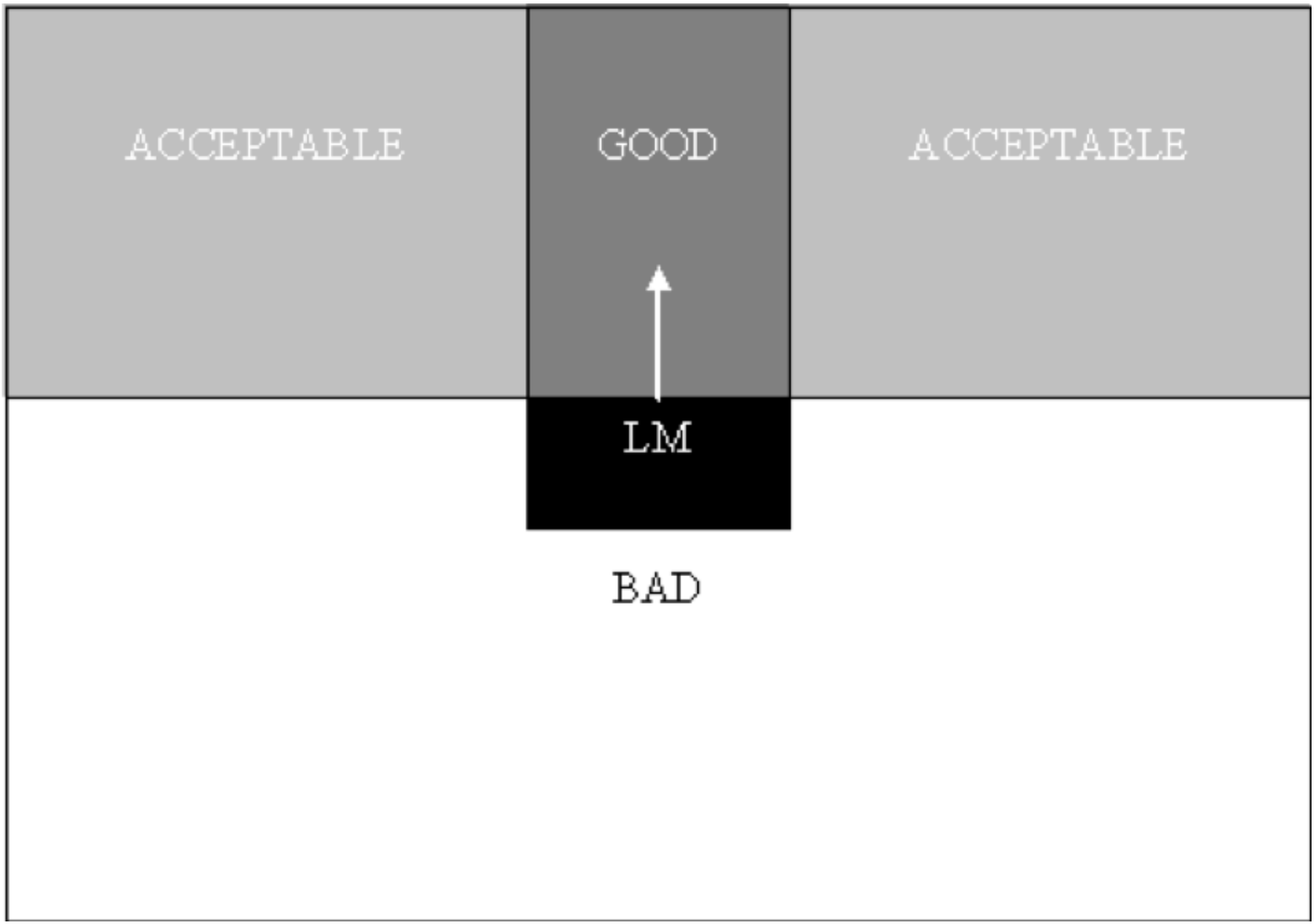


Figure: The Spatial Template for *above* based on results from Logan and Sadler (1996)

Spatial Templates

"Templates corresponding to *above*, *below*, *over*, *under*, *left of*, and *right of* have similar shape but differ from each other in orientation and direction. Templates corresponding to *next to*, *away from*, *near to*, and *far from* have different shapes from *above*, *below*, and so on, but are similar to each other except that *next to* and *near to* are reflections of *away from* and *far from*."
(Logan and Sadler, 1996, pg. 514)

Spatial Templates

- Spatial templates naturally capture the gradation in acceptability of across the region described by a preposition

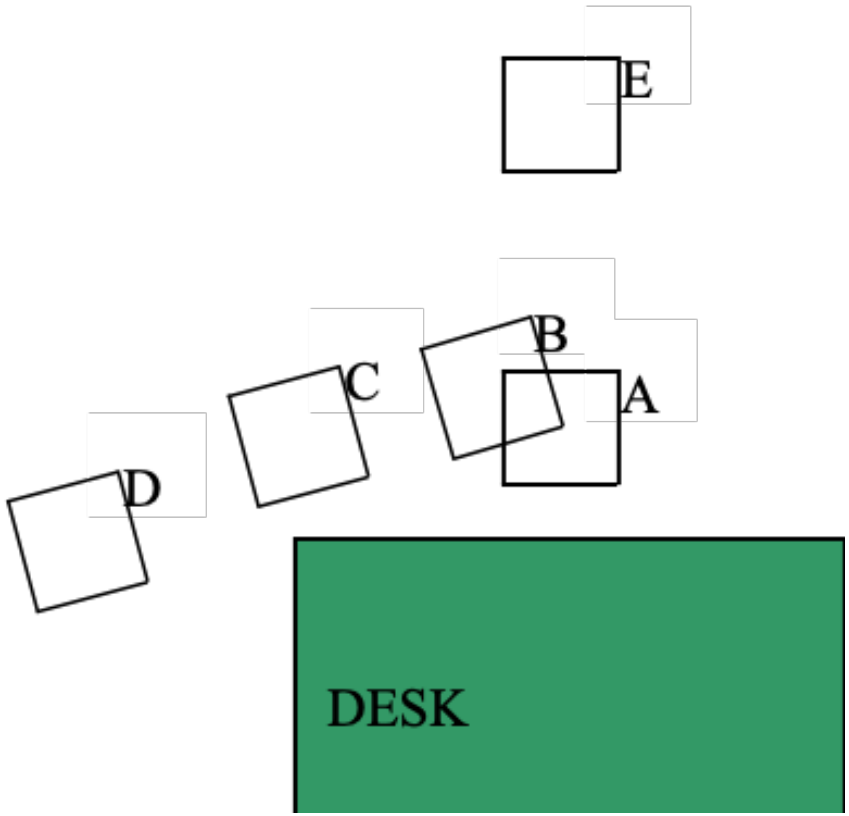


Figure: Spatial terms have graded meanings: chair A is more in front of the desk than char E; based on an example in (Mukerjee, 1998)

near and Distractor Objects

1.7	1.9	2.8	3.2	2.3	1.8	2.1
2.6	3.8	4.7	5.0	4.9	3.6	3.3
4.1	5.6	7.6	8.0	7.3	4.8	3.9
4.5	5.9	8.5	**L**	7.9	6.1	4.5
3.5	4.8	7.0	7.6	7.3	5.6	3.6
3.3	4.0	4.5	4.8	4.4	3.5	3.1
1.8	2.2	2.0	3.1	2.5	2.1	2.0

Figure: The Spatial Template for *near* from Logan and Sadler (1996)

- Proximity is inversely related to distance.

near and Landmark Size

- Size of the landmark: given prototypical size, the region denoted by "near the building is larger than that of "near the apple"

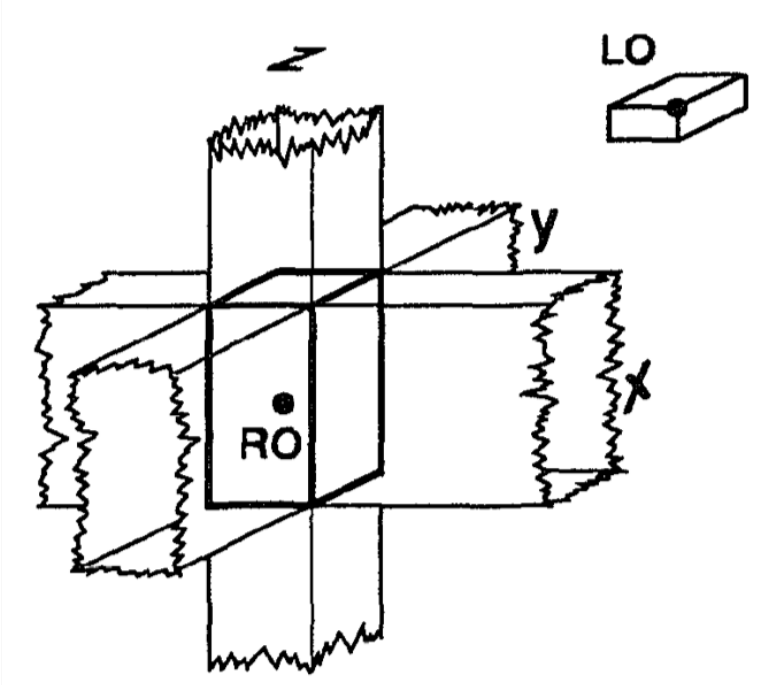


Figure: Scale the dimensions of the space by the bounding box of the landmark

Gapp (1994)

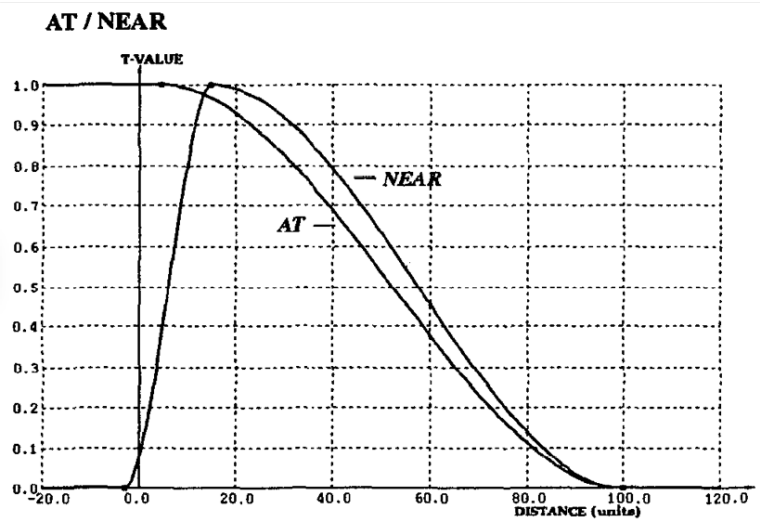


Figure: This enables us to apply the same function on distance to define proximity over different size landmarks.

near and Distractor Objects

1.7	1.9	2.8	3.2	2.3	1.8	2.1
2.6	3.8	4.7	5.0	4.9	3.6	3.3
4.1	5.6	7.6	8.0	7.3	4.8	3.9
4.5	5.9	8.5	**L**	7.9	6.1	4.5
3.5	4.8	7.0	7.6	7.3	5.6	3.6
3.3	4.0	4.5	4.8	4.4	3.5	3.1
1.8	2.2	2.0	3.1	2.5	2.1	2.0

Figure: The Spatial Template for *near* from Logan and Sadler (1996)

- But when is something not proximal?

near and Distractor Objects

- Also it seems that the presence of distractor objects can have a strong influence on proximity judgments

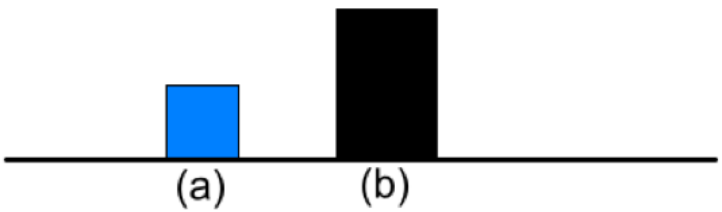


Figure: Is a near b?

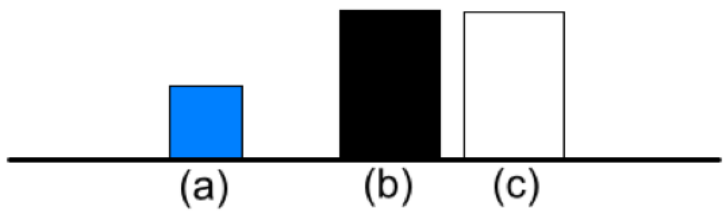
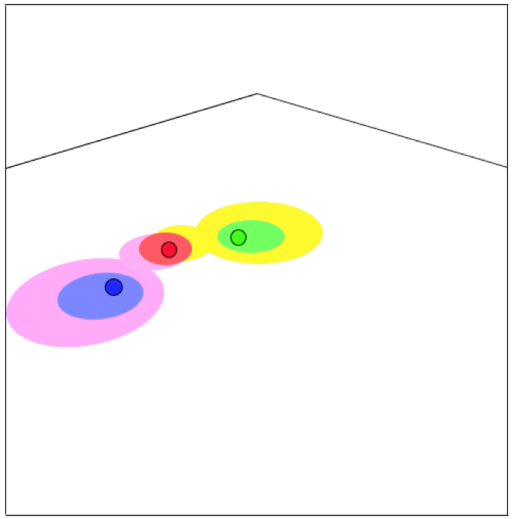


Figure: Is a near b?

near and Distractor Objects

- Kelleher and Kruijff (2005) proposed a relative model of proximity that considered the affect of distractor objects on the extent of prioximity around a landmark.



- Costello and Kelleher (2006) and Kelleher and Costello (2009) present psycholinguistic experiments that validated the affect of distractor objects on proximity.

Spatial Templates Projective Prepositions

- There are three regions of acceptability: good, acceptable and bad.
- These regions are symmetric around the canonical direction of the preposition.
- Acceptability approaches 0 as the angular deviation from the canonical direction approaches 90 degrees.

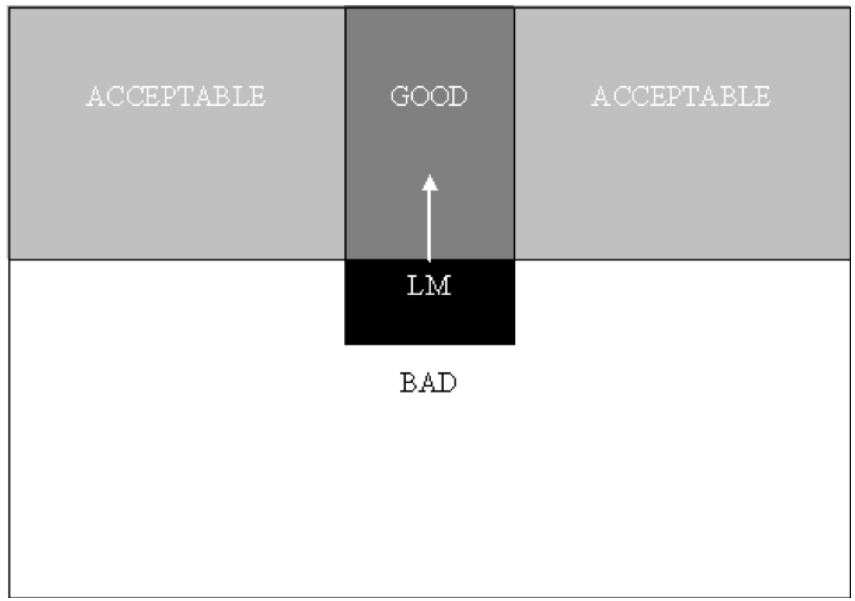


Figure: The Spatial Template for *above* from Logan and Sadler (1996)

Spatial Templates and Frames of Reference

- The directional component of a projective preposition's semantics is dependent on the frame of reference being used.
- When frames of reference are dissociated multiple frames of reference are activated and compete (Carlson-Radvansky and Irwin, 1994)
- The competition effects the construction of the preposition?s spatial template (Carlson-Radvansky and Logan, 1997; Kelleher and Costello, 2005)

Spatial Templates Projective Prepositions

- In this orientation the landmark's intrinsic spatial template overlaps with the viewer-centred/absolute frame of reference.

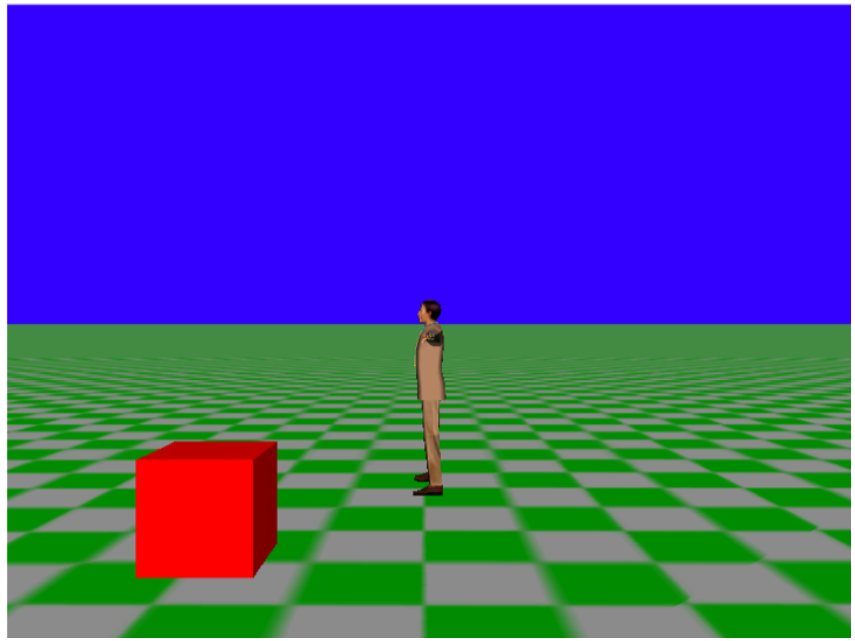


Figure: *The box is in front of the man*; image from (Kelleher and Costello, 2005)

Spatial Templates Projective Prepositions

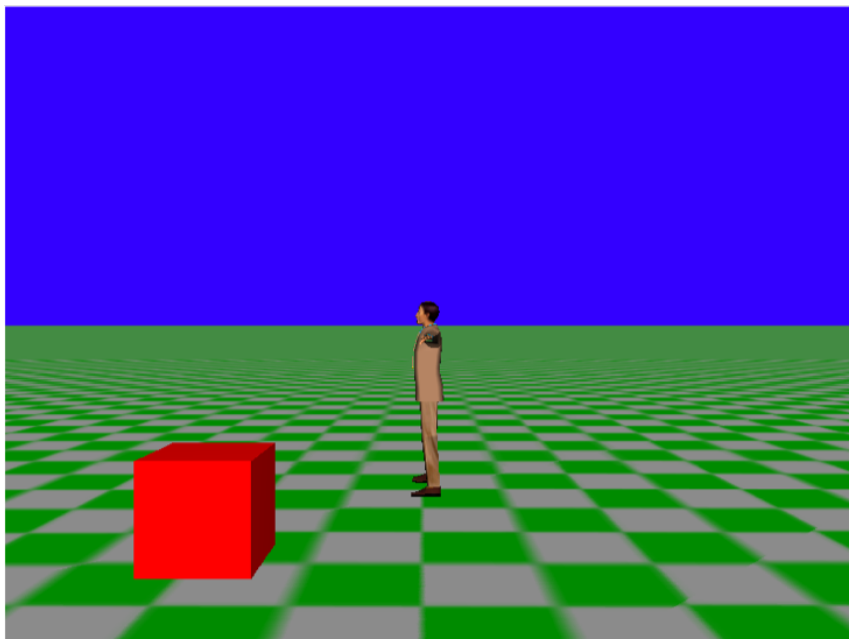


Figure: *The box is in front of the man*

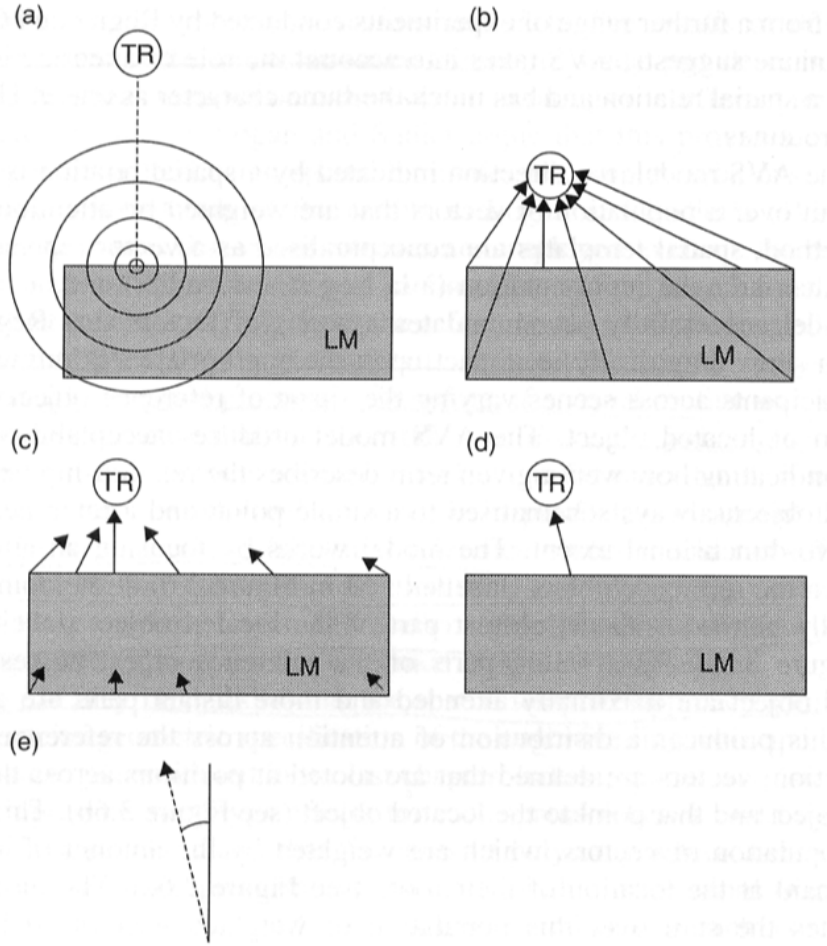
6.9	5.9	5.3	1.1	0.4	0.1	0.1
6.9	6.7	6.3	1.0	0.0	0.3	0.1
7.4	7.5	7.4	0.8	0.2	0.1	0.2
7.9	7.6	8.1		0.2	0.2	0.4
7.7	7.6	7.5	4.7	2.1	1.7	1.7
7.2	7.4	7.2	4.9	2.6	2.5	1.8
7.0	7.1	6.4	4.7	3.6	3.5	2.4

Figure: Cells that are acceptable in both the viewer-centred and intrinsic FoR have a higher rating than the cells in the acceptable area of only one of the spatial templates

From (Kelleher and Costello, 2005)

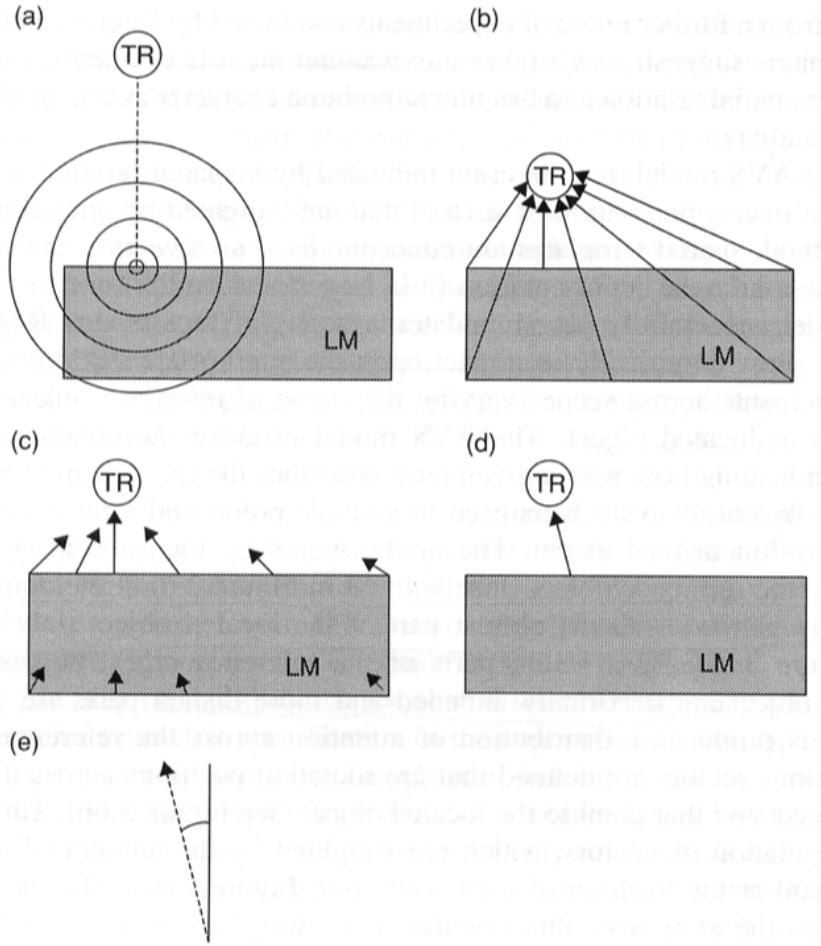
Spatial Templates and Attention

- Attentional Vector Sum Model of (Regier and Carlson, 2001)
- Input: geometric description of landmark as a 2D bounding box and target as a point.
- Features: closest point on landmark to target, gold-standard orientation vector, parameter controlling attention distribution (among others)



Attentional Vector Sum Model

- (a) attention is focused at the point on the landmark that is closest to the target, producing a distribution of attention across the landmark.
- (b) for each point on the landmark a vector is defined that points to the target object
- (c) each vector is weighted by the attention at its landmark root location
- (d) compute a sum over the weighted vectors, yielding an orientation
- (e) compare the orientation with the prototypical direction of the relation



Attentional Vector Sum Model

- The Attentional Vector Sum model is one of the most popular computational models for spatial templates in robotics.
- It has been extended in several ways, for example Kelleher et al. (2010) extended the model to include perceptual cues such as occlusion.

Beyond Geometric Information

Examples that break geometric formalizations:

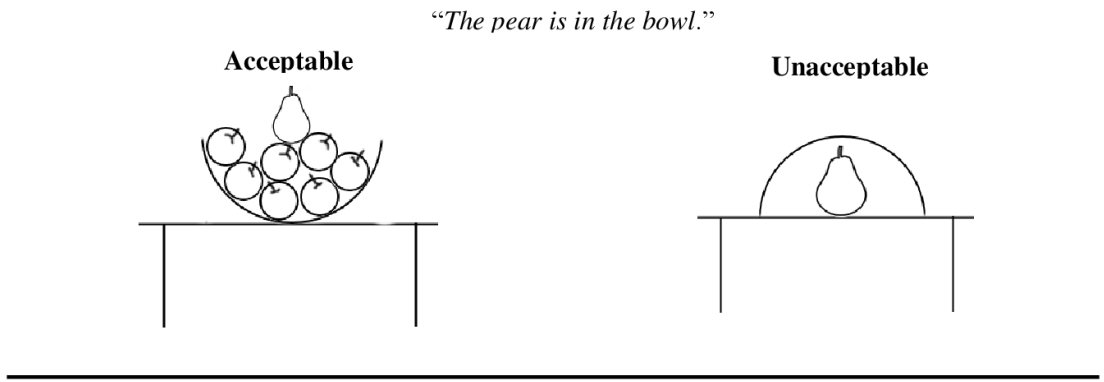


Figure 4: Scenarios presented in Coventry and Garrod (2004) that showcase the limitations of only referring to geometric properties for the preposition *in*

Figure: *the pear is in the bowl*

Figure: the bulb is in the socket

- the semantics of *in* is sensitive to location control

Images from: Smith (2016) and `https://www.nedgis.com/en/products/socket-for-e40-bulb-silver-metal-h10cm-o6-2cm-zangra`

Beyond Geometric Information

- Coventry and Garrod (2004) argue that geometry is not enough to model spatial semantics
- Contrary to the idea of schematisation (Talmy, 1983), that coarse grained representations of objects are used in spatial cognition; Coventry and Garrod (2004) argue that What an object is fundamentally influences how we talk about Where they are.
- Extra-geometric information (such as the location control or functional role of an object, e.g. *protection*, *support*, and so on) affect spatial meaning

Beyond Geometric Information

- *above* is sensitive to geometry with relatively little tolerance for movement away from the geometric vertical whereas
- *over* is more sensitive to functional aspects such as protection

Figure: The umbrella is **above**/**over** the man

The Functional Geometric Framework

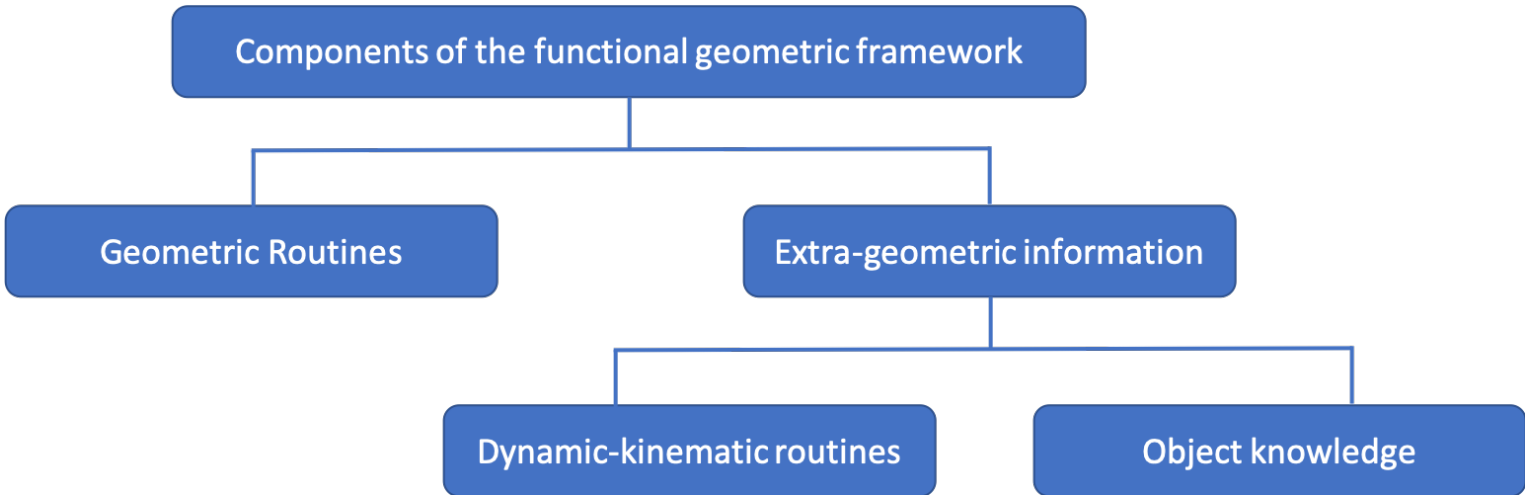


Figure: Components of the functional geometric framework; image based on Figure 3.7 in (Coventry and Garrod, 2004)

- Geometry of the scene is clearly important to how we talk about the location of objects in the scene.
- Extra-geometric factors:
  - dynamic-kinematic routines: location control (e.g. *the flower is in the vase*), prediction of where things will go (e.g., *the kettle is over the cup*)
  - world knowledge of the function of objects and how they interact, (e.g., rain and an umbrella)

Overview of Computational Models

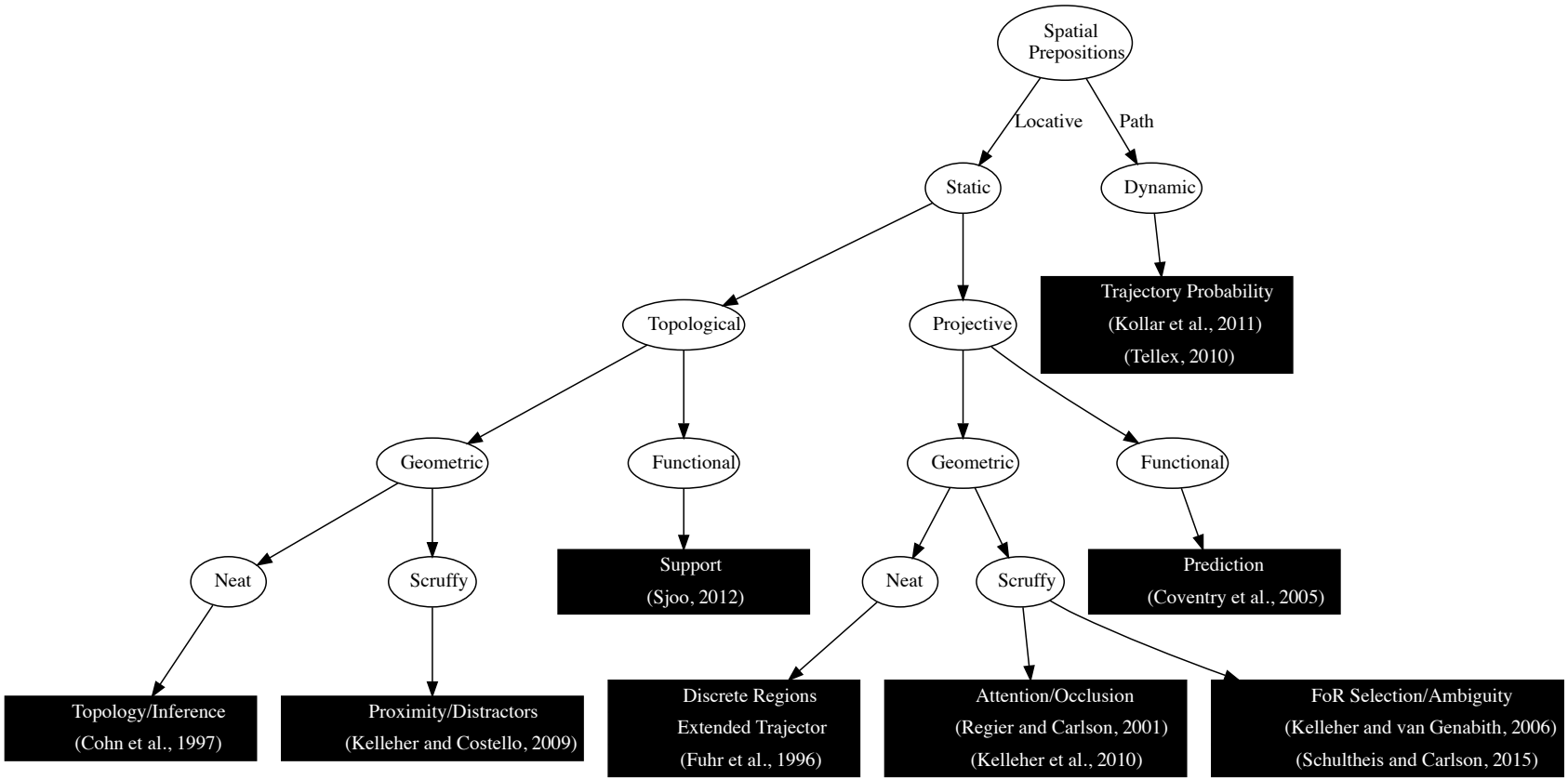


Figure: A (non-exhaustive) overview of computational models

Summary

Summary

- The grounding of spatial language is contingent on a large array of situational factors.
  - Abstraction
  - World Knowledge
  - Categorization
  - General Spatial Ability
  - ...
- This points to the fact that semantics should consider embodiment, interaction, and perception.

Spatial Template Experiment

https://www.dobnik.net/simon/semant-o-matic/create-conversation.aa.en.php

References I

Bierwisch, M. (1996). How much space gets into language. *Language and space*, 31–76.

Carlson-Radvansky, L. and D. Irwin (1994). Reference frame activation during spatial term assignment. *Journal of Memory and Language 33*, 646–671.

Carlson-Radvansky, L. and G. Logan (1997). The influence of reference frame selection on spatial template construction. *Journal of Memory and Langauge 37*, 411–437.

Clark, H. H. (1973). Space, time, semantics, and the child. In *Cognitive development and acquisition of language*, pp. 27–63. Elsevier.

Cohn, A. G., B. Bennett, J. Gooday, and N. M. Gotts (1997). Qualitative spatial representation and reasoning with the region connection calculus. *GeoInformatica 1*(3), 275–316.

Cooper, G. S. (1968). A semantic analysis of english locative prepositions. Technical report, BOLT BERANEK AND NEWMAN INC CAMBRIDGE MA.

References II

Costello, F. and J. D. Kelleher (2006). Spatial prepositions in context: The semantics of *Near* in the presense of distractor objects. In *Proceedings of the 3rd ACL-Sigsem Workshop on Prepositions*, pp. 1–8.

Coventry, K., A. Cangelosi, R. Rajapakse, A. Bacon, S. Newstead, D. joyce, and L. Richards (2005). Spatial prepositions and vague quantifiers: Implementing the funcitonal geometric framework. In *Spatial Cognition IV. Reasoning, Action, Interaction*. Springer Berling Heidelberg.

Coventry, K. and S. Garrod (2004). *Saying, Seeing and Acting: The Psychological Semantics of Spatial Prepositions*. Psychology Press.

Dobnik, S., C. Howes, K. Demaret, and J. D. Kelleher (2016, 17–18 November). Towards a computational model of frame of reference alignment in Swedish dialogue. In J. Björklund and S. Stymne (Eds.), *Proceedings of the Sixth Swedish language technology conference (SLTC)*, Umeå, pp. 1–3. Umeå University.

References III

Dobnik, S., C. Howes, and J. D. Kelleher (2015, 24–26th August). Changing perspective: Local alignment of reference frames in dialogue. In C. Howes and S. Larsson (Eds.), *Proceedings of goDIAL – Semdial 2015: The 19th Workshop on the Semantics and Pragmatics of Dialogue*, Gothenburg, Sweden, pp. 24–32.

Fillmore, C. J. (1997). *Lectures on deixis*. CSLI publications.

Fuhr, T., G. Socher, C. Scheering, and G. Sagerer (1995). A three-dimensional spatial model for the interpretation of image data. In *IJCAI-95 Workshop on Representation and Processing of Spatial Expressions*, Volume 14, pp. 93–102.

Gapp, K. (1994). Basic meanings of spatial relations: Computation and evaluation in 3d space. In *Proceedings of AAAI*.

Harnad, S. (1990). The symbol grounding problem.

Herskovits, A. (1987). *Language and spatial cognition*. Cambridge University Press.

References IV

Hill, C. (1982). Up/down, front/back, left/right. a contrastive study of hausa and english. In W. Klein (Ed.), *Here and there: Crosslinguistic studies on deixis and demonstration*, pp. 11–42. Benjamins, Amsterdam.

Kelleher, J. D. (2003). *A perceptually based computational framework for the interpretation of spatial language*. Ph. D. thesis, Dublin City University.

Kelleher, J. D. (2010). How to preposition a robot: A case-study in symbol grounding. Presentation at the University College Dublin Research Seminars.

Kelleher, J. D. and F. Costello (2005). Cognitive representations of projective prepositions. In *Proceedings of the Second ACL-Sigsem Workshop of The Linguistic Dimensions of Prepositions and their Use in Computational Linguistic Formalisms and Applications*.

Kelleher, J. D. and F. Costello (2009, June). Applying computational models of spatial prepositions to visually situated dialog. *Computational Linguistics 35*(2), 271–306.

References V

Kelleher, J. D. and G.-J. Kruijff (2005). A context-dependent model of proximity in physically situated environments. In *Proceedings of the 2nd ACL-SIGSEM Workshop on The Linguistic Dimensions of Prepositions and their use in Computational Linguistic Formalisms and Applications*.

Kelleher, J. D. and R. J. Ross (2010). Topology in compositie spatial terms. In D. Rapp (Ed.), *Proceedigns of Spatial Cognition 2010: Poster Presentations*, pp. 46–50. SFB/TR8 Spatial Cognition.

Kelleher, J. D., R. J. Ross, C. Sloan, and B. Mac Namee (2010). The effect of occlusion on the semantics of projective spatial terms: a case study in grounding language in perception. *Cognitive Processing 12*(1), 95–108.

Kelleher, J. D., C. Sloan, and B. Mac Namee (2009). An investigation into the semantics of english topological prepositions. *Cognitive processing 10*, 233–236.

Kelleher, J. D. and J. van Genabith (2006). A computational model of the referential semantics of projective prepositiosn. In *Syntax and Semantics of Prepositions*, pp. 211–228. Springer.

References VI

Kollar, T., S. Tellex, D. Roy, and N. Roy (2010). Toward understanding natural language directions. In *Proceedings of the 5th ACM/IEEE international conference on Human-robot interaction*, pp. 259–266. IEEE Press.

Landau, B. (1996). Multiple geometric representations of objects in languages and language learners. *Language and space*, 317–363.

Landau, B. and E. Munnich (1998). The representation of space and spatial language: Challenges for cognitive science. In *Representation and processing of spatial expressions*, pp. 263–272. L. Erlbaum Associates Inc.

Leech, G. N. (1970). Towards a semantic description of english. indiana studies in the history and theory of linguistics.

Levelt, W. J. (1996). Perspective taking and ellipsis in spatial descriptions. *Language and space*, 77–107.

Levinson, S. C. (1996). Frames of reference and molyneux's question: Crosslinguistic evidence. *Language and space 109*, 169.

References VII

Logan, G. (1994). Spatial attention and the apprehension of spatial relations. *Journal of Experimental Psychology: Human Perception and Performance 20*, 1015–1036.

Logan, G. (1995). Linguistic and conceptual control of visual spatial attention. *Cognitive Psychology 12*(523-533).

Logan, G. and D. Sadler (1996). A computational analysis of the apprehension of spatial relations. In P. Bloom, M. Peterson, L. Nadel, and M. Garret (Eds.), *Language and Space*, pp. 493–530. MIT Press.

Miller, G. A. and P. N. Johnson-Laird (1976). *Language and perception.* Belknap Press.

Mukerjee, A. (1998). Neat vs scruffy: A survey of computational models for spatial expressions. In K. Gapp (Ed.), *Computational representation and processing of spatial expressions*. Lawrence Erlbaum Associates.

Peterson, M. A., L. Nadel, P. Bloom, and M. F. Garrett (1996). Space and language. *Language and space*, 553–577.

References VIII

Regier, T. and L. Carlson (2001). Grounding spatial language in perception: An empirical and computational investigation. *Journal of experimental psychology: General 130*(2), 273–298.

Roy, D. (2005). Semiotic schemas: A framework for grounding language in action and perception. *Artificial Intelligence 167*(1), 170 – 205. Connecting Language to the World.

Schultheis, H. and L. Carlson (2015). Mechanisms of reference frame selection in spatial term use: Computational and empirical studies. *Cognitive Science 41*(2), 276–325.

Sjoo, K. (2011). *Functional Understanding of Space*. Ph. D. thesis, KTH Computer Science and Communications, Sweden.

Smith, M. G. (2016). Talking about objects in motion: investigating the meaning of in front of, behind, leading and following.

Talmy, L. (1983). How language structures space. In *Spatial orientation*, pp. 225–282. Springer.

Tellex, S. (2010). *Natural language and spatial reasoning*. Ph. D. thesis, Massachusetts Institute of Technology.

References IX

Vandeloise, C. (1991). *Spatial prepositions: A case study from French*. University of Chicago Press.