The Geography of Temperature Space

George A. Wright[1,2,*,†], Matthew Purver[1,3,†]

[1]School of Electronic Engineering and Computer Science, Queen Mary University of London, United Kingdom
[2]School of Computing and Mathematical Sciences, Birkbeck, University of London, United Kingdom
[3]Department of Knowledge Technologies, Jožef Stefan Institute, Ljubljana, Slovenia

Abstract

This paper takes as its basis, Gärdenfors' [1] description of conceptual spaces and sets about sketching an initial geography of the conceptual space for temperature. In doing so it highlights important differences between the behaviours of temperature space's constituent concepts and the variability of their behaviour in different contexts. The purpose of this is to aid the practical implementation of semantic representations based upon conceptual spaces.

Keywords

Conceptual Spaces, Comparatives, Natural Language

1. Introduction

Conceptual spaces are an approach to the representation of meaning where related concepts and their instances occupy the same quality dimensions and where semantic similarity corresponds with proximity along those dimensions. The approach allows for graded and ambiguous class membership. Gärdenfors [1, 2] describes how conceptual spaces can be used to describe a wide range of concepts involved in perception and in natural language semantics.

An important yet seemingly simple conceptual space is that for temperature. Perception of temperature is important for survival (and comfort) so is also a frequent topic of conversation. Although temperatures occupy just one dimension — a number line — close consideration of English words for temperature unveils a complex arrangement of that space and a range of types of concept within it.

This paper is an attempt to formulate a basic geography of temperature space and its constituent concepts. The aim is to highlight the diversity of concept types and the issues to consider when developing a practical implementation of conceptual spaces. This paper focuses on adjectives for describing temperature. It begins with a summary of relevant literature on the representation of adjective semantics in terms of dimensions. Following this, temperature space is introduced along with a discussion of the behaviour within that space of adjectives, qualifiers, and comparatives.

CAOS: Cognition And OntologieS at the 14th International Conference on Formal Ontology in Information Systems, Enschede, Netherlands (15-19 July 2024)
george.a.wright@qmul.ac.uk (G. A. Wright); m.purver@qmul.ac.uk (M. Purver)
http://georgeaw.com/ (G. A. Wright); http://www.eecs.qmul.ac.uk/~mpurver (M. Purver)
0000-0002-2036-7737 (G. A. Wright); 0000-0003-2297-1273 (M. Purver)

2. Conceptual Spaces

Conceptual Spaces order concepts along quality dimensions, with similar concepts close to one another. Gärdenfors [1] pairs conceptual spaces with prototype theory. Each concept has a prototype which occupies a point in the space. Objects closer to the prototype are more likely to be members of its class and, because they are more similar to the prototype, have higher typicality. Voronoi tessellation of a space, such that boundaries are drawn equidistant from each prototype, divides a space into a set of discrete regions, each corresponding to a concept.

2.1. Conceptual Spaces for Adjectives

Paradis [3] identifies three classes of adjectives according to their gradability and boundedness:

Scalar adjectives These are adjectives which exist on a scale. The scale contains two antonyms (such as *tall* and *short*); has a region between the two antonyms where neither applies; and is open-ended. Because the adjectives exist along a scale, they have comparative and superlative forms and can be combined with scalar modifiers (*very tall*). Because the scale is open-ended, adjectives cannot be combined with totality modifiers (**completely tall*).

Extreme adjectives These also exist on a scale with two antonyms (such as *terrible* and *excellent*). But the scale is not open-ended; instead the adjectives exist at the extremes of the scale. For this reason, they cannot combine with scalar modifiers (**very terrible*), but can combine with totality modifiers (*completely terrible*). There is disagreement over whether or not these adjectives have a comparative form.

Limit adjectives These are adjectives (such as *dead*) which do not exist on a scale and do not have graded membership. They do not have a comparative form (**deader*) and combine only with totality modifiers (*completely dead*, *almost dead*).

A large number of basic adjectives fit within the scalar category. According to Barsalou [4], when concepts such as these exist along a single dimension (or *ideal*), the typicality of instances increases as they take a more extreme position along it. Since the dimensions that scalar adjectives belong to are unbounded, this makes questionable the existence of prototypes for these adjectives.

But, Hampton [5] and Kamp and Partee [6] point out that membership of a given category is often ill-defined without a specific context. It would be reasonable for *tall* to refer to different heights when describing mountains, buildings, or people. Prototypes for *tall* and *short* would therefore occupy different points in a conceptual space depending on context. Nonetheless, according to Hampton, the typicality of an instance of *tall* would still be unbounded: someone who is taller than the prototype would still have a high typicality and high degree of membership. Hampton does not consider phrases such as *unusually tall*, the existence of which suggests that an object can have a value so far along a dimension that it ceases to be typical.

2.2. Conceptual Spaces for Comparatives

As described above, only scalar adjectives have comparative forms. According to Gardenfors [2, p.136], the meaning of comparatives depends upon the dimensionality of the space.

Comparison of objects along a single dimension, such as HEIGHT, requires consideration of their position along the dimension, but not the position of the prototype. Dietz [7], defines comparatives as asymmetric and transitive relations: *B* can be *taller* than *A*, and *C taller* than *B* and so on until the objects under discussion are far away from the prototype for *tall*.

On the other hand, comparison of objects within a multi-dimensional space, such as COLOUR, involves comparing their proximity to the prototype. For *A* to be *redder* than *B*, *A* must be closer than *B* to the prototype for *red*. It also seems meaningless to use the term *redder* if neither *A* nor *B* are at all red [7].

3. Temperature Space and its Inhabitants

TEMPERATURE space has one dimension [1]. For the most part, it contains scalar adjectives just as HEIGHT does. Indeed TEMPERATURE can be mapped onto HEIGHT words *high* and *low* via conceptual metaphor [8]. But, TEMPERATURE contains multiple concepts, each of which has slightly different behaviour. Their presence also makes pragmatic considerations of word choice more complex.

3.1. Temperature Concepts and their Arrangement

TEMPERATURE contains the antonyms *cold* and *hot*. But depending on context, a greater variety of adjectives are also available. The words *cool* and *warm* are used in many contexts as gentler compliments to *cold* and *hot* respectively. When describing the weather, *mild* can also be used.

Placing these words along a single dimension, *cold* and *hot* sit opposite one another, leaning towards the two extremes; *cool* and *warm* are closer to the middle; and *mild* sits in the middle.

All except *mild* belong to a pair of antonyms. Since *mild* sits in the middle of TEMPERATURE its opposite is either extreme of the space. Both extremes of TEMPERATURE space can be mapped onto an *extreme* concept located opposite *mild* along a MILDNESS/EXTREMENESS dimension which maps onto TEMPERATURE space just as the natural numbers map onto to the integers.

Such an arrangement is displayed in figure 1. It shows approximate locations of basic temperature adjectives according to their coldness or hotness and their mildness or extremeness. TEMPERATURE space has *mild* at its origin. In figure 1, TEMPERATURE space is folded at its origin in order to show the corresponding level of mildness/extremeness of the space's antonyms.

Further concepts not shown in figure 1 include *boiling* and *freezing*. When used literally these constitute limit adjectives with strict definitions, usually at or above 100 degrees centrigrade and at or below 0 degrees centigrade respectively.

3.2. Temperature Concepts and their Behaviour

Hot and *cold* are unbounded scalar adjectives, analogous to *tall* and *short* in HEIGHT space and a number of other antonym pairs.

Mild behaves more like a multi-dimensional concept in that proximity to the prototype is used for classification. This is perhaps because it is not a native of temperature space, but of a MILDNESS/EXTREMENESS dimension itself analogous to HEIGHT. As with height, extremeness is

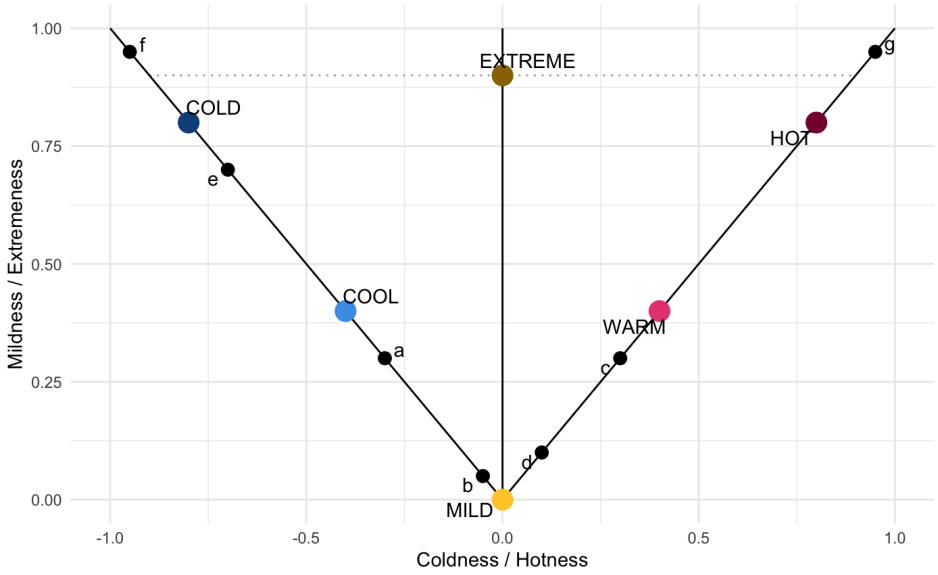

Figure 1: Concepts and their positions in both TEMPERATURE and MILDNESS/EXTREMENESS space.

unbounded in one direction (neither *tall* nor *extreme* have a limit) and bounded in the other (you cannot be shorter than 0 or milder than the middle of TEMPERATURE space).

Warm and *cool* seem to be in between these two types of behaviour. They are not strictly bounded, but at distances increasingly far from their prototype, alternative concepts become more salient.

It is not clear that hard boundaries can be drawn between each of these concepts with Voronoi tessellation. Some temperatures could perhaps be described as either hot or warm and others as either warm or mild. Empirical confirmation of this would be welcome.

3.3. Comparatives and Modifiers

Because temperature concepts for the most part have the behaviour of scalar adjectives, they have comparative forms and can combine with scalar modifiers.

3.3.1. Comparatives

To determine semantically valid and pragmatically appropriate comparative concepts for the description of a given situation, both the ordering of points in temperature space and their proximity to prototypes is important.

To describe a point x as *hotter* or *colder*, *less hot*, or *less cold*, than point y, only the relative position of the two points along the TEMPERATURE dimension is required in order to produce a logically true predicate.

But further consideration of their position in TEMPERATURE is necessary in order to produce a pragmatically sensible sentence of English. The situation is further complicated by the presence of *warm* and *cool*, which provide a further array of comparatives to choose from.

The phrases *A is hotter than B*, *A is warmer than B*, and *A is less cold than B* all correspond with the inequality $A > B$, but to English speakers they each have a slightly different meaning, which relates to the original adjective's location along the TEMPERATURE dimension.

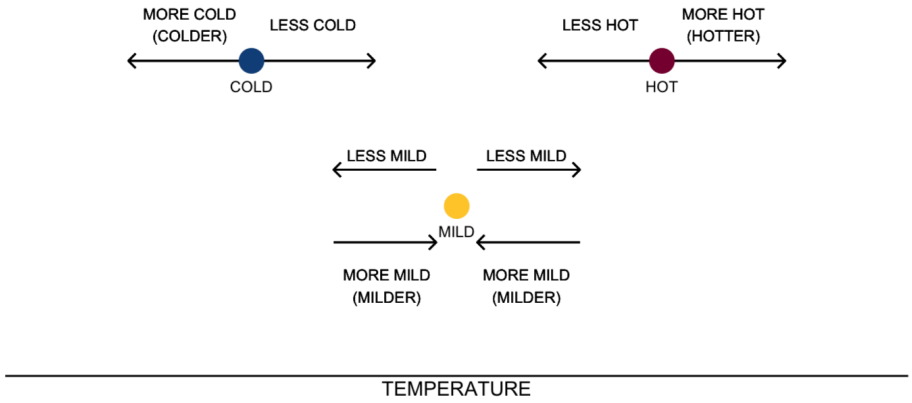

Figure 2: Three different meanings of *more* and *less* in TEMPERATURE space.

For example, in figure 1: *a* is strictly speaking *hotter* than *e*, but it is better to describe it as *less cold* than *e*; similarly *c* is strictly speaking *hotter* than *a*, but it is better to describe it as *warmer* than *a*

Adjectives' comparative forms (*hotter*, *colder*) are equivalent to prefixing the adjective with *more*. If *A is more X than B* then *A* is further out along the unbounded dimension than *B*. If *A is less X than B* then *A* is closer to the centre of the space than *B*. In the case of *mild*, *A is milder/more mild than B* means *A* is closer to the prototype for *mild*. On the other hand, *A is less mild than B* means that *A* is further away than *B* (in either direction) from the prototype for *mild*. Figure 2 illustrates these differences in behaviour. While *warm* and *hot* have positive polarities, and *cool* and *cold* have negative polarities, *mild* has neither.

3.3.2. Modifiers

An adjective's polarity also governs the interpretation of grammatical modifiers such as *very*, *quite*, and *extremely*. When conjoined with an adjective they form a compound with a prototype that is shifted from the location of the lone adjective (see figure 3).

Words such as *very* and *extremely*, which increase the magnitude of the adjective they are attached to, follow the same rules as the comparative *more*: when attached to a positive adjective such as *warm*, they shift meaning further in the positive direction; when attached to a negative adjective such as *cold*, they shift meaning further in the negative direction; when attached to an adjective at the space's origin (*mild*), they shift meaning closer to the origin and contract its boundaries: *extremely mild* has a more limited purview than *mild*.

Words such as *quite*, *slightly*, or *a bit* have the opposite effect and are therefore more akin to the comparative *less*. Since they shift meaning away from the extreme of the prototype, when combined with *mild* two prototypes are formed: one in the colder half of space, and one in the warmer half. *Quite mild* therefore occupies a non-convex region of temperature space. This

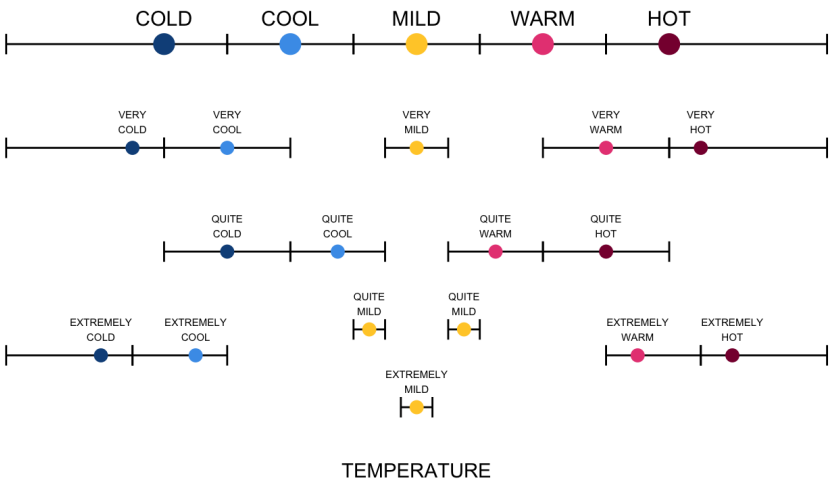

Figure 3: The effect of modifiers on TEMPERATURE adjectives.

is a further sign that *mild* does not really belong in TEMPERATURE space, but is temporarily introduced in certain contexts.

When an unbounded concept such as *hot* has a magnitude-increasing modifier such as *extremely* applied to it, the resulting compound is also unbounded. When it has a magnitude-decreasing modifier such as *quite* applied to it, the resulting compound becomes bounded. The phrase *quite hot* only has limited applicability before *hot* or *very hot* become more appropriate descriptions. To say *the surface of the Sun is quite hot* would be acceptable only in a non-literal, sarcastic context, or perhaps when comparing with even hotter stars.

3.4. Context and Space Warping

As mentioned by Hampton [5], the precise meaning of an adjective is often unclear without a context. The prototypes of basic temperature adjectives can therefore be quite different in contexts such as the weather, dining, cookery, or cosmology. Within these contexts, there are further sub-contexts: a warm winter is normally colder than a warm summer; a cold dish is normally warmer than a cold drink. Figure 4 suggests approximate locations of temperature adjectives in broad contexts.

In the contexts shown in figure 4, *hot* and *warm* shift position more than *cool* or *cold* and limit adjectives such as *boiling* and *freezing* do not move at all unless they are used metaphorically or for exaggeration. This can be the case when describing the weather. It therefore probably makes more sense to think of concepts changing location instead of the overall stretching or contracting of the space.

Certain concepts are not shown in figure 4 and are not necessarily available in all contexts. For example, *mild* is largely restricted to describing the weather, *lukewarm* to describing food, and

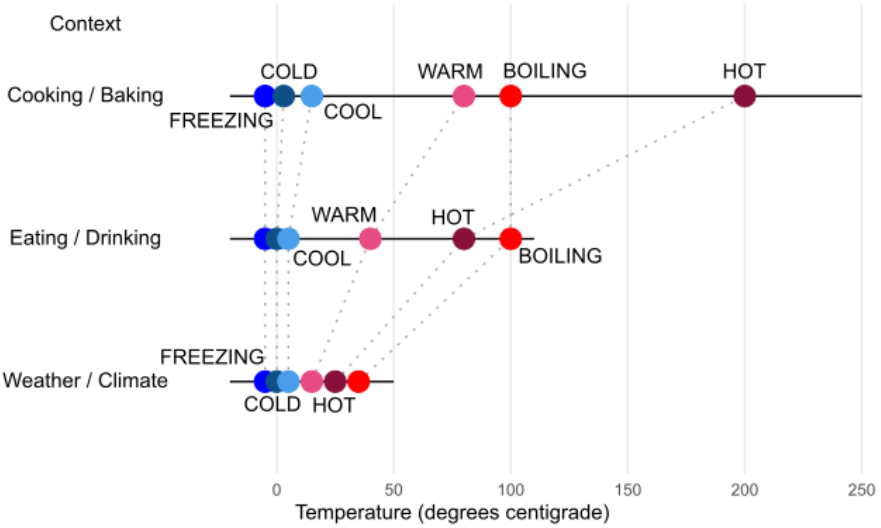

Figure 4: The effect of context on TEMPERATURE adjectives.

tepid to describing water [9]. Since *lukewarm* and *tepid* also have quite negative connotations (despite being in the positive part of TEMPERATURE space), they perhaps also belong to other dimensions which only become active in particular contexts.

4. Implementing Temperature Space

It is clear that there are a number of issues that need to be considered when using a representation based on conceptual spaces, even for a simple, unidimensional space such as TEMPERATURE.

Flexible prototype locations Adjectival concepts have prototype values, but these must be capable of changing (potentially by orders of magnitude) depending on the context where they are used. Certain adjectives, such as *lukewarm* are also unavailable or less available in given contexts.

Flexible concept behaviour Not all adjectives within the same space have the same behaviour. In TEMPERATURE, most adjectives are scalar, but there are also limit adjectives. Limit adjectives can adopt the behaviour of scalar or extreme adjectives if they are used metaphorically, for example *boiling weather* has graded membership, whereas *boiling water* does not.

Concept polarity As well as a prototype value, concepts should also be associated with a polarity, or direction. This helps to determine how comparatives are formed and how modifiers affect meaning. Temperature concepts display three types of behaviour in relation to comparatives and modifiers: for positive adjectives such as *warm*, *more* and *very* indicate higher temperatures; for negative adjectives such as *cool*, *more* and *very*

indicate lower temperatures; for *mild*, at TEMPERATURE's origin, *more* and *very* indicate temperatures closer to the prototype value.

The applicability of Voronoi tessellation The existence of potentially overlapping concepts (e.g. *cold* and *cool* or *cool* and *mild*), the introduction of compounds (e.g. *quite cold*, *very cool*), and the metaphorical use of concepts (e.g. *freezing*) means that there is a plethora of ways to describe the same temperature. It is therefore unclear if it is useful to divide a space into disjoint regions belonging to separate concepts.

Odd behaviour of non-native concepts A space can gain non-native concepts, even without metaphorical usage, just as TEMPERATURE space gains *mild* and *extreme*. These concepts or compounds involving them can occupy non-convex regions and therefore have unusual behaviour compared with other concepts.

5. Conclusion

Temperature is an everyday topic and its perception is fundamental to human existence. Ways of describing temperature indicate a variety of types of concept, not all of which match fully with the use of prototypes and Voronoi tessellation or with the identification of a concept with a dimension.

Representations of natural language semantics based on conceptual spaces need to take into consideration the variability of concept types within a single conceptual space; the likelihood that multiple concepts are relevant in any given situation; and the fact that concepts can shift as context changes, or alter their behaviour entirely when used metaphorically.

Other issues not described in this paper include the problem of negation, and the association of concepts across conceptual spaces, for example the relationship in different contexts between temperatures and *good* or *bad*. These important issues no doubt cause further complications.

Acknowledgments

This research has been supported by EPSRC grant EP/R513106/1.

References

[1] P. Gärdenfors, Conceptual Spaces: The Geometry of Thought, The MIT Press, 2004.
[2] P. Gärdenfors, The Geometry of Meaning: Semantics Based on Conceptual Spaces, The MIT Press, 2014.
[3] C. Paradis, Adjectives and boundedness, Cognitive Linguistics 12 (2013) 47–64.
[4] L. W. Barsalou, Ideals, central tendency, and frequency of instantiation as determinants of graded structure in categories, Journal of Experimental Psychology: Learning, Memory, and Cognition 11 (1985) 629–654.
[5] J. A. Hampton, Typicality, graded membership, and vagueness, Cognitive Science 31 (2007) 355–384.

[6] H. Kamp, B. Partee, Prototype theory and compositionality, Cognition 57 (1995) 129–191.
[7] R. Dietz, Comparative concepts, Synthese (2013).
[8] G. Lakoff, M. Johnson, Metaphors We Live By, The University of Chicago Press, 2003.
[9] Oxford English Dictionary, Oxford University Press, 2024.