

# The Geography of Temperature Space

George A. Wright<sup>1,2,\*†</sup>, Matthew Purver<sup>1,3,†</sup>

<sup>1</sup>School of Electronic Engineering and Computer Science, Queen Mary University of London, United Kingdom

<sup>2</sup>School of Computing and Mathematical Sciences, Birkbeck, University of London, United Kingdom

<sup>3</sup>Department of Knowledge Technologies, Jožef Stefan Institute, Ljubljana, Slovenia

## Abstract

This paper takes as its basis, Gärdenfors' [1] description of conceptual spaces and sketches an initial geography of the conceptual space for temperature. It highlights important differences between the space's constituents, including: how category membership differs for concepts along different parts of the dimension; how comparatives and compounds are formed; how context affects concept location and behaviour; and how non-literal usage allows concepts to be used outside of their conceptual space or in a different way within their own conceptual space. The purpose of this tour of temperature space is to aid the practical implementation of semantic representations based upon conceptual spaces.

## Keywords

Conceptual Spaces, Temperature, Adjectives, Comparatives, Metaphor, Natural Language

## 1. Introduction

In the *conceptual spaces* approach to the representation of meaning, concepts and their instances occupy spaces composed of *quality dimensions*. The proximity of objects along those dimensions equates to semantic similarity. 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 and provides example spaces such as for colour, shape, and kinship relations.

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 forms a guide through temperature space which highlights the issues that need to be considered when developing a practical implementation of conceptual spaces. It begins with a summary of relevant literature on the representation of adjective semantics along dimensions. The constituent concepts of temperature space are then introduced, followed by a discussion of their positions, compound forms, and behaviour in different contexts.

## 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

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\*Corresponding author.

†These authors contributed equally.

✉ [george.a.wright@qmul.ac.uk](mailto:george.a.wright@qmul.ac.uk) (G. A. Wright); [m.purver@qmul.ac.uk](mailto: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)



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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 Gärdenfors [2, p.136], the meaning of comparatives depends upon the dimensionality of the space.

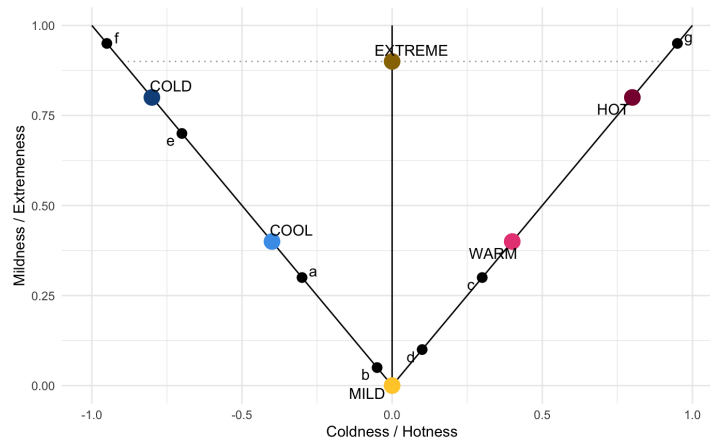
Comparison of objects along a single dimension, such as HEIGHT, requires consideration of their position along the dimension, but not the position of the prototype. Dietz [7], defines comparatives as asymmetric and transitive relations: *B* can be *taller* than *A*, and *C* *taller* than *B* and so on 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 with different behaviour, whose presence complicates pragmatic considerations of word choice.

### 3.1. Temperature Concepts and their Arrangement



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

TEMPERATURE contains the antonyms *cold* and *hot*. But depending on context, a greater variety of adjectives are also available. The words *cool* and *warm* act as gentler compliments, and sometimes *mild* can also be used. Along the dimension of TEMPERATURE, the antonyms *cold* and *hot* sit opposite one another, leaning towards the two extremes; the antonyms *cool* and *warm* are closer to the middle; and *mild* sits in the middle.

The antonym of *mild*, is *extreme*, which can occupy either end of TEMPERATURE space. Alternatively, *mild* and *extreme* can sit along a MILDNESS/EXTREMENESS dimension which maps onto TEMPERATURE in the same way that the integers map onto the natural numbers via the *absolute value* function. Figure 1 shows such an arrangement, with temperature concepts ordered along a COLDNESS/HOTNESS dimension that has *mild* at its origin. The TEMPERATURE line is folded at the origin in order to demonstrate its mapping onto MILDNESS/EXTREMENESS.

Concepts not shown in figure 1 include limit adjectives such as *boiling* and *freezing*, which have strict definitions when used literally, and adjectives such as *lukewarm* and *tepid*, which are restricted to certain contexts. It makes less sense to place these adjectives along a scale.

### 3.2. Temperature Concepts and their Behaviour

*Hot* and *cold* are unbounded scalar adjectives which behave analogously to *tall* and *short* in HEIGHT space. The typicality of instances of these concepts increases as they get further along the dimension, even as they surpass the prototype value of the concept.

On the other hand, temperatures become more typical instances of *mild* as they get closer to its prototype. This behaviour is more typical of concepts in a multi-dimensional space, but *mild* is perhaps not strictly native to TEMPERATURE space, but rather to MILDNESS/EXTREMENESS space where its behaviour is more similar to that of *short* in HEIGHT 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 should be drawn between each of these concepts with Voronoi tessellation as suggested by Gärdenfors [1]: some temperatures can be described as either hot or warm and others as either warm or mild.

### 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.

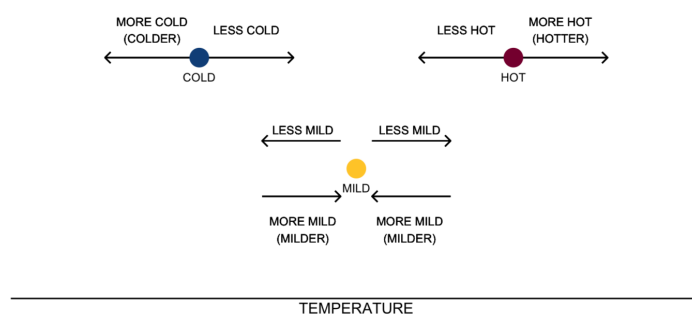
### 3.3.1. Comparatives

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  $a$ .

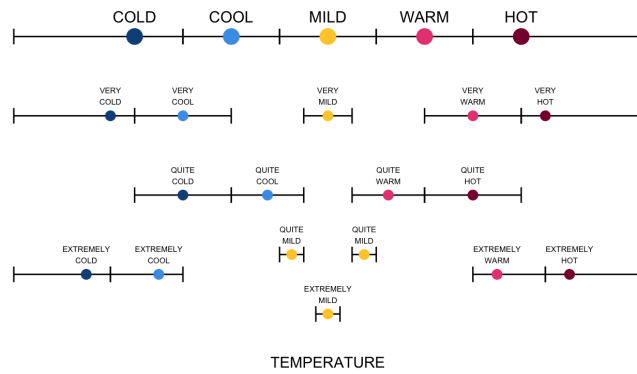
Adjectives' comparative forms (*hotter*, *colder*) are equivalent to prefixing the adjective with *more*. If  $A$  is *more X than B then  $A$  is further out along the unbounded dimension than  $B$ . If  $A$  is *less X than B then  $A$  is closer to the centre of the space than  $B$ . In the case of *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 is a further sign that *mild* does not really belong in TEMPERATURE space, but is temporarily introduced in certain contexts.

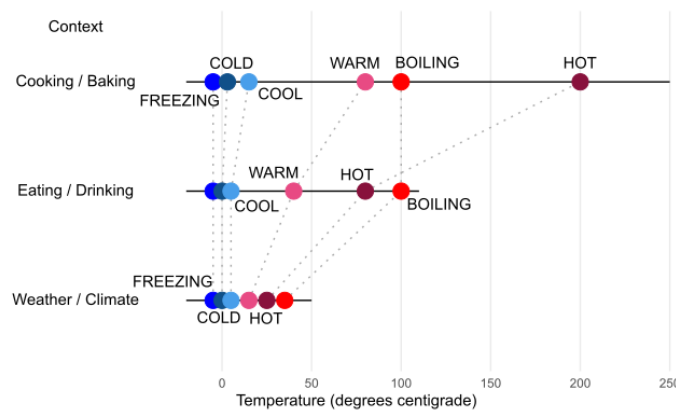


**Figure 3:** The effect of modifiers on TEMPERATURE adjectives.

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. Meaning is also necessarily subjective, thus what counts as *hot* or *cold* will vary from person to person. Figure 4 suggests approximate locations of temperature adjectives in broad contexts.



**Figure 4:** The effect of context on TEMPERATURE adjectives.

The non-uniform warping of space caused by the context changes in Figure 4 cause *hot* and *warm* to shift more than *cool* or *cold*. The limit adjectives *boiling* and *freezing* do not move at all unless they are used for exaggeration as when describing the weather, in which case they adopt the graded category membership of scalar adjectives. They could also shift if applied to more exotic contexts such as chemicals other than water.

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

### 3.5. Metaphor and Projection Across Spaces

Not only can context shift the position of concepts within a space, it can also project them from one space to another. This occurs when words from one conceptual space are used metaphorically to describe entities from a different conceptual space. Temperature adjectives are commonly used metaphorically for example in descriptions of spicy food or of people.

But in metaphorical usages, only a subset of temperature adjectives are imported into their new context: food's degree of spiciness can be described as *hot* or *mild*, but not *warm* or *cold*; people's behaviour to others can be described as *warm*, *lukewarm*, or *cold*, but not *hot* or *mild*; and people's attractiveness can be described only as *hot* (or *not*).

Adjectives can be used and re-used metaphorically. If someone were to describe the weather as *lukewarm*, this would be an odd use of words since *lukewarm* is usually reserved for descriptions of food. But the description could also be interpreted as a personification of the weather into a *person* who is lukewarm, this in turn being a metaphorical description of someone with an unfriendly disposition.

## 4. Conclusion: How to Implement Temperature Space

Temperature is an everyday topic and its perception is fundamental to human existence. Ways of describing temperature indicate a variety of types of conceptual behaviour that need to be covered by a representation based on conceptual spaces, even in the case of a simple, unidimensional space.

**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. There are at least three types of behaviour in relation to comparatives and modifiers: for positive adjectives (e.g. *warm*) *more* and *very* indicate higher temperatures; for negative adjectives (e.g. *cool*) *more* and *very* indicate lower temperatures; for neutral adjectives (e.g. *mild*) at the conceptual space's origin, *more* and *very* indicate temperatures closer to the origin.

**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.

**Exaggeration and metaphor** Words can be used non-literally within a conceptual space for exaggerated effect (*boiling weather*); metaphorically in a foreign conceptual space (*a warm person*); and can be projected metaphorically out of and back into their home conceptual space (*lukewarm weather*).

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

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