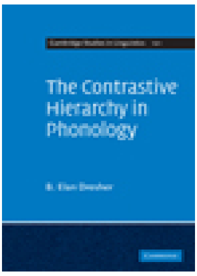

The Contrastive Hierarchy in Phonology

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2 *The logic of contrast*

2.1 Contrastive specification: an elusive problem

It is far from obvious how to decide, for a given phoneme in a given language, which of its features are contrastive and which are not. The problem is made even more elusive by the fact that it does not appear to be difficult. In particular situations we may have intuitions about what the answer must be. But our common-sense intuitions may lead us astray, in this area as in others. Or we may find that we can follow more than one logical chain of reasoning, each of which may appear to be sound, but which lead to different and incompatible conclusions.

To give something of the flavour of this problem, both its seeming obviousness and real difficulty, I would like to begin with a quote from Stephen Anderson (1985: 96–7). Anderson is illustrating Trubetzkoy's (1939) notion of *phonemic content*, intended to be the sum of the contrastive properties of a phoneme: 'If we consider [English] /t/, for example, we can see that this segment is phonologically *voiceless* (because it is opposed to /d/), *non-nasal* (because opposed to /n/), *dental* (because opposed to /p/ and /k/), and a *stop* (because opposed to /s/ and to /θ/).'

Anderson is not proposing a detailed analysis of English; he is simply illustrating what some of the contrastive features of English /t/ would be in a Trubetzkoyan analysis, and presumably in any analysis of contrast that used these features. And yet, none of the features listed above are uncontroversially contrastive. Assuming that English /t/ and /d/ differ only in their laryngeal specifications, it is possible that /t/ is contrastively voiceless, though other laryngeal features are also possible: thus, /t/ and /d/ differ also in *aspiration* (/t/ is aspirated, /d/ is not), and in *tension* (/t/ has a tenser articulation than /d/). It is not obvious which of these laryngeal features is contrastive in English. Similarly, we could agree that /t/ differs from /p/ and /k/ with respect to its place of articulation, but it is not obvious that this feature should be designated dental as opposed to the more general *coronal*.

The other contrasts are even more problematic. The segment /t/ is opposed to /n/ not only in nasality but also in *voicing* (/t/ is voiceless, /n/ is voiced) and *sonority* (/t/ is an obstruent, /n/ is a sonorant): how do we know that nasality is the contrastive feature and not one of the others? And while /t/ differs from the continuants /s/ and /θ/ in being a stop, it also differs from these phonemes in various other ways. For example, /t/ is *non-strident*, in contrast to /s/, and *apical* in contrast to /θ/. How do we know, then, that the contrastive features of /t/ are those designated by Anderson and not any of the alternatives?

This example is not intended to show that Anderson (1985) was being particularly imprecise; on the contrary, Anderson is more careful than most, and his discussion of the contrastive features of /t/ is entirely typical of what one finds throughout the literature. Anderson's choices are not obviously wrong, but it is not clear that they are right, either. More fundamentally, he provides no procedure for making such distinctions, nor does he discuss how such decisions were made in the history of phonology. Given the centrality of the issue in many phonological theories, this is a striking omission, in my view, and yet again entirely typical of most treatments of the subject. There has been much discussion of the *status* of contrastive representations in phonology; Anderson (1985), for example, is particularly concerned with the question of whether only contrastive features should be included in lexical representations, or all features. This has been a central issue in phonological theory, but it presupposes the answer to a more humble question: how do we decide which features are contrastive in any given segment?

We will see that this more basic question has been answered in different ways. One way proceeds from making pairwise comparisons between the segments of an inventory; the other involves successively dividing up the inventory by an ordered list of features. These approaches are not equivalent, and typically yield different results. Both have a certain common-sense appeal; but I will argue that one of them cannot be correct.

To illustrate each approach, we will look at a very simple problem: how to specify the features that distinguish the three bilabial stops /p, b, m/, such as occur, for example, in Standard French. This problem has been treated by numerous authors over the years. To illustrate the two approaches, we will consider the analyses of Martinet (1960) and Jakobson and Lotz (1949). Both of these analyses emerge from the Prague School and share certain general background assumptions. But their approaches to contrastive specification are quite different.

2.2 Contrastive specification by pairwise comparisons

Martinet (1964: 62–4) considers how to isolate the relevant (i.e., contrastive) features of the Standard French consonants. To simplify the discussion we will focus here only on the bilabial stops /p, b, m/. Martinet proposes that /p/ is contrastively 'unvoiced'; /b/ is 'voiced' and 'non-nasal'; and /m/ is 'nasal'. We can convert these specifications into two binary features, [voiced] and [nasal]: [+voiced] is equal to 'voiced', [−voiced] is equal to 'unvoiced', [+nasal] is equal to 'nasal', and [−nasal] is equal to 'non-nasal'. In these terms, the specifications proposed by Martinet amount to those in (1).

(1) Contrastive specifications for French bilabial stops (Martinet 1964)

	p	b	m
[voiced]	−	+	
[nasal]		−	+

Martinet arrived at these specifications by isolating those features that serve to distinguish phonemes that are minimally different in terms of their full feature specifications. To follow his reasoning, let us start with the full (not just the contrastive) specifications of the phonemes /p, b, m/ for the features [voiced] and [nasal], shown in (2).

(2) Full specifications for French bilabial stops

	p	b	m
[voiced]	−	+	+
[nasal]	−	−	+

We observe that /p/ and /b/ differ only with respect to the feature [voiced]. Therefore, by any definition, this feature must be contrastive in these segments; if it were absent, we could not distinguish /p/ from /b/. By the same token, /b/ and /m/ are distinguished only by the feature [nasal], which must, too, be designated as contrastive. Let us circle these two undisputedly contrastive features:

(3) Circled features certainly contrastive

	p	b	m
[voiced]	⊖	⊕	+
[nasal]	−	⊖	⊕

What about the features that have not been circled? These are the features Martinet leaves out of his contrastive specifications, so evidently in his view they are not contrastive. He explains (1964: 65) why /m/ is not to be considered as contrastively [+voiced]:

> It is likewise to be noted that ... the segments /m n ñ/ are not only nasal but also voiced. However, here voice cannot be dissociated from nasality since in this position there are no voiceless nasals. This is why /m n ñ/ do not figure in the class of the 'voiced' elements, which are defined as such solely in virtue of their opposition to 'voiceless' partners.

By similar reasoning we can see why /p/ is not classed as 'non-nasal', even though it is phonetically non-nasal, just like /b/. It is because /p/, unlike /b/, has no nasal 'partner'; such a partner would have to be otherwise identical to /p/, that is, a voiceless nasal stop /m̥/. Since there is no such phoneme in French, /p/ is not contrastively non-nasal.

This method proceeds in terms of pairwise comparisons. It designates as contrastive all and only features that serve to distinguish between pairs of phonemes. An explicit algorithm for extracting contrastive features by this method was proposed by Archangeli (1988).[1] I will call this the Pairwise Algorithm, given in (4).

(4) Pairwise Algorithm (Archangeli 1988)

a. Fully specify all segments.
b. Isolate all pairs of segments.
c. Determine which segment pairs differ by a single feature specification.
d. Designate such feature specifications as 'contrastive' on the members of that pair.
e. Once all pairs have been examined and appropriate feature specifications have been marked 'contrastive', delete all unmarked feature specifications on each segment.

Pairwise comparison seems to make sense, and it has been widely used in phonology (not always explicitly) as a way to isolate contrastive features.

2.3 Contrastive specification by feature ordering

The above analysis of the contrastive features of the Standard French bilabial consonants is not the only one in the literature. An entirely different analysis is given by Jakobson and Lotz (1949). As with the Martinet example above, I will focus only on their analysis of the bilabial consonants, extracting it from

1 Archangeli (1988) presents this algorithm as part of an argument *against* the sort of contrastive specification proposed by Steriade (1987). Her argument is that the algorithm is faulty, and hence so is contrastive specification. I will show that while the algorithm, and the general approach it instantiates, are indeed faulty, contrastive specification does not necessarily depend on this approach. A more elaborate algorithm was formulated by van den Broecke (1976); see section 2.5.5 below for discussion.

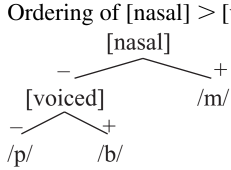
their larger analysis of the contrasts in the French consonant system. I will also modify their features to conform with the example we have been using; specifically, I will continue to use [voiced] in place of their *tense* (tense stops are voiceless, non-tense stops are voiced). With these adjustments, their analysis of the contrastive features for the bilabial consonants is as in (5).

(5) Contrastive specifications for French bilabial stops (Jakobson and Lotz 1949)

	p	b	m
[voiced]	−	+	
[nasal]	−	−	+

Notice that the contrastive specifications in (5) differ from Martinet's in (1) in that /p/ in (5) is specified as [−nasal], a specification omitted in (1). Jakobson and Lotz arrived at a different contrastive specification from that of Martinet because they used a different method. They themselves do not make their method explicit, but we can reconstruct it from later work by Jakobson and his collaborators. Rather than make pairwise comparisons of fully specified segments, they put all the potentially distinctive features into an ordered list, and divide the inventory successively on the basis of this list until every segment has received a distinct representation. In this case they order [nasal] ahead of [voiced]. We will represent the ordering of feature [F] ahead of feature [G] by the notation '[F] > [G]'. We can represent the result of feature ordering by a tree, as in (6).

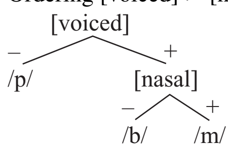
(6) Ordering of [nasal] > [voiced] applied to /p, b, m/



First we divide the inventory into two sets on the basis of the feature [nasal]: one set contains those phonemes that are nasal and the other contains those that are non-nasal. In the small inventory of bilabial consonants we are concerned with, /m/ is the only nasal consonant, and so is already distinct from the others. There are two non-nasal consonants, however, and they need to be distinguished by the feature [voiced], which is contrastive only in the [−nasal] set. Thus, we obtain the specifications in (5).

When we derive contrastive specifications from ordered features, the ordering makes a difference. To see this, consider what we would obtain if we reversed the order of the two features [voiced] and [nasal]. The results are shown in (7) in the form of a tree, and in (8) as a table of contrastive specifications.

(7) Ordering [voiced] > [nasal] applied to /p, b, m/



(8) Contrastive specifications with the ordering [voiced] > [nasal]

	p	b	m
[voiced]	–	+	+
[nasal]		–	+

This time we first divide the inventory on the basis of the feature [voiced]: /p/ is the only voiceless consonant, and this feature suffices to set it apart from the other consonants. There are two voiced consonants, however, and they need to be distinguished by the feature [nasal], which is now contrastive only in the [+voiced] set.

On this approach, contrastive specifications are determined by splitting the inventory by means of successive divisions, governed by an ordering of features (Jakobson, Fant and Halle 1952; Cherry, Halle and Jakobson 1953; Jakobson and Halle 1956; Halle 1959). An algorithm corresponding to this idea, the Successive Division Algorithm (SDA; Dresher 1998b, 2003, 2008, based on the work of Jakobson and his collaborators cited above), is given in (9):

(9) The Successive Division Algorithm

a. Begin with *no* feature specifications: assume all sounds are allophones of a single undifferentiated phoneme.
b. If the set is found to consist of more than one contrasting member, select a feature and divide the set into as many subsets as the feature allows for.[2]
c. Repeat step (b) in each subset: keep dividing up the inventory into sets, applying successive features in turn, until every set has only one member.

2 This algorithm does not require any particular set of features. I assume that the set of relevant distinctive features is given by the theory of features, whatever that may turn out to be.

The algorithm in (9) is a very general formulation for defining contrast and redundancy for members of an inventory.[3] It designates feature values as being contrastive or redundant in terms of an ordering of features, which I will call a *contrastive hierarchy*.[4] In this approach, contrast is a matter of *relative scope* or ordering of contrastive features.

2.4 Contrastive specification as a logical problem

We have now seen two different approaches to deriving contrastive feature specifications. These are not simply two ways of arriving at the same answer; the fact that they yield different answers shows us that the methods are fundamentally different, and inconsistent with each other. In the example of the bilabial stop consonants characterized in terms of the features [voiced] and [nasal], pairwise comparison yields the contrastive representations in (1), and feature ordering gives the representations in (5). To be more precise, feature ordering can give us more than one answer, depending on how the features are ordered. In the above example, we obtain (5) in the ordering [nasal] > [voiced], and (8) with the ordering [voiced] > [nasal]. This is another important way in which the two approaches differ: given a phonemic inventory and a fixed set of features, pairwise comparison always gives the same answer (if it gives an answer at all); feature ordering can give different answers.

The flip side of contrast is *redundancy*, which is often equated with *predictability*: if, after we remove a feature, we can predict what it is, based on our knowledge of the inventory and the other features, then it stands to reason that it is redundant; and if it is redundant, it cannot be contrastive, or so it would

3 A more procedurally explicit version of the SDA is as follows:

a. In the initial state, all tokens in inventory I are assumed to be variants of a single member. Set I = S, the set of all members.
b. i) If S is found to have more than one member, proceed to (c).
   ii) Otherwise, stop. If a member, M, has not been designated contrastive with respect to a feature, G, then G is *redundant* for M.
c. Select a new *n*-ary feature, F, from the set of distinctive features. F splits members of the input set, S, into *n* sets, $F_1 - F_n$, depending on what value of F is true of each member of S.
d. i) If all but one of $F_1 - F_n$ is empty, then loop back to (c). (That is, if all members of S have the same value of F, then F is not contrastive in this set.)
   ii) Otherwise, F is *contrastive* for all members of S.
e. For each set F_i, loop back to (b), replacing S by F_i.

4 As far as I know, the earliest appearance of this term in print in this sense is in Walker (1993).

appear. This kind of reasoning, which I will argue is flawed, would appear to support the pairwise method. For both features omitted from the specifications in (1) are predictable from the other specifications, and can be filled in by redundancy rules as shown in (10).

(10) Contrast by pairwise comparison

a. Contrastive specifications

	p	b	m
[voiced]	−	+	
[nasal]		−	+

b. Redundancy rules

i. [−voiced] → [−nasal] ii. [+nasal] → [+voiced]

Let us define *logical redundancy* as in (11).

(11) Logical redundancy

If Φ is the set of feature specifications of a member, M, of an inventory, then the feature specification [F] is *logically redundant* iff it is predictable from the other specifications in Φ.

The omitted features in (1), repeated as (10a), are logically redundant in the sense of (11) because they are predictable from the other features, given this inventory. Thus, because /p/ is the only [−voiced] member of the inventory, its feature value [−nasal] is predictable by rule (10bi); similarly, the value [+voiced] for /m/ is predictable by rule (10bii) because /m/ is the only [+nasal] phoneme.

The specifications derived from feature ordering do not omit all logically redundant features. In the ordering [nasal] > [voiced] (5), /p/ is contrastively specified as [−nasal], even though this specification is logically redundant, as we have seen. And in the order [voiced] > [nasal] (8), the value [+voiced] for /m/ is not omitted, though it, too, is logically redundant.

The concept of contrast that emerges from feature ordering, then, is not based on logical redundancy as defined in (11). Nevertheless, *in any particular feature ordering* some features are defined as redundant (equivalent to those features not designated as contrastive). To avoid confusion, let us call this type of redundancy *system redundancy* and define it as in (12).

(12) System redundancy

The feature specification [F] is *system redundant* iff it is not contrastive in terms of the method used for determining which features are contrastive in an inventory.

System redundancy is relative to a particular method for designating features as contrastive, whereas logical redundancy is fixed for a given inventory and set of features. Since a specification that is not logically redundant is not predictable under any procedure, it follows that the specifications designated as system redundant in any system of contrastive specification will also be logically redundant. The converse does not necessarily hold: a specification may be logically redundant but not system redundant, as we have seen. Many discussions of redundancy in phonology fail to distinguish the two types of redundancy, and this conflation of two different concepts can lead to considerable confusion.

Which approach to contrastive specification is correct? From the point of view of phonology, the question is ultimately an empirical one: which of these approaches, if any, yields representations that are significant in the phonology? The answer to this question could conceivably be 'neither', if in fact contrastive specifications play no special role in the phonology. I will continue to assume, however, that phonology is sensitive to contrastive specifications and that empirical evidence can be adduced to show that the feature ordering approach is correct. Evidence to this effect will be presented in subsequent chapters.

Putting this sort of empirical evidence aside for now, it was already recognized by Trubetzkoy (2001[1936]: 15) that the question of contrast (what he called 'the concept of the opposition') 'is not exclusively a phonological concept, it is a logical one, and the role it plays in phonology is strongly reminiscent of its role in psychology. It is impossible to study phonological oppositions (of which phonemes are only the terms) without analyzing the concept of the opposition from the point of view of psychology and logic.'

In the remainder of this chapter I will consider the logic of contrast. We will see that the pairwise approach suffers from severe logical problems. Feature ordering appears to be impeccable from a logical point of view, though it challenges us to order the features correctly for every language.

2.5 Arguments against the pairwise approach to contrastive specification

2.5.1 Distinctness

Let us consider the contrastive specifications in (1) a bit more closely. They are repeated here as (13) for convenience.

(13) Contrastive specifications by the pairwise method

	p	b	m
[voiced]	−	+	
[nasal]		−	+

Recall that these representations were derived by making a pairwise comparison between /p/ and /b/ on one side, and between /b/ and /m/ on the other. Each of these involves a minimal difference in one feature, which must therefore be contrastive. Let us call these *minimal pairs*, defined as in (14):

(14) Definition of a minimal pair
Two members of an inventory that are distinguished by a single feature are a minimal pair.[5]

Minimal pairs play a crucial role in the pairwise approach. But let us now observe that there is in fact a third pairwise comparison we can make in (13), between /p/ and /m/, and it is not obvious that they are properly distinguished in (13). The segment /p/ is characterized as being [−voiced] and /m/ is characterized as [+nasal]. Thus, they are not in contrast with each other along some common dimension. Where /p/ has a specification, /m/ has none, and vice versa. Their specifications look different, but they are not necessarily distinct. Without applying the redundancy rules, we would not know if /p/ and /m/ are distinct from each other or not. But then we have failed in our attempt to represent all the relevant contrasts in the chart.

The representations in (13) would be ruled out by a criterion in the linguistic literature known as the Distinctness Condition, proposed by Halle. He formulates it as in (15), and gives the examples in (16).

(15) Distinctness of phonemes (Halle 1959: 32)
Segment-type {A} will be said to be *different from* segment-type {B}, if and only if at least one feature which is phonemic in both, has a different value in {A} than in {B}; i.e., plus in the former and minus in the latter, or vice versa.

(16) Examples of distinctness and non-distinctness (Halle 1959: 32)
a. {A} is not ‘different from’ {C}

	{A}	{B}	{C}
Feature 1	+	−	+
Feature 2	0	+	−

5 This kind of *featural* minimal pair differs from the usual sense of ‘minimal pair’ in linguistics, which is a pair of *words* that differ by a single phoneme: for example, *bit* and *pit*, or *cat* and *cap*. Determination of word minimal pairs does not require us to identify in what way one phoneme is crucially distinguished from another.

b. All three segment-types are ‘different’.

	{A}	{B}	{C}
Feature 1	+	−	−
Feature 2	0	+	−

By the terms of the Distinctness Condition, /p/ and /m/ in (13) are not different from each other. Therefore, the pairwise approach fails to contrast these elements of the inventory, and hence fails to provide an adequate set of contrastive specifications, according to the Distinctness Condition.

The Distinctness Condition has not been uncontroversial in linguistic theory, and some readers may question whether it is really necessary. Why *can’t* the absence of a specification count as a value distinct from the presence of a value? After all, the system in (13) will result in three distinctly specified members once we apply the redundancy rules, so what is the problem?

The problem is that we are abusing the notion of contrast. Consider a language that has bilabial /p/ and /m/, but lacks /b/ (a fairly common situation, as many languages lack phonemic voiced obstruents). If asked to provide a contrastive specification of such an inventory, would anybody choose (17)? The relation between /p/ and /m/ in (17) is the same as that between /p/ and /m/ in (13); but without the middle member /b/ that forms minimal pairs with both of them, the specifications in (17) appear bizarre. It does not make sense to assert that one member in a two-member set is contrastively voiceless and the other is contrastively nasal. In contrast with what? If something is contrastively voiceless, it can only mean in contrast to something that is voiced, and the same holds for [nasal]: what is contrastively not nasal must be non-nasal (oral).[6]

(17) Contrastive specifications of /p/ and /m/?

	p	m
[voiced]	−	
[nasal]		+

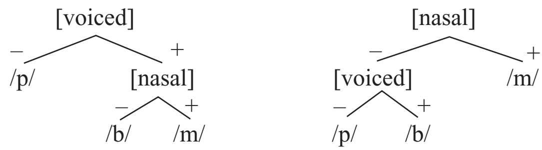
On further reflection, it appears that the chart in (13) results from a misconstrual of our original observations about the inventory. When we observed above that ‘/p/ is the only member that is [−voiced]’, what we had in mind was that, once we made a contrast between [−voiced] /p/ on one side and [+voiced] /b/ and /m/ on the other, there was no need to further specify /p/ for [nasal]. The relevant contrasts can be pictured as in (18a). And when we observed that ‘/m/ is the only member that is [+nasal]’, we had in mind a picture such as

6 Recall that we are using binary features. In a privative feature system, to be discussed below, the absence of a value acts like a value, and the conclusions drawn above do not hold.

(18b), where, once /m/ is specified [+nasal] and /p/ and /b/ [−nasal], there is no need to further specify /m/.

(18) Two ways of viewing the contrasts

a. [voiced] > [nasal] b. [nasal] > [voiced]



Thus, the observations that /p/ is the only voiceless member and /m/ is the only nasal member are correct, but in terms of contrastive force they derive from two different ways of cutting up the inventory, corresponding to the feature ordering approach. The ultra-minimal specification in (13) results from trying to put together two observations that derive from incompatible ways of dividing up the inventory. For this reason, it fails to adequately contrast /p/ and /m/.

2.5.2 The problem of too many features

Whatever one thinks of the Distinctness Condition and the above logical argument, the inventory in (17) shows us a fundamental problem with the pairwise approach: in many cases, there are too many logically redundant features. In (17), *every* feature specification is redundant given the others: in /p/, [−voiced] predicts [−nasal] and [−nasal] predicts [−voiced], and in /m/, [+voiced] predicts [+nasal] and [+nasal] predicts [+voiced]. Thus, all four feature specifications are logically redundant, but they can't all be omitted! But this is what the Pairwise Algorithm (4) does in such situations: the inventory in (17) contains no minimal pairs, as defined above, because the two members differ from each other by two features, not by one. Therefore, no features are designated as contrastive, and all are removed. Clearly, removing all logically redundant features in this inventory does not work, and the Pairwise Algorithm fails in such cases.

The problem of too many features not only arises in atypical inventories, but is ubiquitous and affects almost every phonological inventory in some way. For example, it arises in the most common vowel inventories.

Consider first the most commonly attested vowel system, the five-vowel inventory /i, e, a, o, u/.[7] If we include only the features [high], [low], [back]

7 According to the UCLA Phonological Segment Inventory Database (UPSID) (Maddieson 1984), sixty-eight of the listed languages (21 per cent of the sample) have five-vowel systems, by far the highest number of any vowel system. Of these, thirty-one have the indicated inventory.

and [round], we already have too many features for the pairwise method to function, as shown in (19).

(19) Five-vowel system, features [high], [low], [back], [round]

a. Full specifications

	i	e	a	o	u
high	+	−	−	−	+
low	−	−	+	−	−
back	−	−	+	+	+
round	−	−	−	+	+

b. Contrastive specifications according to the pairwise method

	i	e	a	o	u	*Minimal pairs*
high	+	−		−	+	{i, e}; {o, u}
low						none
back						none
round						none

The only minimal pairs are {i, e} and {o, u}; the features [back] and [round] double each other for every vowel except /a/, making each other logically redundant, but not leaving behind enough features to make a contrast between /i, u/ and /e, o/, and leaving /a/ without any contrastive feature.

The same point applies a fortiori with the simple three-vowel system /i, a, u/. If we confine ourselves to two features, say [high] and [round], the vowels fall into minimal pairs and the pairwise method can assign them distinct representations.

(20) Three-vowel system, features [high], [round]

a. Full specifications

	i	a	u
high	+	−	+
round	−	−	+

b. Specifications according to the pairwise method

	i	a	u	*Minimal pairs*
high	+	−		{i, a}
round	−		+	{i, u}

Adding one more feature, say [back], wipes out the minimal pairs (21), causing the pairwise method to fail to distinguish them.

(21) Three-vowel system, features [high], [round], [back]

a. Full specifications

	i	a	u
high	+	−	+
round	−	−	+
back	−	+	+

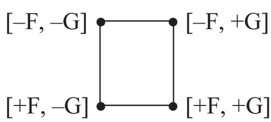
b. Specifications according to the pairwise approach

	i	a	u	*Minimal pairs*
high				none
round				none
back				none

2.5.3 *Minimal pairs and feature space*

We can approach the problem of algorithms that depend on minimal pairs by considering more generally how inventories fill out the available space of feature specifications. Two binary features, F and G, define a two-dimensional feature space with nodes at four possible values: [−F, −G], [−F, +G], [+F, −G], and [+F, +G]. This space can be diagrammed as in (22).[8]

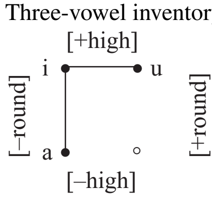
(22) Space defined by two features



The lines connect nodes that are separated by one feature value. Such nodes, which we will call *neighbours*, are minimal pairs. In (22), each node has potentially two neighbours, and hence can form minimal pairs with two other members of the inventory, if they are present.

If an inventory completely fills the feature space, then it is guaranteed that the pairwise method will find sufficient minimal pairs to arrive at a contrastive specification. The pairwise method can tolerate some gaps in the feature space, as long as there are sufficient neighbours. For example, the inventory in (20) can be diagrammed as in (23), where ◦ indicates an unfilled position.

(23) Three-vowel inventory, features [high], [round]

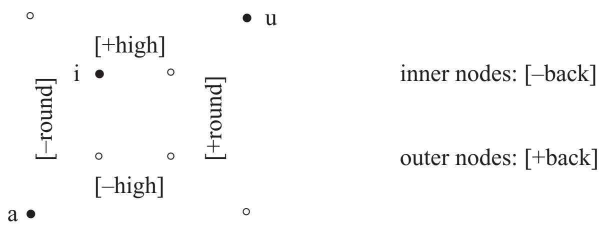


We can observe graphically how adding the feature [back] isolates the members of the inventory in the larger feature space (24). The feature space in (24)

8 Compare the information-theoretic adjacency graphs employed by Shannon (1993 [1956]); see D. C. Hall (2004, 2007) for discussion.

is an expansion of the one in (23): the features [high] and [round] remain as before, but now the inside nodes are [−back] and the outside nodes are [+back]. The addition of the feature [back] exiles the [+back] segments /a/ and /u/ to the outer nodes, away from /i/ that had formerly connected them.

(24) Three-vowel inventory, features [high], [round], [back]



It follows, then, that the pairwise approach to contrastive specification fails in the simplest vowel systems, when all features are taken into account. The reason that this simple fact has not disqualified it long ago as a theory of contrast is that many analysts tacitly reduce the feature set to a minimal set. That is, if an inventory is classifiable using a proper subset of the full set of features, then the ‘extra’ features are quietly discarded until the set is minimal, but still able to distinguish every member of the inventory.

In such cases, the analyst chooses which logically redundant features to delete and which to retain. Such a choice implies some notion of a hierarchy, and is in fact a tacit use of feature ordering. Therefore, even an algorithm formulated to remove redundancies from fully specified specifications must be supplemented by some device that orders the redundant specifications so that some take priority over others. That is, some notion of a feature hierarchy is required even in a pairwise approach to contrastive specification. But if a feature hierarchy is independently needed, there is no further rationale for the pairwise method, since the hierarchy can do all the work by itself.

2.5.4 The problem of too few minimal pairs

In the type of case discussed above, the pairwise approach can be salvaged (ignoring violations of the Distinctness Condition) by removing features (that is, appealing to a feature hierarchy for this limited purpose) until a minimal set of features remains. But this approach fails in more spectacular ways when faced with inventories that use a minimal set of features whose members do not fill the space of feature values in the right way. In such cases no feature may be removed from the set of relevant features specifying the inventory, but there are still not a sufficient number of minimal pairs to fuel the Pairwise Algorithm.

Consider again the common five-vowel system in (19), this time without the feature [round]. According to the pairwise method, this five-vowel system, fully specified for the features [high], [low] and [back] in (25a), would be underspecified as in (25b).

(25) Five-vowel system, features [high], [low], [back]

a. Full specifications

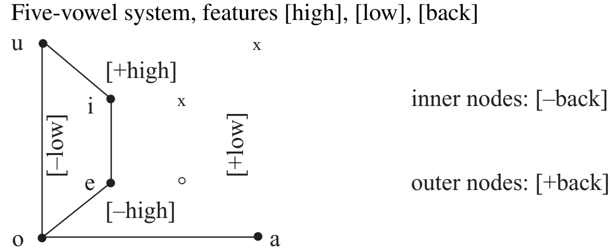
	i	e	a	o	u
high	+	–	–	–	+
low	–	–	+	–	–
back	–	–	+	+	+

b. Specifications according to the pairwise method

	i	e	a	o	u	*Minimal pairs*
high	+	–		–	+	{i, e}; {o, u}
low			+	–		{a, o}
back	–	–		+	+	{i, u}; {e, o}

That the pairwise method gives a contrastive specification at all, whether correct or not, is due to the connectedness of the paths through the space of the three features being considered here. As before, we can model the space and the minimal pair paths through it with a diagram as in (26). An x represents an impossible combination of [+high, +low].

(26) Five-vowel system, features [high], [low], [back]



Archangeli (1988) points out that not every five-vowel system can be assigned a contrastive set of specifications by the Pairwise Algorithm. An example of such an inventory is the vowel system of Maranungku (Tryon 1970), given in (27).

(27) Maranungku, features [high], [low], [back]

a. Full specifications

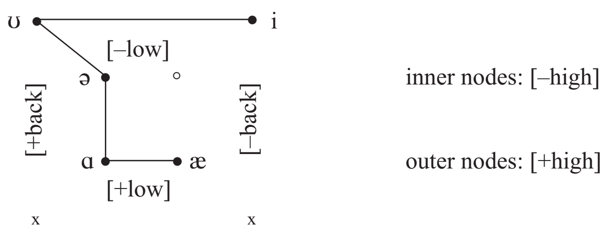
	i	æ	ɑ	ə	ʊ
high	+	−	−	−	+
low	−	+	+	−	−
back	−	−	+	+	+

b. Specifications according to the pairwise method

	i	æ	ɑ	ə	ʊ	*Minimal pairs*
high				−	+	{ə, ʊ}
low			+	−		{ɑ, ə}
back	−	−	+		+	{i, ʊ}; {æ, ɑ}

In this vowel system, /i/ and /æ/ have the same contrastive specification because they occupy parallel positions in a [back] contrast, but have no other neighbours that could further differentiate them in terms of the pairwise method. This situation is represented graphically in the diagram in (28).

(28) Maranungku, features [high], [low], [back]



Now, if it were the case that Maranungku represented a relatively rare situation, one could argue that such examples are not serious problems for the pairwise method. One might reason the other way around: if the Pairwise Algorithm is correct, we expect that actual phonological inventories ought to have sufficient minimal pairs. However, D. C. Hall (2004, 2007) argues that this expectation is seriously misguided. For actual inventories do not aim for minimal phonetic contrasts, free of all redundant differences. On the contrary, there is much evidence that minimal phonological contrasts are *enhanced* by additional phonetic distinctions, or that members of an inventory are *dispersed* so as to maximize the perceptual salience of contrasts (see chapters 7 and 8 for further discussion and references).

As D. C. Hall (2007: 165) demonstrates, the three-vowel inventory /i, a, u/ diagrammed in (24) is problematic for the Pairwise Algorithm because its members differ with respect to too many features. He shows that the algorithm would have no difficulty finding contrastive features for an inventory like /ɨ, ə, ʉ/, whose members are closer together; but this type of inventory is non-existent, whereas /i, a, u/ is the most common three-vowel inventory. It appears that the pairwise approach rests on exactly the wrong assumption about real phonological inventories, which are designed to thwart an algorithm that relies on phonetic minimal pairs.

2.5.5 Extending the Pairwise Algorithm

The pairwise approach as instantiated in the Pairwise Algorithm (4) identifies as contrastive only features that distinguish minimal pairs, and finds no contrastive features for members of an inventory that are distinguished by more than a single feature. There is no reason in principle why pairwise comparison must be limited in this way. To deal with situations where members of an inventory are distinguished by more than one feature, there must be a way of selecting one of them as being contrastive. The simplest way to do this is to order the features, selecting the feature that is highest in the ordering. But this is to adopt feature ordering, and makes pairwise comparison superfluous.

A sophisticated version of pairwise comparison was devised by van den Broecke (1976: 33−4). He wrote a computer program that takes as input a phonological inventory with fully specified feature matrices, with the aim of arriving at a set of contrastive specifications. The first step of this algorithm is equivalent to the Pairwise Algorithm, except that for each pair of phonemes the program records every feature that distinguishes the two. As in the Pairwise Algorithm, features that uniquely distinguish a pair of phonemes are designated as contrastive for that pair.

But whereas the Pairwise Algorithm stops at this point, van den Broecke's program is just getting started. If a pair of phonemes is distinguished by more than one feature, but one of those features has already been marked as contrastive for another pair, then that feature is selected. If none of the distinguishing features has been marked as contrastive elsewhere, then the program creates several columns and in each column marks one of the features as contrastive and the others as redundant. These columns multiply as a function of the number of such choices. For example, for an English inventory of 48 phonemes characterized by 14 distinctive features, van den Broecke reports that the program generated up to 52 columns, with an average number of 10.5 columns per segment.

The next step in van den Broecke's procedure is to assign a relative weighting factor to each candidate contrastive feature based on the number of columns in which the feature is listed as being obligatory. The feature with the highest weighting is selected as contrastive.

As van den Broecke (1976: 35) points out, the specifications arrived at in this fashion are based only on considerations of economy, and do not take phonological patterning into account. As a result, the specifications tend to be highly counter-intuitive and not the specifications that any phonologist would propose.[9] For example, the major class features [vocalic], [consonantal] and [sonorant] are rarely marked as contrastive by this method, because they are predictable from more specific features, like [strident]. Thus, [sonorant] is marked as contrastive in only a single segment, /ð/, a typically strange result of this method.

Van den Broecke does not advocate this method for arriving at contrastive specifications; on the contrary, he presents it to show that attempts to remove redundant features based only on a notion of feature economy or minimality (a criterion allied to logical redundancy, as it aims to reduce the set of specifications to a minimum) result in unnatural contrastive specifications that no phonologist would posit. I am unaware of any other attempt to apply an algorithm along these lines.

2.5.6 Summary

The preceding sections have argued that the pairwise approach, despite its common-sense appeal, faces serious logical problems. In the cases where it yields a set of contrastive specifications that make all the segments look different, it is not at all clear that the specifications are properly contrastive. More usually, the analyst must remove certain logically redundant features *before* making the pairwise comparisons, thus tacitly putting the features into a partial order. Finally, there are cases where pairwise comparisons simply fail to distinguish some members of an inventory even when the features are reduced to a minimal set. In short, the pairwise approach to contrastive specification is simply too problematic and too sensitive to the vagaries of the distribution of members of an inventory to serve as a principle for assigning contrastive specifications. While one can imagine ways of trying to extend the pairwise approach, the one extension I am aware of (van den Broecke 1976) results in bizarre specifications and has never actually been used in a phonological analysis.

2.6 Feature ordering

The feature ordering approach, instantiated by the SDA, is not subject to these difficulties. As long as the members of an inventory can be distinguished by the full set of relevant distinctive features, the SDA is guaranteed to arrive at

9 But see Jakobson's specifications for Serbo-Croatian discussed in section 4.5.1.

properly contrastive specifications. To see this, we will consider the various difficulties faced by pairwise comparison in turn.

First, all members of an inventory assigned contrastive features by the SDA are guaranteed to pass the Distinctness Condition. This was demonstrated by Halle (1959). Since the SDA works by successively splitting an inventory and does not stop until each segment has been assigned a unique set of features, it is guaranteed that every phoneme will be distinct from every other phoneme in the sense of the Distinctness Condition. In a sense, every time the SDA splits an inventory on the basis of a feature, F, it applies the Distinctness Condition with respect to F: assuming a binary feature, every member of the relevant inventory is assigned either [+F] or [−F]. Therefore, every phoneme in one set is distinct from every phoneme in the other set. Phonemes in the same set are not distinct with respect to F (or with respect to any feature ordered higher than F); but since the procedure iterates, it is guaranteed that eventually every set will have just one member.

Second, the SDA does not depend on any particular distribution of the members of an inventory in feature space. No matter how sparse the inventory or how long the list of features, the SDA functions in the same way. It starts by selecting the first feature in the list, F_1. If this feature is contrastive within the inventory, then the SDA splits the inventory into two sets (assuming binary features), one contrastively specified [$+F_1$], the other [$-F_1$]. It is possible that this feature is not contrastive: it could be that the members of the inventory are all [$+F_1$], or all [$-F_1$]; or F_1 may not be relevant to the members of the inventory (in the case of features defined to apply in limited circumstances). In any of these cases, the SDA will move on to the next feature. As long as the full set of features is capable of characterizing each member of the inventory in a unique way, the SDA is guaranteed to find a unique set of contrastive features. Given a small inventory, the SDA will stop sooner; a larger inventory will require more splits. In every case, the SDA assigns a minimal set of specifications that meet the Distinctness Condition.

Therefore, I conclude that of the two methods for arriving at contrastive specifications, the pairwise method is inadequate on purely logical grounds, whereas feature ordering is logically sound.

The hierarchical approach to contrastive specification imposes a task on language learners and analysts that pairwise comparison does not: it requires that the features be ordered. Although the feature order, or contrastive hierarchy, is crucial to the functioning of the SDA, it is not itself discovered by the SDA. Where does the ordering come from? I will return to this important issue in subsequent chapters.

2.7 Other issues in a theory of contrastive features

The above sections have been concerned with how one decides which features are contrastive in a set of phonemes: whether one does so in terms of minimal pairs and logical redundancy or by feature ordering. This is the most fundamental issue in an investigation of the logic of contrast. However, there are other issues that arise in a theory of contrastive features that bear some discussion here, because they interact with the logical questions considered above, and in some cases may produce results that look different from the ones we arrived at above. In the rest of this chapter I consider three such issues: whether contrast is to be assessed in an inventory as a whole or is limited by position (section 2.7.1); whether features (binary features, in this case) have two values or one value (section 2.7.2); and the relationship between contrastive specification and theories of underspecification (section 2.7.3).

2.7.1 Contrast limited by position

Up to here we have viewed contrasts as being defined over the entire inventory: we have considered, for example, the contrastive specifications of phonemes /p, b, m/ as if these were fixed once and for all for the whole language. But the sounds of a language are arranged *syntagmatically* as well as *paradigmatically*, and phonotactic restrictions can alter the set of contrasts at particular positions in a language. English, for example, observes the restriction that the first in an initial sequence of three consonants must be *s*: hence, *splash*, *stretch*, *squat*, are well-formed words, but no English word results from substituting another consonant for *s* in these examples. If we evaluate the contrastive status of *s* in this position only, it would suffice to specify it as [+consonantal]. Thus, contrastive evaluation limited by position can yield different results from evaluating contrasts globally.

Should we evaluate contrasts globally or by position? And if by position, how do we define the positions? In the above example we singled out a position before two consonants and following a word boundary; clearly, there are many other possible positions of varying degrees of specificity. We could, for example, focus on initial single consonants in monosyllables (*pick*, *tail*, *comb*, *fuse*, etc.), or limit the vowel to [ɪ] (*pick*, *rig*, *win*, *fill*, etc.), or further limit the final consonant to [k] (*pick*, *tick*, *wick*, *sick*, etc.). A variety of prosodic and morphological considerations may also play a role, allowing us to distinguish between stressed and unstressed syllables, stems and affixes, and so on.[10]

10 See Beckman (1997) and Dresher and van der Hulst (1998) for two approaches to picking out positions that have a special status in the phonology.

As in other matters concerning contrast, phonologists have not been consistent in this regard. Unless the sets of relevant positions can be somehow limited in reasonable ways, however, positionally limited contrastive evaluation can get out of hand. Therefore, for the most part I will continue to assume that contrasts are defined globally for phonemes in inventories. However, we will return to this topic in section 7.5, where we will see that there is a place for positionally defined contrasts in phonology.

2.7.2 Types of features: equipollent and privative

The SDA works on all types of features. For purposes of exposition I have been assuming binary features, but this assumption is not crucial to the validity of the arguments against the pairwise method. However, the type of feature adopted can affect the results produced by the SDA, and for this reason it is worth considering this issue here.

There are different kinds of binary features.[11] The kind discussed above have two values, one positive and one negative. As long as we do not attribute special status to + or −, the two values of a binary feature have equal status. To borrow the Prague School term (Trubetzkoy 1969), such features are *equipollent*.

The [+F] ∼ [−F] notation introduces an inherent asymmetry, however: [+voiced] feels psychologically different from [−voiceless], because each names the feature after a different one of its values. It is a small step to suppose that the two values are not equal in status. One could be the *default*, or *unmarked*, value, and the other could be the *marked* value. The terms 'marked' and 'unmarked' are also borrowed from the Prague School, who took it somewhat literally, as meaning that an unmarked feature value is simply not indicated, whereas a marked value is indicated by a mark. This kind of contrast can be represented as Ø ∼ [F], where Ø represents the *absence* of a mark and [F] is the marked value. In Prague School terminology, this kind of binary contrast is called *privative*.

Privative contrasts impose more structure on representations than equipollent ones, and hence require more information. To make an equipollent contrast between nasal and oral, it is enough to write [+nasal] ∼ [−nasal], or, equivalently, [−oral] ∼ [+oral] (which name we choose has no significance). To make a privative contrast, we have to decide which is the marked feature.

11 It is also possible to have *multi-valued* features, either *discrete* or *continuous*. There have been proposals that multi-valued, even continuous, features play a role in linguistic theory (Broe and Pierrehumbert 2000; Pierrehumbert, Beckman and Ladd 2000). Nevertheless, I will continue to assume that phonological features are discrete and mainly binary.

Privative features act differently from equipollent ones with respect to contrast. For the sake of discussion, let us suppose that the marked values for the features [voiced] and [nasal] are the positive values in both cases. The *full* (not contrastive) specifications of the simple inventory in (2) will now look like (29).

(29) Full specifications: privative features

	p	b	m
[voiced]		✓	✓
[nasal]			✓

In the fullest possible set of specifications, /p/ is completely unmarked and has no specifications. Looking at the inventory as a whole, the 'full specifications' of (29) look like very minimal contrastive specifications. However, these are not contrastive specifications in the sense of the previous section.

Let us consider what effects contrastive feature ordering has on the specifications in (29). If [voiced] is the first feature, we mark /b/ and /m/ for this feature and leave /p/ unmarked. The next feature, [nasal], distinguishes between /b/ and /m/, and marks /m/ as [nasal]. Now we have the specifications in (30a), which are the same as in (29). That is, the contrastive specifications are the same as the full specifications in this ordering of the features. Proceeding in the other order, we first mark /m/ [nasal] in contrast to /p/ and /b/, which are unmarked; we then draw a contrast between /p/ and /b/ by marking /b/ [voiced], deriving the contrastive values in (30b). In this order, one of the full specifications is omitted.

(30) Contrastive specifications: privative features

a. [voiced] > [nasal]				b. [nasal] > [voiced]		
p	b	m		p	b	m
	✓	✓	[voiced]		✓	
		✓	[nasal]			✓

We observe that the effect of feature ordering is greatly reduced with privative features as opposed to equipollent features. This is because privative features conflate two situations that are distinct in equipollent features; the two are compared in (31).

(31) Contrastive specifications with equipollent and privative features

a. Equipollent features
   Member M is contrastively specified for a feature F iff M contrasts with at least one other member with respect to F.

b. Privative features
Member M is contrastively specified for a feature F iff M contrasts with at least one other member with respect to feature F, *and* M is marked for F.

Looking at it from the other side, M will remain unspecified for F in a privative system if *either* (i) F is not contrastive in M, *or* (ii) M is unmarked for F; whereas in an equipollent system, M will remain unspecified for F in case (i), but will receive a value for F in case (ii). This means that in a privative system we cannot tell from the representations which unmarked segments are contrastive; nor can we reconstruct what the scope of a contrast is, because only the marked members of a contrast receive a feature value, leaving it unclear which of the phonemes that are unmarked for a feature are in the scope of the contrast and which fall outside it. It follows that if it is important to know the scope of a contrast and which segments it affects in a privative feature system, we will have to keep track of this information with some machinery in addition to the representations themselves.

2.7.3 Contrast and underspecification

There is a natural, but by no means necessary, connection between contrast and underspecification. In a theory where contrastive feature specifications are assigned hierarchically by the SDA, it is natural to suppose that contrastive specifications are specified and redundant specifications are unspecified. Consider again our example of bilabial stops /p, b, m/, assuming an ordering [nasal] > [voiced]; the contrastive specifications are as in (5). It is natural to assume that the contrastive feature values in (5) are specified whereas the redundant values (in this case, the feature [+voiced] for /m/) are unspecified. This is not necessarily the case, however. We have seen that it is not necessary for all contrastive values to be specified. In a privative feature system, only *marked* contrastive values are specified, as in (30b).

In (30), representations are underspecified beyond the requirements of contrast, by omitting also unmarked contrastive specifications. The converse is also theoretically possible: representations may be specified over and above the requirements of contrast. Thus, it is possible to interpret the SDA not as an algorithm that *assigns* feature values in contrastive fashion, but rather as an algorithm that *designates* which values are contrastive. In such a theory, all possible feature values are always present, but some of them are designated as being contrastive. In this kind of theory, the specifications in (5) can be viewed as shorthand for the more complete listing in (32); specifications designated $_{\mathrm{C}}$ are contrastive.

(32) All specifications, [nasal] > [voiced], $_C$ = contrastive

	p	b	m
[voiced]	$-_C$	$+_C$	$+$
[nasal]	$-_C$	$-_C$	$+_C$

We can take a similar approach to markedness; rather than assume that only marked values are specified, as is the case with privative features, we can designate which values of each feature are marked, as in (33). In such a theory, the phonology has the option of targeting all features, or contrastive features, or marked features; this is the approach of Calabrese (2005) and Nevins (2004), discussed further in section 8.6.

(33) All specifications, [nasal] > [voiced],], $_C$ = contrastive, $_M$ = marked

	p	b	m
[voiced]	$-_C$	$+_{C,M}$	$+_M$
[nasal]	$-_C$	$-_C$	$+_{C,M}$

2.8 Conclusions: one approach to contrast left standing

In this chapter we have looked at how we might determine which features are contrastive in a given phoneme. I have identified two approaches to this question: the pairwise approach, based on making comparisons of fully specified phonemes with special attention to minimal pairs, and contrastive specification by feature ordering. The pairwise approach identifies as contrastive only specifications that are not logically redundant. While this may seem to be a point in its favour, I have argued that it is actually the source of a number of insurmountable problems.

The feature ordering approach, on the other hand, poses no logical difficulties. This approach is based on the notion that the scope of a contrast depends on where a feature is ordered in the hierarchy: features ordered higher up take wider scope than features ordered lower down. The feature ordering approach is not dependent on any particular distribution of minimal pairs, and separates the notions of logical redundancy and system redundancy.

Another difference between the two approaches is that pairwise comparison always produces the same results, given an inventory and a set of features, whereas feature ordering can give different results depending on the ordering. Again, this property might at first seem to favour pairwise comparison, for it is automatic and imposes less of a burden on the analyst as well as on the learner, who must determine the correct ordering of features in the latter approach. I will argue, however, that the advantage here again is on the side of feature ordering, for there is empirical evidence that similar-looking inventories can indeed have different contrastive specifications.

I conclude, then, that the SDA applied to features ordered into a contrastive hierarchy must be the basis of any theory of phonological contrast.

Another issue in the determination of contrast involves the syntagmatic dimension, the extent to which contrast is evaluated globally over an inventory or is tied to particular positions. From a logical point of view there is no way to decide this question. I will argue in section 7.5 that there are practical constraints that limit the degree to which contrasts can be tied to particular syntagmatic contexts; but where these constraints do not hold, there is evidence for contrasts limited to certain positions.

An issue orthogonal to the evaluation of contrast is the question of whether features are equipollent or privative. This issue has important implications for the identification of contrasts and the scope of a contrast. Also orthogonal to contrastive specification is whether redundant features are entirely absent from the phonology.

A study of the logical problem of contrast can take us only so far. The important question, from the point of view of phonology, is what role, if any, contrastive specifications actually play in phonological theory, and the extent to which a theory of contrastive specifications helps to illuminate phonological phenomena. In the next chapter we will find some preliminary answers to these questions in the work of some major figures in the formative years of phonological theory.