section four

Seeing the Dynamics

chapter seven

Components of Expertise in the Perception and Interpretation of Meteorological Charts

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Contents

Keywords: *meteorologists, nonmeteorologists, expertise, perception, interpretation, knowledge, mental models, visuo-spatial, meteorological, domain-specific knowledge, domain-general knowledge, weather maps, expert, novice, perceptual salience, relationships*

7.1 Introduction

Meteorological charts, commonly known as "weather maps" are a form of visual display that is used both as a specialized professional tool for practicing meteorologists and as a resource for teaching students of meteorology. These two types of audiences bring very different levels of meteorological expertise to their interactions with meteorological charts. The purpose of this chapter is to explore the effects that such expertise differences may have on the ways that meteorological charts are interpreted and perceived. The chapter reviews a set of research studies that investigated the way experts and novices interacted with weather map information across a varied set of processing tasks. The underlying motivation for these investigations was to seek expert/novice differences in the way weather maps are mentally represented, as a basis for helping beginning students of meteorology to develop weather map interpretation skills more efficiently. However, the conceptual frameworks and research approaches developed during this research program also appear applicable more generally to studies of expert/novice differences in the interpretation of a broad range of remote sensing data displays.

This chapter begins with an overview of the theoretical foundations supporting the set of research studies. It then presents a brief account of each study that covers its specific theoretical framework, methodology, and results. Finally, some overall conclusions are drawn, reflections about training implications made, and recommendations for future research given.

7.2 Theoretical foundations

A particular focus of this research is the role that knowledge plays in perception and interpretation of weather maps. What we perceive when viewing a visual stimulus depends both on the characteristics of that stimulus (external to the viewer) and on the knowledge we bring to that viewing experience (internal to the viewer). Similarly, there are both external and internal influences on our ultimate interpretion of what we see. The extent to which perception and interpretation are shaped by each of these two influences is likely to depend in part on the nature of the stimulus involved. In the case of visual displays, it seems reasonable to suppose that the less information a display explicitly depicts, the greater would be the reliance on the existing knowledge that a viewer brings to the processes of perception and interpretation. This knowledge is generally considered to be stored as structures in the mind that mentally represent information acquired as a result of an individual's prior experience.

Weather maps are abstract displays that give an economical representation of their referent situation. This representation is very selective in the content it includes, stylized in the graphic notation it employs to depict that content, and highly conventionalized in the way the markings constituting that notation system are used. Because weather map displays are in various respects a quite minimalist representation of information, it is likely that their perception and interpretation will be heavily reliant on the viewer's knowledge base.

There are two important classes of knowledge that could be involved here: everyday visual knowledge that can be applied broadly across a variety of subject-matter domains (i.e. domain-general), and more specialized domain-specific knowledge that characterizes a particular knowledge domain (in this case, meteorology). Two major components of everyday visual knowledge are (1) generalized visuo-spatial knowledge about aspects such as the size, shape, and apparent grouping of the entities we see that can be applied to any visual experience, irrespective of its content or format, and (2) visual knowledge about the content of our everyday experiences such as the materials, objects, systems, and events we routinely encounter as we interact with our environment. For successful perception and interpretation of visual information in a highly specialized domain such as meteorology, everyday visual knowledge should play a role that is subservient to that played by domain-specific knowledge. Some aspects of everyday knowledge may be irrelevant, unsuitable, or even misleading if directly and indiscriminately applied to a specialized domain.

Our perceptions provide the raw material upon which interpretation can operate, and so they determine what interpretations are possible. Incomplete or inappropriate perception of the information in a visual display can therefore derail interpretation processes. The research reported in this chapter focuses on how the external visual information presented in weather maps is represented in the minds of viewers with different levels of expertise in meteorology. The particular class of mental representation of interest here is the mental model, a type of representation that is assumed to be constructed on the basis of what has been perceived during viewing. Mental models are characterized as consisting of mental tokens and relationships that stand for the subject matter they represent. To be a useful basis for interpretation, a mental model should represent the meaning of the situation that is the depiction's referent, and not be merely a literal representation of the depiction itself. In the case of a weather map, this means the viewer's mental model would be of a particular meteorological situation in the real world, not merely a snapshot or image of a set of graphic elements arranged on a page.

However, it seems likely that this ideal would be difficult to achieve for viewers with a low level of meteorological expertise, because their mental model building capacities would be constrained by their lack of domain-specific knowledge. Without such a knowledge base, novices in the domain of meteorology could have little alternative but to invoke other types of knowledge to support their perception and interpretation of the highly parsimonious information presented in a weather map. Everyday visual knowledge of the type described above would appear to be a likely candidate. On this basis, we can speculate about the nature of the mental model that a nonmeteorologist could construct as a result. Perhaps the mental model would be based upon a mixture of (1) visuo-spatial information about the depiction itself, (2) tokens and relationships borrowed from everyday experience about how the world around us is constituted and works, and (3) any fragments of domain-specific knowledge (accurate or otherwise) that have been acquired from sources such as weather reports in the media.

If this were the case, domain novices—such as beginning students of meteorology—would be poorly equipped to process the weather maps they encounter. Providing maps to these students on the assumption that the maps themselves could make a significant contribution to the learners' understanding of meteorology would be useless if the students were not equipped to process them properly. This could help explain why those who teach introductory meteorology find that their students can have great difficulty with weather maps and seem initially to benefit little from their use as an instructional resource.

The research studies surveyed in this chapter formed the foundation for instructional interventions designed to help beginning students of meteorology use weather maps more effectively. The research aimed to explore differences between the knowledge that experts and novices appear to use in dealing with weather maps as a means of characterizing their mental representations of this class of depictions. The goal was to find ways in which novice meteorologists could be trained to perceive and interpret weather map displays more appropriately by taking account of, and dealing with their initial knowledge structures then developing suitable support systems.

7.3 Perceptual and meteorological significance

The patterning of the set of markings on a given weather map can be considered from both domain-general (visuo-spatial) and domain-specific (meteorological) perspectives. In a domain-general sense, the shape, size, and arrangement of certain graphic elements may lead to their being perceived together as part of a broader visuo-spatial pattern. In some cases, these sets of elements also correspond to components of the underlying meteorological situation. So, a series of tightly spaced concentric closed-loop isobars is both a distinctive visuo-spatial feature and an indication of the presence of a cyclone. In addition, the visual significance of certain types of patterns (as signalled by how readily perceptible they are) may happen to correspond to their meteorological significance. For example, there is correspondence between high perceptual salience and a high level of meteorological significance for the series of concentric isobars that represents a cyclone. Similarly, the high perceptual salience of the barbed-line symbol that marks the location of a cold front is a good guide to its meteorological significance. However, there are other cases in which there is poor correspondence between meteorological significance and general perceptual salience. For example, troughs and ridges are often indicated not by isolated features but rather by patterning that is superficially quite unremarkable in a perceptual sense. In these cases, minor local convolutions that are echoed across a series of adjacent isobars indicate the presence of a meteorologically significant feature. However, this subtle patterning of isobars can be obscured to a large extent by their visually distracting context, and so these features are more likely to be overlooked unless given special attention. Examples of these less-perceptible aspects are shown in Figure 7.1 in which broad shaded lines have been added to a weather map to reveal the location of troughs and ridges that run across the component isobars.

The way in which a viewer processes a given weather map's specific markings is likely to be influenced by the basis upon which that viewer

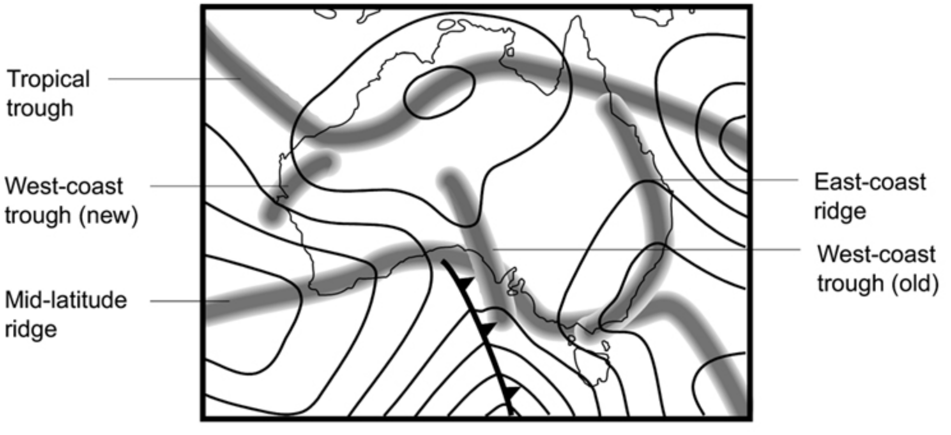

Figure 7.1 Australian weather map showing location of perceptually subtle patterns across markings indicating presence of troughs and ridges (gray shaded bands).

mentally represents weather map patterns in general. For example, if a viewer's mental representation of the weather map display genre is predominantly visuo-spatial in nature, that viewer's activity in processing a specific weather map could be expected to focus on the visuo-spatial characteristics of the display. Further, highly conspicuous aspects would be likely to receive most of the attention while more subtle aspects escape notice. Conversely, if a viewer's mental representation was predominantly meteorological in character, it would be more likely for processing activity to be dominated by the meteorological significance of the markings. Observable aspects of processing activity in both cases could include behaviors such as the order in which individual markings are dealt with in a weather map processing task, and the relative amounts of time devoted to the processing of the markings in different regions of the map. One of my experiments used such observations to explore the basis for meteorologists' and nonmeteorologists' mental representations.[2]

7.4 Copy-recall study

This study involved two groups of participants who were either experts or novices in the field of meteorology (16 in each group). The experts were experienced professional meteorologists employed by the Bureau of Meteorology in Western Australia whose daily forecasting activities involved concentrated work with weather maps. The novices were university students in teacher education who reported having only occasional, informal experience with weather maps, largely from newspapers and television. Participants individually copied the markings from an Australian weather map (the "original") onto a blank map of Australia. The task regime was designed so that the original map was not continuously visible to the experimental participant. Rather, participants were able either to view or to draw the markings but were not able to do both at once. This meant they had to copy the markings using an alternating succession of glances and drawing actions. After finishing this copying task, the copy was removed and the participant worked at a drawing recall task with the aim of regenerating the original markings onto a blank map.

Analysis of video records of participants' performance was made with respect to (1) the sequences in which markings were drawn, and (2) the duration of glances associated with the drawing activity involved in copying the original map. A cluster analysis procedure based upon local temporal clustering was used with the compiled data for each of the participant groups (meteorologists and nonmeteorologists) to assign a relational structure to the map's set of markings.

There was no direct attempt in this investigation to collect specific explanatory information, such as participants' characterizations of the particular element properties or relations upon which the clusters that emerged from the analysis were based. Nevertheless, there were indications of various differences between the two groups, including (1) the associations of graphic elements that emerged, (2) the sequence in which elements were processed, and (3) the effectiveness of recall. A discussion of selected findings illustrates some of the more important differences.

7.4.1 Results

The cluster analysis results suggested that meteorologists and nonmeteorologists have fundamentally different ways of grouping the meteorological markings comprising a weather map. For example, meteorologists' groupings indicated division of the map overall into a northern chunk and a southern chunk, which corresponds with the quite different meteorological influences that operate for these two halves of the Australian region.

This is shown in Figure 7.2 by the unshaded and shaded areas of the map. Such a subdivision is what would be expected if markings were treated in terms of the underlying meteorological situation represented by the map, not simply their visuo-spatial characteristics. In contrast, the nonmeteorologists' groupings divided the map into a western half and an eastern half. The shaded and unshaded areas in Figure 7.3 indicate these two chunks. This subdivision has no real meteorological foundation but is consistent with the fact that the markings on the west side of the map that was used formed a group of figurally similar elements in close proximity that are visually distinct from

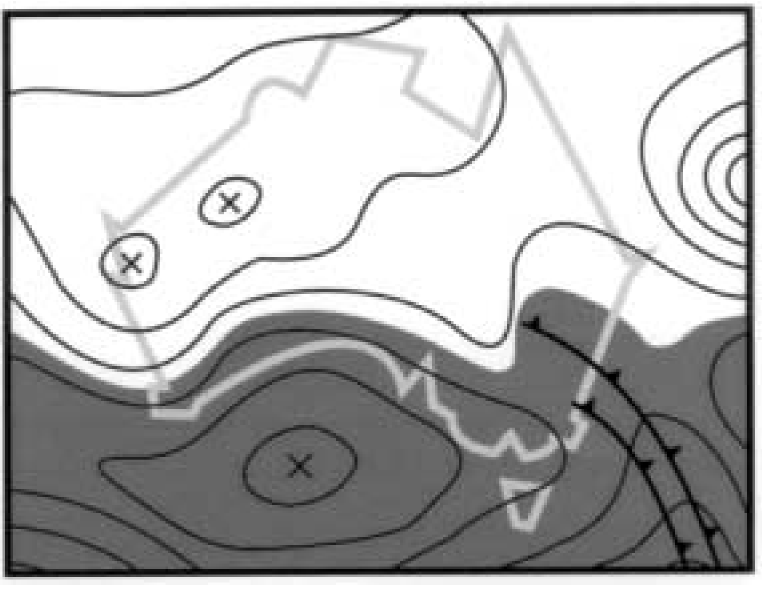

Figure 7.2 Meteorologists' north-south subdivision of meteorological pattern.

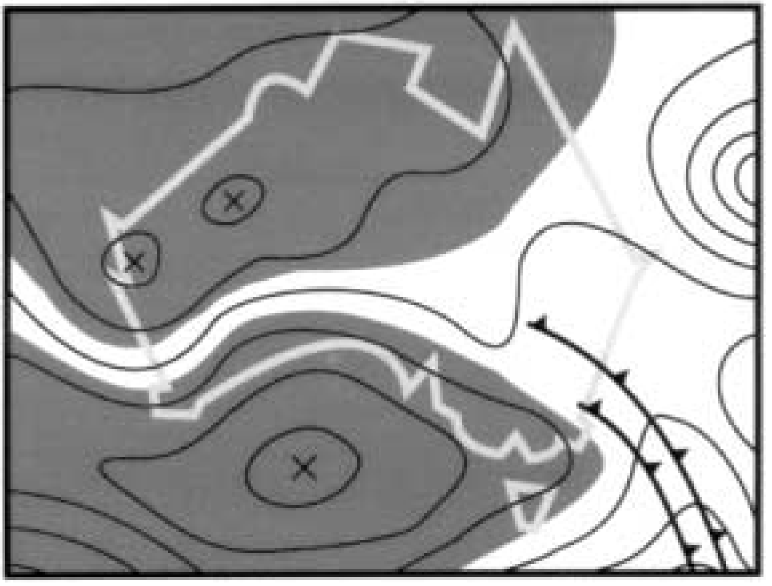

Figure 7.3 Nonmeteorologists' east-west subdivision of meteorological pattern.

the elements on the east side of the map. This explanation involves the low level visuo-spatial characteristics of the markings rather than their higher-level meteorological significance. (Further possibilities are other nonmeteorological influences such as the physical convenience of carrying out the drawing process during copying or the effect of habituated left-to-right patterns based upon the way people write English text.)

The sequence data indicated that meteorologists and nonmeteorologists used very different approaches during the copying process. In Figures 7.4 and 7.5 the outline of the Australian continent has been removed for the sake of clarity but the meteorological markings remain. The two superimposed pathways in Figure 7.4 indicate that the meteorologists typically used a two-stage strategy for copying the markings. The first stage (path 1) begins at the bottom right (cold front) then progresses via the high center and low centers to the cyclone. The meteorologists distributed several key elements around the map in positions that marked the location of major meteorological features. In effect, a general skeleton was initially set out for the whole map. The second stage (path 2) was then to pass through the map again in order to fill in subsidiary elements around this overarching framework. This pathway began with the cluster of isobars on the western edge, then progressed through the major features, adding isobars associated with each feature in turn. This approach was interpreted as evidence that the meteorological significance of markings plays a dominant role in the meteorologists' processing and that they characterize weather map markings in a structured fashion.

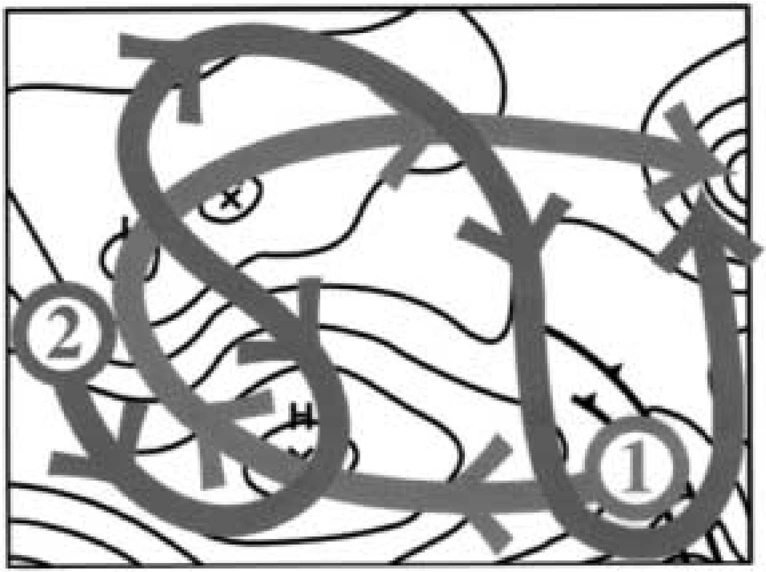

Figure 7.4 Meteorologists’ two-stage strategy for copying weather map markings.

Figure 7.5 Nonmeteorologists’ one-stage strategy for copying weather map markings.

In contrast, Figure 7.5 shows that the nonmeteorologists tended to use a one-stage strategy involving a single continuous pass around the map. Typically, this entailed starting from the top left of the map then working gradually around it in a clockwise sweep, exhaustively filling in all elements in each region as they progressed. Their sequencing of elements during this process was confined to a quite local focus and appeared to be influenced by the figural similiarity of elements and their spatial proximity. For the nonmeteorologists, approaches based upon superficial visuo-spatial characteristics of the map and habituated reading-writing processes suggest themselves as explanations, rather than a regard for the meteorological significance of the markings.

The meteorologists were significantly more successful overall than the nonmeteorologists at recalling the map's markings, both in terms of the proportion of elements recalled and the accuracy of recall. This suggests that the mental representation of the weather map constructed by the meteorologists during the copying task was generally more effective in terms of either or both storage and retrieval. These results are consistent with the meteorologists' ability to combine the many individual markings on the weather map into a richly interconnected and coherent array because of the multilevel meteorological relationships that they can invoke to bind these markings strongly together. The wealth of domain-specific meteorological knowledge possessed by the meteorologists could provide a basis for forming relational structures that facilitate storage and retrieval. In contrast, the nonmeteorologists' lack of such knowledge would presumably mean that their storage and retrieval largely depended on weakly connected low level domain-general visuo-spatial characteristics. This is unlikely to provide anything approaching the same multilayered network of relationships that would be available to the meteorologists.

Although the meteorologists' recall was superior overall, there was one revealing aspect for which their recall was actually inferior to that of the nonmeteorologists. This was the case of the number of triangular barbs that occurred on the cold front symbols. While the meteorologists had better recall of the cold front lines, their recall of the number of barbs was actually worse than that of the nonmeteorologists. This was interpreted as the meteorologists' concern with the meteorologically important component of the cold front symbol (the cold front line itself) while glossing over the more optional aspect of the symbols (the precise number of barbs on the line). By this type of explanation, the visuo-spatial basis of nonmeteorologists' processing would not have provided such a differentiation and so the barbs share as much status as the other markings comprising the map.

7.5 Relationships: visuo-spatial or meteorological?

Results from the first study indicated a need to gather more specific information about the nature of the relationships involved in structuring meteorologists' and nonmeteorologists' knowledge of weather maps in general.

Although the copy-recall study had identified ways in which markings were clustered into groups, it did not directly investigate the basis for these groupings. Nevertheless, there were some indirect signs that the processing differences observed could possibly be explained by meteorologists' capacity to characterize a weather map in terms of powerful meteorological relationships, whereas the nonmeteorologists were largely confined to using superficial visuo-spatial relationships.

7.6 Element sorting study

The basis for the groupings that had emerged was investigated in a study that required experts and novices to make explicit decisions about how elements were related to each other and to provide explicit information about the nature of the relationships involved.[6] The experts were eight professional meteorologists while the novices were eight university teacher education students. The study used a card-sorting task during which participants grouped the graphic elements comprising a weather map in three stages and generated explanations for the basis of their groupings. Participants were given a randomly ordered set of cards, all of which showed the same weather map printed in black and white. Although all cards were otherwise identical, each card had a different element of the meteorological pattern highlighted in color.

Figure 7.6 shows two examples of these cards, each with a different graphic element highlighted. The first stage of the task involved participants freely sorting the card set into groups which they considered to contain related elements (elements that belonged together). In the second stage, they divided these original groups into smaller groups while in the third stage they returned to their original groups and combined them into larger groups. At each stage of the grouping process (original, subordinate, and superordinate), participants were required to give a verbal explanation for each group formed as to why its component elements were related to each other.

Figure 7.6 Examples of cards used for sorting task with different elements highlighted.

Records of the groupings' constituents were submitted to a cluster analysis that generated patterns of hierarchical organization involving groups, subgroups, and elements. In addition, a qualitative analysis of the grouping explanations was carried out to determine the extent to which domain-general or domain-specific relationships were used to account for the groups produced.

7.6.1 *Results*

The cluster analysis indicated that at a broad level, weather map markings were organized for the meteorologists according to large-scale patterns that corresponded to the locations of extended zones of regional meteorological significance.

The tree-diagram in Figure 7.7 summarizes the results of the cluster analysis and shows that each of these regions is comprised of a number of visually distinct but meteorologically related features. The overall clustering patterns for the meteorologist group as a whole were structured into the features found in the northern and southern halves of the map, a result consistent with that from the cluster analysis in the copy-recall study described above. This subdivision was further broken down into those in the extreme south, those in the midlatitudes, and those in the tropics. These zones differ from each other in terms of their meteorological environments due to the specific nature of the local and global influences involved. Each zone has its own particular climatology and is inhabited by a distinctive set of meteorological features.

As with the copy-recall study, the meteorologists' clusterings appeared not to be primarily based upon superficial visuo-spatial characteristics of the

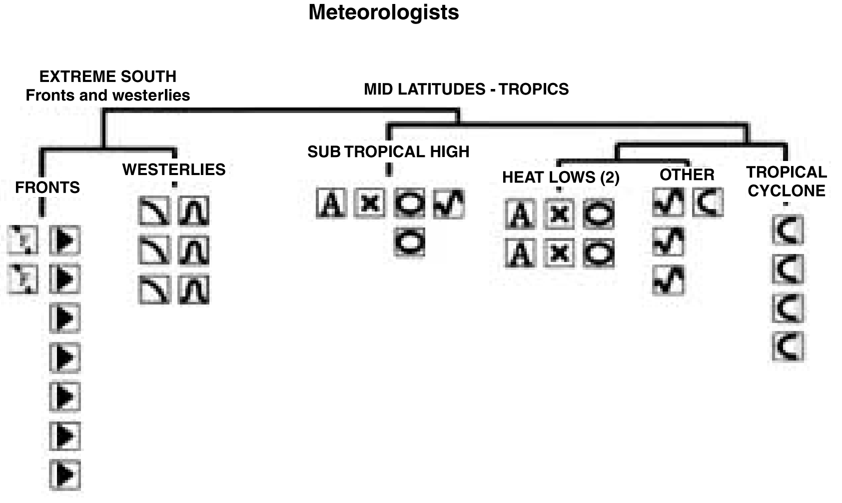

Figure 7.7 Summary of cluster analysis for meteorologists' results in card-sorting task.

markings but rather upon the deeper meteorological relationships in which they were involved. This conclusion is supported by the nature of the meteorologists' explanatory statements, which were highly domain-specific and indicated that the meteorological relationships involved ranged across multiple levels.

Example meteorologists' statements:

> "Isobars showing the trough in which the fronts are embedded; frontal trough."
>
> "(This marking is) . . . associated with a high in the Pacific to the south of the tropical cyclone; related to weather system not appearing on the weather map; Tasman high."

Meteorologists appeared to have a coordinated, hierarchical knowledge structure in which graphical information about markings was subservient to multilayered meteorological information about the atmospheric situation captured in the weather map. Further, there were indications in the meteorologists' statements that they used contextual knowledge to link markings shown within the map's boundaries to more global influences associated with meteorological zones that extended beyond those boundaries.

In contrast, Figure 7.8 shows that results of the cluster analysis for the nonmeteorologists' suggest an organization of elements that is primarily based on their appearance and proximity. Thus, the elements comprising the visually distinctive cold fronts were quite separate from those constituting the much less perceptually salient set of isobars in the two bottom corners of

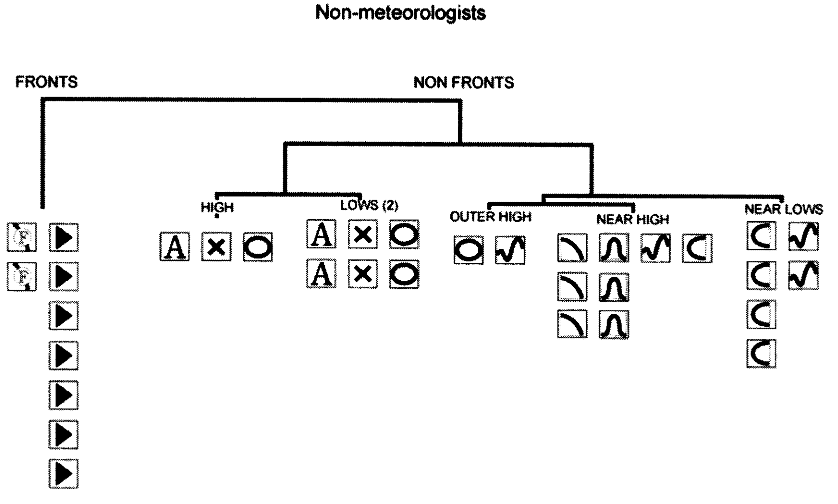

Figure 7.8 Summary of cluster analysis for nonmeteorologists' results in card-sorting task.

the map. However, this is a quite inappropriate distinction to make from a meteorological viewpoint, because these very different looking features all belong to the same southern meteorological zone. The nonmeteorologists' explanatory statements confirmed that they used a low-level visuo-spatial basis for combining the weather map markings into groups. In addition, these statements gave no indication that anything beyond the boundaries of the map was considered in making decisions about how markings were to be grouped.

Example nonmeteorologists' statements:

> "Curved lines or a second circle outside an inner circle; such as number 18 or 22; wavy lines or circular."
>
> "The cold front; threatening lines that move across at right angles to the other lines of pressure; only two so put together; lines of cold front."

7.7 Scope of representation

The processing behavior of nonmeteorologists was not only largely visuo-spatial in character; it also appeared to be based solely upon information which was depicted within the borders of the map. This latter constraint did not seem to apply for meteorologists, whose processing of within-map markings appeared to be modulated by consideration of the wider meteorological context. A normal Australian weather map covers a region only slightly larger than the Australian continent itself. However, a substantial proportion of the markings comprising such a map reflect broader-scale phenomena that contribute to the global meteorological pattern (e.g., the location of the subpolar jet stream). Therefore, the markings that are explicitly depicted within the borders of an Australian weather map should properly be interpreted in an implied context of their continuation well beyond the scope of those borders.

For example, the two widely separated (and, from a purely visuo-spatial viewpoint, apparently distinct) sets of concentric isobars in the southwest and southeast corners of the map shown in Figure 7.9 are actually both parts of the same band of meteorological macro structure. In order to interpret these appropriately, a viewer presumably would need to know about the types of meteorological markings to expect in the region beyond the borders of a normal Australian weather map. The following study explored meteorologists' and nonmeteorologists' mental representations of this broader meteorological context.

7.8 Map extension study

The experts in this study were 16 experienced professional meteorologists (forecasters with the Bureau of Meteorology in Western Australia) while the novices were 16 university students in the field of education who had no

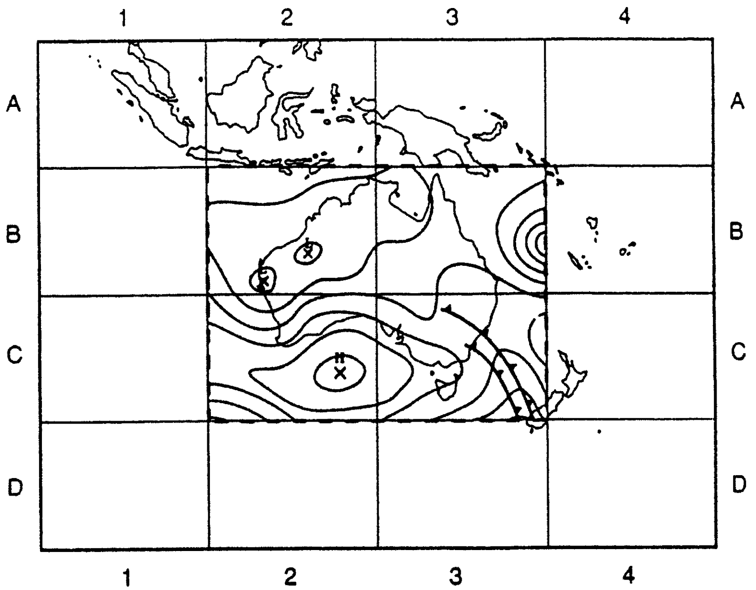

Figure 7.9 Australian weather map plus extension to region beyond that covered in standard regional map (used as basis for map extension study).

specialist training in meteorology. Participants were provided with a map that had been extended on all sides to cover an area far beyond that normally encompassed by an Australian regional weather map.[3] The central part of the full display was a normal Australian weather map (complete with meteorological markings) but the surrounding extended area was blank, except for land outlines where appropriate. Participants were asked to draw the meteorological markings that would be expected in the extended region.

7.8.1 Results

The two illustrative examples given in Figure 7.10 reflect the typical differences between meteorologists and nonmeteorologists in the sets of markings drawn in the extended region around the original map.

As well as producing significantly fewer markings in the extended region, the nonmeteorologists' markings appeared to have been derived quite directly from the visuo-spatial characteristics of the existing original markings. Typically, their new markings could be readily accounted for by assuming markings to result largely from the application of simple domain-general processes (such as extrapolation or interpolation) to the original markings. It was inferred that one of the nonmeteorologists' main frameworks for applying these processes was a visuo-spatially based "completion" strategy. In some cases, this strategy seemed to involve an attempt to turn as

(a)

(b)

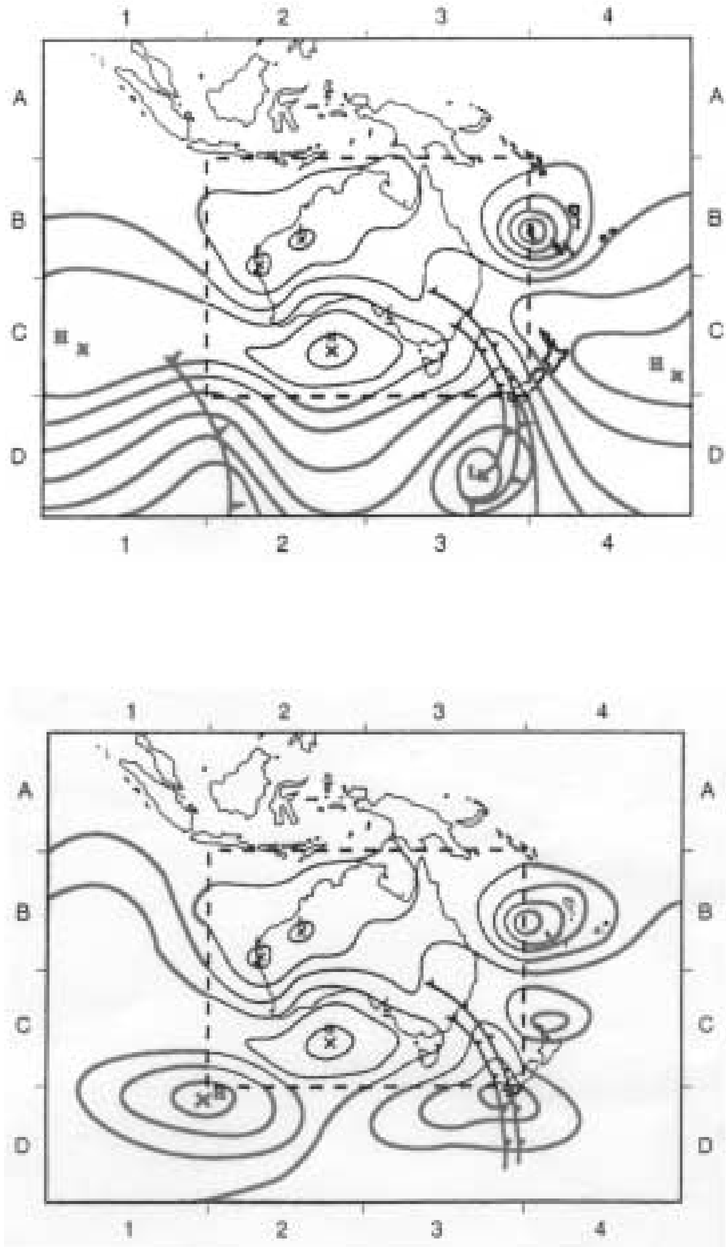

Figure 7.10 **(a)** Meteorologist's completion of the map extension task (illustrative example). **(b)** Nonmeteorologist's completion of the map extension task.

many simple curves as possible into closed figures (for example, closing arcs in the southwest corner to produce a figure resembling a pressure cell). In other cases where the curve was too complex for this simple conversion, the motivation appeared to be to continue existing patterns (for example, by extending open isobars that finished at the original map's border until they reached the extended region's border). The strategy can be interpreted as a reliance on internal, domain-general relations that were local in their scope and quite firmly anchored in the original map.

In contrast, the meteorologists' use of existing markings for generating markings within the extension area appeared to based upon far more than their literal visuo-spatial characteristics. Rather, their approach indicated they were operating in accordance with superordinate constraints involving a variety of external relations that integrated the original map area with the wider meteorological context. The resulting patterns in markings suggested the progressive clustering of lower-level weather map elements into high-level composite structures that correspond to meteorologically significant features and systems of wider significance. The superordinate constraints provided by relations involving the context of the Australian weather map region can be interpreted as a powerful framework that drives the meteorologists' interpretation of markings within that region.

The findings of this map extension study support the indications in the previous studies that meteorologists' and nonmeteorologists' mental representations of weather maps differ both in their fundamental basis (meteorological vs. visuo-spatial) and their extent (contextually situated vs. decontextualized). They also raise the issue of the temporal dimension of weather maps that is involved both in the way meteorological features change within a map's boundaries over time and in the way features enter and leave the weather map area as time passes.

7.9 Weather map dynamics

The investigations discussed thus far have been limited to single static depictions and so do not directly address weather map dynamics. However, one of the most important uses of weather maps is in making forecasts. These have traditionally relied heavily on reviewing past and current weather maps to predict the future pattern of meteorological markings, then interpreting that prognosis in terms of its real-life meteorological consequences. A well-rounded investigation of the mental representation of weather maps requires that this dynamic aspect be addressed. The next study compared the way experts and novices made predictions from a given weather map as a means of investigating their mental representations of weather map dynamics. It was based on the assumption that when meteorologists were given a weather map for a particular day, their efforts to predict the pattern of meteorological markings likely appear on the following day would be based on running a mental model of the current situation forward by a day.

Using the information on a given weather map to predict the pattern of markings expected on a later map is a direct test of the efficacy of the mental model constructed from the original map. For example, the indications from other studies that meteorologists' mental representations of weather map diagrams included contextual elaboration (that was largely absent from non-meteorologists' mental representations) should be supported by evidence from the type of predictions produced by these different participant groups. The running of a mental model built upon the basis of a well-contextualized domain-specific mental representation would be expected to produce a different prediction from that produced by running a model derived from a contextually impoverished domain-general representation.

7.10 Prediction drawing study

The experts in this study were 16 experienced professional meteorologists (forecasters with the Bureau of Meteorology in Western Australia) while the novices were 16 university students in the education field who had no specialist training in meteorology. Participants were given both a typical midsummer Australian weather map (including the main meteorological markings) and a blank map that showed only the outline map of Australia.[4,8] The blank map was printed on tracing paper so that the initial meteorological markings were visible when the blank map was superimposed on the original. Participants drew on the blank map the markings they expected to appear one day later than those shown on the original map.

7.10.1 Results

For the nonmeteorologists, markings on the forecast maps could be largely accounted for as the results of simple graphic manipulations of the original markings. Overall, these participants tended to move markings *en masse* from west to east without regard to meteorological dynamics. However, near the borders of the map, this general approach of translation could be modified to some extent by (1) stretching markings on the western edge to fill empty spaces that would have otherwise appeared, and (2) reducing the relative movement of markings close to the eastern edge so that they were retained on the map.

A more detailed examination of the nonmeteorologists' prediction markings revealed that the approaches described above were accompanied by problems with inter-isobar spacing and coordination. For example, there were irregularities in the isobar gradient pattern drawn by the nonmeteorologists across the prediction map as a whole that are inconsistent with the fluid nature of the atmosphere. There were also deficiencies at a more local level with the contouring and coordination of intra-isobar convolutions (such as would indicate the presence of a trough). For example, a major trough on the west coast of the continent that the meteorologists either maintained or deepened between the original and forecast maps tended to be reduced or to disappear completely in the nonmeteorologists' predictions.

In contrast, the meteorologists' predictions showed a much greater differentiation in the way the various markings on the map were treated. Rather than moving markings *en masse*, most of the displacement in the meteorologists' predictions was confined to markings in the southern half of the map and was quite differentiated according to feature type. Although this shift was in the same overall west-to-east direction as that produced in the nonmeteorologists' predictions, there was no evidence of the stretching or delaying of markings near the edges of the map as was found with the nonmeteorologists. Rather, completely new markings were added entering the western edge of the map (presumably having been moved in from the region beyond the map's boundaries). Markings near the eastern edge of the original map tended to disappear or become cut off at the border (as if they had continued their movement to take them beyond the map's boundaries). The markings in the meteorologists' forecast maps showed quite extensive changes from their original form, whereas those from the nonmeteorologists tended to retain much of their original form. Despite these changes in form made by the meteorologists, the overall isobar gradient patterns for the forecasts were adjusted to preserve the fluid-like character of the display.

The results of this investigation supported the earlier findings that nonmeteorologists' mental representations of a weather map are essentially confined within the boundary of the map while for the meteorologists they extend into the surrounding meteorological context. In addition, it seems that the nonmeteorologists' mental models of dynamic aspects of weather maps are highly simplistic and lacking in appropriate constraints on the form and movement of markings. These deficiencies are likely to be the result of nonmeteorologists' lack of experience with the temporal changes that occur across a sequence of weather maps. In contrast, professional meteorologists would have built up rich knowledge structures about weather map dynamics as a result of their long experience in daily forecasting activities.

If beginning students of meteorology are to obtain more instructional benefit from the weather maps they meet in their studies, perhaps they need to develop mental representations that are more consistent with the fundamental aspects of those possessed by professional meteorologists.

7.11 Summary and implications

The investigations reported here studied perceptual and interpretative processing from which inferences were drawn regarding the mental representation of weather maps. The results provided evidence that the nature of this mental representation varies greatly with meteorological expertise. The representational differences found between meteorologists and nonmeteorologists were indicated consistently across different types of tasks (copying, sorting, extending, and predicting), suggesting that they are not methodological artifacts. Knowledge appeared to play a dominant role in participants' performance on weather map processing tasks, which is as would be expected, considering the abstract nature of this type of depiction. A contrast between the dominance of either meteorological (domain-specific) knowledge or visuo-spatial (domain-general) knowledge with meteorologists' and nonmeteorologists respectively was consistently indicated across the various studies. Another major difference was in the far more elaborate knowledge structuring that was apparent for the meteorologists, with rich, hierarchical, and extensively interconnected networks linking basic visuo-spatial information through to high-level meteorological structures. The meteorologists' structuring extended to include the wider context beyond the weather map area itself. The nonmeteorologists' knowledge structures were impoverished, decontextualized, and lacking in an appropriate temporal dimension.

Although the studies reviewed here focussed upon questions about the processing of weather maps, it should be important to ask similar fundamental questions across a whole range of remote sensing domains. This is because there are many characteristics shared by remote sensing displays as a class due to the nature of their referents, the way information about these referents is depicted, and the perceptual/interpretative tasks required of those who use these displays. Both the theoretical framework supporting this program of weather map research and the novel methodologies developed to address the questions raised appear quite broadly applicable, even to remote sensing domains that are superficially very different from those of weather maps. A recent example of adaptation of these approaches is the work of Hoffman[1] who applied methodologies formerly used with weather maps to the study of expertise in processing meteorological satellite imagery. This is a significant step because weather maps and satellite images are superficially very different in terms of their graphic characteristics. Despite these differences, the investigations with satellite images have produced findings that are generally consistent with the theoretical frameworks developed during the studies of weather maps.

As was mentioned in the introduction to this chapter, the underlying motivation for this program of research was the desire to improve the efficiency with which students of meteorology develop weather map interpretation skills. The consistent and complementary pattern of findings that emerged from this research suggested possible training interventions that could help students develop these skills more rapidly than via conventional university instruction. Such interventions would target the specific knowledge differences found between experts and novices with a view to providing students with a more extensive, powerful, and meteorologically appropriate mental representation of weather maps. The anticipated benefit from this type of training is that it would provide students with a short cut whereby they could partly bypass the traditional route to development of expertise (i.e., the type of experience-dependent component of expertise that practicing meteorologists currently acquire only as a result of years of working in their profession). However, beyond its specific potential to improve students' weather map skills, we can speculate that there could be much broader application of this type of research to in-service training of professionals in a whole variety of domains that already use remote sensing displays. This would be especially valuable when new display types are introduced or when more advanced interpretative techniques are developed.

As a result of the studies, interactive animated training was developed to address the fundamental differences found in the way meteorological experts and novices dealt with static weather maps.[7] It portrays temporal changes that occur across a sequence of weather maps and was developed to help meteorological novices build more sophisticated meteorological knowledge structures. The intention was to improve the way they conceptualized individual static weather maps to better equip them for performing interpretative tasks such as prognosis.

The animation provided novices with opportunities to explore the behavior of meteorological features and so confront their simplistic preconceptions about meteorological dynamics. Underlying this approach was the assumption that it would provide a route by which they could improve the quality of their meteorological knowledge structures via an upgrading process that worked through a series of intermediate mental models.[5] Because the training was designed to promote free exploration of weather map sequences, it allowed each user of the animation to follow an individually appropriate pathway for upgrading his or her mental representations of this domain.

Making the dynamics of weather maps explicit via an animation has the potential to supply nonmeteorologists with the information they need to build more effective mental models. However, a recent study of the information that students extracted from the animation mentioned above suggests that it is not enough simply to supply the dynamic information that is absent from nonmeteorologists' mental representations.[9] It appears that animated material introduces perceptual and cognitive processing factors that may actually work against the development of a high-quality mental model of weather map dynamics. Because it depicts a situation that involves a high level of visual complexity, a weather map animation is also capable of imposing a taxing processing load on the viewer. When the information extracted by students interacting with the animation was examined, it was found that they were highly selective in their approach, tending to extract material that was perceptually conspicuous, rather than thematically relevant to the domain of meteorology. This selectivity involved attention to aspects that were readily noticed because of their distinctive visuo-spatial characteristics or their temporal nature. The extraction of information about visually obvious features such as pressure cells dominated, whereas that involving more subtle features such as troughs was missed.

Over and above these visuo-spatial characteristics, the dynamic properties of features provided a factor that appeared to influence the type of information extracted. For highly mobile features such as high pressure cells, trajectory information was extracted while information about internal changes to the form of the feature tended to be lacking. In contrast, for less mobile features such as heat lows, more information about internal changes tended to be extracted. This suggests that the dynamic nature of the more mobile features acts to mask the more subtle intrinsic characteristics that may nevertheless be of particular meteorological significance. There is clearly more research required to tease out the complexities involved in addressing ways to help meteorological novices become more adept at weather map interpretation. In particular, we need to know more about the ways in which they interact with both static and dynamic displays.

As previously mentioned, there are indications that the theoretical frameworks and research methodologies used in these studies of weather maps have the potential for much wider applicability. However, thus far investigations of this type have been largely confined to the domain of meteorology (and even then, to a very limited range of the display types used in that domain). It is therefore important both to probe the generalizability of these findings in other remote sensing domains as well as to investigate the many as yet unresearched aspects of the perception and interpretation of meteorological displays. Further, it is vital to extend these investigations to address the potentially far greater demands made on users by the increasingly sophisticated display types that are evolving with the rapid progress in remote sensing display technologies.

Without a principled basis for designing powerful, appropriate training, skill development in the interpretation of images will remain a slow process that requires many years to develop. With the diverse and growing range of imaging technologies at meteorologists' disposal, it is becoming increasingly impractical to rely on this gradual accretion of skills in the future.

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