Common-sense construction of causal processes in nature: A causal network analysis

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This study is concerned with structural and content features of common-sense beliefs about causal processes in nature. It is an attempt to replicate findings reported by White (1992) using a different method, causal network analysis. Subjects judged the presence and direction of causal relations among a set of entities describing various human, plant and animal parameters. Structurally, the resultant network was linear. In terms of content, human parameters tended to be dominant overall, and plant parameters tended to dominate animal parameters. Both these results replicate White's findings. Results also showed a degree of antagonism between the human and natural worlds: human increases were judged to lead to natural decreases and vice versa; on the other hand, both natural increases and decreases lead to human increases. Natural increases lead to natural increases and natural decreases to natural decreases: there was no sign of the kind of interaction between increase and decrease that would be characteristic of a natural systems view.

It is common knowledge that a certain amount of rain is necessary for plants to thrive; that a shortage of zebras means hard times for lions; that insecticide kills (some) insects. These and many other beliefs make up our common-sense causal understanding of the natural world, including human beings and their interactions with nature. The whole of nature can be viewed as a system in which any given causal link is connected with others. The characteristics and manner of operation of this system are a matter for scientific debate. Is it also the case, though, that common-sense causal beliefs about nature connect into a system or some such kind of structure?

Perhaps surprisingly, this question has received little attention in psychology. There has been research on distantly related problems such as naïve physics (McCloskey, 1983) and the developing concept of life (Gelman & Kremer, 1991; Looft & Bartz, 1969; Siegler & Richards, 1983), and also on common-sense understanding of cause and effect in several kinds of human-related phenomena such as illness and mental health (Furnham, 1988). Research on our understanding of causal processes in nature, however, appears to be limited to one set of studies reported by White (1992).

Those studies used a pair-construction method, described here by White (1993, p. 162):

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A set of file cards (84 in the first study, 64 in the second) was laid out on a table. On each card a short sentence was written describing some event or change in the natural world, such as a winter being warmer or colder than usual, the population of a certain species or type of animal or plant increasing or decreasing, and so on. The cards consisted of pairs of opposites or near-opposites, so that for every card describing a change in one direction there was a card describing a change in the opposite direction. Participants were asked to draw out pairs of these cards that they thought were causally related in some way, and to say which was the cause and which was the effect. The experimenter made a note of the choice and the cards were then returned to the table, so that either or both could be used again if the participant wished. There was no limit placed on either time or the number of pairs chosen.

In both studies the cards were designed to fall into various categories. In the first study the categories were the weather, human activities, animals and plants. A fifth category, physical processes, was also included, but this was a miscellany of different types of things (including cards referring to the ozone layer, floods, etc.), and will not be discussed here. In the second study temperature, water (rain, clouds, etc.), plant and animal cards were used. It is possible to ask, for pairs which relate one category to another, whether there is any overall pattern into which those pairs fall. Specifically, I (White, 1992) considered two kinds of hierarchical patterns, an Aristotelian unidirectional hierarchy and a two-way systems hierarchy. In an Aristotelian unidirectional hierarchy there is a seat of power at the top of the hierarchy and causal influence proceeds down through the levels of the hierarchy to the bottom, but not up. The top level is therefore a causal origin operating in a manner like, or analogous to, the operation of free will, and is not affected by anything lower in the hierarchy. In a two-way hierarchy such as a systems hierarchy, any given level receives inputs from and gives outputs to any adjacent level, so that no level has control of the hierarchy as a whole, and no level is immune to influence from at least some other levels. The results of both studies revealed a strong tendency towards a unidirectional hierarchy. In the first study weather and human activities were at the top, plants in the middle, and animals at the bottom. Weather and human were independent of each other: there were no human–weather links and four weather–human links. Causal links that violate the directionality in this hierarchy accounted for only 5.32 per cent of all pairs, and almost all of these were animal–plant pairs. This pattern is consistent with the Aristotelian model and inconsistent with the systems approach: the latter requires a two-way hierarchy in which no level has absolute control, and the results showed that the hierarchy was not two-way to any significant extent. In the second study the tendency to unidirectionality in the hierarchy was even more pronounced. Again, weather was at the top, plant events in the middle, and animal events at the bottom, and only 3.9 per cent of pairs chosen violated this unidirectionality.

It is perhaps not surprising that people would place weather at the top of the hierarchy, since opportunities for living things to exert a significant influence on the weather are limited, and weather also represents the entry of energy to the natural system from external sources (ultimately the sun). Within the domain of living things, however, the dominance of humans over plants and plants over animals was striking. I illustrated the point with the relation between the insect population and insecticide: 'what more obvious reason for spraying farms with insecticide could there be than an increase in the population of more species of insects?' (White, 1992, p. 75). Yet only one subject produced a pair in which insects were the cause...
and change in insecticide use was the effect, whereas there were 19 instances of the opposite causal direction.

It is also possible to investigate the kind of causal structure that emerges at the level of individual items. Suppose a participant chooses a pair in which card 1 is cause and card 2 is effect. That participant may at some other time choose a pair in which card 2 is the cause and some other card is the effect, making in effect a two-link causal chain. For the first study, with 84 cards, any of the remaining 83 cards may be chosen as the effect. This means that 82 of the possible choices make a linear chain and one (card 1) makes a feedback loop (1–2–1). Longer chains may also be constructed, but the basic principles are the same. Given that we know how many chains have been produced and how long each chain is, it is possible to calculate how many feedback loops should occur by chance, and to compare this chance expectation with the number actually observed.

In the first study 338 chains were produced. Of these, 337 were linear and one was a feedback loop. The number of feedback loops expected by chance is 5.96. This chance expectation is rather small, and this was one reason for decreasing the number of cards from 84 to 64 in the second study: with fewer cards, more and longer chains should be produced. In the second study 1275 chains were produced, of which 1249 were linear and 26 were feedback loops. The number of loops expected by chance was 75.78. There is no easy way to calculate the statistical significance of the observed departure from chance expectation, but it is clearly a highly improbable result. These results thus show, not only that the chains observable in the sets of pairs produced by individual participants tend overwhelmingly to have a linear quality, but that people produce far fewer feedback loops than would be expected by chance.

A loop of the form card 1–card 2–card 1 is a positive feedback loop. That is, it describes a process which, unless interfered with, will run away to an extreme (e.g. total extinction of a species). In nature, states of affairs are often maintained by negative feedback loops (exemplified by the operation of a thermostat). Construction of representations of negative feedback loops is comparatively difficult with this methodology, and requires the use of four cards linked in a particular way. Not surprisingly, therefore, almost all of the loops produced were of the simpler, positive feedback kind. Only one negative feedback loop was produced, and this by a man who had a degree in physics, understood the concept of negative feedback, and deliberately set about constructing such a loop. It would be premature to conclude that most people have no understanding of negative feedback; however, there may be other methods which would make it easier for them to show what understanding they have.

The items in the second study were also designed to investigate the expression of cyclic structures in people’s beliefs about natural processes. For example, the animal and plant cards were divided into subcategories constituting simplified versions of the food chain. One version had three categorical levels (plants, plant-eating animals and carnivores), and one version had four levels (plants, plant-eating insects, insect-eating animals and carnivores). The idea was to see whether participants produced causal chains which traversed a complete cycle of one of these food chains. For the three-level food chain this would require a causal chain of at least four pairs, and for the four-level food chain a causal chain of at least six pairs. The traverse of the cycle was not required to be an exact loop, in the sense of ending with the same card with
which it began: ending in the same subcategory was sufficient. For example, a chain beginning with a plant item could end with any plant item and still qualify as a traverse of the cycle.

As stated above, 1275 causal chains were produced in this study, and of these 754 were at least four pairs long. In fact, since many chains were longer than this and the longest contained 13 pairs, this number somewhat underestimates the potential number of complete traverses of the food chain. Despite this, only two of the chains traversed the complete food chain (both involving the three-level chain). There is no easy way to calculate the number expected by chance, but it hardly matters when the number observed is so small.

Taken together, these findings show no evidence for any appreciation of cyclic processes in nature, and reinforce the impression of an overwhelmingly linear construction of causal chains. I (White, 1992) interpreted these findings as consistent with the hypothesis that people understand causal processes in nature as involving the operation of powers of things (White, 1989, 1993). The Aristotelian concept of a one-way causal hierarchy requires a notion of causation as the operation of a power as the means by which elements lower down the hierarchy are controlled and directed by those above. The presence of Aristotelian hierarchies in common-sense causal structures is therefore consistent with, and grounded in, a basic concept of causation as involving the operation of powers of things. I (White, 1992) interpreted other features of the results as supporting this interpretation.

One problem with the pair-construction method is that the number of possible pairs is very large, and subjects are likely to halt before they have exhausted their repertoire of causal beliefs. The danger is that the trends observed may say more about how subjects make choices from the array than about the structure of beliefs in their heads. They may, for example, concentrate on items that, for one reason or another, are relatively salient. Faced with a large and complex array, people may choose some simplifying strategy for dealing with it. If this happens, simpler kinds of structures may be more likely to emerge, and there is no doubt that linear chains are simpler structures than the complex interaction networks characteristic of natural systems (Laszlo, 1972). The possibility remains that if subjects had continued until they had exhausted their repertoire of causal beliefs for the cards in the array, more complex, interactive, systems-like causal structures might have emerged.

The main aim of the present study is therefore to test the hypothesis that beliefs about causal processes in nature fall into linear and unidirectional structures, using a method that does not suffer from the problems of the pair-construction method. The method to be used is causal network analysis. Network analysis of causal beliefs was pioneered by Lunt (1988) in a study of perceived causes of failure. Network analysis is a way of depicting a set of entities and links between them. For example, in Lunt (1988) the entities were possible causes of failure, such as having little intelligence, poor concentration, etc., and the links were judged causal relations. Lunt’s study revealed a structure of interrelations between the various factors. For instance, little intelligence was causally related to poor concentration, and both were deemed to lead to poor time allotment; but little intelligence and being physically sick were not directly related. In general, Lunt (1988) found that stable causes of failure tended to lead to unstable causes of failure.
In this study the entities will be defined changes in certain human and natural parameters and the links will again be judged causal relations. For a causal network analysis of this sort, subjects must make a judgement about every possible paired comparison between entities. This means that the study must be limited to a smaller number of entities than I used previously (White, 1992); in fact Lunt (1988) used only eight entities, although it is not impractical to use a larger number than that. The advantage, however, is exhaustive investigation of beliefs about all the entities included. Factors which may have affected choice of pairs in the pair-construction method are therefore ruled out by this method.

Causal network analysis has potential problems of its own. In Lunt’s (1988) study subjects were simply asked to indicate whether a given causal link between entities was possible or not. Pilot work for the present study indicated two possible dangers with this approach. Some pilot subjects reported that they found it hard to judge anything as not possible, since there could always be some unusual circumstance under which a certain link might occur. Other pilot subjects reported that the requirement to judge all possible links suggested possibilities to them which they had never previously considered. Obviously, a method that interferes with its object of study to this extent cannot be considered internally valid. In later studies (Lunt, 1991; Lunt & Livingstone, 1991) these problems were effectively circumvented by the use of a likelihood rating scale. With such a scale, unusual possibilities, or possibilities which subjects had not previously considered, would be accorded a low likelihood rating which would suffice to exclude them from the causal network.

In this study a quantitative judgement is also used, with the same effect. Subjects are told that a given amount of change had occurred on some parameter and are asked to judge the amount of change this would cause on each of the other parameters. The amount of change specified in the cause is held constant at 30 per cent. So, for example, subjects might be told that the amount of forest in the area increased (or decreased) by 30 per cent, and they then estimate the effect of this on each of the other entities. They are asked to say whether there would be an increase, a decrease or no change, and for the former two to give an estimate of the amount. The estimate is not used in the construction of the causal network, which is based only on the numbers of subjects endorsing a given kind of change, but is used in other analyses to be reported in the results section. The method does not suggest any particular possibility to subjects, because all three possibilities (increase, decrease and no change) are explicitly presented in the materials. This kind of judgement also avoids the danger that subjects may be unwilling to say that anything is impossible, because a judgement that no change will occur is not the same as a judgement that no change is possible.

Other potential problems with causal network analysis concern the method of selection of items for inclusion. For example, Lunt (1991) ran a causal network study of perceived causes of loneliness. Items were quite properly selected for inclusion on the basis of the findings of past research on people’s beliefs about causes of loneliness. The problem this can pose for a causal network study, however, is that it omits causally relevant factors that may either alleviate loneliness or act against the factors that are judged to cause loneliness. The result, inevitably, is a network representing a kind of vicious circle in which negative factors all interact to exacerbate each other.
In the present context the main danger is that this may produce a network which is unidirectional and linear, simply because the half of the network which acts in the opposite direction has been omitted because of the policy of item selection. In the present study this danger is eliminated by using stimulus materials in which changes in both directions (increase and decrease in this case) are presented both as causes and as possible effects for all items. This allows people to produce a network possessing system or negative feedback properties, even with a comparatively limited number of items.

The final problem for this method is that the items selected do not constitute a closed system. This problem is ineluctable because there is no such thing as a causally closed system, except for the entire physical universe. There is therefore a danger that the structural characteristics of the network may be affected by the omission of causally relevant items. If one item in a causal loop is missing, the remaining items will inevitably appear to be arranged in a linear pattern. The best way to combat this problem is to choose for inclusion items that are the most general and fundamental for the domain of inquiry, because this is in effect to include everything in the domain, only at a relatively high level of description. This criterion was used to select the plant and animal parameters, and two of the human parameters, for this study. For plants and animals these parameters identified general kinds of plant environment and animal and the most easily quantifiable properties, population size and diversity. The parameters chosen for plants were amount of forest, amount of grassland, amount of land without significant plant cover, and number of plant species. The parameters chosen for animals were population of plant-eating mammals, population of carnivores, population of insects, and number of animal species. For human activities two entities were chosen as equivalent to the plant and animal parameters in terms of generality: these were human population and amount of farmland (in the scenario presented to subjects farming was identified as the only significant human occupation in the area under consideration). The remaining two human activities were chosen for their possible relation to the plant and animal worlds respectively: use of fertilizer and insecticide. With the exception of land without significant plant cover, all of these entities had been included in the items used by White (1992), with minor differences in wording, and all had been among the most commonly chosen items. Because they are both general and fundamental parameters, and because of the evidence that they are frequently chosen in the pair-construction method, these 12 entities are suitable choices for inclusion in a causal network analysis.

Twelve entities, each both increasing and decreasing (as both cause and effect), gives a causal network with a maximum of 24 nodes. The method enables the investigation of both structural and content features, and it should therefore be possible to show whether the findings of White’s (1992) studies prove to be reliable with a different method.

Method

Subjects

The subjects were 50 first-year undergraduate students of subjects other than psychology at University of Wales College of Cardiff, who were recruited by means of advertisements around the campus and paid. There were 26 women and 24 men, with a mean age of 21.8 years (range 18–31).
Materials and procedure

The 12 entities selected for this study, as presented to the subjects, were as follows: (a) Human: human population, amount of farmland, use of insecticide, use of fertilizer. (b) Plant: amount of forest, amount of grassland, amount of land without significant plant cover (identified as ‘desert’ in this paper), number of species of plants. (c) Animal: population of carnivores, population of plant-eating mammals (identified as ‘herbivores’ in this paper), population of insects, number of species of animals.

The task was presented to subjects in the form of a questionnaire. The first page introduced the task with the following written instructions:

I would like you to imagine a large area of the environment, say about one hundred square miles. The area contains roughly equal amounts of forest, grassland, and farms. There is also a certain amount of waste land, that is, land with few or no plants growing on it. People live on the farms, but there are no towns or cities in the area. The climate is temperate, similar to Britain’s. Other than that, you needn’t worry about where in the world it is.

I am interested in your beliefs about how changes to one aspect of this environment may affect the rest of it. On each of the following pages you will see, at the top, some change described. The amount of the change is always given as 30 per cent: this is just a convenient figure with no special significance. Only the type of change varies from one page to the next. Under each change are listed a number of other things that may or may not change as a result of the change described at the top of the page. I would like you to estimate how much of an effect the change will have on each of these other things.

As you will see, each thing is accompanied by the words ‘increase’, ‘decrease’ and ‘no change’ (have a look at the next page now to see what I mean). I would like you to decide whether there will be an increase, a decrease or no change. When you have decided, put a circle round the one you’ve chosen. If you have chosen increase or decrease, please also put your estimate of how much change will occur. You should do this by giving a percentage estimate, from 1 to 100 per cent (0 per cent would be no change, of course).

It isn’t easy giving an exact percentage judgement, but please do the best you can, basing your judgements on your understanding of the environment and how it works. This is not a test and there are no right or wrong answers: I’m simply interested in the kind of understanding people have of these things.

You may look back at these instructions whenever you wish. However, please do not look back and forth through your judgements. When you have completed all the answers on one page, please move on to the next and do not look back at judgements you have already made. Don’t worry about whether you’re being perfectly consistent or not: I’m not at all interested in that. Just make each judgement as you come to it, as best you can. Please make sure that you answer all the questions and don’t miss any out. Please check through when you get to the end to make sure that you have done this.

Please feel free to ask questions if anything in these instructions is not clear.

One page of the questionnaire was devoted to each change. At the top of the page subjects would see an underlined statement of a change in a parameter, such as ‘the amount of forest in the area increases by 30 per cent’. This form of wording was used throughout: the change was always 30 per cent, and was always either an increase or a decrease. With 12 entities, each both increasing and decreasing, the questionnaire was therefore 24 pages long (not including the instructions). Entities were randomly ordered, both as cause and as effect.

Beneath the stated change each of the other 11 parameters was listed. Under each of these the three terms ‘increase’, ‘decrease’ and ‘no change’ were given. Lines were used to separate items from each other, so that there was no ambiguity over which set of terms was for which parameter.

Subjects proceeded through the questionnaire at their own pace. One subject checked on the meaning of the word ‘carnivorous’; two others asked whether they should make judgements of direct effects of the change only, or whether indirect effects were also permitted (they were told to judge only direct effects). There were no other questions. Altogether, 53 subjects were run, but three were withdrawn before analysis for failing to complete the questionnaire according to the instructions (one gave no percentage estimates, the other two each omitted one page, presumably by accidentally turning over two
together). These errors were not detected until after the subject had departed. At the end each subject was paid and thanked, and the experimenter discussed the study with them. No subject reported any difficulty with the task.

**Results**

*Causal network analysis*

For the causal network analysis the quantitative estimates were disregarded, and only the direction of change (increase, decrease or no change) was recorded. The data from each subject therefore consisted of a 24 (cause) × 11 (effect) matrix. Any given cell in the matrix could contain either + (judged increase), − (judged decrease) or 0 (judged no change). Scoring judged increase as +1 and judged decrease as −1 enables a net score to be calculated across subjects for each cell of the matrix. For example, for the cell representing *increase in amount of forest* as the cause and *population of carnivores* as the effect, 39 subjects judged an increase, three judged a decrease, and the remainder (eight) judged no change. This yields a net score of +36 (39−3). This means that the causal relation *forest increase–carnivore increase* has a net score of 36. These net scores formed the basis for the construction of the causal network.

Lunt (1988) proposed two criteria for selecting links to be included in the causal network. One is the ‘minimum system criterion’. This is the highest value (net score in the present case) at which all entities are included in the network with at least one link. The rationale behind this criterion is the assumption that all the entities form a single system. This may not be the case, however. If some entities do not form part of a system including the others, or if there is more than one system, then an empirical sign of this can be found by plotting number of links against link strength (net score). Separation between systems is indicated if there is an entity such that adding that entity to the network incurs a large cost in terms of the number of other links that must also be added. By this criterion Lunt (1988) found that one entity in his materials was separate from the rest, and this entity was not included in the network.

In this study the minimum system criterion was a net score of 34. There are two points above this figure where a case could be made for separation between systems. One comes at a net score of 40, where adding the next entity to the system costs 12 links. There are four reasons, however, why this would not be a good choice of criterion. (a) It would mean excluding links which have a high rate of endorsement: a net score of 39 means endorsement by at least 78 per cent of subjects, and the network could not be said to represent commonly held beliefs if it excluded such commonly endorsed links. (b) It would mean excluding six entities from the network, with consequent loss of information about their links with entities included in the network. (c) The criterion results in a network with only 18 links, and two of these are not attached to any of the others. This suggests that the system is not complete at this level. (d) If this network underrepresents commonly held beliefs then it is also likely to oversimplify the organization of those beliefs. It would be better to construct a network with a greater number of links, data permitting, because this increases the chance that non-linear structures actually present in common-sense beliefs would be revealed.
The other point comes at a net score of 35, where adding the next entity costs 11 links. This is a large cost. For comparison, Lunt (1988) excluded one entity with a cost of 10 links. Adding the next entity in this study would cost only five links. This is evidence that the score of 35 marks a real point of separation between systems. In addition, with 35 as the criterion only one entity is omitted from the network. This is decrease in land without significant plant cover. The network was therefore constructed using links at and above the criterion of net score of 35. The 38 links included in the network were all endorsed by at least 70 per cent of subjects, so each can claim to represent a commonly held belief.

A network with 23 entries and 38 links cannot easily be accommodated within one figure, but as it happens the network falls into two halves, connected by a single link. For this reason, the network is shown in two figures, Figs 1 and 2, with the connecting point indicated in each.

The figures represent entities classified as top, middle and bottom. Top entities are those with no causal antecedents in the network. Middle entities are those with both antecedents and effects. Bottom entities are those with causal antecedents but no effects.\(^1\) The main features of both structure and content of this network will now be described.

**Structural features.** The main structural feature of the network is pronounced linearity. This can be ascertained by choosing an arbitrary starting point and tracing a path through the network. Such a path will always take a course in the same direction to a definite terminus. One path includes a recursive loop involving *animal species decrease* and *herbivore decrease* (a positive feedback loop). There is no other recursive path in the network: all others are unidirectional and linear. This feature replicates the findings of White (1992) using the pair-construction method: as described in the introduction, almost all causal chains constructed in that study, and considerably more than would be expected by chance, were unidirectional linear chains.

**Content features.** The most striking feature of the network is the general tendency for human parameters to come at the top of the network, plants in the middle, and animals at the bottom. There are exceptions. *Fertilizer increase* and *fertilizer decrease* are both at the bottom, but both have only human causal antecedents, so do not violate the human–plant–animal hierarchy. Some plant parameters come at the top of the hierarchy, but have fewer direct effects, and tend to feed into lower levels of the hierarchy, than the human top entities. This hierarchical ordering, human–plant–animal, also replicates the findings of White (1992).

The network also shows, however, that the place of an entity in the network depends not only on its category membership but also on its particular identity. The top of the hierarchy is occupied specifically by *human population*, and even other human parameters come below this. The bottom of the hierarchy is occupied by *carnivores*, and other animal parameters come above it.

\(^1\) The terms ‘distal’, ‘mediating’ and ‘proximal’ have also been used (Lunt, 1988; Lunt & Livingstone, 1991). Since ‘distal’ means ‘away from centre of body or attachment; terminal’, and ‘proximal’ means ‘situated towards centre of body or of point of attachment’ (from the Concise Oxford Dictionary), I am not convinced that they are entirely appropriate or unambiguous in application to a causal network, and I therefore prefer the terms used in this paper.
Two further features of content are worthy of comment. One is the apparent antagonism of the human and natural worlds. Figure 1 shows human increases leading to decreases in natural parameters; Fig. 2 shows human decreases leading to increases in natural parameters. This feature is further investigated with quantitative analysis, reported below. The other feature is that, if human parameters are left out
Figure 2. Right half of causal network.
of the account, there are in fact two separate causal networks of natural parameters: a linear increase network (Fig. 1) and a linear decrease network (Fig. 2). This will also be investigated quantitatively: for now, it is relevant to observe that the evident separation of these two networks reinforces the notion that the common-sense construction of causal beliefs about nature does not resemble a natural system, for in such a system increases and decreases would be integrated in processes of feedback control.

Quantitative analyses

Subjects gave percentage estimates of the amount of change in each parameter that would follow from each cause. Many analyses could be carried out on these judgements. Most of them would not be meaningful, however, because of the danger that they reflect nothing more than the particular choice of entities for this study. Finding, for example, that estimates of effects of human population changes are greater than estimates of effects of carnivore population changes might turn out not to generalize beyond the effect parameters used in this study.

Some analyses, however, do not suffer from this problem. The amount of change specified in the causal statements was held constant at 30 per cent, and, moreover, for each entity both increase and decrease were included in the causal statements. One might therefore expect that for each entity the net change would be zero. For example, if increasing human population by 30 per cent is judged to lead to a 15 per cent reduction in amount of forest, then one might expect that decreasing human population by 30 per cent would be judged to lead to a 15 per cent increase in amount of forest, the two changes cancelling out. In fact most entities suffered a net change. For any given entity, say amount of forest, there are two scores per subject: the sum of judged increases across all causes, and the sum of judged decreases across all causes. These scores can be compared across subjects for each entity to investigate whether there is a significant difference from zero net change. These comparisons were carried out using the t test for related means, and results are listed in Table 1.

Table 1 shows a consistent tendency for human parameters to show increases. Effects for natural parameters are more mixed: forest, desert, carnivores and animal species show net decreases, whereas insects show a net increase and no significant trends emerge for the other parameters. Applying the Bonferroni correction would mean adopting a significance level of .005, with the consequent loss of the results for forest, carnivores, animal species and human population. On the other hand, with 12 comparisons, less than one significant result would be expected by chance, against the nine observed (at $p = .05$), and the marginally significant results suggest phenomena worthy of investigation in further studies.

For each entity, it is also possible to compare the amount of change that entity is judged to cause in the others (for example, 30 per cent change in amount of forest might be judged to lead to a mean of 10 per cent change in the other 11 entities) with the amount of change it is judged to undergo as a result of changes in the other entities (for example 30 per cent change in each of the other 11 entities might be judged to lead to a mean of 15 per cent change in amount of forest). The comparison is essentially a doer vs. done-to comparison, the power of the entity to cause change versus its
Table 1. Net change in entities as effects of changes in other entities

<table>
<thead>
<tr>
<th>Entity</th>
<th>t</th>
<th>p</th>
<th>Direction of change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human population</td>
<td>2.078</td>
<td>&lt; .05</td>
<td>Net increase</td>
</tr>
<tr>
<td>Farmland</td>
<td>4.695</td>
<td>&lt; .0001</td>
<td>Net increase</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>3.367</td>
<td>&lt; .005</td>
<td>Net increase</td>
</tr>
<tr>
<td>Insecticide</td>
<td>5.038</td>
<td>&lt; .0001</td>
<td>Net increase</td>
</tr>
<tr>
<td>Forest</td>
<td>2.164</td>
<td>&lt; .05</td>
<td>Net decrease</td>
</tr>
<tr>
<td>Grassland</td>
<td>0.186</td>
<td>&gt; .05</td>
<td>—</td>
</tr>
<tr>
<td>Desert</td>
<td>3.615</td>
<td>&lt; .001</td>
<td>Net decrease</td>
</tr>
<tr>
<td>Plant species</td>
<td>0.215</td>
<td>&gt; .05</td>
<td>—</td>
</tr>
<tr>
<td>Carnivores</td>
<td>2.174</td>
<td>&lt; .05</td>
<td>Net decrease</td>
</tr>
<tr>
<td>Herbivores</td>
<td>1.841</td>
<td>&gt; .05</td>
<td>—</td>
</tr>
<tr>
<td>Insects</td>
<td>3.915</td>
<td>&lt; .001</td>
<td>Net increase</td>
</tr>
<tr>
<td>Animal species</td>
<td>2.602</td>
<td>&lt; .02</td>
<td>Net decrease</td>
</tr>
</tbody>
</table>

*Note.* d.f. = 49 in each case.

Table 2. Power versus liability comparisons for each entity

<table>
<thead>
<tr>
<th>Entity</th>
<th>Power</th>
<th>Liability</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human population</td>
<td>363.38</td>
<td>112.92</td>
<td>79.185</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Farmland</td>
<td>337.06</td>
<td>241.84</td>
<td>19.802</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>210.06</td>
<td>222.30</td>
<td>0.514</td>
<td>&gt; .05</td>
</tr>
<tr>
<td>Insecticide</td>
<td>208.92</td>
<td>279.34</td>
<td>17.177</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Forest</td>
<td>297.10</td>
<td>198.18</td>
<td>25.17</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Grassland</td>
<td>231.00</td>
<td>250.56</td>
<td>2.828</td>
<td>&gt; .05</td>
</tr>
<tr>
<td>Desert</td>
<td>247.00</td>
<td>247.98</td>
<td>0.005</td>
<td>&gt; .05</td>
</tr>
<tr>
<td>Plant species</td>
<td>222.94</td>
<td>270.62</td>
<td>5.682</td>
<td>&lt; .05</td>
</tr>
<tr>
<td>Carnivores</td>
<td>169.72</td>
<td>215.66</td>
<td>8.736</td>
<td>&lt; .01</td>
</tr>
<tr>
<td>Herbivores</td>
<td>206.20</td>
<td>294.60</td>
<td>30.292</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Insects</td>
<td>187.40</td>
<td>335.02</td>
<td>48.710</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Animal species</td>
<td>223.78</td>
<td>239.94</td>
<td>0.490</td>
<td>&gt; .05</td>
</tr>
</tbody>
</table>

*Note.* d.f. = 1, 49 in each case.

liability to be changed. In this case it is the gross change that is of interest, i.e. the amount of change, not the direction of change. This will be termed a ‘power versus liability’ comparison. This comparison was carried out for each entity with a one-way analysis of variance with repeated measures. Means and results are reported in Table 2. The means shown are of scores per subject, i.e. summed across entities. The mean change per judgement per subject for a given entity would be the figure given in Table 2 divided by 22 (11 other entities, each with increase and decrease versions).
Not surprisingly, the entities near the top of the causal network are also those judged to have more power than liability to change, and those near the bottom of the network are also those judged to have more liability than power to change. It is striking, however, that most of the entities turn out to be either ‘doers’ or ‘done-to’s’: eight out of 12 differences are statistically significant at \( p = .05 \), against a chance expectation of less than one, and most of those are very strongly significant. A similar finding was reported by White (1992, Figs 1 and 5). This is consistent with a notion of nature (and human activities) as organized in a roughly unidirectional causal hierarchy.

The remaining tests investigate phenomena observed in the causal network. It was noted there that human parameters tended to fall near the top of the network, plant parameters in the middle, and animal parameters at the bottom. This pattern resembles the categorical hierarchy found by White (1992). The tendency can be assessed by comparing causal relations across categories. For example, the mean effect of plants on animals can be compared with the mean effect of animals on plants. If plants are above animals in a categorical hierarchy, then the former should be greater than the latter. The relevant means are presented in Table 3. These are gross scores because decreases were added to, not subtracted from, increases: it is the amount of change, not the direction of change, that is of interest.

**Table 3. Paired comparisons between categories**

<table>
<thead>
<tr>
<th>A-B Cause</th>
<th>Effect</th>
<th>Mean</th>
<th>B-A Cause</th>
<th>Effect</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human</td>
<td>Plant</td>
<td>391.54</td>
<td>Plant</td>
<td>Human</td>
<td>295.60</td>
</tr>
<tr>
<td>Human</td>
<td>Animal</td>
<td>391.62</td>
<td>Animal</td>
<td>Human</td>
<td>221.44</td>
</tr>
<tr>
<td>Plant</td>
<td>Animal</td>
<td>394.02</td>
<td>Animal</td>
<td>Plant</td>
<td>265.38</td>
</tr>
</tbody>
</table>

*Note.* Means are per subject, summed across links.

Adjacent pairs in this table were compared with one-way analyses of variance with repeated measures. All differences were significant. For human–plant versus plant–human, \( F(1, 49) = 18.984, p < .001 \). For human–animal versus animal–human, \( F(1, 49) = 36.346, p < .001 \). For plant–animal versus animal–plant, \( F(1, 49) = 26.226, p < .001 \). These results confirm the notion of a causal hierarchy with human parameters at the top, plants in the middle, and animals at the bottom. As Table 3 shows, the categorical hierarchy is not exclusively unidirectional, as a pure Aristotelian hierarchy would be; it does nevertheless show a kind of dominance hierarchy of the different categories.

Finally, it was noted that the causal network shows a degree of antagonism between human and natural parameters, with human increases tending to lead to natural decreases, and human decreases tending to result in natural increases. This was further investigated using the quantitative judgements of change. A \( 2 \times 2 \times 2 \) analysis of variance with repeated measures on all factors was carried out with the
following independent variables (apart from subjects): cause type (human vs. natural); direction of change in cause (increase vs. decrease); and effect type (human vs. natural).

The dependent variable was the judged amount of change in the effect. In each case this was a summed net score. For example, the score for a given subject for human cause, increase, human effect, was the sum of judged effects of increases in human population, farmland, fertilizer and insecticide on the same four parameters. (This makes a total of nine scores summed together, as subjects did not judge the effect of a parameter on itself.) The score is net rather than gross because decreases were subtracted from, not added to, increases. Scores could therefore be positive (net increase) or negative (net decrease). By contrast with the previous analysis, it is the direction of change, not the amount of change, that is of interest here.

There were several significant effects. There was a main effect of cause type, with higher scores for natural than for human causes ($F(1, 49) = 6.57, p < .05$). There was a significant main effect of effect type, with higher scores for effects on human parameters than on natural parameters ($F(1, 49) = 16.68, p < .001$).

There was a significant two-way interaction between cause type and cause direction ($F(1, 49) = 21.90, p < .001$). Under this interaction, increases result from human decreases and natural increases, and decreases result from human increases and natural decreases (all simple effects comparisons were strongly significant). There was also a significant two-way interaction between cause direction and effect type ($F(1, 49) = 61.48, p < .001$). Under this interaction, increases result in human increases and natural decreases, and decreases result in natural increases and human decreases (again, all simple effects comparisons were strongly significant).

There was also a significant three-way interaction ($F(1, 49) = 81.59, p < .001$), and it is this interaction that gives the clearest picture of the judged relation between the human and natural realms. The means for this interaction are presented in Table 4.

<table>
<thead>
<tr>
<th>Effect type</th>
<th>Human cause</th>
<th>Natural cause</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Increase</td>
<td>Decrease</td>
</tr>
<tr>
<td>Human effect</td>
<td>$+175.50$</td>
<td>$-118.56$</td>
</tr>
<tr>
<td>Natural effect</td>
<td>$-217.24$</td>
<td>$+196.58$</td>
</tr>
</tbody>
</table>

This table shows a pattern that is simple to describe. For human causes, increases lead to increases for humans and decreases for natural parameters; the opposite holds for decreases. For natural causes, however, increases lead to increases for both human and natural parameters; decreases lead to decreases for natural parameters, but to increases for human ones. Paired comparisons show that all but two of the components of this interaction are strongly significant. The two non-significant comparisons involve natural increases, where the difference between human and
natural effects is not significant, and effects of natural changes on human parameters, where the differences between natural increases and natural decreases is not significant.

This interaction also confirms another feature noted in the causal network: for natural parameters, increases lead to increases and decreases lead to decreases. As already noted, this is contrary to a systems view, in which equilibrium is maintained by negative feedback processes. If nature actually worked according to this commonsense representation, in no time at all any increase would result in explosive increase in related parameters, and any given decrease would result in catastrophic decline. There would be no remediation of either direction of change, once begun.

Discussion

The causal network constructed in this study shows that common-sense beliefs about causal processes in nature are organized in a linear, unidirectional structure with no evidence of system-like constructions. This finding replicates that of White (1992). The convergent validity of these studies using different methods constitutes a case for taking seriously the claim that these structures do indeed represent the organization of causal beliefs in common sense.

This linearity is particularly surprising in view of the fact that there were at least two fairly obvious opportunities for the creation of negative feedback loops: (a) herbivore increase–carnivore increase–herbivore decrease–carnivore decrease–herbivore increase; (b) insecticide increase–insect decrease–insecticide decrease–insect increase–insecticide increase. In the latter case three of the four links are included in the network, but the net score for the fourth (insect decrease–insecticide decrease) was well below the criterion for inclusion. In the former case only one of the four links was included in the network.

To some extent the structural features of a causal network depend on the choice of criterion for inclusion of links. With lower criteria, and consequently greater numbers of links, non-linear structures would be expected to emerge by chance alone. Conversely, it could be argued that adopting a high criterion unfairly reduces the chance of revealing a non-linear structure that is actually present in the beliefs being studied. There is little danger of this in the present study, however, because the criterion adopted meant the inclusion of 38 links in the network. (For comparison, the network constructed by Lunt (1988) had 11 links). If common-sense beliefs are really organized in a non-linear structure, it should be apparent in a network including this large number of links.

What would happen if the minimum system criterion of 34 had been adopted in this study? This would mean the inclusion of 12 extra links. As it turns out, these links all enhance the linearity already present in the system. Six of them are effects of human activities, of the same kind and in the same direction as those included in the network. Of the other six, two describe decreases in one natural parameter leading to increases in another natural parameter, but neither of them completes a feedback loop or violates the linearity present in the network. The missing entity, decrease in land without significant plant cover, enters as an effect of forest increase, but has no effects itself. The conclusion is that, even if this lower criterion had been adopted, the 50 links in the network would still constitute a unidirectional linear structure.
Quantitative analysis also replicates the categorical hierarchy found by White (1992), with humans at the top, plants in the middle, and animals at the bottom. This replication occurred despite not only the difference in method but also differences in the particular items used. This strengthens the case for the categorical hierarchy as a robust phenomenon.

In addition to this replication, some novel findings also emerged from this study. Quantitative analysis revealed evidence of a complex interaction between the human and natural realms. It is not completely accurate to say that these two realms are mutually antagonistic in common-sense understanding. Certainly people have a strong tendency to judge human increases as leading to natural decreases, and human decreases to result in natural increases. Where the causes are changes in natural parameters, however, any kind of change tends to be viewed as leading to increases in human parameters. Natural decreases lead to human increases just as much as natural increases do.

Within either realm increases lead to increases, decreases to decreases. Within the human realm this is not an unexpected finding: naturally the more people there are, the more farming is likely to go on; and the more farming goes on, the greater the use of substances that have a part to play in agriculture, in this case fertilizer and insecticide. Within the natural realm the tendency is perhaps less easy to understand. After all, an increase in carnivores might be expected to lead to a decrease in herbivores; an increase in herbivores to a decrease in the plants they eat, and so on. The evidence of this study, however, is that these antagonistic relations in the natural world are more than cancelled out by increase–increase and decrease–decrease relations. At present this is a judgemental tendency still awaiting explanation.

Finally, entities near the top of the network were judged to have more power than liability to change. This is also consistent with the hypothesis that people have an understanding of natural processes as an Aristotelian hierarchy: in such a hierarchy the top level is the source of the power that drives the system, but is not affected by the activities of things at lower levels in the hierarchy.

This study and those by White (1992) have uncovered many phenomena that appear to merit further research, particularly as several findings have occurred in both investigations. I (White, 1992) speculated that tendencies such as the evident linearity of causal chains and networks revealed in these studies might have a cultural or historical origin. The main ground for this was the resemblance between certain features of the evidence and the Aristotelian world view, under which nature is viewed as a unidirectional causal hierarchy. If this is the case then the findings might be specific to cultures that can trace their intellectual history back to ancient Greece. Different patterns might be found in cultures with other intellectual histories.

An alternative possibility is that linearity is a natural feature of all causal networks constructed in common sense, regardless of their subject matter. That is, the tendency to organize causal beliefs into linear relationships might be universal, perhaps reflecting some fundamental feature of human cognition. This seems unlikely, however, because the networks constructed by Lunt (1991) and Lunt & Livingstone (1991) were more mixed. In both cases some entities were origins, not affected by anything else in the network, which is a characteristic of a unidirectional hierarchy. At lower levels, however, entities interacted in more complex ways and
there was no entity which did not have an effect on something else in the network. If there is a natural tendency to construct linear causal structures, it can at least be overridden in belief acquisition.

A third possibility is that linearity and unidirectionality are natural characteristics of belief systems at a primitive or early stage of development (White, 1993). As more beliefs about the relevant entities are added, more interactive causal structures would be expected to emerge as a natural feature of the increasing number of beliefs relative to the number of entities in the structure. Under this possibility, people have simply acquired more beliefs relative to entities in the case of loneliness (Lunt, 1991) and personal debt (Lunt & Livingstone, 1991) than they have in the case of natural processes. This would imply that people who have acquired more beliefs about natural processes, perhaps through having a job that requires expert knowledge of such things, would also show a more complex and interactive causal structure of those beliefs.

To some extent this is a methodological issue. For any given number of entities and links, it should be possible to calculate how much tendency to linearity would be expected to occur by chance. For example, given X entities and Y links, what are the odds that one entity will be an origin, unaffected by anything else in the network? Having calculated the chance degree of linearity, it is then possible to judge whether the actual network constructed from subjects’ responses has more or less linearity than would be expected by chance. If tendency to linearity is simply a function of number of beliefs possessed, then the tendency to linearity observed will be equal to that expected by chance. If there is a natural tendency in human thought to organize beliefs into linear relationships, then the tendency to linearity observed will be greater than chance expectation. This is for future research to investigate.

It is most important to ensure that the kind of causal structure obtained is not merely a consequence of the method used. In this study, subjects were asked to imagine that a certain sort of change had occurred, and then to judge what effects would follow. Could it be that the linearity in the causal network is a consequence of being asked to make this kind of judgement? This is not possible, for two reasons. (a) There is no specified end-point: that is, subjects are not asked to construct a model of antecedents to a terminal event. Not only that, but the criterion for selection of the entities was not their prior identification as putative causes of a given terminal event (as in Lunt, 1988), but instead their generality as parameters in the domain of interest. (b) There is no point of origin, either. Everything presented as a cause is also presented as a possible effect of every other cause. The method therefore allows subjects to connect any entity to any other entity. There is therefore no reason in the method why a more complex structure such as a systems structure could not have emerged from their judgements.

Some aspects of the present findings will be disturbing to those with an interest in conservation. I (White, 1992) suggested that, in common sense, nature is viewed as a bottomless pit, in the sense that almost anything can be done to nature by human beings without repercussions for the human world. This belief is a natural consequence of the categorical hierarchy in which human activities are placed at the top: to the extent that the hierarchy is unidirectional, they are out of reach of influence from lower levels, where natural phenomena reside. This study has shown
Causal network

(see Table 4) that, where natural phenomena do affect human parameters, the effect is always an increase. If natural populations increase, so do human populations and the other parameters studied here. If natural populations decrease, human populations and other parameters still increase. As the subjects in this study understand the matter, almost nothing that happens in nature leads to decreases in human parameters. Admittedly it is hard to know whether this result would generalize beyond the particular parameters used in this study, but even the spectre of a belief that large amounts of damage to nature may have little if any deleterious effects on human life surely merits further investigation.

Common-sense understanding of cause and effect in nature, and between the human and natural realms, is an important topic, from both a scientific and a practical point of view. How humans treat the world must to some extent reflect what they believe about the effects of that treatment, for nature and for themselves. From either point of view the neglect of this topic in psychology, compared with other topics in causal understanding, is hard to understand. Hopefully the present research has yielded some useful ideas and possibilities for future studies to investigate further.

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References


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