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Causal Explanations as Mediators for Remembering Correlations[1]

by

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Running Title: Remembering Correlations

Abstract

We believe that people remember lawful correlations between two events, A and B, by constructing some causal chain in thought, linking changes in A to those in B. In consequence, correlations that the person can explain will be remembered much better than those he considers but is unable to explain. An experimental demonstration of the role of explanation in law-learning used three groups of subjects. The Control subjects simply read and classified 31 conjectured correlations. In addition, the Read subjects read an explanation of each correlation, and the Generate subjects tried to explain each correlation. An unexpected cued recall test showed highest recall for the Generate subjects, followed by Read and Control subjects. Generate subjects also recalled many more of the correlations they could explain that those they couldn't. Thus, discovery of a causal linkage between two events causes that pathway to be stored and used like a mnemonic for remembering the correlation.

Historically, when empiricist philosophers discussed the acquisition of world knowledge, the concept of association and the doctrine of associationism played a central role. The prototypic use of association was to encode or record in the mind the fact of a causal connection: the observer, noticing that event A caused event B, would record this knowledge in terms of an associative linkage between two internal representations, the idea of event A linked to the idea of event B. By extension, the concept of association became applied to all manner of empirical contingencies--to arbitrary conventions (eg., the date of Easter Sunday), to arbitrary names of things, to arbitrary orders of objects, etc. By historical accident, it would seem, when laboratory studies of associative learning commenced with Ebbinghaus, these arbitrary contrived contingencies were the materials selected to be studied. Nonsense syllables were arranged and learned in arbitrary, random orders, or syllables were put together in random ways to be learned as pairs. The aim was to construct senseless orders and pairings, so that "pure contiguity" of experience would be the sole influence in acquiring the associations. This methodology of studying memory for arbitrary, senseless pairings, has persisted throughout the 85 years of laboratory studies of memory.

Relatively few dissenting voices have been raised in opposition to this overwhelming use of arbitrary nonsense in laboratory studies. The Gestalt psychologists (e.g., Kohler, 1929; Koffka, 1935; Asch, 1968) were the primary dissenters. For example, Asch (1968) pointed out the large number of meaningful relationships that could hold between two "contents", A and B, and suggested that memory for each such relation could be studied in the learning laboratory. Thus, A could be a part of B, could imply B, could be transformed into B in various ways, could cause B, could oppose or negate B, could be an attribute of B, could be a continuation of B, could be an antecedent or consequence of B, and so on. One can imagine conducting studies--some have in fact been conducted (see Asch, 1969)--in which the materials, the A and B pairings, exemplify one or another of these relation-ships. It would be expected that if content A is "naturally related" to content B, then they will cohere in memory, and will be learned more rapidly than when the same contents are placed in an arbitrary relation to one another.

This better memory for "naturally related" contents has been demon-strated for several perceptual and conceptual relations (see the review in Hilgard & Bower, 1975, pg. 264 ff). It is frankly a puzzle as to why such naturally cohering relations are easier to learn or remember. Nothing in the modern memory theories, such as HAM (Anderson & Bower, 1973) or ELINOR (Norman, Rumelhart, and the LNR Research Group, 1975), predicts or explains such advantages. Thus, in theories which view pairwise learning as reflecting acquisition of a proposition, the relation "Content A is <u>next to</u> Content B" is just as simple and encodable as is "Content A <u>causes</u> Content B". Clearly something else is involved in differential learning of A-B pairs depending on the relation involved.

Perhaps what is involved has to do with assimilating the asserted pairings onto pre-existing cognitive schema. One important schema people use is a causal one. In the following experiment, we are concerned with how people learn and remember causal assertions of the form "Event A causes Event B". To be concrete, suppose you had to learn the following assertion: "As the price of Idaho potatoes increases or decreases, so does the weight of the Sunday edition of the New York Times." Introspect for a while on how you treat such assertions. First, the assertion is about real concepts and the events *per se* are not improbable--only their correlation or causal connection is problematical. Second, in a first quick check, you know that Event A in this case can not be a direct cause of Event B, since they are in different domains. That could mean that A is an indirect cause of B, or that both A and B are independent reflections (consequences) of a common cause (antecedent). Third, upon concluding the A-to-B connection is indirect, most people automatically search for some explanation of the connection.

Searching for a causal connection is rather similar to proving a theorem or solving any well-structured problem with a starting place (Event A) and an ending goal (Event B). The standard techniques of "means-ends" analysis would seem applicable (see Newell & Simon, 1972). To solve the problem of how Event A could cause or be correlated with Event B, the person can generate cause-effect chains forwards from Event A and effect-cause chains backwards from Event B. The goal of the search is to find an intersection of the two chains. The successive "moves" or transformations in the causal reasoning are dictated by the person's knowledge of cause-effect relations in the world. Any single event may have multiple causes and multiple effects and these may be exclusive (one only) or complementary (several simultaneously). Furtheremore, the causes may be examined several time periods (or "generations") before the event in question, and the effects examined several generations afterwards. It is this multiplicity that necessitates a difficult search in order to find a causal connection (commonly, it need not be a unique connection).

The search process terminates either if a chain is found linking A forward causally to B, or if a third event, X, is found which causes both A and B. The diagram in Figure 1 illustrates the two directions of search.

Insert Figure 1 about here

The arrows represent a direct, one-step causal link and the arrow points from the cause to the effect. Starting from the assertion that B is caused by A, the person moves to temporal and causal antecedents of B; these will be called the "parents" of B, and their collection will be called the "parent set". Event A may be the causal antecedent of B, in which case its causal "successors" are relevant, or A and B may both be a reflection of a third factor, X, in the parent sets of A and B. Successive layers of cause-effect events can be generated from each layer of nodes in this search tree, always looking for an intersection or common node. If an intersection is found in the successor set of Event A, then the explanation of the connection is a forward causal chain from A to B. If an intersection is found in the parent set of Event A, then the A to B connection is explained by a third factor, X, which has forward causation linkages to both Events A and B.

To illustrate with our example, fluctuations in the price of Idaho potatoes may cause changes in the income of Midwestern farmers, in consumer's use of Idaho potatoes, and correlated changes in use of competing food staples. These are but a few elements in the successor set of Event A. Price fluctuations may be caused by (have a "parent set" comprised of) variations in weather in the Midwest, the price of competing foodstuffs, or by inflation or recession in the general economy. Similarly, in the parent set of possible causes of varying weights of the New York Times, we could conjecture changes in the paper stock, the size of print (and hence pages), the amount of news, the amount of advertising, etc. Since we have no intersection yet, the processor generates another layer of successors or predecessors from those already generated. In this next generation, we would find that fluctuations in advertising budgets are correlated with inflation or recession in the general economy. Thus "general economy" fluctuations is in the parent set of Event B and also in the parent set of Event A. Therefore, it is an explanatory intersection: fluctuations in the general U. S. economy causes both increases in the price of Idaho potatoes and in the amount of advertising, and hence weight of, almost any newspaper, including the New York Times. The person now has a way to connect the two events in thought; he has subsumed these specific events under a more general rule (correlation) which says "Prices of foodstuffs and the amount of advertising covary with the health of the general economy". He "understands" the connection because he has used only his knowledge of relatively direct causes, and has chained them together to build an explanatory bridge between the two events.

When given such correlations concerning remote events, after a brief period of complete puzzlement, people may begin to work feverishly on constructing an explanation. The conjecture sets up a tension to explain it. If the person can construct an explanation, he has a distinct "aha!" experience of insight, almost as though the tension of searching is released across the intersecting pathway the person discovers connecting Event A to B. We believe that the person efficiently stores in memory the solution of problems he has worked on. Organisms constructed according to that storage principle tend to survive. Our hypothesis, then, is that memory for causal laws is greatly increased by "understanding" the law. In other words, a person is more likely to remember a causal conjecture if he can concoct an imaginary pathway causally connecting Event A with Event B. This outcome may arise because the pathway uses, refreshes, and combines familiar bits of causal knowledge, and/or it may arise from the extra processing "effort" assigned to that pathway once the person discovers it is a solution to a problem he has set for himself. For whatever reason, correlations which can be explained should be well remembered. The purpose of the following experiment was to test this elementary prediction.

To this end, subjects engaged in an incidental learning task. They read a series of rather remote correlational conjectures (like the price of potatoes vs. weight of the Times) and were given 15 sec. to try to concoct an explanation for each correlation. They also had to categorize the correlation in a manner to be explained below. We recorded whether or not they could explain each correlation. Later, subjects received an unexpected recall test: when cued with Event A of each pair, they were to recall Event B of the correlation. Our hypothesis is that a subject will better remember correlations he can explain than correlations he was unable to explain in the time allotted during initial exposure.

In the condition just described, the subject generated his own explanation of the A-B correlation--and, of course, on a substantial fraction of our difficult correlations, he failed to concoct an explanation in the time allotted. We may inquire about how memory in this "generate explanation" condition compares with two other incidental learning conditions. In one of these conditions, subjects read the correlation statement and then simply classified it according to which of four governmental agencies would probably have reported that correlation--the Bureau of Labor Statistics (Labor), the National Weather Service (NWS), the Department of Defense (DD), or Department of Health, Education and Welfare (HEW). Subjects accepted this as a valid task which required semantic processing of the correlation to some level. However, these subjects were not asked to explain the correlation, and we will presume that they often did not search for an explanation during the time available. Therefore, these Control subjects should not learn the correlations to the same degree as the "Generate" subjects who were forced to search for explanations of the correlations.

The third group of subjects we tested read the correlations, read an explicit explanation of the correlation (supplied by us), and then classified it according to the interested agency. We will call this the "Read" group. They are similar to the Generate group in experiencing an explanation of the correlation; they differ in that it was provided for them to contemplate and study, whereas the Generate subjects had to come up with their own. The Read subjects are similar to the Control subjects in so far as both only read experimenter-supplied materials. If memory for a correlation is aided by having an explanation provided, then Read subjects should recall more than Control subjects.

Method

Subjects. The subjects were 45 Stanford undergraduates assigned equally in random alternation to the three experimental conditions. They were run in groups of one to five. Twenty six were participating to fulfill a course requirement for Introductory Psychology, and 19 received $2.50 for their participation.

Materials. We constructed 31 correlational conjectures, stated in the form "As Event A increases (or decreases), Event B increases (decreases)". A few stimuli did not have this exact form (see example 2 below), but did express lawful correlations of the sort we are interested in. About half stated positive correlations, and half negative. We used familiar events but many of the conjectured correlations were very remote, almost bizarre. All were completely confabulated. Three examples are: 1) When there is a war in the Middle East, New York Stock Market prices go up. 2) People who draw arrows in doodles are more likely to be aggressive. 3) As volcanic activity decreases, so does the beauty of sunsets. These 31 correlations were typed at the top of 5.5 x 8.5 in. pages, and presented as a booklet for the subject to read. For Read subjects, a brief one-or two-line causal explanation immediately followed each correlation. This was generated by the experimenters and seemed about as plausible as we could make it, given the bizarre conjecture. None of the explanations given to the Read subjects contained words used in the correlation statement; this avoided confounding word repetition effects with the Control vs. Read condition.

Procedure. This was an incidental learning experiment. The subjects read through the 31 correlations, turning one page of their booklet at a signal given every 15 sec., and classified each correlation according to which of four governmental agencies (Labor, NWS, DD, or HEW) would be responsible for reporting that "fact". They indicated their judgment by placing a check beside one of the four agencies listed at the bottom of the page. Subjects appeared to accept this categorization task, and most expressed surprise when the recall test was announced later.

Besides classifying each correlation, subjects in the Generate condition were also asked to think about it to see whether they could explain it. The subject had to check a box, "Can Explain" or "Can't Explain" in the middle of the booklet page for each correlation. Moreover, if he checked "Can Explain", the subject was told to place a check next to one of 3 words following "Can explain" on the test booklet ("easy", "moderate", "hard"), depending on the difficulty he had in arriving at an explanation for that correlation. If the subject did arrive at an explanation, he was also told to write down a few content words of the explanation he had thought of. He was told that this recording was done to "keep people honest" about reporting their discovery of explanations.

The 15 sec. period was chosen in pretesting to allow Generate subjects sufficient time to check their agency classification for the correlation, to think about its explanation, and to write a few hints suggesting their explanation if they discovered one quickly. They felt very rushed to do all these things in 15 sec. Control and Read subjects, on the other hand, felt that 15 sec. was more than enough time to read and classify each correlation.

Once the booklet of correlations had been read, it was collected, and then the subject studied completely different materials for 10 min. for another, unrelated experiment. That experiment required the subject to read and try to remember 48 trait names (e.g., honest, out-going) ascribed to four pictured, middle-aged males. After that learning task was completed, the recall test for the 31 correlations of this experiment was given. The subject was given a booklet with three pages, with the test cues slightly rearranged from the presentation order of the learning series. Subjects were given the first parts of the correlation statements, Event A, such as "As the price of Idaho potatoes increases, ____________". Subjects were given as much time as necessary to recall and write in the missing consequence, Event B. They had to write the event and identify its direction of change. Subjects had only to remember Event B, and not how they had classified the fact (nor did Generate subjects have to remember their explanation).

Results

The protocols were scored by a lenient gist criterion of meaningful recall. No problems were encountered at this step. Noteworthy is the fact that whenever a subject recalled the B event correctly (e.g., changes in the weight of the Times), he was very likely to recall correctly the positive or negative direction of the correlation. These seemed tied together in an "all-or-nothing" manner. The conditional percentages of errors in direction of correlation given recall of correct content were 10% for the Control group, 6% for the Read group, and 4% for the Generate group.

The primary results are the cued recall probabilities for the three treatment conditions. The Generate subjects far exceeded the others in recall. Correct recall average 73% for the Generate subjects, 45% for the Read subjects, and 39% for the Control subjects. These differ reliably, with $\underline{F}(2,42) = 21.54$, $\underline{p} \leq .001$. Furthermore, two-group comparisons show that the Generate subjects recalled more than the Read subjects ($t(28) = 5.37$, $\underline{p} \leq .001$. However, the advantage of the Read subjects over the Controls was not statistically significant, $\underline{t}(28) = 1.01$, $\underline{p} \geq .10$. We may conclude, therefore, that the Generate condition produced superior learning of the correlations; the Read and Control subjects learned less and hardly differed from one another.

Next, we examined explanations of the correlations by Generate subjects. Subjects were able to explain an average of 69% of the correlations, with individuals varying from 45% up to 90% in percentage of correlations they could explain. There was also variability in difficulty of explaining particular correlations, with the hardest correlation being explained by three subjects and the easiest correlation by 13 subjects.

Separating explained from unexplained correlations for each Generate subject, we calculated the percentage recall for each subset. These differed significantly. Explained correlations were recalled 81% of the time; unexplained correlations were recalled only 57% of the time. Fourteen of the 15 subjects recalled a higher percentage of explained than unexplained correlations. The remaining subject deviated from this group trend by recalling one too many unexplained correlations (of six for him). A $\underline{t}$-test for matched pairs of recall percentages (arc sine transforms) showed a highly significant advantage for explained correlations, $t(14) = 5.26$, $p < .001$.

It occurred to us that the difference in recall between explainable and unexplainable items might be due to differences among the items in memorability (the explainable items might be easier to recall), and not the success of imposing a causal schema. To investigate this possibility, correlations of items were computed between conditions. There were significant correlations between the rank orders of items for the number recalled: for the Generate vs Read conditions, $r = .74$; for the Generate vs Control conditions, $r = .61$; for the Control vs Read conditions, $r = .76$. These correlations are all significant ($p < .001$). These consistent item differences in recall across conditions can be explained by a factor like "familarity". However, the correlations between the rank order of the explainability of items (percent of people who could explain it) in the Generate condition and the rank order of items for the number recalled in the Read and Control conditions were not significant: for the Generate vs Read conditions, $r = .08$; for the Generate vs Control conditions, $r = -.02$. Therefore, we can conclude that the recall difference between explainable and unexplainable items in the Generate condition was not an artifact of item selection, or there would have been a correlation between the explainability of an item and its recall in the Read and Control conditions.

Next, we were interested in whether recall of an explainable item in the Generate condition varied with the subjective difficulty of finding an explanation for it. Recall that the subject checked, for each correlation, whether it was unexplainable or easy, moderate, or hard to explain. The recall results were partitioned according to this rating. The percentages correctly recalled for easy, moderate, and hard correlations were 87, 79, and 74%, respectively. These do not differ reliably by an overall test ($F(2,28) = 1.45$), but a t-test on the means of the easy vs. hard items is marginally significant, $t(14) = 1.60$, $p < .10$.

A more sensitive statistic obtains a "weighted difficulty" score for each item. The conditional percentages of easy, moderate, and hard explainable judgments were multiplied by 1, 2, and 3, respectively, and then summed to form a weighted difficulty score for that item. The difficulty scores for the 31 items correlated $r = -.39$ with their recall percentages. This is a significant correlation ($p < .025$) and indicates that items that are easier to explain are easier to recall.

This negative correlation is explicable by the "explanatory search" model of Figure 1. The difficulty of finding an explanation should increase with the number of intermediate steps in the causal chain linking Events A and B, and decrease with the availability of each link in that chain. Other things being equal, therefore, longer or less available chains would also be less likely to support recall on the memory test, simply because failure of any link in the mediating chain would abort recall.

A final topic of interest concerns the comparison of recall of explained and unexplained items for Generate subjects to the unconditional recall percentages of the Read and Control subjects. Quite clearly, recall of explained items by Generate subjects (81%) significantly exceeds recall of all items by Read and Control subjects (45% and 39%, respectively). A closer comparison contrasts recall of unexplained items by the Generate subjects (57%) to that of the Read and Control subjects. Testing arc sine transformations of recall percentages, we find that the unexplained items of Generate subjects are recalled at a much higher level than are all items of the Control subjects ($\underline{t}(28) = 2.86$, two-tailed $\underline{p} < .005$) and also somewhat higher than recall of the Read subjects ($\underline{t}(28) = 2.01$, two-tailed $\underline{p} < .05$). Thus, the sheer act of trying to think up an explanation, even though it does not succeed, helps the person remember a correlation somewhat more than if he had merely read and classified that correlation without trying to explain it.

Discussion

We have found that subjects learn correlations to a higher degree if they are required to try to explain them. The correlation was explained presumably by the subject conducting a tree-search along causal chains, as mentioned earlier. We found that almost every subject recalled more of the correlations he could explain than he did of the correlations he could not explain. As always, subjects showed a surprising ability to discriminate their mediators from the material to be recalled, so that intrusions of obvious causal intermediaries in the A-to-B chain were extremely rare. We may thus conclude that when a person discovers a causal pathway linking Event A to Event B, he automatically stores that causal chain with a high probability (81% in this experiment). It is as though finding a solution path releases some "tension", which causes extra rehearsal or activation of the familiar propositions used in constructing that pathway.

We also found that correlations that were harder to explain were recalled more poorly than those easier to explain. This outcome is understandable if hard-to-explain correlations are those involving longer causal chains with less available links. If recall of Event B when cued with Event A is mediated by the subject retracing the successful causal chain he constructed between them earlier, that retracing is more likely to fail the longer is the chain and the less available are its links. The correlation reported here between difficulty and recall was attenuated because it was conditionalized upon finding a successful explanatory chain within the brief time allotted, and that severely restricts the range of chain-length and availability within our items.

Earlier, we mentioned the two types of explanations subjects could discover--a forward causal chain from Event A to B, or a common factor X which causes both A and B. Although we should have liked to compare recall of correlations explained in these two ways, the data were insufficient for this purpose. Generate subjects had so little time to write clues to the explanations they constructed (recall we restricted time per item to make the groups comparable) that we could not reliably determine the explanation-type from their hurriedly scribbled protocols. Differentiating recall of those two types of explanations remains on the research agenda.

In our conditional analyses, we saw too that Generate subjects recalled even unexplained correlations much better than both Control and Read subjects. That is, the very effort of working on the explanatory puzzle seems to have left greater memory residues than did merely reading the statement of the correlation. It seems likely that the Generate subjects store a large portion of their thoughts--at least the relevant ones--that occurred as they searched for an explanation of the correlations. Subjects doubtless could tell us, during the memory test, which correlations they had been unable to explain.

The recall advantage for our Generate condition over our Read condition is rather like that found for noun-noun paired-associate learning by Bobrow and Bower (1969). For incidental learning of long lists of noun-noun pairs, some of their subjects were asked to generate a sentence linking the nouns in each pair; other subjects read linking sentences for the same nouns (in some experiments, the control subjects read the same sentence that was generated by their yoked mate in the Generate condition). Later recall of the second noun when cued with the first was always much higher for Generate than for Read subjects. The explanation offered for that result was that the Generate subjects "comprehended" the noun-pair relationship to a deeper degree than did subjects who merely read that sentence among a long list of arbitrary sentences. That "depth of processing" idea was elaborated in several directions by Craik and Lockhart (1972).

A similar explanation applies to the recall difference we have found here between our Generate and Read conditions. Subjects who must construct an explanation are subjectively elaborating each event to a greater event, increasing the richness of encoding in memory of the events and of connecting pathways between them (see Anderson & Reder, in press). Anderson and Reder have shown theoretically how elaborateness of encoding can result in better memory for the items and pairings that have been elaborated.

A disappointment of this study is that the Read subjects did not recall the correlations reliably better than the Control subjects. Spontaneous comments of Read and Control subjects suggested a possible reason. They noted that for classifying the correlations as to the interested agency they did not really have to read the full correlational statement nor understand it at all. The classification could usually be done by classifying Event A alone (or Event B alone), as to whether it was an economic indicator, a health statistic, a military-technological fact, or a weather statistic. To the extent that subjects used only the category of either event to classify a statement, they did not have to fully process the asserted correlation, and so their memory of it would necessarily be poor. The Generate subjects were favored, on this account, because their explanation task forced them to understand the asserted correlation to at least some minimal level in order to try to explain it.

Clearly, the outcome calls for follow-up research using experimental conditions which insure that Read and Control subjects actually attend to the stated correlation. In designing our experiment we considered, as an orienting task, having all our subjects rate the plausibility of the asserted correlations rather than classifying them according to the interested agency. But we rejected that orienting task because it seemed likely that people would judge plausibility of a correlation according to how easily they could construct an explanation of it--and we did not want all our groups to construct explanations since the influence on recall of doing so was the point at issue in the experiment. Thus, a better estimate of the "true" differences among our three conditions would use an orienting task that insures that the Control subjects will attend to the relation asserted in a correlational statement, yet a task that does not cause an automatic search for an explanation of the correlation.

As a final comment, we should point out how easy our subjects found the task of generating explanations for these rather obscure and bizarre correlations. Apparently undergraduate subjects are no less adept at confabulating ad hoc explanations for apparent "facts" than are the psychologists who study them. What is remarkable is the extent of subjective certainty or belief in the explanation found, and in the correlation that it accounts for. In testament to this fact, Ross, Lepper, Strack, and Stienmetz (1977) had subjects concoct explanations for similarly obscure, asserted correlations, then later told them that the experimenter had misled them and that he did not in fact know whether there was any such correlation. Later the experimenters asked subjects what they felt the true correlation might be. They found that debriefed subjects overwhelmingly believed the true correlation would be approximately the same as the earlier spurious one they had explained. Ross et al. explained this "perseverance effect" by supposing that a person's belief in a given correlation is based partly on how rapidly he can generate a causal explanation for it; and when the debriefed subject considers the Event A-to-B relation a second time, the explanation he had given earlier for a specific correlation is the most available causal chain that comes rapidly to mind; and so, in the absence of contrary arguments, he perseverates in estimating the "true" correlation to be close to the spurious one he had explained before.

Our subjective belief in a correlation we have explained fits into our normal habits of "checking out" conjectures or arguments we encounter in conversation or while reading. The subjective certainty of our belief in an explained correlation is particularly remarkable given the ease with which we generate explanations. One would think that people's experience with their own explanatory facility should have taught them that they can readily concoct two or three explanations for a given correlation (hence, none should be considered unique), and that they could just as readily explain the opposite correlation if they are asked to. The appropriate conclusion from such experiences is that being able to explain a conjectured, lawful regularity should have no actuarial bearing whatsoever upon its truth. But it seems that subjects—and even scientists who study them--simply cannot discount that insightful glow that persists from discovering an explanation for a conjecture. Well, ah, maybe we should qualify that . . . .

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Figure Caption

Figure 1. Schematic of generation of causal antecedents (parents) or consequences (successors) from Events A and B in the tree-search for an explanation.

Footnote

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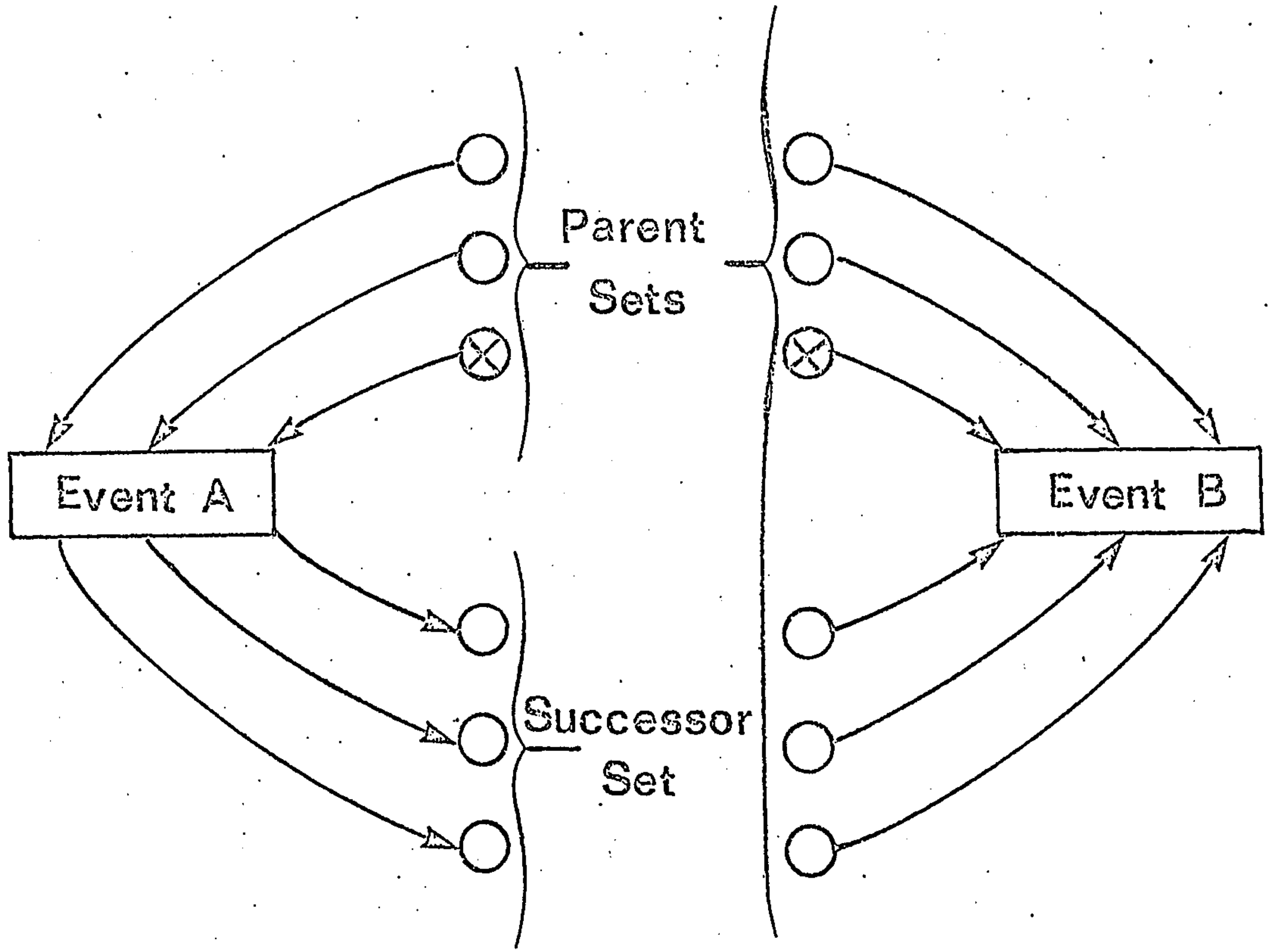
Event A
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