

Entailment

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EUTRALITY, like objectivity, is a virtue. It is a virtue that we formal logicians in particular have learned to cultivate over the last quarter century. Consider, by contrast, the situation in 1946, just after a great war fought (among other things, not relevant here) that reason itself should not perish. After the war, most logicians and philosophers—in this country, at any rate-concluded that this meant that the truth-functional, twovalued classical logic should not perish. Accordingly, anyone in those days caught writing a diamond or a square on a piece of paper -even in front of a material horseshoe, which the accused might swear (to no avail) was the only genuine, true-blue, honest-to-Hume version of the conditional-was immediately put away as an unregenerate modalitarian; expulsion by the Association for Symbolic Logic's use-mention committee, then located in 'Boston', was sure to follow.1 Outside Poland and its colonies—e.g., Great Britain ditto for anyone caught constructing a truth table with more in it than T and F; the simple notions of truth and falsity were unfortunately beyond him.

In the Age of Aquarius things aren't like that, despite well-known efforts to hold the line. But there are now more modal logics than elementary particles. Scarcely a month goes by without the discovery of a new, 13-valued analogue of the Sheffer stroke. Free logics, epistemic logics, deontic logics, causal logics, counterfactual logics, relevant logics, and entailment logic proliferate. Overarching the whole has been a new spirit of tolerance—you do your thing and I'll do mine, in the modern mood, and if you're a little confused on use and mention and I'm a little confused on truth and falsehood, we won't quarrel about it—no doubt we both have axioms and a semantics (probably got by making minor changes in somebody

* To be presented in a joint APA-ASL symposium on Entailment, December 27, 1971. Dana Scott and H. P. Grice will be co-symposiasts. For Professor Scott's paper, see this JOURNAL, this issue, pp. 787-807; Professor Grice's paper is not available at this time.

Technical results and philosophical insights alluded to in the course of the paper are due variously to Chisholm, Nakhnikian, Lewis, Quine, Boole, Bennett, Anderson, Belnap, Dunn, Woodruff, Routley, Urquhart, Leblanc, Curry, Scott, Heyting, Castañeda, Lambert, van Fraassen, Carnap, Pap, Church, Ackermann, Goodman, Daniels, Corcoran, Moh-Shaw-Kwei, Hilbert, and St. Paul; errors, fany, are St. Paul's. Evidence for the results and insights exists presently in widely scattered articles; it will be collected in the soon to be published Anderson-Belnap treatise Entailment. My thanks are also due to the National Science Foundation for partial support of this research through grant GS-2648.

1 It might have been "Boston."

else's axioms and semantics), and if your \$0.001 doesn't come to my \$0.002, who cares?

Neutrality is a virtue, if only because new and philosophically fertile ideas are apt to begin their careers vague, rough, and a little ridiculous; anyone who thinks that they should be immediately squelched on that account ought to reflect a little on Galileo and his steamboat; entrenched ideas, even if wrong, are apt to have the better *legal* counsel.

Thus it has been, in particular, that in battle entailment theorists -people who think that the theory of logical consequence is irreducible to either truth-functional or Lewis-style modal insightshave usually been counted out. Aside from the flack they have gathered from the use-mention crowd, already alluded to, entailment theorists have been accused of numerous other breaches of the reigning logical etiquette. At a time when everybody had a formal semantics for his system, they had none. They rested their case on intuitions, whereas others had proofs. They were forced, if coherent, to deny fundamental principles of reasoning, like the transitivity of entailment or the disjunctive syllogism, it was claimed. They sought to make relevance of antecedent to consequent a necessary condition for the validity of a valid entailment, whereas everybody knew relevance to be a pragmatic notion not to be caught at the syntactical level. They were victims of the old disease of psychologism in logic, confusing the task of explicating the way we think with that of providing normative criteria for the validity of arguments. They were insensitive to the straightforward demonstrations of C. I. Lewis that, e.g., a contradiction entails any proposition. In sum, in the words of one reviewer, they were anti-scientific.2

Happily, in these permissive times even general agreement that their insights were mistaken and their project wrong-headed has failed to cause even a single partisan of formalized systems of entailment to be burned at the stake. Much as this might have been regretted in certain circles, research on the subject has now progressed to the point where neutrality is no longer a virtue with respect to the formalization of entailment. Within the limits of experimental error, it can now be reported that the Anderson-Belnap system E of entailment, identical in its stock of theorems and in other

² This is unfair. What was said was that some argument or other of Anderson and Belnap was in an anti-scientific spirit, which probably it was, since they didn't say much about prime numbers or rationals or the Promised Land, which is what the review seemed to be about. It is to be hoped that before Anderson and Belnap write any more about entailment they will bone up on their mathematics and their Hebrew.

significant respects (as it has turned out) with the earlier systems of strenge Implikation of W. Ackermann, furnishes a true and correct formal counterpart of the intuitive notion of entailment. One more philosophical problem, you will be happy to know, has been definitively and finally solved; anyone who might have been tempted to work on it is referred instead to the mind-body problem, which if we all pull together ought to be disposed of shortly. Meanwhile, I shall devote the remainder of this essay to the solution of the problem of entailment, examining how it came about, why the earlier criticisms were mistaken, and summarizing as space allows the conclusive evidence for the correctness of E.

т

Even though it is correct, I personally don't care much for E. The system I like is the Anderson-Belnap calculus R of relevant implication, which I drag in below to explain why E is correct. But my second favorite system is my own pure calculus I of irrelevance, which we may look at first to show why the arguments against E are incorrect.

I formulate I as a sentential logic, though extension to quantification theory, number theory, infinitary logics, and so forth is straightforward. I has formulas as usual (technically, we call them wfs), a single axiom 'p', and a rule of substitution for sentential variables. (Note that we could have dispensed with this rule by adopting von Neumann's device of axiom schemata, though this will not be essayed here.) Although the formulation given here is new, the historically minded reader will note the equivalence of this system and the propositional fragment of the system proposed by Frege.³ Note that I, or rather its higher-order version IH, is sufficient for all of classical mathematics.

While all will applaud the pure calculus of irrelevance on grounds of simplicity and glorious richness, there might be some demand nevertheless for its philosophical justification. This demand might be made by proponents of such post-Fregean logics as that of Whitehead and Russell, in which it is not known that 'p' is provable. It might indeed be argued that our intuitions rebel against some substitution instance of 'p', e.g., 'R ϵ R & \sim (R ϵ R)', where 'R' stands for the Russell class. But this is clearly for those recalcitrant individuals who prefer their intuitions to what the Russell proofs show.

Since Lewis (who, incidentally, discussed a system weaker but similar in spirit to I in "A too-brief set of postulates for the algebra

³ We mean the propositional fragment of Frege's full, inconsistent system. Philosophers of logic ought to note how Frege's greatness survived the inconsistency.

of logic"—thus showing the modal logician's typical condemnation of all but bloated postulate sets, Universes, and so forth) has also showed that any substitution instance of $q \& \bar{q}$ strictly implies p', all but the most grudging must gulp down their intuitions and affirm the theoremhood of p'. It is their weakness which causes certain post-Fregean systems to lack p'; given sound classical principles, their claims would vanish like the morning mist outside the small pockets of consistency in human ratiocination.

To clinch the superiority of the pure calculus of irrelevance, consider the following argument suitably formalized:

- (a) Everybody's intuitions are linguistic prejudices.
- (b) Lewis's intuitions are proofs.

Therefore, (c) The owl, for all his feathers, was a-cold.

Since the argument is valid, and since the premises conjointly express a true contradiction, the conclusion is true. But in the pure calculus of irrelevance the conclusion does not require the premises, thus ending dependence on intuition once and for all.⁴

77

For all its advantages, I is a little disturbing in that it has no nontheorems, which deprives it of a semantics in the ordinary sense. No such problems afflict its negation-free fragment I+. For, just as standard quantification theory presupposes that its individual constants be interpreted as names of actuals—i.e., it will do to think of the individual constant 'a' as George Washington but not as Ichabod Crane—just so we might think of the sentential variables of I+ as names of (real) facts-i.e., and for the less ontologically minded, we might allow that 'p' might be interpreted as true but never as false: giving the positive connectives their usual truth-functional interpretation, all formulas then turn out true-which is a good thing, since they're all theorems; proofs of the semantic consistency and completeness of I+, relative to this intended interpretation, may then be carried out along well-known lines. (Indeed, certain simplifications can be made in the standard proofs—e.g., even for uncountable languages the axiom of choice is never used.)

So I+ is an improvement on I in that the former has a formal semantics, smooth, simple, and efficient. Yet neither system, evidently, is of much use. For we justified I by virtue of a breakdown in our logical intuitions—the Russell paradox—which we confronted not by re-baptizing the area of logic in which the breakdown had occurred, but by bearing the insult and buying the sorry consequences;

I am indebted to Professor Anderson for having pointed out an error in (c).

⁶ Professor Belnap and I agree in holding set theory the child of logic; we differ in that he insists that it's a *legitimate* child.

and we justified I+ by so restricting the area of the applicability of logic as to make the subject utterly trivial, useless, and uninteresting.

Similarly, the claim that 'q & q' entails 'p', in general, signals a breakdown in our intuitions not different in kind, though different perhaps in severity, from the kind of breakdown whose result is outright inconsistency, and similarly for the other paradoxes of implication, material or strict. Because intuitions are after all vague, and because no outright contradiction results, it is often held that the paradoxes of implication do no harm. One might as well argue that arson does no harm because it is not murder, as though burning down a man's house is of no import if one does not kill him.

In fact, the shallow and spurious arguments that have placed ' $q \& \bar{q} \to p$ ' alone among the received logical truths have warped logic in ways awful even to recapitulate. They have distorted the methodology of the deductive sciences. They have encouraged fairy-tale views of mathematics. They have rendered the application of logic mysterious in epistemic and deontic contexts. They have created pseudo-problems in philosophy. Our intuitions, in truth, may be vague, but ignoring them leads alike to philosophic blunder and to wild-goose chase; here are some to which the assertion that a contradiction entails anything has led.

1. Suppose we have a theory T whose purpose it is to capture some definite empirical or mathematical situation—e.g., the arithmetic of the natural numbers. On the assumption that we have a definite interpretation of T in mind and not a variety of possible interpretations, it is obvious that we desire T to be consistent and complete with respect to negation—we should like to think in the arithmetical case, for example, that exactly one of each sentence A and its negation $\sim A$ is true, and T is all that we might have hoped if it asserts exactly the true one from each pair A, $\sim A$.

Our hopes, however, may have little to do with the case; we are not Gods, or even Laplacian demons, and for theoretical or practical reasons our efforts to get a theory T to our liking may be utterly ineffective. The utility of the T that we actually construct effectively lies accordingly in its power of discrimination with respect to the A, $\sim A$; when T picks exactly one out of this pair for given A, it has discriminated; it has not discriminated if it picks both or neither. Thus, when a definite interpretation is in mind, there is an intuitive parity between underdetermination and overdetermination with respect to a given A; in either case, we get no usable information about A.

But on the plausible condition that theories be closed under logical consequence (what else would logical consequence be for?), this

parity is wrecked by the paradox of implication. Overdetermination—asserting both A and $\sim A$ for any A—triggers in T classically a psychotic break; T henceforth discriminates nothing, collapsing uselessly into the pure calculus of irrelevance. Underdetermination—incompleteness—is by contrast relatively painless; it may yield, as in the case of classical formalized arithmetic, unintended non-standard interpretations of T, but these do not conflict with the claim that T is right as far as it goes.

2. Ever since Plato, or maybe Pythagoras, mathematics has been the playground of metaphysicians. Even metaphysicians, I allow, have the right to some recreation, and if they wish to trip out on sums, products, and the continuum it would be decidedly un-Aquarian to try to inculcate in them a feeling for reality! (It's probably a lost cause anyway.) Philosophers of mathematics, however, tend to work both sides of the street, and the claim that a contradiction entails everything is there to aid them in their endeavors. On the one hand, everyone respects mathematics as the handmaiden of natural science; on the other, there are those who respect her as the free creation of the human spirit.

It is strangely overlooked that on neither of these views is there any particular reason why mathematics should be consistent. As the servant of the empirical sciences, consistency is indeed of importthat the same thing should be both blue and not blue in the same respect does boggle the mind-but it is obvious that consistency is important here only for those assertions of mathematics which can indeed be given an empirical interpretation. Even this is not hard and fast, since in most interesting cases the fit between mathematical law and empirical reality is only approximate in any event, so that isolated inconsistencies even among interpretable sentences of mathematics would not inevitably be shattering; and the Russell set, being devoid to all appearances of empirical significance except as its introduction leads on classical logical principles to the collapse of classical mathematics, is all the more harmless in itself from this point of view. As the free creation of the human spirit, there is even less reason why mathematics should be consistent; a number or a set is not a rock or a tree, and, though it may be interesting to abide by old rules-e.g., no contradictions-there is no evident penalty attached to breaking them, either. To the reply that one couldn't imagine what it would be like for a contradiction to hold in mathematics, one can only reply that one can't imagine what sets are like, either. There ain't no sets, though it's fun to pretend that it makes sense to say that there are; while we are pretending, we can go on to pretend that they have contradictory properties. Or, if we are truly persuaded that mathematical entities constitute a supersensible realm and that they have supersensible properties not shared by the objects of our common experience, on what grounds should it then horrify us that contradictory statements force themselves upon us with respect to some of these objects?

In short, on any plausible and popular view of the nature of mathematical truth—instrumental, esthetic, or even reportorial—consistency in the formal sense just isn't what it's been cracked up to be; for certain purposes an inconsistent system might be more useful, more beautiful, and even—at the furthest metaphysical limits—as the case may be, more accurate. Again, it is the paradoxes of implication—not any requirement intrinsic to mathematics itself—that impose an absolute requirement of consistency on formal mathematical systems; who wants, after all, the pure calculus of irrelevance? But why, on the other hand, subject mathematics to these trivial logical constraints?

3. Mathematics is a playground, and if in the end the playground directors ban inconsistency ("Keep off the grass"), we shall have to call the interesting kind of fun just suggested something else. Life isn't all fun, though, and on returning to serious subjects—like what we believe, and what we ought to do—we find the paradoxes of implication again at work warping and constraining. On the former subject, it is an evident empirical fact that (1) some people sometimes are committed to some contradictory beliefs. And again, what else is logic for if it is not the case that (2) a man committed to certain beliefs is committed as well to their logical consequences? Friends, it is downright odd, silly, and ridiculous that on classical logical terrain (1) and (2) cannot be held together, except on pain of maintaining that some people sometimes are committed to absolutely everything. Desperate expedients are recommended instead; e.g., a man committed to 'p' and to 'q' is not necessarily committed to '\$\psi & q', it has been argued; e.g., a man committed to a set of beliefs is committed only to what follows logically from consistent subsets of this set, somehow or other selected and ranked. The psychological point seems to be that a man committed to an inconsistency generally doesn't know that he is so committed, and so we should give him the benefit of the doubt by not making him look any sillier than he is. We reject, however, psychologism in logic, holding rather that ignorance of one's commitments is not an excuse; indeed, since Socrates everyone has known that the way to get a man to change his beliefs is to show him what he has committed himself to; the dialogues might have been greatly shortened, for example, if Meno has been permitted the reply, "Well, Socrates, I believe 'p' and I

believe 'not p', but, having had my memory jogged in conversing on epistemic logic with yonder slave boy, I fail to see how it follows that I am committed to 'p and not p', wherefore since no inconsistency has arisen let us knock off this stuff and attend instead the Be-In over at Agathon's." But the truth is that we sometimes make mistakes—indeed, some mystics, Marxists, and metaphysicians might even wish to assert a contradiction without either acknowledging it a mistake or denying a grounding rationale—and that when we make mistakes we are stuck with what follows from them but not with what does not follow; evidently, not everything follows.

What was just said epistemically can now be said more shortly deontically. Again, one cannot hold classically that (3) some people sometimes have conflicting obligations and (4) one is obligated to bring about what follows logically from what one is obligated to bring about. The tasks classically imposed on people with conflicting obligations being frightening even to contemplate if (3) and (4) both hold, we hear rather that "'Ought' implies 'can'." another of those Boy Scout views so popular among philosophical ethicists; classically, of course, it had better. A view more accurately representative of moral reality would seem to be the New Testament view that "'Ought' implies 'cannot'," a better world-if such there bedrawing us, given the harsh realities of this world, not to but towards its realization. It is undesirable, as anyone will agree, to have obligations that genuinely conflict; that it is impossible on classical logical grounds is to encourage a fairy-tale ethics to go with the fairy-tale mathematics and the fairy-tale epistemic logic already encouraged.

4. Scratch an inadequate theory of entailment and you find an inadequate theory of the conditional; scratch the paradoxes of implication (strict or material), and you uncover the material conditional. (Even Quine, to give credit where it is due, has called attention in print to this fact.)

For a simple subject, the real relationship between a theory of entailment and that of the conditional has occasioned much more than its share of misunderstanding. The main point, to introduce here a distinction I have made elsewhere, lies in whether we seek to express entailment or are content merely to indicate entailment. A connective \rightarrow indicates entailment for a logic L when it is held metalogically true that A entails B if and only if $A \rightarrow B$ is a theorem of L. A connective \rightarrow expresses entailment if and only if $A \rightarrow B$ means that B is a logical consequence of A—e.g., that $A \rightarrow B$ shall be true on an interpretation I of L if and only if A entails B on I.

The distinction just made is only as good as the formal semantical machinery that can be introduced to give it substance; a simple se-

mantical tool is the notion of a metavaluation, which enables us to interpret logics that profess to express entailment in their own metalogics. Briefly, a metavaluation V for a logic L is simply a function from sentences of L to T,F that respects truth-functional connectives in the usual way but which has the property that $V(A \rightarrow B) = T$ if and only if $A \rightarrow B$ is a theorem of L. A logic is coherent if all its theorems come out true on all metavaluations; coherence, in view of the remarks just made, appears to be the least that one would expect of a logic that purports to express entailment.

Sure enough, classical truth-functional logic is not coherent. $p \vee (p \to q)$ is a counterexample, on the metavaluation that makes p false; since p doesn't entail q, $V(p \to q) = F$ by definition of a metavaluation, whence truth-functionally the whole disjunction is false. (It's interesting, incidentally, why classical truth-functional logic is incoherent; the reason is that there is a metavaluation V and a formula $A \to B$ such that $V(A \to B) = T$, V(A) = T, and V(B) = F; indeed, let B be the above counterexample, V the suggested metavaluation, and A be the instance $((p \to q) \to p) \to p$ of Peirce's law; the moral is that, as a theory purporting to express entailment, truth-functional logic isn't truth-functional enough; by contrast, the system E of entailment really respects truth-functionality, since it—in company with S4 and a number of other logics—turn out coherent.)

Its incoherence, however, does not bar truth-functional logic from indicating entailment; Quine and others have argued that this is precisely what it does. Our biggest gripe—against a contradiction entailing anything—then turns into a gripe against $A \rightarrow B$ being true on any interpretation I that makes A false. And that, indeed, is the nub of the problem.

Consider the poor maligned problematic counterfactual conditional. Its problem is that it may be false. For all the discussion, the simple moral seems to have escaped almost everyone; the existence of false conditionals with false antecedents is an immediate and shattering counterexample to the classical claim that falsity of antecedent suffices for the *truth* of an honest conditional. For is it really the case that counterfactual conditionals, particularly subjunctive counterfactuals, are the black sheep of a family of otherwise solid citizens, where the measure of solidity is ease of translation into an overtly truth-functional vocabulary?

In fact, the attempted isolation of allegedly recalcitrant conditionals overlooks the absence of a sharp dividing line between the counterfactual and the factual, between the subjunctive and the indicative. Ordinarily, one takes it that he who utters a conditional

sentence is in fact ignorant with respect to whether the antecedent is or will be true; a fortiori this is the case with respect to so-called universal conditionals (Russell's formal implications), from which follow a particular conditional statement for every item in a certain range. Likewise, one takes it that he who frames his utterance in the subjunctive rather than the indicative mood asserts the conditional and reflects his conviction that the state of affairs expressed by the antecedent is rather unlikely to occur—e.g., "If wishes were horses, beggars would ride." But in the garden-variety counterfactual (e.g., if match M were struck, it would light) there is ordinarily not much to choose between an indicative and a subjunctive formulation (contrast, if match M is struck, it will light); our principal interest, rather, would seem to be the sufficiency of antecedent for consequent, while we ignore the minor insinuations that the grammatical devices at our disposal permit.

In short, there is at first glance nothing odd about a counterfactual conditional. At second glance, there is something odd about counting a conditional true when its antecedent is false, except sometimes. The oddity has sometimes appeared in strange ways; recall the agonies the old verification theorists went through trying to explain what it was for a substance x to be soluble in water; after starting out plausibly—that x is water-soluble just in case, if placed in water, x dissolves—they were then tortured with questions like, "What if x is never placed in water? What if x in principle never could be placed in water?" Oh, though defenders of the material conditional are still with us, the old zeal is gone-who today even worries that the moon, or the number 3, might turn out vacuously soluble? For today everyone knows that the conditionals-which turn out, sadly, to be the scientifically interesting ones—are of the odd sort, whose truth is to be determined by exhibiting microstructures, or projecting predicates, or employing a specially designed modal logic.

No. The truth is that when the King is in the altogether, debate over how to alter his clothes to make him appear more decent is vacuous. The solution is to dress him. The solution to the problem of contrary conditionals is to make a fresh start on the theory of the conditional; this is what Anderson and Belnap, building on the work of Church and Moh-Shaw-Kwei, have done in producing the system R of relevant implication. And the system R, as it turns out, encompasses not only a theory of the relevance-regarding conditional that captures the lawlike connection at the heart of the counterfactual debate, but it also churns out not only the material but also the intuitionist conditional as special cases of the relevant con-

ditional. Moreover, R indicates precisely the theory of entailment expressed by the system E. If one wants moreover to express entailment in R, the addition of an explicit S4-style theory of the necessity operator N produces a system NR which satisfies all the modal motivating conditions placed by Anderson and Belnap on the system E of entailment on the NR-analysis of entailment as strict relevant implication. (The motivational point is that E and NR have a twostep motivation; relevance criteria are built into the conditional, and then a Lewis-style theory of modality is added; the superiority of NR lies in the fact that the two tasks are undertaken independently; the fundamental character of R, in the fact that it was the the Anderson-Belnap insights about relevance that were new, exciting, and important, whereas adding the Lewis-style theory of modality may be viewed by contrast (though not in order of discovery) as more or less old hat. Lewis himself, whose principal interest was after all in entailment, did discover a new world in sailing the hitherto uncharted modal seas: he missed, however, the treasures that he sought in failing to round the Horn of relevance.)

R, in short, is the basic relevant logic. It has a Kripke-style semantics, easily extended to NR and adapted to E. R rejects the paradoxes. It has a nice and well-motivated deduction theorem and a corresponding pretty natural deduction formulation. Its algebraic analysis is simple and straightforward; Gentzen methods yield a corresponding syntactical analysis. For the technically minded, deep and pleasant theorems abound; for the philosophically inclined, correspondingly deep and pleasant truths. It is, of course completely adequate to all the purposes of mathematics, philosophy, and natural science. What more could one ask?

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NOTES AND NEWS

The editors regret to report the untimely death of Robert S. Guttchen, Associate Professor of Education at Hofstra University, in August of this year. Professor Guttchen was a former president of the Middle Atlantic States Philosophy of Education Society and active in other philosophical associations. At the time of his death he was 45 years old.

The editors of the Journal of Philosophy congratulate the editors of the Zeitschrift für philosophische Forschung on their twenty-fifth anniversary; 1972 will be the twenty-fifth year of this distinguished publication.