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Authors
Schroyens, Walter
Sevenants, Aline

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Issues in Reasoning about Iffy Propositions: Reasoning times in the Syntactic-Semantic Counter-Example Prompted Probabilistic Thinking and Reasoning Engine (SSCEPPTRE)

Walter Schroyens (Walter.Schroyens@hec.ca)
HEC Montreal, Université de Montréal, 3000 Ch. de la Côte St.-Catherine, H3T 2A7 Montreal, QC, Canada

Aline Sevenants (Aline.Sevenants@psy.kuleuven.be)
University of Leuven, Laboratory of Experimental Psychology, Tiensestraat 102, B-1000 Leuven, Belgium

Abstract

The Syntactic-Semantic Counter-Example Prompted Probabilistic Thinking and Reasoning Engine (SSCEPPTRE; Schroyens et al., 2001; Schroyens & Schaeken, 2003) predicts both conditional inference rates and reasoning times. Acceptance times of MP ('A therefore C"), AC ("C therefore A"), MT ("not-C therefore not-A) and DA (not-A therefore not-C) would follow the order: RT(MP/1) < RT(AC/1) < RT(DA/1) < RT(MT/1). For each of these arguments rejection times would be longer than acceptance times. These predictions are corroborated by an extensive study (N= 350) in which reasoning times were recorded. Participants also solved a truth-table task in which they had to evaluate the different contingencies ('A and C', 'A and not-C', 'not-A and C', 'not-A and not-C'). Truth-table evaluation times confirm SSCEPPTRE's expectation that evaluating "not-A and C" takes more time than evaluating "A and not-C".

Introduction

If you are sceptical about the import(ance) of conditional reasoning, then consider that you would not even be able to understand the very sentence you are reading now. Our ability to reflect on potential implications of what is, could have been, or will be predicates some of the prime examples of the human marvel. The elusive nature of conditionals has accordingly received much interest from psychology, AI, linguistics, neuro-science, and philosophical-logic.

In the reasoning literature few papers have considered reaction or reasoning times (RTs). We suspect that the complexity of the analyses might have kept theorists from taking up the challenge. We take up this challenge and present a computational model of conditional reasoning that yields fine-grained predictions about reasoning times. Insights about human reasoning do not come as such. 'Facts' only become interesting and interpretable within the context of a theoretical narrative. We therefore ask the reader to bear with us when we first present the general model theory of conditionals. Once we have the general theory, we can specify its principles to a particular topic of interest. Our specification of conditional by model is referred to as the _S_yntactic-_S_emantic-_C_ounter-_E_xample _P_rompted _P_robabilistic _T_hinking and _R_easoning Engine (SSCEPPTRE). The general model theory of conditionals, and the specific computational processing model of conditional reasoning (SSCEPPTRE), provides the conceptual background against which RTs emerge.

The Model Theory of Conditionals

This section summarizes the main principles of the model theory of conditionals. The model theory postulates that individuals understand sentences by representing possibilities. In accordance with the Gricean principles of conversation (Grice, 1975, also see Levinson, 2000), people will assume that the information they are confronted with is true: They will initially consider only possibilities that are compatible with the conditional. This is the so-called truth-principle (Johnson-Laird, 1999, p. 116). Moreover, since people are bounded in their rationality (Simon, 1957), they cannot and hence will not even consider all true possibilities from the outset. This is the implicit-model principle. Content and context will aid the construction of alternative possibilities that are not represented *ab initio*. This is the idea behind the so-called principles of semantic and pragmatic modulation. Let us elaborate.

Initial representations Sentential Information will be processed to yield semantically rich representations. These representations can be described at a biological, sub-symbolic, or symbolic level of detail. There is no immaculate perception; one has to start with something. At the surface, a sentence like <if A then C> describes some sort of relation between <A> and <C>. (We leave it up to the reader to use his/her imagination to specify an antecedent and consequent event, <A> and <C>). As the bare minimum, this relation captures the idea that <C> occurs within the context of <A>. That is:

A (C)

This initial model reflects the bare minimum[1]. Some reasoners might note that <A> is exhaustively represented. An exhaustively represented token signifies that there are no

[1] Our notation deviates from the one used by Johnson-Laird and Byrne (2002). They did not present a notation that reflects the idea that <C> occurs within the context of <A>. We place <C> in round brackets to reflect this. As Johnson-Laird and Byrne (2002) expressed it: "The antecedent refers to a possibility, and the consequent is interpreted *in that context*" (p. 649, italics added) or "the antecedent of a basic conditional describes a possibility, at least in part, and the consequent can occur *in this possibility*" (p. 650, italics added).

other situations in which <A> occurs than those wherein <C> is also the case. By implication, all other possibilities depict <not-A> events, i.e., state of affairs in which <A> is not the case. It also implies that <not-C> events that occur within the context <A> are inconsistent with the conditional: <A(not-C)> cases falsify the conditional. Exhaustiveness is conventionally denoted by square brackets around the exhausted event token.

[A] (C)

Johnson-Laird and Byrne (2002) state "modulation can add information about temporal and other relations between antecedent and consequent" (p. 646). They present these processes of semantic or pragmatic modulation as two fundamental processing principles. One part of these twin principles of content and context refers to the process of enriching models. For instance, "If the cardinality of the set matters, then models can be tagged with numerals, just as they can be tagged to represent numerical probabilities" (Johnson-Laird & Byrne, 2002, p. 655).

Looking for alternative possibilities Content and context not only adds information to the initial model. A second import of semantic and pragmatic modulation concerns constructing alternative models: content and context "can prevent the construction of otherwise feasible models and aid the process of constructing fully explicit models". Indeed, we have as yet not considered the implicit model to which the implicit-model principle thanks it name. The model theory assumes that most people realize that more possibilities are consistent with <if A then C>, without explicitly representing which these possibilities are. The convention is to denote this implicit model by an ellipsis.

A (C)   [A] (C)
 …   …

The model theory holds that at a basic level of processing, some people forget about the empty model. If so, then people will not consider alternative possibilities. They are satisficing. The likelihood of looking for alternative possibilities is context and context dependent. A conditional of the form <if A then C> could for instance be interpreted as a tautological utterance <if A then possibly C>. It allows for all four contingencies: *<A(C)| A(not-C)| not-A_C| not-A_not-C>*. Another interpretation of <if A then C> refers to the conditional interpretation, in which three possibilities are considered: *<A(C) | not-A_C | not-A_not-C>*. People who represented <A> exhaustively in relation to <C> can use the exhaustiveness tag to explicate the alternative models. The <A(not-C)> contingency is excluded since it incorporates the exhausted token <A>, which can thus not be used to construct alternative models. The only possible alternatives are events in which A is not the case: <not-A_C> or <not-A_not-C>. Depending on content and context these contingencies will be more or less plausible. They are accordingly more or less likely considered as alternatives to the initial <[A](C)> model. When people have a so-called bi-conditional interpretation, for instance, they will not consider <not-A_C> a true possibility.

Interpretational processes are not distinct from reasoning processes. Both are representational processes. That is, 'the' interpretation of a conditional does not exist. Interpretations are ephemeral and reflect ongoing processes of constructing and modulating mental model like representations. For instance, as will be illustrated below, to have the conditional interpretation it is required that reasoners engage in a search for alternatives to the initial model.

Pragmatic and semantic modulation aids the process of constructing alternatives models. In the absence of specific pragmatic and semantic cues, people need to resort to syntactic procedures or more systematic strategies in constructing alternative models. SSCEPPTRE assumes that people will engage in a goal-directed search for alternatives: the alternative models are constructed by denying the possibility one looks and alternative for.

Conditional Reasoning with SSCEPPTRE

Conditional inference problems are set by a categorical premise that affirms or denies either the antecedent <A> or consequent <C> of the conditional statement, <if A then C>. The top panel of Figure 1 presents the four basic inference problems. The two affirmation problems are referred to as Modus Ponens (MP, i.e., an affirmation of the antecedent problem) and Affirmation of the Consequent (AC) problems. The two denial problems are known as Denial of the Antecedent (DA), and Modus Tollens problems (MT, i.e., denial of the consequent). Performance on these problems is mostly discussed in terms of the standard affirmation and denial inference rates.

MP If A then C; A, therefore C
AC If A then C; C, therefore A
DA If A then C; Not-A, therefore Not-C
MT If A then C; Not-C, therefore Not-Ca

The content of the antecedent and the consequent can be formed by virtually any well-formed lexical term, for instance: " If the letter is a 'A', then the number is a '2'". Studies of human reasoning competence commonly use knowledge-lean utterances. The rational is that such abstract materials are less likely to cue prior beliefs.

Figure 1 presents the parameterized processing tree of constructing and manipulating mental models within SSCEPPTRE. In a simplified form, the likelihood by which people would endorse the standard determinate inferences is captured by the following equations:

$P(MP) = 1\text{-}LCE_{TF}$
$P(AC) = 1\text{-}LCE_{FT}$
$P(MT) = LCE_{FF}.(1 - LCE_{TF})$
$P(DA) = LCE_{FF}.(1 - LCE_{FT})$.

The MP and AC functions express that affirmation inferences (MP/AC) are endorsed by all people (p = 1.0) except those who accept a counter-example to it (with a probability of LEC_{TF} or LCE_{FT})[2]. Initially people only consider the *True-*

[2] The <LCE_{FT}> and <LCE_{TF}> parameters are a composite of (a) the likelihood by which people **L**ook for a counterexample, (b) the ease of **C**onstructing it and (c) the likelihood of **E**valuating and accepting the hypothetical possibility. The latter component is

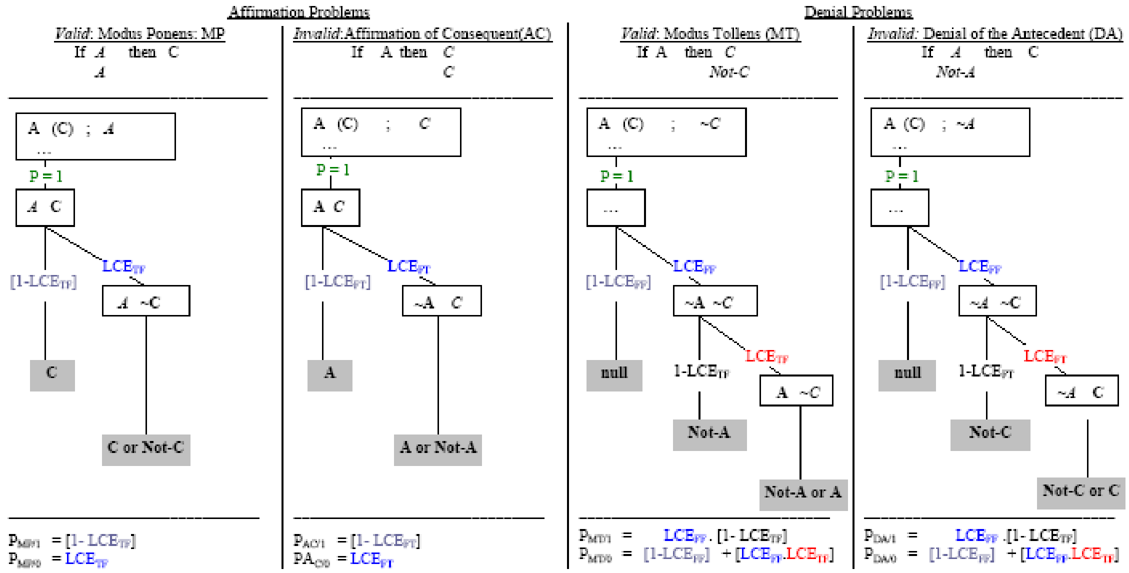

Figure 1: Simplified parametric processing tree of solving conditional inference problems by constructing and manipulating mental models.

antecedent-True-consequent contingency: *TT<A(C)>* vis-a-vis *<if A then C>*. The two model sets are compatible and yield the affirmation inferences. We assume that everybody can generate the affirmation inference (p=1). Hence, the likelihood of endorsing vs. generating the inference equals unity minus the likelihood of rejecting them subsequently on the basis of a counterexample.

If the falsity of the conclusion is considered possible, it follows that it is possibly false and hence not necessarily true. The relevant counterexamples are captured by the contingency reflecting the falsity of the conclusion in combination with the given truth of the categorical premise. This means that MP is validated by considering the *True-antecedent-False-consequent, TF<A_not-C>* contingency, whereas AC is validated by considering the *False-antecedent-True-consequent, FT<not-A_C>* contingency. Figure 1 shows that accepting the counterexamples results in rejecting the standard inferences. A failure to accept the counterexamples (with a probability of [1- LCE_{TF}] or [1-LCE_{FT}]) results in endorsing them.

The initial model does not support the denial arguments. It does not include a representation of the falsity of the consequent/antecedent (as asserted categorically by [not-C]/[not-A] in MT/DA; see Figure 1). It is consequently eliminated and people are left with only the empty model, [...], which does yield any conclusion: "nothing follows" (*null*). As before, supposedly all people infer this initialmodel conclusion (*p* = 1). They are only able to generate the denial inference provided they construct and accept an alternative to *<null>*. This alternative represents the contingency wherein both the antecedent and consequent are false and yields the denial inference. That is, the likelihood by which people *generate* the denial inference would equal the likelihood (i.e. LCE_{FF}) of looking for, constructing and accepting *FF<not-A_not-C>*. Again, having *generated* a conclusion does necessarily imply that the inference will be *endorsed*. Some people will attempt to validate their conclusions. Of those people who generate the denial inference, some could look for a counterexample. DA ("not-A therefore C") is countered by *FT<not-A_C>*. The falsity of the antecedent is given by the categorical premise and the truth of the consequent is determined as the only alternative to the falsity of the consequent. When people look for a counterexample to MT, they would consider TF<A_not-C>. Upon accepting the counterexample, they reject the putative inference countered by it. That is, as shown in Figure 1 the denial inferences (MT/DA) would be endorsed by those who generated it (with a probability of LCE_{FF}) except those who generated it but considered and accepted a counterexample to it (with a probability of <LCE_{FT}>).

SSCEPPTRE's reasoning behaviour

Conditional inference rates SSCEPPTRE predicts the relative difficulty of the conditional arguments. First, the affirmation inferences are more likely than the denial inferences. In the later case, there is an additional weight. This weight (a multiplication factor, i.e. $LCE_{FF} < 1$) corresponds to the additional processing difficulty of generating the denial inferences. The initial models do not yield these denial inferences. Second, the logically valid arguments, MP and MT, are more likely than the logically invalid arguments, AC and DA. TF cases are impossible given the truth of the conditional, and people almost indeed almost unanimously judge them as such (Barrouillet & Lecas, 1998; Evans, 1983). FT is however possible and a sizable proportion of people state such. That is, everything else being equal, people are more likely to reject the logically invalid arguments. Third, the logical validity effect is caused by the

probabilistic in nature: The higher the frequency of counterexamples, the more likely people are to reject their initial model inferences (see, e.g., Schroyens et al., 2001). All processing step (i.e., parameters) have a particular likelihood of being successfully executed. When people fail to executed a step, the path is closed. Hence, the likelihood of reaching the end of this part of the processing chain is formed as the product of the likelihood of successfully executing each of the processing steps.

difference in the likelihood of accepting TF versus FT. In the case of the denial problems this difference is conditional upon first having generated and evaluated the denial inferences. Generating and accepting these denial inferences is less likely than generating the affirmation inferences ($LCE_{FF} < 1$). Hence the logical validity effect will be smaller on the denial versus affirmation problems. See Schroyens and Schaeken (2003, Schroyens et al., 2001) for meta-analyses and a comparative model fitting exercise.

Reasoning times In the following we first consider the accepted arguments. We then specify the novel predictions as regards the difference between reasoning times of accepted ($RT_{/1}$) versus rejected ($RT_{/0}$) arguments.

Accepted Affirmation Arguments We know that people are less likely to accept TF vs. FT (Barrouillet & Lecas, 1998; Evans, 1983). For MP, the validating search TF cases is almost literally a waste of time. Indeed, virtually nobody accepts TF. The *validation times*, i.e, reasoning times associated with the search for counterexamples, will therefore be added to the accepted MP latencies, $RT(MP_{/1})$. In AC, a proportion ($1-LCE_{FT}$) of these validation times adds to the rejected AC latencies. That is, *ceteris paribus*, we could expect $MP_{/1}$'s to take longer than $AC_{/1}$'s. But, not everything else is equal. First, we assume that there is a difference between evaluating TF and FT. People are relatively certain TF is impossible, whereas they are relatively uncertain that FT is possible. The increased doubt about FT would be reflected in longer evaluation times. It follows that the longer evaluation times counterbalance the lower proportion of validation-times in the $AC_{/1}$ arguments. Second, SSCEPPTRE assumes that the representations are relational in nature (cf. Footnote 1). The consequent event occurs within the context of the antecedent event. This factor introduces a directional relation between <A> and <C>. This affects one of SSCEPPTRE's procedures. Counterexamples are formed as the categorical premise in combination with the denial of the to-be tested conclusion. That is, in case of "A therefore *C*" (i.e., MP) the counterexample is formed as "A and *not-C*". This concurs with the directionality in <A(C)>. In case of "C therefore A" (i.e., AC) the goal-directed search for counterexamples yields "C and *not-A*". This is incongruent with the <A> to <C> directionality. That is, in AC the evaluation times of the *incongruent FT<C_not-A>* would be even higher, as compared to the evaluation times of the *congruent TF<A_not-C>* counterexample.

In summary, we expect that the reasoning times of accepted MPs are equal or longer than RTs for accepted ACs: $RT(MP_{/1}) \geq RT(AC_{/1})$. The higher proportion in MP of *validation times* is counterweighted by the longer latencies for evaluating AC's directionally incongruent counterexamples.

Accepted Denial Arguments The above derivation also applies to MT vs. DA. The implications of some of our assumptions differ however for denial arguments. First, we could expect that, *ceteris paribus*, $RT(MT_{/1})$ >RT(DA/1). Once people have generated the denial argument, some will look for a counterexample. The extra time it takes to look for, construct and evaluate the counterexamples will have a larger import on $MT_{/1}$, as compared to $DA_{/1}$. Since almost nobody will accept the TF counterexample to MT, almost all these extra validation times are included in the overall reasoning times of $MT_{/1}$. In $DA_{/1}$, fewer such validation times will increase the overall reasoning times. Indeed, more than for MT (because FT > TF), some of these longer validation times will become part of the reasoning times of the rejected DA arguments, $DA_{/0}$.

Second, not everything else is equal. It takes more time to evaluate the less certain FT vs. TF. That is, the higher proportion of validation times, as compared to the proportion of faster un-validated (but also accepted) MT reasoning times, is counterbalanced by shorter latencies in evaluating TF vs. FT. That is, RTs would again tend toward a null-effect. Third, this annulling effect of counterexample evaluation times is itself countered however by directionality. MTs counterexample is incongruent with the conditional. We therefore expect that the base prediction is reinstated: $RT(MT_{/1}) > RT(DA_{/1})$. Endorsing MT will generally take longer than endorsing DA.

In summary, first, the affirmation arguments will be endorsed faster than the denial arguments. The initial model does not represent FF, needed to endorse the denial arguments and people are consequently less certain and will take more time to accept the denial arguments. Second, there will be an interaction between problem type and logical validity. On denial the invalid argument (DA) will be endorses faster, whereas on affirmation problems the valid argument (MP) is the one that will be endorse faster.

Rejected Versus Accepted Arguments. SSCEPPTRE predicts that the $RT_{/0}$s for all four basic arguments will be longer than their $RT_{/1}$s. Figure 1 clearly shows this for rejected versus accepted affirmation arguments. When people reject the affirmation arguments, we know ex hypothesis that they have completed the entire time-consuming validation process of looking for, constructing and evaluating (i.e., accepting) the counterexample. The predictions are a mathematical consequence of the computational model. With each extra processing step (successfully executed, or not, with a particular likelihood) there is an additional processing time. Within the scope of the present paper we cannot present the proof. We therefore need to suffice with the heuristic device of Figure 1.

The processing chain associated with the denial inferences is somewhat more complicated in detail. The general idea however is relatively simple. The non-acceptance times are a composite of fast "nothing follows" conclusions, <*null*>, which are based on the initial representations, and slow "nothing follows" inferences, <*NULL*>, based on the accepted counterexamples. Figure 1 shows that the slow <*NULL*> reflects the conclusion that both the denial inference (e.g., <A>) and its counterexample (i.e., <not-A>) are judged possible. The $RT_{/1}$s are somewhere in between the fast <*null*> and slow <*NULL*> inferences. Hence, we cannot make an unequivocal prediction without specifying the relative proportion of the fast <*null*> and slow <*NULL*> inference reasoning times. However, Schroyens et al. (2001) already proffered that looking for counterexamples to <*null*> is more likely than looking for alternatives to a determinate conclusion. 'Nothing' does not satisfy the task demand to decide *what* follows from the premises. People will tend to look for a determinate inference, unless researchers emphasise that "nothing' is an acceptable conclusion. Indeed, most tasks employ an evaluation format. It follows that the initial null inference is bypassed by the given denial inferences (see Schroyens, 2005, for further support of this analysis).

Given the low proportion of people who satisfice with <*null*>, overall $RT_{/0}$s will tend to be longer for both MT and DA. Moreover, this effect will be stronger for DA than for MT. That is, the difference between $RT(MT_{/0})$ and $RT(DA_{/0})$ will tend to smaller than the $RT(MT_{/1})$ vs. $RT(DA_{/1})$ difference. The reason is fairly simple. The denial $RT_{/0}$s are a composite of fast <*null*> and slow <*NULL*> inferences. As argued above, the proportion of fast <*null*> inferences would be relatively small compared to the proportion of slow <*NULL*> inferences. In $MT_{/0}$ (vs. $DA_{/0}$) this proportion of slow <*NULL*> inferences would be smaller. Indeed, we know that people are less likely to accept TF as compared to FT. The RTs of the proportion of people who reject TF will generally not make part of the overall $RT_{/0}$s. People who reject TF will tend to accept MT.

Experiment

Method

Design All Participants evaluated the four standard conditional arguments. Three sub-groups were formed by also presenting the participants with a truth-table task. (The presentation order of the inference and truth-table task was counterbalanced). Participants completed a truth-based or possibility based truth-table task. One of the three subgroups solved the truth-based truth-table task after responding to a meta-theoretical question about truth.

Participants All participants (N = 350) were first year psychology students at the University of Leuven who participated in partial fulfilment of a course requirement. They were randomly allocated to three groups (100, 100 and 150 participants).

Materials and Procedure The conditional inferences task followed an evaluation format. Participants evaluated the randomly presented affirmation and denial arguments. All problems concerned letter-number combinations and were presented as follows (translated from Dutch).

Given: If the letter is an A, then the number is a 2.
Given: The number is not a 2.
Conclusion: Hence the letter is not an A.
Does this conclusion follow necessarily?

Participants responded by clicking the mouse cursor on 'follows' or 'does not follow'. RTs were recorded from presentation onset until the response was given.

In the truth-table tasks, people evaluated the four randomly presented truth-contingences: e.g., "an A in combination with a 2", "not an A in combination with not a 2", etc. In the possibility-based truth-table task, participants responded to the question "is this situation possible or impossible according to the rule" by clicking on <possible> or <impossible>. In the truth-based truth-table task, participants responded to the question "does the situation make the rule true or untrue, or is she irrelevant regarding the truth of rule" and clicked on <true>, <irrelevant> or <untrue> to provide their answer. (In Dutch, 'untrue' and not 'false' is more common). In the meta-theoretical condition, participants indicated whether they agreed or disagreed with the following paragraph:

> A situation that is IMPOSSIBLE according to a rule makes this rule UNTRUE. (e.g. 'The letter is an A and the number is a 4". If this rule is true, then the letter-number combination 'B-5' is impossible. 'B-5' shows that the rule 'A AND 4' is untrue about the set of letter-number combination from which 'B-5' was taken).
>
> A situation that is NOT IMPOSSIBLE according to a rule does NOT make this rule UNTRUE. Something that is NOT IMPOSSIBLE is POSSIBLE and something that is NOT UNTRUE is TRUE. This means that a situation that is POSSIBLE according to a rule makes this rule NOT UNTRUE and therefore TRUE.

We do not have place here to discuss the reasons for including this meta-theoretical question. The same goes for the possibility vs. truth-based truth-table task.[3]

Results and Discussion

Response frequencies. The inference rates (see Table 1) are in line with Schroyens et al.'s (2001) meta-analytic conclusions, and SSCEPPTRE's predictions. First, affirmation problems are easier than denial problems (.811 vs. .697: $T = 1667.5$, $Z = 5.68$, $p < .0001$). Second, logically valid arguments are endorsed more frequently than logically invalid once (.851 vs. .657: $T = 1610$, $N = 153$, $Z = 7.80$, $p < .0001$). Third, the logical-validity effect is larger for affirmation than denial arguments (.35 vs. .04: $T = 1564$, $N = 138$, $Z = 6.678$, $p < .0001$).

Table 1: Conditional inference rates (P) and RTs for accepted ($_{/1}$) and rejected ($_{/0}$) arguments.

	Argument			
	MP	AC	MT	DA
P	.986	.637	.717	.677
RT/1	9.32	11.56	14.42	12.00
RT/0	n < 5	14.53	18.52	17.05

Table 2 shows that all three truth-table tasks confirm the standard order in the acceptance rates ('true' or 'possible') of the four truth-contingencies: $1 \approx P(TT) > P(FF) > P(FT) > P(TF) \approx 0$. The overall linear contrast is highly are reliable (*Page* $L = 9708.5$, $Z_L = 33.18$, $p < .0001$). These

[3] The following citation might be enlightening though: "Each entry in a truth table represents the truth or falsity of an assertion given a particular possibility. In contrast, each mental model in a set represents a possibility. A corollary is that possibilities are psychologically basic, not truth values. Discourse about the truth or falsity of propositions is at a higher level than mere descriptions of possibilities" (Johnson-Laird & Byrne, 2002, p.653).

results confirm SSCEPPTRE's assumption about relative likelihood by which people will accept the different truth contingencies. The high proportion of 'false' evaluations of FT points towards so-called bi-conditional interpretations.

As noted above, an in depth discussion of true versus possible situations falls beyond the scope of the present manuscript. The expert reader will recognize the theoretical import of the higher acceptance rates of FF cases in the possibility-based task (e.g., .87 vs. .38). He/she will also appreciate (cf. Footnote 3) the import of their decreased irrelevancy evaluations in case participants first thought about the relation between the 'true' and the 'possible' (.54 vs. .41; $\chi^2 = 3.29$; $p < .05$, one-tailed).

Table 2: Frequencies and reaction times (RT in sec.) associated with evaluating the four truth-contingencies as possible or true.

	Truth Contingency			
	TT	FF	FT	TF
Possibility based task (N=100)				
Possible	.91	.87	.52	.19
Impossible	.09	.13	.48	.81
Overall RT	13.30	15.80	16.33	13.67
Truth based task (N = 100)				
True	.84	.38	.08	.06
False	.05	.08	.63	.85
Irrelevant	.11	.54	.29	.09
Overall RT	13.20	18.63	15.15	12.79
Meta-Truth based task (N =150)				
True	.93	.41	.13	.04
False	.02	.18	.65	.89
Irrelevant	.05	.41	.21	.07
Overall RT	12.14	17.32	16.62	13.92

Note. TT is the True-antecedent-True-Consequent contingency; TF is the True-antecedent-False-consequent contingency, etc.

Response Latencies Table 1 shows that the rejection times are longer than their acceptance times for AC, MT and DA: respectively, $t = 3.49$, $p < .0006$; $t = 3.46$, $p < .0006$, $t = 4.67$, $p < .0006$.

Acceptance Times. To test the predicted main effect of problem type, and the ordinal interaction between logical validity and problem type on the $RT_{/1}$s, we need to reduce the data set is to 45.7% of its original size, i.e. to the RTs of the 160 participants who endorsed all four arguments. With $RT_{/1}$'s of 9.65, 11.61, 12.91 and 12.25 we indeed find that affirmation arguments are endorsed faster than denial arguments (10.63 vs. 12.08; $F = 9.53$, $p < .005$). The expected difference between $RT(MP_{/1})$ and $RT(AC_{/1})$ ($F = 6.59$, $p < .05$) is in the opposite direction from the expected difference between $RT(MT_{/1})$ and $RT(DA_{/1})$, $F = 6.45$, $p < .05$. The interaction is reliable ($F = 11.91$, $p < .001$).

The two pair-wise comparisons between $MP_{/1}$ vs. $AC_{/1}$ and $MT_{/1}$ vs. $DA_{/1}$ can be done independently, which means that fewer cases are excluded. The additional data points do not make a difference. We have, respectively, 9.33 vs. 11.59, $n = 222$, $t = 3.804$, $p < .001$ and 13.56 vs. 11.89, $n = 186$, $t = 2.609$, $p < .01$. It will be recalled that these predictions hinge on the assumption that evaluation times of FT are slower than those of TF cases. Table 2 shows that all three truth-table tasks corroborate the assumption (p's <.001 for all comparisons).

General Conclusion

The theoretical import(ance) of our findings as regards reasoning times can be summarized in one sentence: They corroborate the detailed processing assumptions of SSCEPPTRE. We asked readers to bear with us in presenting the detailed picture of reasoning by model in SSCEPPTRE. We hope the effort has paid off in virtue of seeing a picture that approaches the indeed rather complex reality of thinking and reasoning about 'if'.

To derive our predictions about conditional reasoning we needed to make additional assumptions about reasoning times associated with component processes. For instance, we assumed that relatively uncertainty is reflected in the evaluation times of the possibilities that people would consider in the process of constructing and manipulating mental models. This yielded the novel prediction and observation that evaluating the "not-A and C" combination (TF) takes longer than evaluating the "A and not-C" combination (FT) vis-à-vis a conditional of the form "if A then C".

We took up the challenge of putting SSCEPPTRE to the test of explaining not only inference rates but also problem solving latencies. We hope that our results and analyses provide a similar challenge to alternative contemporary theories of human reasoning.

Acknowledgments

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