## Title
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# The Psychological Reality of Local Coherences in Sentence Processing

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**Abstract**

Dynamical systems of language processing predict that sentence processing complexity is not only a function of the globally coherent structure ranging from the beginning of the sentence to its current point of processing, but also a function of locally coherent sub-parses. This paper presents an experiment that tests whether locally coherent, yet globally false continuations affect on-line anomaly detection times. The results indicate that they do interfere with processing, but only if the global analysis is not too demanding. This result can be seen as an indicator of the psychological reality of local coherence processing, and hence supports the dynamic system view on language processing.

**Keywords:** local coherence; sentence processing; parsing complexity; relative clauses; anomaly detection; dynamical systems; simple recurrent networks.

## Introduction

There has been considerable debate as to why some sentences are more difficult to process than others, and why some people are more affected by this difference than others. Sentences can differ on a variety of dimensions affecting working memory demands, such as the number and place (left, centre, right) of embeddings, the number and range of open dependencies within a sentence, word order regularity, and the number and locality of integrations to be made at each word. The language-related, working memory-oriented literature has emphasized the notion of one or several memory resources, whose capacity or capacities may vary between individuals (Just and Carpenter, 1992, Caplan and Waters, 1996). Exceeding this capacity leads to an impaired comprehension quality, as intermediate processing results may be forgotten. More complex sentences draw more on these resources, leading to reduced reading speed. For instance, relative clauses (RCs) are harder to process when the relative pronoun represents the object of the RC (so called object-extracted relative clauses, ORCs, as in 1.) than when it is the subject (SRCs, as in 2., King and Just, 1991; Gibson, 1998; Traxler, Morris, and Seely, 2002).

1. The reporter who$_i$ the senator attacked $t_i$ admitted the error (ORC)
2. The reporter who$_i$ $t_i$ attacked the senator admitted the error (SRC)

In English, whether the relative pronoun (who) is the subject or the object of the RC is determined by the word order within the RC: in ORCs, where *who* is followed by an NP and then the verb, the pronoun represents the object of the sentence, while the NP is the subject. When *who* is immediately followed by the verb, it must be the clause-subject (SRC).

There have been numerous proposals to explain the RC-type effect. Sheldon (1974) pointed out that the same element (reporter) bears the same function (subject) in an SRC as it does in the matrix clause, whereas it carries different functions when it is the object of the ORC. Processing and memorizing *parallel functions* for the same entity should be less demanding than doing so with different functions. Wanner and Maratsos (1978) attribute the ORC difficulty to the fact that the filler (i.e. the host of the relative pronoun, here *reporter*) must be carried unattached longer in the ORCs than in SRCs, where the verb immediately follows the pronoun. Clifton and Frazier (1989) proposed the *active filler strategy* as a heuristics employed by the human parser. According to that strategy, which assumes that a trace co-indexed with the filler is proposed as soon as it is grammatically permissible during incremental parsing, memory load is held minimal. Of course, the earliest permissible filler position is right after the relative-pronoun *who*, as in SRCs. Gibson (1998) provided a metric of integration and memory costs associated with the number of new discourse elements intervening dependents. Both cost components are higher for ORCs: the prediction of a verb and a trace must be kept in memory across the RC subject (where memory cost is highest), and integration of the clause final verb with its complements requires crossing more discourse entities (the subject and the verb). Gordon, Hendrick, and Johnson (2001) propose similarity-based interference as the primary source of difficulty when the complements must be retrieved from memory. MacWhinney and Pleh (1988) pointed out that comprehenders want to take the perspective of the subject of the sentence, which requires them to *shift perspective* when an ORC is entered, and shift back when processing continues with the matrix clause. In SRCs on the other hand, they can keep the same perspective throughout the entire sentence, which is favourable.

Interestingly, readers with a low reading span show more difficulties with ORCs than others (King and Just, 1991). The reading span test used here (Daneman and Carpenter, 1980) was designed to involve both processing and memory skills.

Just and Carpenter (1992) proposed a model, named *CC-Reader*, which has at its core a parallel production system, whose rules spread activation to memory elements when they fire. Once a memory element receives enough activation to pass a threshold, it can be retrieved from memory. Crucially, the amount of activation available is limited (capacity constrained, hence CC), so that an activation increase of one element results in the decline of activation of other elements. Activation is considered a single resource that all language related cognitive processes have access to.

High span readers naturally have a larger capacity than low span readers, so that they can (*i.)* parse more complex sentences more easily, (*ii*.) pursue multiple analyses in parallel (MacDonald, Just and Carpenter, 1992), (*iii.)* use more higher level information to exclude implausible analysis paths in case of a temporal ambiguity, and (*iv.)* are less affected by extrinsic memory load (Just and Carpenter, 1992).

While the single resource idea has received considerable criticism (Caplan and Waters, 1996, 1999), there is little dispute about the assumption that some sentences are less memory intensive than others. Despite their differences, all proposals share the view that complexity is a function of certain construction-specific factors of *globally correct analyses* of a sentence. This view has recently been questioned by connectionist researchers.

## The dynamical system view on complexity

Tabor, Juliano and Tanenhaus (1997) proposed a dynamical systems approach to parsing based on a Simple Recurrent Network (SRN, Elman, 1990) in which syntactic hypotheses are associated with competing attractors in a metric space. When a reader/listener encounters a local ambiguity, the time to resolve it depends upon the point in the multi-dimensional space where the system starts out and on the number of cycles needed to settle down in an attractor position. Crucially, while their account mainly focussed on local ambiguities in sentences, it was later demonstrated that ungrammatical influences of local coherences can also affect comprehension performance. To test this hypothesis, Tabor, Galantucci and Richardson (2004) conducted a series of self-paced reading studies with sentences such as (3-6).

3. The coach chided the player tossed a frisbee by the opposing team.
4. The coach chided the player who was tossed a frisbee by the opposing team.
5. The coach chided the player thrown a frisbee by the opposing team.
6. The coach chided the player who was thrown a frisbee by the opposing team.

The verb *tossed* in (3) is morphologically ambiguous: it can be either a past participle or a past tensed main verb. For that reason, sentence (3) contains as a local subsequence the main clause … *the player tossed a frisbee* …, where *tossed* is a past-tensed verb (in fact, this is an instance of the standard *main clause/reduced relative* garden path construction, as in "the horse raced past the barn fell", cf. Bever, 1970). However, the subsequence is embedded in a context that would exclude the main verb analysis, because the NP *the player* must be the object of *The coach chided*, so that it cannot be the subject of *tossed*. If the human sentence processor pursues only global analyses, it should never consider the past-tense alternative of *tossed* and the main clause continuation, given that the previous context excludes that analysis. Reading times on *tossed the Frisbee* should hence not differ from unambiguous counterparts 4-6, where the main clause analysis is further excluded by the RC beginning *who was* … (4,6), and the use of the synonymous but unambiguous past participle *thrown* instead of *tossed* (5,6). However, reading times were elevated in (3) on that region. Tabor et al. interpreted this result as evidence for the interference of globally ungrammatical, yet locally coherent analyses.

This interpretation has recently been criticized by Gibson (submitted), whose account assumes an interaction of global top-down and local (unigram) lexical statistics. According to this view, strong unigram lexical preferences can override weak global top-down predictions so that readers can be fooled by strongly biased ambiguous words. The verb *tossed* is statistically much more likely a main verb than a participle and can hence override the global expectation.

Crucially, Gibson's account requires lexical ambiguities to predict an interference effect. While Gibson's hypothesis can account for the Tabor et al.'s data, it also predicts that no local coherence interference should be observable when no ambiguous words are included in the sentence. This question will be addressed in the experiment presented below.

Furthermore, neither Tabor et al.'s, nor Gibson's work have taken into account inter-individual differences in disruption, and there is yet no reference to the working memory debate in the psychological literature at all.

Nevertheless, there has been one notable attempt to tackle working memory issues with dynamical system accounts. MacDonald and Christiansen (2002, henceforth MC) proposed an experience-based account of linguistic performance. Like Tabor et al's work, MC used Simple Recurrent Networks (Elman, 1990) to model processing difficulty. SRNs acquire implicit grammatical knowledge when they are trained to predict every next word given the words of sentences one at a time. MC's networks were trained in three training epochs. Each epoch comprised ten thousand grammatical sentences generated by a probabilistic grammar, with complexity ranging from simple intransitive and transitive main clauses to multiple center-embedded relative clauses.

When MCs' SRNs where tested with SRCs and ORCs, they produced *grammatical prediction error* (GPE) patterns that resemble the reading times found in high- and low-span readers (King and Just, 1991): The GPEs started high for ORCs but then quickly decreased with each training epoch, while they stayed constantly low for SRCs.

Because SRNs are only presented with sequential information, processing complexity differences between SRCs and ORCs can best be attributed to their differential degree of word order regularity. This claim is based on the observation that SRCs exhibit subject-verb-object (SVO) word order, just as simple transitive main clauses do. ORCs, on the other hand, show irregular word order (OSV). While the odds for RCs are generally rather low in corpora, processing SRCs should benefit from word order regularity being transferred from main clauses. Furthermore, the amount of training affected the error-patterns in much the same way as reading span did affect reading times: While there were basically no differences between more and less experienced networks for SRCs, more experienced networks were better then less experienced ones for ORCs. Inter-individual differences in memory capacity – as measured by the reading span test – were hence attributed to the differential amount of experience with language processing, as simulated by the three training epochs[1]. Since SRNs lack a clear functional distinction between the linguistic knowledge, processing, and a knowledge-free notion of a working memory and its capacity, MC's account has been first and foremost posited against capacity-based working memory models such as 3CAPS (Just & Carpenter, 1992), and generally against any account that claims a knowledge-independent notion of working memory capacity.

*Local coherences.* In MCs networks, parsing complexity is affected by activation erroneously assigned to ungrammatical words (so called *false alarm predictions*) and by missing activation of grammatical words (*misses*). Crucially, false alarm predictions stem from local coherences that the networks attempt to continue, so that activation is distracted from the globally grammatical continuation prediction. A detailed analysis of MCs' output activity patterns (Konieczny and Ruh, in prep.) shows that the higher error at the matrix verb after ORCs is mainly due to the networks predicting another NP after the embedded verb, as in the locally coherent sub-sequence NP-verb$_{trans}$-NP. Similar locally coherent false alarm effects are predicted for German RCs (Konieczny and Müller, 2004) which even remain stable over more than a hundred learning epochs when the network has already established the farther reaching agreement dependency between the matrix subject and the verb.

It is exactly this kind of false alarm prediction of an NP following the clause-final verb that the following experiment explores further.

## Anomaly detection experiment

It is essential for the understanding of the human language processor to establish locally coherent false alarm distractions in comprehension, if they exist. It will furthermore be important to establish inter-individual differences in processing local coherences. The present paper addresses this issue with an *on-line anomaly detection* experiment. The rationale behind the experiment is that global syntactic violations that are nevertheless *locally consistent* with a false expectation (i.e., locally coherent) should be *harder* to detect than anomalies that are both global *and* local. Depending on the theoretical point of view, the local analysis might interfere by either distracting attention from the global analysis, or by having the concurrent local analysis compete with the global analysis for memory resources.

[1] This claim was questioned by Caplan and Waters (2002) by showing that the two variables do not seem to be correlated, but see Köckner, 2002, for opposing results.

### Local coherences, working memory, and experience

If locally coherent expectations are psychologically real, it will be interesting to see whether and how their effect is modulated by working memory and experience variables. The capacity-oriented framework predicts that interference occurs only if there are sufficient memory resources available to pursue a parallel local analysis, so that high span, rather than low span readers should exhibit distraction effects, but only when sentences are not too complex. For experience-based models, on the other hand, the most important factor is the relative frequency and regularity of the local coherence, compared to all other interfering coherences, including the global analysis. Furthermore, the relative influence of more distant constraints should grow with more experience, and shorter coherences should lose ground. More experienced participants should hence be better in inhibiting locally coherent false alarm predictions and should therefore be less affected by shorter coherences. In the current experiment, experience was measured with a simple questionnaire, where participants had to indicate how much time per day they spend reading any kind of text.

### Materials and design

In both German SRCs and ORCs, the verb is placed at the end of the RC, and function-assignment is based on morphological case marking. In ambiguous cases, RCs are preferentially understood as SRCs. ORCs also pose more problems to language processors than SRCs (e.g. Mecklinger, Schriefers, Steinhauer and Friederici, 1995; Bader and Meng, 1999).

Four erroneous sentence types (7-10), derived from sentences with centre-embedded SRCs and ORCs, were constructed according to a 2x2 design comprising the factors *type* (SRC, 7-8, vs. ORC, 9-10) and *error coherence* (coherent vs. incoherent). Errors were produced by inserting an NP (*der/den Politiker*) after the embedded RC-verb. Inserting a nominative NP after SRCs yields the locally coherent sub-sequence NP$_{acc}$-verb-NP$_{nom}$, i.e., a topicalized transitive main clause sequence (8). Similarly, an accusative NP after the verb in ORCs (10) yields an NP$_{nom}$-verb-NP$_{acc}$ (canonical main clause) sub-sequence. The incoherent versions were produced by inserting an accusative NP in SRCs (7), yielding a local NP$_{acc}$-verb-NP$_{acc}$ sequence, or a nominative NP in ORCs (9), yielding a local NP$_{nom}$-verb-NP$_{nom}$ sequence.

7. *SRC, incoherent*
   Der Abgeordnete, der *den Journalisten beschimpft* *[*den Politike*r], liefert die Beweise.
   The congressman, who$_{nom}$ *the journalist* $_{acc}$ *attacks* *[*the politician*]$_{acc}$, delivers the evidence.
8. *SRC, coherent*
   Der Abgeordnete, der *den Journalisten beschimpft* *[ *der Politiker*], liefert die Beweise.
   The congressman, who$_{nom}$ *the journalist* $_{acc}$ *attacks* [*the politician*]$_{nom}$, delivers the evidence.

9. *ORC, incoherent*
   Der Abgeordnete, den *der Journalist beschimpft* *[*der Politiker*], lieferte die Beweise.
   The congressman, who$_{acc}$ *the journalist$_{nom}$ attacks* *[*the politician]$_{nom}$*, delivers the evidence.
10. *ORC, coherent*
   Der Abgeordnete, den *der Journalist beschimpft* *[*den Politiker*], liefert die Beweise.
   The congressman, who$_{acc}$ *the journalist$_{nom}$ attacks* *[*the politician*]$_{acc}$, delivers the evidence.

Twenty-four sentences of each type were constructed and distributed to four lists according to the latin square rotation scheme, so that one version of each material appeared in each of the four lists, and each type appeared equally often (five times) in each list. There were another forty sentences with various types of errors (agreement errors, noun omission errors, case errors) and another sixty correct sentences of various types as fillers, so that there were as many wrong sentences as there were correct ones in the stimulus sets.

## Procedure

Sentences were presented in a word-by-word rapid serial visual presentation (RSVP) fashion. Each word was presented 180+*n**28ms, where *n* is the number of characters of the word. Before the experiment, participants were instructed to press, depending on their handedness, the left or right shift button as soon as they noticed an error in the sentence. They could do so during the presentation of the sentences, or shortly afterwards (up to 800 ms after the last word). There was no indication as to what the error would be like. No button had to be pressed if the sentence was entirely correct. Immediate feedback about their decision (correct or wrong) was given after each trial. After a short pause of 500 ms, the next sentence was presented. The time from the onset of the first erroneous word (*der* or *den*) until they pressed the button was recorded as the *anomaly detection* (AD) time. The anomaly detection paradigm was set up with the DMDX display software package (Forster and Forster, 2002), and ran on a 1 Ghz Pentium III computer running Windows XP.
After the experiment, participants were given a questionnaire where they were asked to indicate how much time they spent reading newspapers, literature, e-mail, books, WWW, etc. each day on average. The scale ranged from zero to more than three hours per day.

## Hypotheses

*Accuracy*. There is no grammatically permissible way to add another phrase after a verb in German RCs without adding a comma after the verb. The anomaly detection task is hence fairly easy for the target sentences, as it amounts to noticing whether the embedded verb is followed by a comma (correct) or not (false). Therefore we expected participants to perform with an over-all high accuracy, without differences between conditions.
*Anomaly detection time*. AD time, however, should differ considerably for locally coherent continuation errors, compared to locally incoherent ones, such that coherent ones should take a little longer to be detected.
If experience interacts with AD performance, it should induce a larger coherency effect for more regular local coherences. The coherency effect should therefore be larger for ORCs, where the local coherency is a regular SVO main clause, whereas in SRCs, it is a slightly less frequent topicalized OVS main clause. This difference should be smaller for more-experienced readers.
However, if experience is just an estimate for working memory capacity the results might show the opposite pattern: the coherency effect should be stronger for SRCs, which are easier to process than ORCs and thus leave enough resources for parallel local analyses. However, this difference should vanish for more experienced, and hence high span readers, as they should have sufficient resources for local parses even in more demanding ORCs.

## Participants

Fifty-four students from Freiburg were paid 5 € each to participate in the experiment. Each participant was assigned to one of three experience groups, depending on whether she spent less than an hour per day reading (*low* experience, twenty-four participants), between one and two hours (*middle*, eighteen participants), and more than two hours (*high*, twelve participants).

## Results

*Accuracy.* As expected, participants detected the error (*der/den* instead of a *comma*) with a high precision of more than 93% correct responses. There was no difference in accuracy between conditions (see table 1), and no differences between experience groups.

Table 1: Anomaly detection accuracy for each of the experimental conditions.

| | Correct rejections |
|---|---|
| SRC, incoherent | 93.8 % |
| SRC, coherent | 93.4 % |
| ORC, incoherent | 94.1 % |
| ORC, coherent | 93.2 % |

*Anomaly detection times.* Only trials with correctly rejected sentences were analyzed for AD times[2]. The data were submitted to a 2x2x3 MANOVA for repeated measures, including *clause type* (SRC vs. ORC) and *local coherency* (*coherent* vs. *incoherent*) as within-subject factors and

[2] Before data analysis, outliers were excluded. Outliers were identified for each condition using the SPSS boxplot procedure: a box is defined by the inter-quartile range of values. Cases with values more than 1.5 box lengths from the upper or lower edge of a box were then excluded from data analysis[2]. This procedure affected 2.7 % of all data points, with no differences between conditions.

*experience level* (*low, middle, high*) as between-subject factor[3].

Figure 1 illustrates, with experience groups collapsed, that in SRCs, but not ORCs, AD was reliably (149 ms) longer for locally coherent errors than for incoherent errors, resulting in both significant main effects for *coherency* (F1(1,51)=20.26, MSe=18336, p<.001; F2(1,23)=8.89, MSe=14241, p<.01) and *RC-type* (F1(1,51)=5.79, MSe=36957, p<.05; F2(1,23)=2.83, MSe=28077, p=.106), and a reliable interaction of coherence and RC-type (F1(1,51)=5.58, MSe=35560, p<.05; F2(1,23)=8.31, MSe=46885, p<.01). Simple contrasts between coherent SRC and incoherent SRC errors confirmed the effect within SRCs (F1(1,52)=22.61, MSe=28864, p<.001; F2(1,23)=14.16, MSe=31613, p<.005), and within coherent (SRC vs. ORC) sentences (F1(1,52)=11.99, MSe=44610, p<.005; F2(1,23)=8.32, MSe=42574, p<.01).

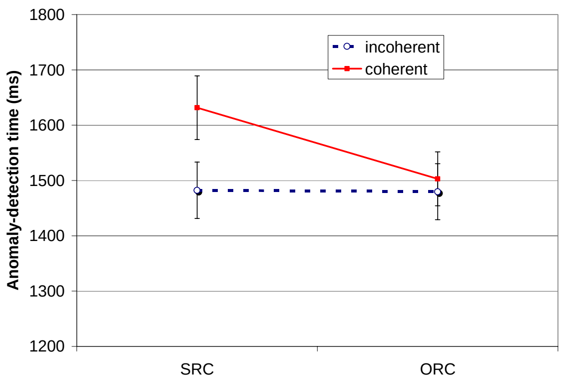


Figure 1: Anomaly detection times for SRCs and ORCs with locally coherent and incoherent errors. Whiskers indicate standard errors.

*Experience level*. There was a significant main effect for experience (F1(2,69)=3.12, MSe=67235, p=.05; F2(2,22)=5.67, p<.05), which was due to the fact that the least experienced participants were faster than any of the other two groups. While there is a clear coherency effect for SRCs in all experience groups, only the most experienced readers showed more difficulty for coherent errors in ORCs as well (see figure 2), though not reliably so. None of the interactions with coherence or RC-type were significant (all Fs < 1.7). The lack of a three way interaction *experience* x *RC-type* x *coherence* might be due to the lack of statistical power, as substantially more participants are needed for a reliable between-subjects analysis.

## Discussion

The anomaly detection time results support the psychological reality hypothesis of locally coherent analyses in comprehension. The fact that the coherency effect is restricted to SRCs for all but the more experienced readers apparently supports the capacity hypothesis, provided that reading span

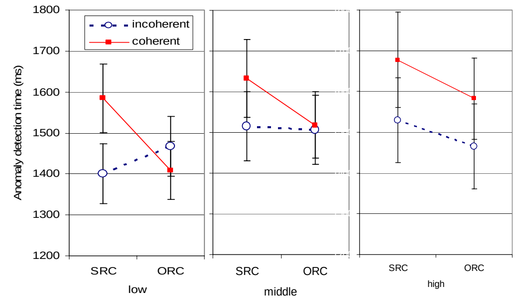


Figure 2: Anomaly detection times for SRCs and ORCs with locally coherent and incoherent errors, separated for three experience groups. Whiskers represent standard errors.

and experience can be shown to be correlated (Klöckner, 2001): Since ORCs are too demanding for less experienced readers, they have no sufficient resources available for a parallel locally coherent analysis. If they are available, as in SRCs and, for highly experienced readers, in ORCs, a local coherency does indeed affect AD times.

However, the results can also be reconciled with an experienced-based framework. The local coherences that we investigated here spread across up to five words (5-gram): *det-noun-verb-det-noun*. More experienced networks are better in incorporating more distant dependencies. More experienced participants could therefore be more sensitive to longer coherencies and better in inhibiting short ones. Now, note that in the materials there is another, shorter (3-gram), coherence hidden within the larger local coherence: …*verb-det-noun*. It turns out that in German, the global sequence $verb_{fin}$-$NP_{nom}$ is quite common, as it is the beginning of a canonical question (as in *Schläft der Junge?, Sleeps the boy?, "Does the boy sleep?"*), or the continuation of a canonical main clause, where the *Vorfeld*-position is occupied by an adverb (*Gestern schlief der Junge, Yesterday slept the boy, "Yesterday the boy slept"*), by a conjunction (*Deshalb kaufte der Mann …; Therefore bought the man … "Therefore the man bought …"*), or any topicalized constituent of the verb-phrase (*Mit dem Fernglas beobachtete der Polizist …; With binoculars watched the policeman …; "With binoculars, the policeman watched …"*).

In SRCs, expecting a nominative after a finite verb is supported by both longer and shorter coherences. In ORCs, however, the long coherence supports an accusative prediction, while the short coherence supports a nominative. Both expectations might then compete with each other, so that the coherency effect is eventually extinguished here. More experienced readers, however, might have learned to better suppress very local (i.e., short distance) distractors, so that only longer ranging coherences can interfere with the global analysis. If so, experienced readers might show the coherency effect even for ORCs, which is, in fact, what the results so far suggest. Further research will be necessary to clarify this issue.

[3] While experience level is a between-participants factor, it is treated as a within-item factor in the item analysis.

The results are in line with Tabor et al. (2004), who found indications of local coherence interference in sentences with locally ambiguous clauses embedded in disambiguating sentence contexts. As in the present experiment, readers seem to have pursued a globally prohibited, but locally coherent analysis. Different from Tabor et al.'s experiments however, the present study does not involve local ambiguities. The NPs added to the sentences are clearly syntactically wrong in all cases, and yet readers do seem to be disturbed more severely when the NPs continue a local coherency. The results are hence hard to reconcile within Gibson's (submitted) account.

## Conclusion

The results presented suggest that local coherences can interfere with 'normal' parsing, as suggested by dynamical system models. In these models, processing difficulty is influenced by the number of potential concurrent analyses, and on-line complexity can be estimated by how much activation is devoted to false alarm predictions induced by local coherences. The false alarm effect has two fundamentally important implications for the nature of parsing complexity: The standard view, by which human sentence processing is considered a depth-first mechanism that pursues only one globally correct parse, must be rejected in favor of a model that can pursue several alternative analyses in parallel, at least locally. Moreover, parallel analyses are not restricted to temporal ambiguities in the global string, they also occur within local sequences starting at positions different from the sentence beginning. The present results support this view.

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