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Abstract:

Evermann and Rönkkö aim to present an overview of recent advances in PLS, and while some advances are described with several useful recommendations, we argue that their article does not fully deliver on its promise. In this response, we argue that their position presents an unbalanced view, ignores several methodological advances by IS scholars. We note that several recommendations are so stringent that implementing that there are philosophical and practical differences that are insufficiently taken into account. Further, several studies that highlight the shortcomings of PLS seem to be based on specially designed cases that are not necessarily representative of typical use of PLS. In our response, we call for a more balanced debate that takes into consideration different perspectives and that studies of the performance of PLS are conducted fairly. While we do not disagree with E&R's recommendations, the implementation of those is challenged by a lack of tool support, and we observe that besides scholars using PLS, editors and reviewers also have a responsibility to be cognizant of methodological advances. We commend E&R for their efforts in studying the limitations of PLS which have spurred several methodological advances, but also caution that we should not 'throw the baby out with the bathwater," by discarding PLS for its known limitations.

Keywords: Structural Equation Modeling, Partial Least Squares.

[Department statements, if appropriate, will be added by the editors. Teaching cases and panel reports will have a statement, which is also added by the editors.]

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1 Introduction

> When [Copernican astronomy's] predecessor, the Ptolemaic system, was first developed during the last two centuries before Christ and the first two after, it was admirably successful in predicting the changing positions of both stars and planets. No other ancient system had performed so well; for the stars, Ptolemaic astronomy is still widely used today as an engineering approximation; for the planets, Ptolemy's predictions were as good as Copernicus'.
>
> —Thomas Kuhn, The Structure of Scientific Revolutions

Throughout history, scholars have developed theories and models to explain and predict the world around them. Claudius Ptolemy (c. 100 a.d. — c. 175 a.d.) developed theories to predict the position of heavenly bodies and tide tables, which were based on the false premise that Earth was at the center of the universe. Copernicus, on the other hand, correctly placed the Sun at the center, and thus his theories should have performed better… except that his theory still made the wrong assumption that planetary orbits were *circular* and thus did not necessarily reflect reality more accurately. In fact, in certain cases, Ptolemy's predictions were more accurate! Other examples of competing and incompatible theories in the history of science include quantum mechanics vs. the theory of relativity, the wave theory of light vs. the particle (corpuscular) theory of light.

We are reminded of these competing theories in the debates on the use of PLS, because PLS is typically used as an alternative to the common factor based approach to structural equation modeling (SEM), commonly referred to as covariance-based SEM (CB-SEM). PLS-SEM and CB-SEM employ different representations of theoretical constructs; both can be used to evaluate structural equation models, but the way they work is different.

In this commentary we respond to Evermann and Rönkkö's (2021) article "Recent Developments in PLS." We recently completed a review of the use of PLS in the Software Engineering (SE) literature (Russo and Stol, 2021); many of the studies that we reviewed, though published in quality SE journals and conferences, seem to have been authored by IS researchers, and thus our observations would be directly relevant to IS researchers also.

We applaud Evermann and Rönkkö (E&R) for taking on the major task of studying PLS as an approach to evaluate structural equation models (SEM). It is essential that scholars stay informed about new methodological advances, and that methods are used and reported appropriately. The mis-use and misrepresentation of methods happens not only for quantitative methods; we also observed this problem in the use of qualitative methods such as Grounded Theory (Stol et al., 2016). Methodological reviews help to offer a mirror to the community to assess the state of practice of reporting our research and identify areas for improvement.

E&R correctly observed that PLS was ascribed properties and benefits that had not been empirically demonstrated. Several misconceptions exist around the PLS approach, many of which have been debated in other critical articles (Aguirre-Urreta and Marakas, 2014; Henseler et al., 2014; Petter, 2018; Rigdon et al., 2014). E&R's concerns about the mis-use, reporting, and, evidently, reviewers' lack of knowledge of PLS are warranted. As our understanding of PLS has advanced over the years, it is imperative that these are clearly communicated to the wider IS community who, as E&R pointed out, were among the early adopters, and who have relied on its use to develop some well-known theories within the IS literature.

And so, the tone of E&R's abstract sounds very promising indeed:

> *"This paper comments on recent developments in PLS to ensure that IS researchers have up-to-date methodological knowledge and best practices if they decide to use PLS."*

Except that the article does not deliver on this promise, in our view, for two reasons. First, discussion of several recent developments that are relevant to IS scholars are notably lacking. Relevant work by Kock and Lynn (2012) and Kock (2015a, 2015b 2018, 2019a, 2019b) offers several approaches to address

some issues in PLS-SEM. For example, Kock (2015a, 2019a) offers a new method to conduct factor-based PLS-SEM analyses. A key issue underpinning the debate between proponents and detractors of PLS-SEM is the representation of latent variables as *composites*, rather than as *common factors* as is the case in CB-SEM. These two representations are incompatible. As Kock pointed out, the proposed factor-based PLS-SEM, which is labeled PLSF-SEM, *"could be a solid step in the resolution of this debate."*

A second reason why we argue that E&R's article does not deliver is, what we perceive to be an overly critical and polarizing position towards PLS, which has been extensively documented in their previous articles (Rönkkö and Evermann, 2013; Rönkkö et al., 2015; Rönkkö et al., 2016; Rönkkö et al., 2021). While we don't disagree with the recommendations that E&R propose, we would argue that to truly achieve their stated goal, namely to "ensure that IS researchers have up-to-date methodological knowledge," a more inclusive review of recent developments is needed, but also a less polarizing presentation of the shortcomings of PLS.

In this commentary we seek to add some nuance to E&R's points of critique. We do not share their critical view on PLS; as scholars, we have used both PLS-SEM (Russo, 2021; Sharma and Stol, 2020) and CB-SEM (Russo et al., 2021; Schaarschmidt and Stol, 2018), and we have no bias towards one or the other. A central argument is that both PLS-SEM and CB-SEM are useful tools to IS and SE scholars, but that both have strengths and weaknesses, much like both the Ptolemaic and Copernican systems. Despite the weakness (indeed, incorrectness) of the Ptolemaic system, it remains to be useful. Hence, we argue, "don't throw the baby out with the bathwater!" Which 'system' to use (PLS-SEM, CB-SEM) depends on the situation, context, and focus of the research (Evermann and Tate, 2016; Petter, 2018), although as we point out later in our response, current guidelines are somewhat limited.

In what follows, we present a number of comments and observations (Sec. 2), and we conclude with a number of recommendations to help the debate forward (Sec. 3).

2 Comments and Observations

We appreciate the detailed presentation that E&R offer on the technical foundation of PLS. They perceive a number of threats to the validity of PLS and based on these they make a number of recommendations. While we do not disagree with these recommendations, we do present four comments and observations that, we believe, add nuance to their critique of PLS.

2.1 Toward a More Balanced Debate of PLS

We argue that E&R present a somewhat, might we say, "confusing" claim that they "do not intend to argue for or against the use of PLS compared or other methods." We believe that this is in effect what E&R's article does. The authors are openly critical towards the use of PLS:

> *"One has to wonder what, despite all these improvements, can be gained by using PLS over well-established, better understood, and conceptually simpler alternatives? Again, this is best left as a rhetorical question for the reader to ponder."*

First, we noticed a number of inconsistent statements. E&R have argued in their previous work against the use of PLS (Rönkkö and Evermann, 2013; Rönkkö et al., 2015; Rönkkö et al., 2016; Rönkkö et al., 2021). Similarly, E&R write in their "recent developments in PLS" paper that "Our critique has been misinterpreted as denying that PLS is a SEM technique. However, we make no such claim [...]" Yet, one of the "highlights" of Rönkkö et al.'s (2015) article states: "Partial least squares (PLS) is simply an indicator weighting system and not SEM." This is why we are somewhat left confused with E&R's statements. It would be curious if their earlier standpoint now changed dramatically—though we acknowledge that everybody is entitled to revisit their opinions!

Second, while E&R state that "it is left to readers to come to their own conclusions" regarding the question of whether or not to use PLS, we argue that their presentation is one-sided on the one-hand, and possibly perceived as "overwhelming" on the other. We believe it is one-sided in that the reader is not presented all information; certain assumptions underpinning E&R's arguments have been left implicit. Further, as E&R point out, the debate about PLS is not new, and several scholars have presented PLS in a more positive light. However, counterarguments in support of PLS, or alternative viewpoints on PLS don't seem to be reflected in E&R's article (cf. Rigdon, 2016; Rigdon et al., 2014; 2017). It might have been prudent to include a summary of the debate thus far to give readers a full account of the issues and perspectives.

The argument is "overwhelming," because we believe it is fair to say that the average IS or SE researcher is not intimately familiar with many of the technical intricacies of the formulas underpinning PLS. By presenting a case that is quite technical in nature, supported by formulas, deductions, and results of simulation studies (which many applied scholars using PLS-SEM, we reckon, would have difficulty performing; we do appreciate Aguirre-Urreta & Rönkkö's (2015) tutorial), E&R's arguments seem quite reasonable; the reader is "overwhelmed" by the arguments, and the formulaic presentation would suggest that "it must be true because the math says so," despite the fact that there have been reasonable counter-arguments that question the assumptions that those formulas are based on (cf. Rigdon 2016).

Third, while E&R do not explicitly compare PLS-SEM to the best-known alternative, namely CB-SEM, scholars interested in researching latent variables have few other options than CB-SEM, and sometimes CB-SEM analyses do not work (e.g. models that don't converge). We appreciate that E&R discuss generalized structure component analysis (GSCA) as an alternative; perhaps a more in-depth comparison between PLS-SEM and GSCA would have made a better topic, to inform IS researchers of viable alternatives to PLS. That would have equally supported E&R's intent of their article as stated in their conclusion: "to help IS researchers remain current with important methodological developments and to provide a sound foundation upon which to base their choice of statistical methods."

Fourth, E&R take a rather hardline stance in their treatment of PLS, which we would argue contributes to a polarization of the debate. We perceive E&R's stance as negative (despite them denying it), and others taking an opposite stance that we would characterize as, perhaps, too optimistic—as exemplified by Hair et al.'s (2011) article entitled "PLS-SEM: Indeed A Silver Bullet." We do not believe in silver bullets; in statistical analysis, every methodological choice comes with affordances, but also at a cost: one has "to pay the reaper" (Curran, 2003). We believe that taking hardline positions on these matters preempts a more fruitful conversation. E&R were right to ask critical and important questions about a decade ago; it is somewhat ironic that their initial critical perspective, which seemed to focus on discouraging scholars to use PLS, has led to several improvements of PLS—clearly, their points of critique have been taken seriously! However, we argue that a more nuanced conversational tone might be more useful to the overall goal of understanding the limitations of PLS and offering solutions where possible.

2.2 Know Your Audience

E&R are clearly experts in the technical intricacies of PLS and CB-SEM, and as such they are able to highlight the various differences to a great level of detail. Perhaps "blinded" by their own expertise, in their collection of issues, they may have lost sight of their audiences. For example, we observed that E&R wrote:

> - *"we, as a discipline, have staked our collective reputation on PLS and 'bet the farm' with very little understanding."*
> - *"Ironically, these tests [e.g., SRMR] are largely ignored by IS researchers who tend to favor the CR and AVE statistics despite their demonstrated incapability to differentiate good models from bad ones."*

In these quotes, "we" and "IS researchers" point to the IS discipline as a whole. Our argument here is that "we," "we as a discipline," and "researchers" are widely varying groups of people with different agendas and expertise. We agree with the general sentiment that all scholars have a responsibility to study and familiarize themselves with the methods they use—this is, after all, the core business of scholars in search for some truth and understanding of the world. We would readily agree (from our experience reviewing papers) that certainly not all scholars do this. However, we argue that those scholars who *did* do due diligence do not believe they are "betting the farm." PLS is but one method of many used in IS research, and so claiming that the reputation of the IS discipline as a whole is at stake, is hyperbolic.

In a similar manner, E&R make several points and recommendations that seem to overestimate the expertise of the average applied IS scholar using PLS.[1] For example:

> - *"Given that simulation studies for PLS are easy to perform with modern PLS software tools..."*

[1] To be clear, we do not suggest that IS researchers using PLS are not experts at what they do, but based on our review (Russo and Stol, 2021) we did find variation in expertise that was exhibited in the various papers.

> - *"If a researcher uses PLS, adequate model fit should be established using d_g prior to interpreting estimates or assessing factorial structure" (Recommendation 6)*
> - *"If a researcher uses PLS for prediction, the study should adequately justify and reflect this motivation and assess out-of-sample prediction at the individual level" (Recommendation 8)*
> - *"If a researcher uses PLS with dependent formative constructs, researchers should verify and publish the statistical model (i.e., the equations) that is assumed and estimated to avoid any confusion" (Recommendation 10)*
> - *"PLS composites should be compared to unweighted composites to demonstrate any possible advantage that the PLS composites might have" (Recommendation 13)*

All of these suggested procedures are rather advanced steps and not straightforward to perform—this is what we mean that E&R may be 'blinded' by their own expertise. These procedures go well beyond the typical introductory textbooks on PLS, though we agree that some tools may provide better support for some of these than others. For example, Recommendation 10 (listed above) suggests that the equations of the statistical model be published; while this may be easier to do in an open source package that requires explicit specification of a model, other popular tools that offer a graphical interface do not readily generate these equations.

Then there is the issue of reviewers, who have the same responsibility of familiarizing themselves with recent methodological advances. For example, CR and AVE statistics, as well as an exploratory factor analysis (EFA) to inspect crossloadings, were used for decades for establishing discriminant validity (Bagozzi and Yi, 1988; Fornell and Larcker, 1981). Indeed, E&R rightly point out that these measures have weaknesses, and that the HTMT criterion would be better. Yet, reviewers who do not keep up to date may simply request that authors report CR, AVE, and results of an EFA out of habit, unaware of their shortcomings. Authors who no longer report these criteria, may simply throw their hands up and comply with reviewers' requests, no matter how unreasonable or inappropriate, simply to progress their paper in the review process. Thus, we cannot 'blame' researchers for using outdated measures without also requiring due diligence from editors handling such papers.

For many researchers, the recommendations and advice by E&R are unrealistic and hard to follow.[2] The use of HTMT is not unproblematic because, as E&R point out, "its use with PLSc presents two challenges," all the while E&R's Recommendation 1 was to use PLSc. Other recommendations are so stringent that, in effect, E&R discourage the use of PLS altogether.

2.3 Philosophical and Practical Differences

There are clearly philosophical differences in how scholars perceive PLS (cf. Rigdon, 2016). Many scholars who simply use data analysis methods neglect the differences between PLS-SEM and CB-SEM. This is not dissimilar to how Principal Component Analysis (PCA) is often (mistakenly) mixed up with factor analysis methods—even one of the most popular statistics packages, IBM SPSS, groups PCA with "real" factor analysis methods in its user interface. For the outsider, the difference is trivial; whether a theoretical construct is measured using a common factor model or as a composite, is then perceived as just a minor issue without clear implications. While several scholars have written extensively on this (Rigdon et al., 2017; Sarstedt et al., 2016), one argument that has been put forth is that a common factor and a composite are two different ways to represent a theoretical construct (Rigdon, 2016). One could even argue that the common factor model might not be an optimal or correct representation, either. For example, latent variables are most commonly modeled as "reflective," which implies that the unobserved latent variable that the researcher believes to exist, *causes* the observed variables. This assumption does not hold when dealing with certain concepts, such as socio-economic status (SES) which is commonly measured by income, education, and occupational status (Bollen and Bauldry, 2011). It cannot be true

[2] In this respect, proper tool support is very important. While there are several commercial packages such as SmartPLS and WarpPLS, we would argue that open source solutions may offer the best option to support transparency. One potential issue with open source solutions is, however, the risk that packages disappear due to a lack of maintainers. This is what recently happened to the plspm package for the R language.

that the "unmeasured" concept SES *causes* income, education, and occupational status. A person does not get higher wages, a better education, or a higher-status job *because* their SES rises; it is the other way around. And thus, SES must be measured as a *formative* variable, something that leads to both practical (Bollen and Davis, 2009) and theoretical challenges (Rigdon, 2016). For example, Rigdon (2016), taking a realist perspective, argues that conceptual (latent) variables "transcend data" and "it is impossible to 'form' conceptual variables out of data." We only can construct proxy variables that we argue represent these conceptual variables. Who is to say, then, that the common factor based proxy is better than a composite-based one?

E&R also question whether the weighted indicator representation used in PLS is appropriate as there has been no demonstration of its benefits over simple unweighted summed scales. In effect, what it comes down to is how latent variables are represented. There are several ways to generate factor scores (DiStefano et al., 2009); PLS weighted indicators model is another. Unweighted scores assume that all indicators (items) contribute equally, or are equally important, which may be an unreasonable assumption. It is very common in certain types of models within the common factor SEM framework to use average or sum scores of a set of indicators. For example, latent growth models (Bollen and Curran, 2006), which are implemented within the CB-SEM framework, require simple scores (as opposed to multiple indicator common factors), as does moderation analysis. With several ways to represent a latent variable with a single score (DiStefano et al., 2009; Skondral and Laake, 2001), one should wonder how much it matters at all? E&R wonder why the generalized structure component analysis (GSCA) approach has not seen more widespread adoption; we do not have the answer to that question. Henseler (2012), who noted that GSCA is a reinvention of Glang's (1988) work, pointed out that all software implementations of the GSCA algorithm suffered from an error (Henseler, 2012, pp. 403); clearly, this would not help instill any confidence in this approach.

It is in this context that we believe it is worth emphasizing that no singular study is sufficient to build rigorous theory or provide evidence for proposed theories. Much research within the IS discipline, but also in many other disciplines that use SEM, focuses on latent, unmeasurable variables. Clear examples within the IS literature are trust and job satisfaction; these constitute feelings, perceptions, and opinions of people, and are inherently hard to measure. As a scholarly community we should never rely on a single study that investigates important relationships between such variables. Instead, we should focus on conducting families of studies, ideally using a variety of methods. The issue of how precise or reliable some of the parameter estimates really are loses importance because other studies may either confirm or disconfirm such findings.

2.4 Exceptional Cases and Flawed Evidence

Various articles that demonstrate the shortcomings of PLS use specific examples, either previous models that were published, or simulations that highlight a poor performance of PLS (cf. Rönkkö, 2014). Clearly, papers that seek to inform the research community about potential issues with methods are very important and welcome. Specific models are used because they can be carefully studied and simulated, thus pinpointing the exact problems.

However, there are two problems with using such studies as a foundation to 'discard' PLS. First, some of these studies that seek to highlight issues such as the known bias in parameter estimates suffer from design flaws (Henseler et al., 2014; Rigdon et al., 2014). For example, simulation studies rely on the generation of some known truth, a known population from which samples are drawn to investigate potential issues. Rigdon (2016) pointed out that these simulations defined their "truth" based on a common factor model to evaluate PLS which uses composites to represent constructs. As others have pointed out (Kock 2015a; 2019a; Rigdon, 2016), and as we briefly mentioned above as well, the composite and factor-based representations are not compatible. This raises serious questions about the validity of such simulation studies.

Second, demonstrating a potential issue does not mean that these issues are prevalent or of concern in all studies using PLS-SEM. Thus, E&R's suggestion that because "many of our main theories are built on empirical research that uses PLS," these theories are 'invalid' in some way is an overreaction in our view. One fruitful avenue for further research could be to conduct several replications to investigate the validity of these "main theories" using different analytical strategies. First, replications could use PLS-SEM while following updated guidelines that include recent methodological advances in recent years, including the recommendations proffered by E&R. Second, replications using CB-SEM, which models latent variables differently, which would provide a realistic and interesting case to better understand differences between

PLS-SEM and CB-SEM. Third, replications following E&R's recommendation to use generalized structure component analysis (GSCA), which also would offer an interesting case study to increase our understanding of benefits and drawbacks of both PLS-SEM and GSCA using realistic examples. Well-designed replications can either give us more confidence in our theories if they remain supported, suggest adjustments if they are not, and offer opportunities to investigate how results vary between different analysis methods using realistic research models, rather than models that were designed to highlight potential issues.

3 Conclusion and Takeaways

We wish to conclude our response, not by discarding all concerns that E&R have highlighted, but by making a number of suggestions as a means to advance the debate on validity issues around PLS.

First, we believe the scholarly debate on the use and misuse of PLS has been a fruitful one (given the advances in PLS in recent years); we recognize and appreciate E&R's contributions in this matter. However, the rhetoric of the debate and the arguments put forth are, at times, perhaps somewhat "overheated" and hyperbolic. Petter (2018) observed that anti-PLS rhetoric has increased in recent years. The seemingly extreme stances that some scholars take may not be beneficial to the overall debate; this polarization will scare away some, while others will simply ignore the issues, hoping that reviewers aren't too bothered by it either. None of those positions are useful to the scientific endeavor.

Second, E&R have made several useful recommendations. We don't argue with these, although as we pointed out, some recommendations may be beyond the average IS scholar's skillset. That is no excuse of course, but it could very well be a barrier to the "proper" use of PLS, as advocated by E&R. Such practical matters, which also include user-friendly and correct software implementations are clearly important for the uptake of new advances (cf. Henseler, 2012). Several open source packages are freely available such as the various libraries for the R language (including "seminr," "semPLS," and "matrixpls") and also for the Python language (e.g., "plspm"). Other users may prefer a graphical user interface offered in commercial packages such as SmartPLS and WarpPLS. We note that using script-based analyses (using R, Python or other languages) allows for better replication packages as every operation is explicitly coded, whereas GUI-based tools do not allow for a "replay" of the analysis. While this may seem a minor point, it does contribute to the transparency of analysis and inspection by readers, which in turn may help give confidence in research findings.

Third, based on our arguments, we make a number of suggestions, summarized in Table 1 below. Central to our suggestions is that a more balanced discussion is necessary. One-sided stances only lead to polarization, which is not helpful to applied IS scholars because this forces them to "take sides," fervently defending their position with references to scientific work that offers support for one claim or another, in order to get their work past reviewers. We hope that, with all the expertise that is clearly present within the IS community, we can come together and make progress on this issue.

Table 1. Summary of comments and suggestions to advance the debate

Theme	Summary	Our Suggestions
Balancing the debate on PLS	E&R's aim to inform the IS community with updated guidelines is commendable. However, in our view treatment of recent methodological advances is incomplete and somewhat unbalanced.	A more balanced and nuanced debate of evidence in favor and against PLS-SEM would be welcome based on a fair discussion that includes all work that makes methodological advances. Extreme positions should be prevented, or else a debate will not progress.
Know Your Audience	E&R make important observations, but many recommendations are hard to implement for the average applied scholar. Scholars, supervisors, editors and reviewers all share a responsibility to remain informed of recent methodological advances. Stating that the IS community has 'bet the farm' on using PLS-SEM to develop key	Some recommendations clearly target PLS-SEM users, and offering further guidance to them is necessary, through editorials, tutorials, and textbooks for example. Other recommendations propose rather technical procedures, and we argue that the average applied researcher is not readily equipped to perform these without sufficient guidance. Other observations suggest a "research roadmap" (see also our observations under the theme "exceptional cases and flawed evidence").

	theories is hyperbolic.	
Philosophical and practical differences	The way latent variables (theoretical constructs) are represented in different approaches (PLS-SEM, CB-SEM) is different, and it is important to recognize the underpinning epistemological and ontological foundations. Practical issues involve the correct modeling of theoretical constructs that are not consistent with the standard reflectively modeled common factor approach, such as socioeconomic status.	Despite several debates around the use of PLS, the various epistemological and ontological perspectives are perhaps not appreciated by different scholars. Debates such as these certainly help to highlight and explicate the different stances, but a more elaborate in-depth discussion that presents an "objective" comparison is needed, illustrated with concrete examples. Practical guidelines that address various issues such as modeling 'formative' constructs are needed. A more clear understanding of when to use PLS-SEM or CB-SEM is needed; current guidelines that are typically offered by advocates of PLS-SEM do not offer insight as to why PLS-SEM would be more appropriate under certain circumstances.
Exceptional cases and flawed evidence	E&R claim that their critiques are based on deductions and simulations. Exceptional cases that highlight problems with PLS-SEM are not necessarily representative of general use of PLS-SEM. As some scholars have shown, some simulation studies highlighting 'problem' were flawed.	Comparisons must be valid and fair. Studies should consider not only extreme or exceptional cases, but also include analyses of 'normal' studies. Study designs demonstrating problems should be sound. Potential barriers to this are the fact that this work may be tedious, boring, and 'high risk', meaning that this type of work can be very hard and may not result in publications in the top venues; this is an inhibitor to junior scholars who do not see this as a "career building" activity. Conducting several types of replication studies to investigate foundational studies is a potential avenue for future work.

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