

# Identification of quality characteristics in mobile applications

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**Abstract.** Mobile devices and their applications became popular since the creation of the app stores' distribution model. There is a great variety of apps available and we are inclined to use the best ones, what make it essential to develop apps of distinctive quality. To identify pertinent quality characteristics of mobile applications based on available literature, we conducted a systematic mapping study regarding the quality of mobile applications. It was executed in five search engines: Scopus, IEEE, Web of Science, Engineering Village and ACM. The resulting papers were analyzed in search of occurrences of quality characteristics of mobile applications. At all, 53 papers were analyzed. From the quality characteristics present in ISO/IEC 25010 models, the most cited were usability, performance efficiency, functional suitability, reliability, and context coverage. Fifteen extra quality characteristics were also found. The systematic mapping study permitted the formulation of an initial list of quality characteristics, which may be the most pertinent in the context of mobile applications.

**Keywords:** Systematic mapping study, Software engineering, Quality characteristics, ISO/IEC 25010, Mobile applications.

## 1 Introduction

Mobile devices and applications became especially popular after the creation of the app stores' distribution model [1]. Since then, the quantity of available mobile applications (apps) has increased significantly every year. There is a great variety of apps available and we are inclined to use the best ones.

Generally, if apps are not developed with distinctive quality, users will naturally find and install better competing apps with the same functionalities. Although the app stores contain publication guidelines, they are not broad enough to prevent the submission of mobile applications not in conformity with the users' expectations.

Given the flaws of the stores' publication guidelines, App Quality Alliance (AQuA) [2] provides documents with best practices guidelines regarding mobile applications. Although, these guidelines are not frequently updated and are not in conformity with international software quality standards.

The ISO/IEC 25000 series defines quality models, measures and requirements for a diversity of generic software quality characteristics [3]. Quality models are general-purpose and made to be applied to any kind of software product. However, not every quality characteristic is appropriate in all cases and some may be more relevant depending on context and stakeholders. This generality makes it necessary to identify which characteristics are more relevant for a certain kind of application.

This paper describes a Systematic Mapping Study (SMS) about the identification of quality characteristics in the context of mobile applications. The results provide a list of quality characteristics to support development and quality evaluation of apps.

The remainder of the paper is structured as follows: Section 2 presents the background. Section 3 explains the research methodology and the results. Section 4 presents a discussion about the results. Section 5 presents the threats to validity. Finally, section 6 concludes the paper.

## 2 Background and related work

In this section, we discuss some concepts related to software quality.

The ISO/IEC 25000, also known as SQuaRE, contains a set of standards relative to software quality. These standards define management guidelines, quality models, measures, requirements and software evaluation processes. ISO/IEC 25010 [3] defines two quality models: **Quality in Use**, with quality characteristics (Effectiveness, Efficiency, Satisfaction, Freedom from risk, and Context coverage) related to the outcome of interaction when a product is used in a context of use; and **Product Quality**, with characteristics (Functional suitability, Performance efficiency, Compatibility, Usability, Reliability, Security, Maintainability, Portability) related to static and dynamic properties of software. This standard defines the quality of a system as the degree to which the system satisfies the stated and implied needs of its various stakeholders, and thus provides value.

The software quality models may not be entirely used to evaluate a product. Every kind of software has its own specific features, stakeholders, hardware and so on. It becomes necessary to particularize quality models in view of these peculiarities.

Barney & Wohlin [4] reports a case study in which a questionnaire was elaborated with the quality characteristics in ISO/IEC 9126 and some other models found in literature. Several employees from Ericsson with different functions and involved in different projects were requested to distribute 1000 points among the characteristics they considered the most important. The objective of the study was to identify different points of view of stakeholders.

A survey was carried out in Haigh [5], with the purpose of identifying opinions about the importance of quality characteristics. The respondents were students and ex-students from an unnamed MBA program in the USA, each performing different roles in software projects. Users prioritized integrity, portability and usability. Developers prioritized maintainability and testability. Managers prioritized accuracy.

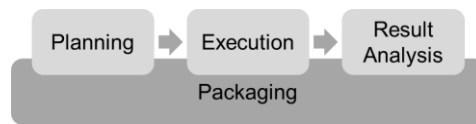
A study with the purpose of determining a quality model for IoT based on ISO/IEC 9126 and ISO/IEC 25010 is described in Kim et al. [6]. The study lists general

characteristics of IoT applications. As a conclusion, metrics were developed for five quality characteristics: Functionality, Reliability, Efficiency, Portability and Security.

The studies described above are some examples of surveys or particularization studies, which reiterates the importance of identifying specific quality characteristics for different types of software.

### 3 Research methodology and protocol

This systematic mapping study (SMS) aims to characterize the current state of research into the quality of mobile applications. To conduct this SMS, we followed Biolchini et al. [7] process, which consists of four phases, as showed in Fig. 1.



**Fig. 1.** Summary of the Systematic Review Process [7]

In the first phase (Planning) we defined the research goal, research questions and methods for the execution and analysis phases. We also defined the search string, the search engines and the inclusion and exclusion criteria. Next, in the Execution phase we executed the search string to obtain the set of papers. The previously defined set of inclusion and exclusion criteria are applied to the resulting papers.

In the third phase (Result analysis) we read the papers and extract their relevant data to an extraction form, according to the research questions. Then, the extracted data are assembled and interpreted to answer the questions. The Packaging phase was executed throughout the whole process, keeping documented all the decisions and information.

Kitchenham and Charters [8] also describe the Reporting phase, in which the produced results and documentation are made available to potential stakeholders. Given that this SMS documents the results but does not report them to potential stakeholders, this approach was not followed. Thus Biolchini's approach is similar to Kitchenham's.

#### 3.1 Research Goal

The main objective of this SMS is to identify which quality characteristics are relevant in the context of mobile applications. Table 1 presents the aim of this study, using the GQM paradigm [9].

**Table 1.** Research goal, according to GQM paradigm

<b>Analyze</b>	Quality characteristics
<b>For the purpose of</b>	Characterizing
<b>With respect to</b>	Pertinence
<b>From the point of view of</b>	Software engineering researchers
<b>In the context of</b>	Mobile applications

### 3.2 Research questions

The original objective of the research was to list pertinent quality characteristics of mobile applications independently of existing quality models, but it seemed clear that the result would contain many occurrences of quality characteristics from the two models in ISO/IEC 25010. Due to this observation, two research questions were developed. They are present in Table 2.

Table 2. Research Questions

	Research Question	Rationale
RQ1	Which quality characteristics from ISO/IEC 25010 are identified as pertinent in the context of mobile applications?	The answer indicates the ISO/IEC 25010 characteristics considered pertinent in several researches about quality of mobile applications present in literature.
RQ2	Which quality characteristics are not present in ISO/IEC 25010, but are identified as pertinent in the context of mobile applications?	The answer indicates the characteristics considered pertinent in several researches about quality of mobile applications present in the literature, but not covered by ISO/IEC 25010.

### 3.3 Search string and search engines

The selection of papers was carried out through a search string, applied in several search engines. The string followed the PICO process [10]. The subject of the research should be decomposed in four parts: population, intervention, comparison and outcome. There is no comparison in the scope of this work. Our search string is composed by the keywords: Population = mobile applications; Intervention = software quality models, quality in use, quality requirements; and Outcome = characteristics, metrics, measures, evaluation criteria, attributes. The terms in both intervention and outcome are common in the context of the ISO/IEC 25000 standards.

The “quality requirements” intervention was not considered in the first version of the string, although they could be helpful to infer implied qualities of a software product. So, the string was modified once to include it. The final search string was: **((“mobile app\*”) AND (“software quality” OR “quality model” OR “quality in use” OR “quality requirement”) AND (“characteristic” OR “metric” OR “measure” OR “evaluation criteria” OR “attribute”)).**

It was executed in five search engines: Scopus, IEEE, Web of Science, Engineering Village and ACM. The first execution occurred in May 2018 and the last (and second) in September 2018.

### 3.4 Inclusion and exclusion criteria

The execution of the search string in the search engines returned several papers, but not all of them might be suitable for the purpose of this study. Therefore, inclusion and exclusion criteria were developed to refine the initial list of papers. Exclusion criteria are in Table 3. The inclusion criteria are the opposite of exclusion criteria (E1 to E4).

**Table 3.** Exclusion Criteria

<b>E1</b>	The paper was not published in conferences or journals.
<b>E2</b>	The paper is not available in the internet.
<b>E3</b>	The paper is not in English.
<b>E4</b>	The paper is not about quality in mobile applications.
<b>E5</b>	The paper is similar to another paper by the same authors.
<b>E6</b>	The paper is about design patterns, source code or quality of services.

### 3.5 Execution

The exclusion criteria E1 to E3, which are not dependent on the reading of the papers, were applied to the initial set of papers. The application of the other exclusion criteria depended on further interpretation, so the authors read the abstracts of the remaining papers, then decided together on more exclusion, based on criteria E4 to E6. Some papers could only be safely excluded after the full text was read. Table 4 shows the number of results before and after the application of exclusion criteria. E6, which comprises qualities of code and services, was also considered because this research analyses specifically app quality from the viewpoint of software products.

**Table 4.** Search Results

<b>Search Engine</b>	<b>Initial Set</b>	<b>After E1, E2 &amp; E3</b>	<b>After E4, E5 &amp; E6</b>
<b>Scopus</b>	57	45	29
<b>IEEE</b>	27	26	13
<b>Engineering Village</b>	27	19	13
<b>Web of Science</b>	30	23	13
<b>ACM</b>	7	7	3

Most of the papers were found in more than one search engine. In total, 35 papers were selected using the search string. In addition, from the included papers' references, 18 other papers were manually selected based on their titles (snowballing). Thus, we have 53 papers selected. At all, 28 papers were excluded, based on Exclusion Criteria. Table 5 shows the papers included via search string and via snowballing.

E4 also considered papers concerning specific types of apps. e.g., papers regarding medical apps would not be excluded. We were aware of the possibility of bias due to a quality characteristic being pertinent just in the context of a specific type of app. In order to reduce the bias, these papers were cautiously read and the occurrences of characteristics which seemed only related to the specific topic were not accounted.

The 53 selected papers were analyzed by means of the two research questions. The extracted data, which answers these questions, were collected with the assistance of a form. As far as possible, the research questions must be objectively answered by the reading and interpretation of each paper. These data would subsequently be merged and analyzed to answer the research questions.

To answer RQ1, the form contains tables to store information on quality characteristics and sub-characteristics of both quality models from ISO/IEC 25010, which might be described as relevant in the paper. To answer RQ2, the form contains a table to retain information on characteristics apparently not related to those proposed

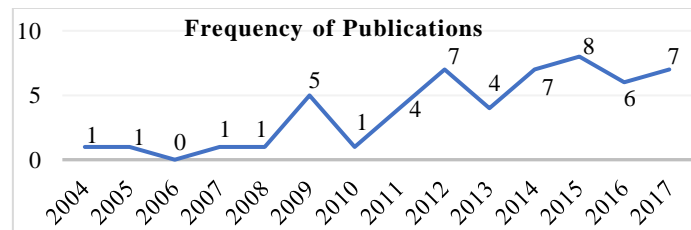
by ISO/IEC 25010. The form also contains tables for measures, requirements and device limitations, which might be important to relate, characterize and interpret the quality characteristics present in each paper. Other information such as the authors, the year of publication, the search engines, the software quality standard, and the definition of mobile application (if present) are included in the form.

**Table 5.** Papers included via search string and snowballing

ID	Papers (search string)	ID	Papers (search string)	ID	Papers (snowballing)
M1	Fauzia et al. [11]	M19	Lew and Olsina [12]	M36	Cortimiglia et al. (2011)
M2	Idri et al. [13]	M20	Zhenyu et al. [14]	M37	Dantas et al. (2009)
M3	Mohsin et al. [15]	M21	Karima and Idri [16]	M38	Spriestersbach and Springer (2004)
M4	Barnett et al. [17]	M22	Lizhi et al [18]	M39	Sá and Carriço (2008)
M5	Idri et al. [19]	M23	Kolski et al. [20]	M40	Huang (2009)
M6	Franke et al. [21]	M24	Moumane et al. [22]	M41	Harrison et al. (2013)
M7	Baloh et al [23]	M25	Corral [24]	M42	Lai (2015)
M8	Yildiz et al. [25]	M26	Holl and Vieira [26]	M43	Lim et al. (2015)
M9	Alaa et al. [27]	M27	Nayebi et al. [28]	M44	La et al (2011)
M10	Kabir et al. [29]	M28	Ryan and Rossi [30]	M45	Gafni (2009)
M11	Idri et al. [31]	M29	Corral et al [32]	M46	Holl and Elberzhager (2014)
M12	Souza and Aquino [33]	M30	Khalid et al. [34]	M47	Holzinger et al. (2012)
M13	Fang et al. [35]	M31	Olsina and Lew [36]	M48	Wasserman (2010)
M14	Pretel and Vilarino [37]	M32	Peischl et al. [38]	M49	Kim et al. (2011)
M15	Franke and Weise [39]	M33	Khalid et al. [40]	M50	Balagtas-Fernandez and Hussmann (2009)
M16	Hess et al. [41]	M34	Grano et al. [42]	M51	Zahra et al. (2013)
M17	Soad and Duarte Filho [43]	M35	Abusair [44]	M52	Hussain et al. (2009)
M18	Marinho and Resende [45]			M53	Savio and Braiterman (2007)

### 3.6 Publication Frequency

Fig. 2 contains a chart regarding the frequency of publications found in this study.



**Fig. 2.** Frequency of publications over the years

Only a few papers are earlier than 2009. Android and iOS technologies emerged in 2007 and popularized the distribution model of the app stores [1]. From this point onwards, it became easier to develop and download applications. It may be the reason for the sudden interest in this research area after 2009, which remains relatively unchanged ever since. By the moment of the SMS' last execution there existed papers from 2018 in the resulting set, but curiously none of them entered the group of included papers.

### 3.7 Research Question 1

The ISO/IEC 25000 series identify 8 product quality characteristics and link them to 30 sub-characteristics. It also identifies 5 quality in use characteristics and link them to 9 sub-characteristics [3]. A process was followed in order to identify characteristics in the included papers:

- Identify quality characteristics and sub-characteristics, both in use or product quality, associated with mobile applications, where authors explicitly reference ISO/IEC 25000.
- Identify quality characteristics and sub-characteristics, both in use or product quality, associated with mobile applications, where authors explicitly reference ISO/IEC 9126 [46], predecessor of ISO/IEC 25010. Both standards were combined using a comparative table in ISO/IEC 25010's annex A [3].
- Identify quality characteristics and sub-characteristics, both in use or product quality, associated with mobile applications, where authors do not explicitly reference SQuaRE standards nor its predecessor ISO/IEC 9126. In this case, there are two possible situations: (1) there is an equivalent and similar definition to those in the standards; or (2) the paper does not contain a definition, but the context permits the association.
- Identify attributes associated with mobile applications equivalent to characteristics and sub-characteristics, both in use or product quality by similarity. In this case it was considered a synonym (e.g. Functional Suitability, Functionality and Functional Quality), following the proposal of Marinho & Resende [45].
- Still following the proposal of Marinho & Resende [45], characteristics and sub-characteristics were added when the paper defines problems or restrictions to the use, suggesting the necessity of a characteristic or sub characteristic (e.g. "abandoning the use of the application due to faults" suggests the necessity of the characteristic Reliability).

Marinho & Resende's methodology was followed as a basis due to its similarity with the current study. As well as us, they also needed to group occurrences of quality characteristics by synonyms. Table 6 and Table 7 contain some characteristics and sub-characteristics from the ISO/IEC 25010 product quality and quality in use models, respectively. Only the characteristics whose sub-characteristics occurred from 5 to 7 times were listed. The characteristics' occurrences were also presented. The complete list can be found in [https://maia.mobi/arq/tech\\_report\\_mapping.pdf](https://maia.mobi/arq/tech_report_mapping.pdf).

In order to achieve the results, described in Table 8 and Table 9, we followed the same previously explained steps. Table 8 presents the product quality characteristics and sub-characteristics do not present in ISO/IEC 25010. Table 9 presents the quality in use characteristics and sub-characteristics not present in ISO/IEC 25010.

**Table 6.** Occurrences of ISO/IEC 25010 product quality characteristics and sub-characteristics

Characteristics & Sub-Characteristics		Occurrences
<b>Functional Suitability</b>		-
<b>Sub-characteristic</b>	<b>Functional correctness</b>	[M8] [M17] [M19] [M22] [M29] [M31] <i>Subtotal: 6</i>
<b>Compatibility</b>		-
<b>Sub-characteristic</b>	<b>Interoperability</b>	[M22] [M29] [M47] [M48] [M53] <i>Subtotal: 5</i>
<b>Usability</b>		-
<b>Sub-characteristics</b>	<b>Appropriateness Recognisability</b>	[M11] [M19] [M22] [M29] [M31] [M38] [M45] <i>Subtotal: 7</i>
	<b>User error protection</b>	[M19] [M31] [M37] [M41] [M50] <i>Subtotal: 5</i>
	<b>User interface aesthetics</b>	[M11] [M13] [M22] [M29] [M37] [M45] [M52] <i>Subtotal: 7</i>
	<b>Accessibility</b>	[M7] [M11] [M29] [M39] [M37] [M52] <i>Subtotal: 6</i>
<b>Reliability</b>		-
<b>Sub-characteristic</b>	<b>Fault tolerance</b>	[M3] [M8] [M9] [M11] [M22] <i>Subtotal: 5</i>
<b>Security</b>		-
<b>Sub-characteristic</b>	<b>Confidentiality</b>	[M20] [M29] [M31] [M33] [M37] [M38] [M51] <i>Subtotal: 7</i>

**Table 7.** Occurrences of ISO/IEC 25010 quality in use characteristics and sub-characteristics

Characteristics & Sub-Characteristics		Occurrences
<b>Satisfaction</b>		-
<b>Sub-characteristics</b>	<b>Usefulness</b>	[M19] [M29] [M37] [M42] [M49] <i>Subtotal: 5</i>
	<b>Pleasure</b>	[M19] [M27] [M29] [M40] [M42] [M49] <i>Subtotal: 6</i>

### 3.8 Research Question 2

This question aims to identify other quality attributes, which authors identified as necessary for mobile applications and which are not present in ISO/IEC 25010.

We tried to identify new quality attributes in the included papers. Initially 90 attributes were identified. Similarities were observed in an in-depth analysis of them. A final list was drawn-up following the proposal of Marinho & Resende [45]:

- Identify attributes listed as important in the included papers, which are not synonyms with ISO/IEC 25010 quality characteristics.
- Group synonyms or similar attributes according to their definitions.
- Add an attribute when the included paper defines problems or restrictions to the use, suggesting the necessity of a quality attribute.



- Select the most suitable definition for the attribute. A definition must be manually composed if the attribute is explained but not defined in the papers.

**Table 8.** Product quality characteristics not present in ISO/IEC 25010

Characteristics & Sub Characteristics		Occurrences
Information Quality		[M19] [M31] <i>Subtotal: 2</i>
Sub-characteristics	Information Correctness	[M31] <i>Subtotal: 1</i>
	Information Credibility	[M31] <i>Subtotal: 1</i>
	Information Conciseness	[M19] <i>Subtotal: 1</i>
Usability (ISO/IEC 25010)		-
Sub-characteristics	Navigation	[M19] [M40] <i>Subtotal: 2</i>
	Visibility	[M19] <i>Subtotal: 1</i>
Use of Clear Forms		[M19] <i>Subtotal: 1</i>
Use of Minimized Forms		[M4] <i>Subtotal: 1</i>
Use of Hierarchical Menus		[M19] [M40] <i>Subtotal: 2</i>
Data Persistence		[M4] [M6] [M15] [M51] <i>Subtotal: 4</i>

**Table 9.** Quality in use characteristics not present in ISO/IEC 25010

Characteristics & Sub Characteristics		Occurrences
Sense of Community		[M10] [M19] <i>Subtotal: 2</i>
Usability in Use		[M19] <i>Subtotal: 1</i>
Sub-characteristics	Learnability in Use	[M19] [M41] [M53] <i>Subtotal: 3</i>
	Continuous Communication	[M19] <i>Subtotal: 1</i>
	Memorability	[M41] <i>Subtotal: 1</i>

### 3.9 Software Quality Standards

The preliminary execution of the search string returned plenty of papers about the quality of mobile applications basing their results in ISO/IEC 9126 or ISO/IEC 25010. Given the degree of formality found in the literature, from this point the research questions were updated to separate the quality characteristics by origin. At all, 25 papers used standards, nearly half of them; 24% used ISO/IEC 9126; 23% used ISO/IEC 25010; and 53% did not reference quality models.

### 3.10 Search Engines

At all, five search engines were selected for the execution of the search string. Out of curiosity, the ones included via snowballing were also manually searched in each engine. A closer look at these tables reveals that almost every paper was found in Scopus. For those included by the execution of the search string, only six were found elsewhere, and for the snowballing papers, six were not found in Scopus nor in any of the other engines and one was only found in Web of Science. It represents a coverage of 75.5% of the results by Scopus.

Scopus indexes the content of several other engines. The papers (M26, M27, M28, M33, M34, and M35) originally not found in Scopus by the execution of the string were manually searched and found in Scopus. The reason for not being returned before lies

on the different indexing of the papers in each engine. A better calibration of the search string could possibly have returned all the included papers in one go.

## 4 Discussion

The selected papers explore a range of points of view: quality of specific categories of apps, researches into device limitations, researches into the importance of a single quality characteristic, proposal of quality models, guidelines, measures, requirements, among others. This variety positively influenced the study and diversified the conclusions about the pertinence of quality characteristics in the context of apps.

The results of the first research question indicate that **usability** is the most addressed product quality characteristic, followed by **performance efficiency**, **functional suitability** and **reliability**. As for quality in use, **efficiency**, **satisfaction** and **context coverage** are the most addressed quality characteristics. Regarding the sub-characteristics of both quality models, the most frequent ones are consequently related to **usability**, **performance efficiency** and **satisfaction**. The results for the second research question indicate the importance of additional quality characteristics strongly related to usability, thereby reinforcing the results obtained from the previous question. Some of the proposed new quality characteristics are **information quality**, **data persistence** and **sense of community**.

Some papers briefly discuss inherent characteristics and limitations of mobile devices and their impact on the quality of the applications. Common limitations such as battery consumption, CPU usage and low memory directly affect the performance efficiency. Limited screen size, few resolutions and limited input directly affect usability. A frequently mentioned limitation concerns the instability of internet connections, due to the mobility of devices, which restricts the use of wireless network. It might outline the importance of reliability and context coverage. Other frequently mentioned limitation is the occurrence of unexpected interruptions (e.g. receiving a call), which outlines the importance of the proposed quality characteristic data persistence.

## 5 Threats to Validity

Threats classification presented by Petersen et al. [47] were followed.

Descriptive validity is the extent to which observations are described accurately and objectively. The extraction form objectively kept relevant information present in each paper regarding the research questions. However, the extraction may not guarantee the correctness of the results. In general, a quality characteristic was included if the paper presented a description and an adequate reason for considering it pertinent. Furthermore, some papers provided quality characteristics with differing definitions from ISO/IEC 25010, which demanded a deep interpretation of what the authors meant.

Theoretical validity is determined by our ability to be able to capture what we intend to capture. The search string may not have captured many other relevant papers. As stated in section 3.10, most of the 53 included papers were present in Scopus, but the

search string did not return most of them there. The same way, other important papers might not have been found. In addition, the interpretation of abstracts and the manual selection of papers via snowballing may have biased the results. To reduce the bias, inclusion and extraction of papers were reviewed many times by two researcher.

Interpretive validity is achieved when the conclusions drawn are reasonable given the data, and hence maps to conclusion validity. The research questions were subjective and demanded effort to both understand what to be extracted and how to interpret the extracted data. To reduce bias, the results were debated over several meetings until a consensus was reached.

Finally, considering the generalizability, the quantity of papers may have been relatively small, possibly due to a too restrictive search string. However, the search engines provided good coverage of the topic, especially Scopus.

## 6 Conclusion

This study investigated quality characteristics pertinent to the context of mobile applications. A systematic mapping study was designed in order to achieve this objective. The research questions were based on ISO/IEC 25010, which was particularized to the context of mobile applications. It was necessary because quality models are general-purpose, made to be applied to any kind of software product.

Occurrences of quality characteristics were accounted when present in the resulting papers of the mapping. It was possible to identify the most cited quality characteristics from ISO/IEC 25010: Usability, Functional Suitability, Efficiency, Reliability and Context Coverage. It was also possible to identify 15 quality characteristics, which were not previewed by the used quality models. It is expected that the results of this study will improve the development and the quality of mobile applications.

**Acknowledgments.** This work was greatly assisted by Guilherme Horta Travassos.

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