Putting Software Testing Terminology to the Test

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Abstract—This document is a model and instructions for LaTeX. This and the IEEEtran.cls file define the components of your paper [title, text, heads, etc.]. *CRITICAL: Do Not Use Symbols, Special Characters, Footnotes, or Math in Paper Title or Abstract.

Index Terms—software testing, terminology, taxonomy, literature review, test approaches

I. Background

Testing software is complicated, expensive, and often expensive. Therefore, automating the software testing process is an area of interest. In particular, test case generation for Drasil, a framework for "generating all of the software artifacts for (well understood) research software" [1] was desired.

Before attempting to automate a knowledge-based process in ad hoc manner, it is important to understand the underlying domain. This allows the information itself to drive the scope, including both what is possible and what is needed. In this case, the goal was to uncover the various approaches towards testing, as well as which prerequisites (e.g., input files, oracles) existed for each. A search for a systematic, rigorous, and "complete" taxonomy revealed that existing software testing taxonomies are inadequate:

- [2] focuses on parts of the testing process (e.g., test goal, testable entity)
- [3] prioritizes organizing testing approaches over defining them
- [4] provides a foundation for classification but not how it applies to software testing terminology

The "solution" to this gap was to examine existing literature (II), which quickly reinforced the need for a taxonomy! Despite the amount of well understood and organized knowledge, there were still many discrepancies and ambiguities, either within the same source or between various sources (III).

II. Methodology

A. Source Order

0) Textbooks trusted at McMaster [5, 6, 7]
   - Ad hoc and arbitrary; not systematic
   - Colored maroon
1) Established standards (such as IEEE, ISO/IEC, and SWEBOK) [8, 9, 10, 11, 12, 13, 14, 15, 16, 17]
   - Standards organizations colored green
   - "Meta-level" commentaries or collections of terminology (often based on these standards), such as [18], colored blue
2) Other resources: less-formal classifications of terminology (such as [19]), sources investigated to "fill in" missing definitions (see Undefined Terms), and testing-related resources that emerged for unrelated reasons
   - Colored black, along with any "surface-level" analysis that followed trivially

By looking at a variety of sources, discrepancies both within and between them can be uncovered, and the various classifications of terminology can be analyzed.

B. Procedure

Except for some sources in Undefined Terms, all sources were looked through in their entirely to "extract" as much terminology as possible. Heuristics were used to guide this process, by investigating…

- …glossaries and lists of terms
- …testing-related terms
  e.g., terms that included "test(ing)", "validation", "verification", "review(s)", or "audit(s)"
- …terms that had emerged as part of already-discovered testing approaches, especially those that were ambiguous or prompted further discussion
  e.g., terms that included "performance", "recovery", "component", "bottom-up", "boundary", or "configuration"
- …terms that implied testing approaches see Derived Test Approaches

If a term's definition had already been recorded, either the "new" one replaced it if the "old" one wasn't as clear/concise or parts of both were merged to paint a more complete picture. If any discrepancies or ambiguities arose, they were investigated to a reasonable extent and documented. If a testing approach was mentioned but not defined, it was still added to the glossary to indicate it should be investigated further. A similar methodology was used for tracking software qualities, albeit in a separate document.

During this investigation, some terms came up that seemed to be relevant to testing but were so vague, they

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didn't provide any new information. These were decided to be not worth tracking (see #39, #44, #28) and are listed below:

- Evaluation: the "systematic determination of the extent to which an entity meets its specified criteria" [11, p. 167]
- Product Analysis: the "process of evaluating a product by manual or automated means to determine if the product has certain characteristics" [11, p. 343]
- Quality Audit: "a structured, independent process to determine if project activities comply with organizational and project policies, processes, and procedures" [11, p. 361]
- Software Product Evaluation: a "technical operation that consists of producing an assessment of one or more characteristics of a software product according to a specified procedure" [11, p. 424]

However, over the course of this research, our scope was adjusted to include some terms for our initial list of test approaches to be filtered out later, such as types of attacks (see #55), meaning that some entries were missed during the first pass(es) of these resources. While reiterating over these resources would be ideal, this may not be possible due to time constraints.

C. Undefined Terms

This process also led to some testing approaches without definitions; [8] and [18] in particular introduced many. Once more "standard" sources had been exhausted, a strategy was proposed to look for sources that explicitly defined these terms, with the added benefit of uncovering more terms to explore, potentially in different domains (see #57). This also uncovered some out-of-scope testing approaches, including EMSEC testing, HTML testing, and aspects of loop testing and orthogonal array testing; since these are out of scope, relevant sources were not investigated fully.

The following terms (and their respective related terms) were explored, bringing the number of testing approaches from 432 to 515 and the number of undefined terms from 153 to 171 (the assumption can be made that about 78% of added terms also included a definition):

- Assertion Checking
- Loop Testing
- EMSEC Testing
- Asynchronous Testing
- Performance(-related) Testing
- Web Application Testing
  - HTML Testing
  - DOM Testing
- Sandwich Testing
- Orthogonal Array Testing
- Backup Testing

Different sources categorized software testing approaches in different ways; while it is useful to record and think about these categorizations, following one (or more) during the research stage could lead to bias and a prescriptive categorization, instead of letting one emerge descriptively during the analysis stage. Since these categorizations are not mutually exclusive, it also means that more than one could be useful (both in general and to this specific project); more careful thought should be given to which are "best", and this should happen during the analysis stage.

III. Observations

A. Categories of Testing Approaches

For classifying different kinds of tests, [8] provides some terminology (see Table I). Related testing approaches may be grouped into a "class" or "family" to group those with "commonalities and well-identified variabilities that can be instantiated", where "the commonalities are large and the variabilities smaller" (see #64). Examples of these are the classes of combinatorial [17, p. 15] and data flow testing [p. 3] and the family of performance-related testing [20, p. 1187][1], and may also be implied for security testing, a test type that consists of "a number of techniques[2]" [17, p. 40].

It also seems that these categories are orthogonal. For example, "a test type can be performed at a single test level or across several test levels" [8, p. 15], [17, p. 7]. Due to this, a specific test approach can be derived by combining test approaches from different categories; for some examples of this. However, the boundaries between items within a category may be unclear: "although each technique is defined independently of all others, in practice [sic] some can be used in combination with other techniques" [17, p. 8]. For example, "the test coverage items derived by applying equivalence partitioning can be used to identify the input parameters of test cases derived for scenario testing" [p. 8]. Even the categories themselves are not consistently defined, as some approaches are categorized differently by different sources; these differences will be tracked noted so that they can be analyzed more systematically (see #21). There are also several instances of inconsistencies between parent and child test approach categorizations (which may indicate they aren't necessarily the same, or that more thought must be given to classification/organization). Examples of discrepancies in test-approach categorization:

1) Experience-based testing is categorized as both a test design technique and a test practice on the same page [8, pp. 22, 34]!
   - These authors previously say "experience-based testing practices like exploratory testing … are

[1]The original source describes "performance testing … as a family of performance-related testing techniques", but it makes more sense to consider "performance-related testing" as the "family" with "performance testing" being one of the variabilities.

[2]This may or may not be distinct from the notion of "test technique" described in IEEE Testing Terminology.

not … techniques for designing test cases", although they "can use … test techniques" [17, p. viii]. This implies that "experience-based test design techniques" are techniques used by the practice of experience-based testing, not that experience-based testing is itself a test technique. If this is the case, it is not always clearly articulated [8, pp. 4, 22], [17, p. 4], [9, p. 5-13], [16] and is sometimes contradicted [18, p. 46]. However, this conflates the distinction between "practice" and "technique", making these terms less useful, so this may just be a mistake (see #64).
- This also causes confusion about its children, such as error guessing and exploratory testing; again, on the same page, [8, p. 34] says error guessing is an "experience-based test design technique" and "experience-based test practices include … exploratory testing, tours, attacks, and checklist-based testing". Other sources also do not agree whether error guessing is a technique [8, pp. 20, 22], [17, p. viii] or a practice [9, p. 5-14].

2) The following are test approaches that are categorized as test techniques in [17, p. 38], followed by sources that categorize them as test types:
   a) Capacity testing [8, p. 22], [12, p. 2] (implied by [18, p. 53] and by its quality [15], [17, Tab. A.1])
   b) Endurance testing [12, p. 2] (implied by [18, p. 55])
   c) Load testing [8, pp. 5, 20, 22], [11, p. 253], [16] (implied by [18, p. 54])
   d) Performance testing [8, pp. 7, 22, 26-27], [17, p. 7] (implied by [18, p. 53])
   e) Stress testing [8, pp. 9, 22], [11, p. 442] (implied by [18, p. 54])
3) Model-based testing is categorized as both a test practice [8, p. 22], [17, p. viii] and a test technique [21, p. 4] (implied by [17, p. 7], [11, p. 469]).
4) Data-driven testing is categorized as both a test practice [8, p. 22] and a test technique [21, p. 43].

B. Derived Test Approaches

Test techniques are able to "identify test coverage items … and derive corresponding test cases" [8, p. 11] (similar in [11, p. 467]) in a "systematic" way [11, p. 464]. "Coverage levels can range from 0% to 100%" and may or may not include "infeasible" test coverage items, which are "not … executable or [are] impossible to be covered by a test case" [p. 30]. The further implication is that different coverage metrics imply test approaches aimed to maximize them; for example, "path testing" is testing that "aims to execute all entry-to-exit control flow paths in a SUT's control flow graph" [9, p. 5013], thus maximizing the path coverage (see also #63, [24, Fig. 1]).

One group of test approaches given in IEEE Testing Terminology is "test types", which can be derived from software qualities: "capabilit[ies] of software product[s] to satisfy stated and implied needs when used under specified conditions" [11, p. 424]. This is supported by [25] which says that reliability and performance testing, both examples of test types [8, 17], are based on their underlying qualities [25, p. 18].

After discussing this further (see #21 and #23), it was decided that tracking software qualities, in addition to testing approaches, would be worthwhile (see #27). This was done by capturing their definitions and any rationale for why it might be useful to consider an explicitly separate "test type" in a separate document, so this information could be captured without introducing clutter.

Similarly, since some types of requirements have associated types of testing (e.g., functional, non-functional, security), it was discussed whether each requirement type implies a related testing approach (such as "technical testing"). Even assuming this is the case, some types of requirements do not apply to the code itself, and as such are out of scope (see #43):

- Nontechnical Requirement: a "requirement affecting product and service acquisition or development that is not a property of the product or service" [11, p. 293]
- Physical Requirement: a "requirement that specifies a physical characteristic that a system or system component must possess" [11, p. 322]

TABLE I
IEEE Testing Terminology

Term	Definition	Examples
Approach	A "high-level test implementation choice, typically made as part of the test strategy design activity" that includes "test level, test type, test technique, test practice and the form of static testing to be used" [8, p. 10]; described by a test strategy [11, p. 472] and is also used to "pick the particular test case values" [11, p. 465]	black or white box, minimum and maximum boundary value testing [11, p. 465]
(Design)[a] Technique	A "defined" and "systematic" [11, p. 464] "procedure used to create or select a test model, identify test coverage items, and derive corresponding test cases" [8, p. 11] (similar in [11, p. 467]) "that … generate evidence that test item requirements have been met or that defects are present in a test item" [17, p. vii]; "a variety … is typically required to suitably cover any system" [8, p. 33] and is "often selected based on team skills and familiarity, on the format of the test basis", and on expectations [8, p. 23]	equivalence partitioning, boundary value analysis, branch testing [8, p. 11]
Level[b] (sometimes "Phase"[c] or "Stage"[d])	A stage of testing "typically associated with the achievement of particular objectives and used to treat particular risks", each performed in sequence [8, p. 12], [17, p. 6] with their "own documentation and resources" [11, p. 469]; more generally, "designat[es] … the coverage and detail" [11, p. 249]	unit/component testing, integration testing, system testing [8, p. 12], [17, p. 6], [11, p. 467]
Practice	A "conceptual framework that can be applied to … [a] test process to facilitate testing" [8, p. 14], [11, p. 471]; more generally, a "specific type of activity that contributes to the execution of a process" [11, p. 331]	scripted testing, exploratory testing, automated testing [8, p. 20]
Type	"Testing that is focused on specific quality characteristics" [8, p. 15], [17, p. 7], [11, p. 473]	security testing, usability testing, performance testing [8, p. 15], [11, p. 473]

[a] "Design technique" is sometimes abbreviated to "technique" [8, p. 11], [16].
[b] "Test level" can also refer to the scope of a test process; for example, "across the whole organization" or only "to specific projects" [8, p. 24].
[c] "Test phase" can be a synonym for "test level" [11, p. 469], [12, p. 9] but can also refer to the "period of time in the software life cycle" when testing occurs [11, p. 470], usually after the implementation phase [11, pp. 420, 509], [22, p. 56].
[d] [9, pp. 5-6 to 5-7], [16], [23, pp. 9, 13].

IV. Introduction

This document is a model and instructions for LaTeX. Please observe the conference page limits. For more information about how to become an IEEE Conference author or how to write your paper, please visit IEEE Conference Author Center website: https://conferences.ieeeauthorcenter.ieee.org/.

A. Maintaining the Integrity of the Specifications

The IEEEtran class file is used to format your paper and style the text. All margins, column widths, line spaces, and text fonts are prescribed; please do not alter them. You may note peculiarities. For example, the head margin measures proportionately more than is customary. This measurement and others are deliberate, using specifications that anticipate your paper as one part of the entire proceedings, and not as an independent document. Please do not revise any of the current designations.

V. Prepare Your Paper Before Styling

Before you begin to format your paper, first write and save the content as a separate text file. Complete all content and organizational editing before formatting. Please note sections V-A to V-H below for more information on proofreading, spelling and grammar.

Keep your text and graphic files separate until after the text has been formatted and styled. Do not number text heads—LaTeX will do that for you.

A. Abbreviations and Acronyms

Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract. Abbreviations such as IEEE, SI, MKS, CGS, ac, dc, and rms do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable.

B. Units

- Use either SI (MKS) or CGS as primary units. (SI units are encouraged.) English units may be used as secondary units (in parentheses). An exception would be the use of English units as identifiers in trade, such as "3.5-inch disk drive".
- Avoid combining SI and CGS units, such as current in amperes and magnetic field in oersteds. This often leads to confusion because equations do not balance dimensionally. If you must use mixed units, clearly state the units for each quantity that you use in an equation.
- Do not mix complete spellings and abbreviations of units: "Wb/m^2" or "webers per square meter", not "webers/m^2". Spell out units when they appear in text: ". . . a few henries", not ". . . a few H".
- Use a zero before decimal points: "0.25", not ".25". Use "cm^3", not "cc".)

C. Equations

Number equations consecutively. To make your equations more compact, you may use the solidus (/), the exp function, or appropriate exponents. Italicize Roman symbols for quantities and variables, but not Greek symbols. Use a long dash rather than a hyphen for a minus sign. Punctuate equations with commas or periods when they are part of a sentence, as in:

$$a + b = \gamma \tag{1}$$

Be sure that the symbols in your equation have been defined before or immediately following the equation. Use "(1)", not "Eq. (1)" or "equation (1)", except at the beginning of a sentence: "Equation (1) is . . ."

D. LaTeX-Specific Advice

Please use "soft" (e.g., \eqref{Eq}) cross references instead of "hard" references (e.g., (1)). That will make it possible to combine sections, add equations, or change the order of figures or citations without having to go through the file line by line.

Please don't use the {eqnarray} equation environment. Use {align} or {IEEEeqnarray} instead. The {eqnarray} environment leaves unsightly spaces around relation symbols.

Please note that the {subequations} environment in LaTeX will increment the main equation counter even when there are no equation numbers displayed. If you forget that, you might write an article in which the equation numbers skip from (17) to (20), causing the copy editors to wonder if you've discovered a new method of counting.

BibTeX does not work by magic. It doesn't get the bibliographic data from thin air but from .bib files. If you use BibTeX to produce a bibliography you must send the .bib files.

LaTeX can't read your mind. If you assign the same label to a subsubsection and a table, you might find that Table I has been cross referenced as Table IV-B3.

LaTeX does not have precognitive abilities. If you put a \label command before the command that updates the counter it's supposed to be using, the label will pick up the last counter to be cross referenced instead. In particular, a \label command should not go before the caption of a figure or a table.

Do not use \nonumber inside the {array} environment. It will not stop equation numbers inside {array} (there won't be any anyway) and it might stop a wanted equation number in the surrounding equation.

E. Some Common Mistakes

- The word "data" is plural, not singular.
- The subscript for the permeability of vacuum μ_0, and other common scientific constants, is zero with subscript formatting, not a lowercase letter "o".
- In American English, commas, semicolons, periods, question and exclamation marks are located within quotation marks only when a complete thought or name is cited, such as a title or full quotation. When quotation marks are used, instead of a bold or italic typeface, to highlight a word or phrase, punctuation should appear outside of the quotation marks. A parenthetical phrase or statement at the end of a sentence is punctuated outside of the closing parenthesis (like this). (A parenthetical sentence is punctuated within the parentheses.)
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- Do not use the word "essentially" to mean "approximately" or "effectively".
- In your paper title, if the words "that uses" can accurately replace the word "using", capitalize the "u"; if not, keep using lower-cased.
- Be aware of the different meanings of the homophones "affect" and "effect", "complement" and "compliment", "discreet" and "discrete", "principal" and "principle".
- Do not confuse "imply" and "infer".
- The prefix "non" is not a word; it should be joined to the word it modifies, usually without a hyphen.
- There is no period after the "et" in the Latin abbreviation "et al.".
- The abbreviation "i.e." means "that is", and the abbreviation "e.g." means "for example".

An excellent style manual for science writers is The Technical Writer's Handbook.

F. Authors and Affiliations

The class file is designed for, but not limited to, six authors. A minimum of one author is required for all conference articles. Author names should be listed starting from left to right and then moving down to the next line. This is the author sequence that will be used in future citations and by indexing services. Names should not be listed in columns nor group by affiliation. Please keep your affiliations as succinct as possible (for example, do not differentiate among departments of the same organization).

G. Identify the Headings

Headings, or heads, are organizational devices that guide the reader through your paper. There are two types: component heads and text heads.

Component heads identify the different components of your paper and are not topically subordinate to each other. Examples include Acknowledgments and References and, for these, the correct style to use is "Heading 5". Use "figure caption" for your Figure captions, and "table head" for your table title. Run-in heads, such as "Abstract", will require you to apply a style (in this case, italic) in

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Text heads organize the topics on a relational, hierarchical basis. For example, the paper title is the primary text head because all subsequent material relates and elaborates on this one topic. If there are two or more sub-topics, the next level head (uppercase Roman numerals) should be used and, conversely, if there are not at least two sub-topics, then no subheads should be introduced.

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a) Positioning Figures and Tables: Place figures and tables at the top and bottom of columns. Avoid placing them in the middle of columns. Large figures and tables may span across both columns. Figure captions should be below the figures; table heads should appear above the tables. Insert figures and tables after they are cited in the text. Use the abbreviation "Fig. 1", even at the beginning of a sentence.

TABLE II
Table Type Styles

Table Head	Table Column Head		
	Table column subhead	Subhead	Subhead
copy	More table copy[a]		

[a]Sample of a Table footnote.

Fig. 1. Example of a figure caption.

Figure Labels: Use 8 point Times New Roman for Figure labels. Use words rather than symbols or abbreviations when writing Figure axis labels to avoid confusing the reader. As an example, write the quantity "Magnetization", or "Magnetization, M", not just "M". If including units in the label, present them within parentheses. Do not label axes only with units. In the example, write "Magnetization (A/m)" or "Magnetization {A[m(1)]}", not just "A/m". Do not label axes with a ratio of quantities and units. For example, write "Temperature (K)", not "Temperature/K".

Acknowledgment

The preferred spelling of the word "acknowledgment" in America is without an "e" after the "g". Avoid the stilted expression "one of us (R. B. G.) thanks ...". Instead, try "R. B. G. thanks...". Put sponsor acknowledgments in the unnumbered footnote on the first page.

References

Please number citations consecutively within brackets. The sentence punctuation follows the bracket. Refer simply to the reference number; do not use "Ref. [1]" or "reference [1]" except at the beginning of a sentence: "Reference [1] was the first ..."

Number footnotes separately in superscripts. Place the actual footnote at the bottom of the column in which it was cited. Do not put footnotes in the abstract or reference list. Use letters for table footnotes.

Unless there are six authors or more give all authors' names; do not use "et al.". Papers that have not been published, even if they have been submitted for publication, should be cited as "unpublished". Papers that have been accepted for publication should be cited as "in press". Capitalize only the first word in a paper title, except for proper nouns and element symbols.

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