## A Manifesto for Applicable Formal Methods

Mario Gleirscher<sup>1</sup> · Jaco van de Pol<sup>2</sup> · Jim Woodcock<sup>3</sup>

<sup>1</sup>gleirscher@uni-bremen.de, University of Bremen, Germany

<sup>2</sup>jaco@cs.au.dk, Aarhus University, Denmark

<sup>3</sup>jim.woodcock@york.ac.uk, University of York, United Kingdom

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#### Abstract

Formal methods were frequently shown to be effective and, perhaps because of that, practitioners are interested in using them more often. Still, these methods are far less applied than expected, particularly, in critical domains where they are strongly recommended and where they have the greatest potential. Our hypothesis is that formal methods still seem not to be applicable enough or ready for their intended use. In critical software engineering, what do we mean when we speak of a formal method? And what does it mean for such a method to be applicable both from a scientific and practical viewpoint? Based on what the literature tells about the first question, with this manifesto, we lay out a set of principles that when followed by a formal method give rise to its mature applicability in a given scope. Rather than exercising criticism of past developments, this manifesto strives to foster an increased use of formal methods to the maximum benefit.

### 1 Introduction

Formal methods (FMs) have been an active research area for decades. Theoretical foundations [36], method applications [2, 10, 27], as well as effective ways to transfer [47, 50] them to the practising engineer have been thoroughly discussed and empirically evidenced [52, 57]. The resources to learn about these methods range from early syllabuses [24] to recent course materials, tutorial papers (e.g., [8]), tool manuals, text books (e.g., [41], [49]), and a community wiki. However, evidence on successful formal method teaching, training, and teaching-based transfer is still missing [23, 26].

Driven by the inspiration and critique of expert voices from academia [4, 11, 29, 42, 45, 51] and industry [1], formal methods are considered to be one

<sup>1</sup> Available from the Formal Methods Europe association https://fme-teaching.github.io/courses

<sup>&</sup>lt;sup>2</sup>E.g., http://www.prismmodelchecker.org/manual

<sup>&</sup>lt;sup>3</sup>The Formal Methods Body of Knowledge (FMBoK): https://formalmethods.wikia.org

of the most promising tools to develop highly dependable software for critical applications [23]. Developers of formal methods have always aimed at applicability in practical contexts, notably with different degrees of success. Indeed, many practitioners believe in the high potential of such methods and would use them to their maximum benefit, whether directly or through powerful software tools [26]. Although, there is wide interest in applying these methods in the engineering practice of dependable systems and software, this domain has not yet successfully adopted formal methods. It is observed (e.g., [23, 26]) that their use is still significantly weaker than expected, most alarmingly, even in critical domains [25] where their application is, in parts and through a wide range of standards (e.g., IEC 61508 and 62443, DO-178), strongly recommended.

It is thus reasonable to assume that FMs (still or again) seem not to be applicable enough (or ready) for their intended purpose. An alternative explanation would be that modern programming languages and environments implicitly support a good part of what would have been called formal development in the period from the 1970s to the 1990s and avoid many of the hard sought-after errors, FMs were originally supposed to unveil. This explanation is, however, only reasonable if we ignore the massive increase in software and hardware complexity since then and the increase in use of software in critical areas. Consequently, new kinds of problems and errors have shown up and the original justification for the use of FMs remains valid, albeit at different levels of abstraction.

In that light, the beneficial use of formal methods is hindered, for example, by poor scalability, missing or inadequate tools, scarce teaching and training, and thus a lack of trained personnel [26]. The lack of recent knowledge about these obstacles and the effectiveness and productivity of formal methods [25] raise a high demand for formal method research and goal-directed collaborations between academia, regulators, and industry. To help research and transfer efforts gain momentum and foster success, we suggest some guiding principles of applicable formal methods in form a manifesto.

**Outline.** The Sections 2 and 3 provide the background and motivation of this manifesto and highlight related work. Section 4 presents the manifesto and its principles. Section 5 highlights several formal methods success stories. Section 6 summarises aims, suggests actions to implement the manifesto, and outlines expected impacts of these actions. Section 7 warns about potential consequences of inaction by the community, and Section 8 concludes.

## 2 Background

What is a "formal method"? There are many useful characterisations available from the literature. For example, the *IEEE Software Engineering Body of Knowledge* says: "formal methods are software engineering methods used to specify, develop, and verify the software through application of a rigorous mathematically based notation and language" [37, p. 9-7, Sec. 4.2]. This recent definition [6] covers the relevant aspects quite well, stating that "formal

methods are a set of techniques based on logic, mathematics, and theoretical computer science which are used for specifying, developing, and verifying software and hardware systems." We slightly refine this notion, saying that, by a formal method, we refer to an explicit mathematical model and sound logical reasoning about critical properties [55]—such as reliability, safety, security, dependability, performance, uncertainty, or cost—of a class of electrical, electronic, and programmable electronic or software systems. Model checking, theorem proving, abstract interpretation, assertion checking, and formal contracts are classical examples of versatile formal methods.

What makes formal methods so special? Generally, a method can be thought of as a step-wise recipe providing guidance for its user regarding the next steps to take in certain situations. In analogy to other engineering disciplines, a formal method pushes the role of mathematics and logic in software engineering to

- make objects explicit (e.g., natural processes, information, peoples' thoughts) through *notation* with a precise *meaning* agreed within a domain,
- reduce ambiguity about or subjective interpretation of these objects (e.g., a system or its functioning) and foster a precise understanding of that domain, and
- support mechanisation of critical or tedious tasks (e.g., analysis, verification).

These features enable one to distinguish formal from informal (or "non-formal") methods.<sup>4</sup> A formal method is more than a (modelling) notation or a development or analysis method and different from a programming language or a software engineering tool.

Although there is no clear boundary between formal and informal methods (formality may occur in degrees), one can be of the opinion that a software engineering method is "informal" if the use of mathematics and logic is neither essential nor required to create reliable results, and it is "formal" otherwise.

What do we mean by "applicability"? Generally, "applicable" means capable of being applied, within some defined and practically relevant scope. More specifically, applying a formal method involves its use in the design, development, and analysis of a critical system and its substantial integration with the used development methodologies (e.g., structured development, model-based engineering, assertion-based programming, test-driven development), specification and modelling notations (e.g., UML, SysML), programming languages, and

<sup>&</sup>lt;sup>4</sup>For example, UML is a standardised notation and carries, through its many historically-inspired concepts, flavours of methods. However, to obtain a corresponding FM, UML's concepts need to be underpinned with a precise semantics and a method to construct and reason about UML models. Similarly, Java has a fairly well specified grammar and platform. However, to obtain an FM for Java, executions of a Java program need to be given a precise semantics as well as a method to reason about it logically and conceptually.

tools. When we use the terms "applicable" or "applicability", we refer to a desirable degree or level of  $maturity^5$  of a formal method. Consequently, this notion suggests some quantitative (e.g., performance or economic) assessment to be able to make objective statements about the level of maturity and, thus, the applicability of a formal method.

When do we expect a formal method to be applicable? We need applicability whenever we suggest a FM as a critical (quality assurance) *instrument* to be used in a critical engineering *task*. That task will primarily be a practical software engineering task but it can also be an engineering task in computer science research and teaching.

We need applicability if the expected benefit from using a formal method in a task (e.g., early error reduction, design improvement, didactic gain, scientific insight) justifies the expected cost of applying it (e.g., formalisation effort, time, and resources) but it does not justify the cost of not applying it (e.g., late failure handling costs, failure consequences).

What makes formal method applicability so special? What makes it different from applicability of other modelling or programming methods, techniques, or languages? A formal method requires one to use (through tools and with guidance) mathematical structures to represent and make concise the meaning of objects (e.g., software or system behaviour, data sets) to be reasoned upon. The proper understanding and efficient use of such structures needs special abstraction capabilities, mathematical skills to be taught, and continuous application-oriented training. An applicable formal method is a method that addresses these very specific requirements in this particular context.

What is a manifesto and why do we need one? A manifesto can be understood as "a series of technical or expert views on a particular engineering task" [43], "a set of commitments" of a community [53], or "a focal point of reference" catalysing communities [7]. Inspired by successful similar efforts in other domains [7],<sup>6</sup> we summarise: A manifesto expresses consensual agreement among stakeholders (e.g., experts, thought leaders, users) in a domain, it is based on corresponding definitions, it concisely conveys guidance in terms of principles, it discloses aims and commitments in form of an appeal, it suggests actions, and it can join forces and, thus, initiate change.

### 3 Related Work

Our manifesto can be seen as a specific supplement of the Verified Software Initiative [34], which has the long-term aim to perform wide-ranging verification

 $<sup>^5\</sup>mathrm{In}$  analogy to NASA's Technology Readiness Levels (NASA) and the CMMI framework from CMI

<sup>&</sup>lt;sup>6</sup>See also the GNU Manifesto (1985, https://www.gnu.org/gnu/manifesto.html) and the Agile Manifesto (2001, http://agilemanifesto.org).

experiments and case studies, improve the tool landscape, and foster transfer of FM research to industry. Ladkin's manifesto [43, Ch. 10] includes principles and steps of how formal methods could be used in practical and standard-compliant software assurance. While his manifesto covers many areas of software assurance, the section on FM guidance concentrates on the use of FMs in assurance. Our manifesto complements Ladkin's with guidance on how to prepare FMs to be applicable in assurance and beyond. Rae et al.'s manifesto [53] aims at an improvement in the use of research methods in safety science, not touching on FM applicability in software safety.

## 4 The Manifesto and Its Ten Principles

We present the manifesto with its goals, principles, and aims concisely in Table 1 and then explain and comment on each principle in more detail.

The Ten Principles of Applicable Formal Methods. In order to evidence applicability both in research and in practical software engineering, a formal method should ideally implement all of the following principles.

**Scope** It should clearly define its scope of applicability<sup>7</sup>, its domain specificity, and come with comprehensible guidance on how it is to be applied within that given scope. The restriction to a limited scope can reduce the complexity of the formal model and, thus, increase *Ease of Use* and support other principles.

Methodology It should provide a step-wise recipe, procedural guidance for method users regarding possible next steps to be taken in corresponding situations. For example, it should support composition, modularity (e.g., using formal reasoning [16] about contracts [46]), and refinement, and come with a variety of sound abstraction or simplification techniques.

Integration It should create benefits through integration with other methods. For example, it should be integrated<sup>8</sup> with (i) an established formal method or (ii) a widely-used modelling technique (e.g., UML State Charts), (iii) programming language (e.g., Java), or (iv) process model (e.g., Scrum). Integration in this way is supposed to increase *Usefulness* and *Ease of Use*.

**Explainability** After a successful application of a formal method, it should be clear what has been demonstrated. A minimal requirement is that it can be stated precisely which claim has been established (as in a mathematical theorem). A stricter requirement is that a certificate can be generated,

 $<sup>^7{</sup>m For}$  example, embedded software engineering research or safety-critical software practice in the automotive control domain.

<sup>&</sup>lt;sup>8</sup>Conceptually aligned, representing a semantic layer for another method, represented to the user through a common tool layer.

which enables checking the claim independently. Last but not least, it requires that the claim (including the underlying modeling assumptions) can be communicated to human domain experts and maybe even to end users. Explainability in this way is supposed to increase *Usefulness*.

Automation It should come with tool support that prevents its user from tedious work steps and helps them to focus on essential and creative steps. In particular, it should provide automation support for any obvious/useful abstraction required to be crafted to apply the method to the maximum benefit. Automation usually pertains to difficult or tedious tasks and can, thus, increase Scalability towards industrial-sized systems.

**Scalability** It should be applicable at a practically relevant scale, <sup>9</sup> manageable with reasonable effort as a function of that scale. This principle is likely to be fostered by a clear *Methodology* (e.g., superior algorithms, abstraction, modular approaches) and strong *Automation*.

**Transfer** It should be accompanied with a teaching and training strategy and corresponding materials. This strategy and the materials may differ from one formal method to another. However, also average graduate students and experienced engineers should be able to learn and apply a method with reasonable effort.

Usefulness Its effectiveness should be evidenced. For example, it should be demonstrated (e.g., by means of case studies or controlled experiments) what would have been different if a conventional or non-formal alternative had been used instead (e.g., through comparison of relative fault-avoidance or fault-detection effectiveness and the economic impacts of these metrics). Usefulness as the governing factor for applicability will be a result of other principles, such as *Explainability*.

Ease of Use It should be efficiently<sup>11</sup> applicable. For example, it should provide concepts, abstractions, or modelling and reasoning primitives that help users with appropriate skills (cf. *Training*) to apply it with reasonable effort (e.g., low abstraction effort, low proof complexity, high productivity) within the specified scope. Ease of use will be a result of other principles, such as *Scalability* and *Automation*. *Usefulness* and *Ease of Use* refer to the two main constructs of the *Technology Acceptance Model* [17], a widely used model for the assessment of end-user information technology.

**Evaluation** It should demonstrate its applicability in a credible way (e.g., with representative examples, with tools usable by other researchers or prac-

<sup>&</sup>lt;sup>9</sup>Where scale may be quantified as, for example, lines of code, the number of fulfilled requirements or discharged theorems, the size of a state space, or by a measure of complexity.

 $<sup>^{10}</sup>$ Educational prerequisites, theoretical background material, examples, case studies, user guides, tool manuals.

<sup>&</sup>lt;sup>11</sup>Note that the term "efficiency" here refers to the gain/effort ratio on the user's side. Efficiency in terms of short tool run-time or low algorithmic complexity is subsumed under *Automation*, *Scalability*.

titioners) that it is applicable to the range of engineering problems and systems in its specified scope. It should provide information about both its benefits and foreseen challenges, limitations, or barriers when applied. This principle integrates the scientific method into the argumentation of FM applicability.

# 5 Success Stories of FM Integration and Transfer

There is plenty of anecdotal and stronger evidence on applicable formal methods, not least in the form of success stories of research integration, application, and transfer.

Unifying Theories of Programming (UTP) is Hoare & He's long-term research agenda [33]. Their intention is to explore a common basis for understanding the semantics of the modelling notations and programming languages used in describing the behaviour of computer-based systems. Their technique is to describe diverse modelling and programming paradigms in a common semantic setting. They isolate the individual features of these paradigms to emphasise commonalities and differences. They devise formal, often approximate, links between theories to translate predicates from one theory into another. The links also translate specifications into designs and programs as a development method. Understanding the links between formal methods is important, especially for building tool chains for heterogeneous approaches.

Beyond the bottom-up construction of tool chains, the AUTOFOCUS project<sup>12</sup> [12, 35] is an example of a long-term effort to provide a formally based seamless specification, modelling, and development environment, with methodological support from requirements capture down to code generation, testing, and artefact evolution. Several large case studies in model-based development of embedded software were conducted over the years using different AUTOFOCUS generations.

The profit from FMs is supposed to be maximal, when thoroughly integrated in a company's design and verification processes [25]. The chip industry was one of the first sectors where (automated) theorem provers and model checkers have been routinely applied to scrutinize their ever more complex circuits, for instance at INTEL [22, 30], IBM [9] and Oracle [54]. Perhaps this is due to the fact that chips are mass produced, hence the costs of errors are high, thus the effort of applying FMs paid off early.

Another traditional sector for the application of formal methods is the rail-way signalling domain, which can be easily explained by their safety-critical nature. Very early applications of formal methods to railways have been reported [20]. Many European projects (e.g., FMERail, INESS) and indeed whole conferences (e.g., RSSRail<sup>13</sup>) studied the application of such methods to the

<sup>12</sup>https://www.fortiss.org/ergebnisse/software/autofocus-3

<sup>13</sup>https://rssrail2022.univ-gustave-eiffel.fr

railway domain. Although this could still be an academic exercise, increasingly the agenda of formal methods in railways is set by engineering companies (SHIFT2RAIL<sup>14</sup>) and infrastructure managers (EULYNX<sup>15</sup>). Indeed, the latter are fastly building up expertise centers in model based software engineering and formal verification.

In the past, a successful route to the wider deployment of formal methods in practice has been the standardisation of their notations, for example, through ISO. Notable standardisation efforts in this regard are, for instance, LOTOS [38], SDL [40], and the Z notation [39].

Finally, formal methods are now also applied routinely in purely software-based platforms. An important initial example was the SLAM project at Microsoft [3], aimed at Windows device driver compliance. Also Facebook [18, 50] and Amazon Web Services [15, 48] have reported on the application of formal methods for their infrastructure at a massive scale. Perhaps, this happened because FMs have matured. Another possible explanation is that the availability and security requirements to contemporary software platforms are extremely high. These platforms have taken up the role of critical infrastructure. Other highlights in verified software are the formally verified optimizing compiler CompCert [44] and the formally verified Operating System Microkernel seL4 [31].

It could be argued that an even wider adoption can only be realized by making FM available to average software engineers, who have received a MSc degree in computing or engineering. Apart from professional, easy to use tool support, this requires insight in the trade-off between investments in and benefits from FM application, as advocated in [21]. It also requires an integration of FM tools with other artefacts in the usual design processes, for instance in agile development [28].

The evidence available from these success stories ranges from single to aggregated opinions of experts as well as anecdotal to very systematic case studies and thorough yet sporadic tool evaluations. However, data from across a representative range of samples has hardly ever been rigorously measured (e.g., using controlled method experiments). Hence, albeit impressive, this evidence is still insufficient to underpin a strong argument for a wider deployment of formal methods in industry. And without such a deployment, further FM research is at risk of getting inapplicable.

## 6 An Impact-oriented Plan for Actions

A manifesto should of course follow a certain aim, suggest possible actions, disclose the various impacts hoped for, and discuss relevant implications.

Overview of Expected Impacts of the Manifesto. We expect a manifesto on applicable formal methods to:

 $<sup>^{14} {</sup>m https://shift2rail.org}$ 

<sup>15</sup>https://www.eulynx.eu

- 1. Foster the **collection (and curation) of** real (small, medium, large) **open problems** (inspired by the success stories in Section 5) to be tackled by formal methods. At the lowest level, these can be benchmarks defined by practitioners, formal method users, or regulators (e.g., a "FM with industry week" with short-term interactions to identify problems at a national or international level and follow-up commitments).
- 2. Provide **guidance on** how to perform formal method **case studies** and write case study papers and how to review them. We define a case study as an intensive examination of a single example with an aim to generalise across a larger set of examples. It's this generalisation that makes case studies useful in teaching and in industrial practice.
- 3. Stimulate new research proposals and interdisciplinary research collaboration, for example, to improve the interface between different formal methods and their users (e.g., increase trust through *Explainability*, see Table 1), to investigate the economic benefits through formal methods (e.g., economical value, metrics), or to develop new business models integrating such methods.
- 4. Strengthen the community of researchers that (i) perform evaluations of existing formal approaches and new variants in practical contexts, (ii) develop new formal approaches with an interest on achieving applicability early, and (iii) support the transfer of these methods into dependable systems practice.

We detail some of these impact categories below.

Impact on the Conduct, Writing, and Review of Formal Method Research. Showing the novelty of research on applicable formal methods w.r.t. the state of the art is more complicated than showing the novelty of a particular formal technique. A formalism and its expressive power can be explained by examples and the superiority of an algorithm or tool can be demonstrated by experiments, e.g., comparing a range of settings. However, the *evaluation of the applicability of a formal method as a whole* is more intricate. So, what is the recommended way for research on applicable formal methods? How can one demonstrate its novelty w.r.t. the state of the art?

A few (old) answers [5] within software engineering research are: case studies [59], action research [56, Sec. 5.5] and controlled method experiments [58] [56, Ch. 8]. Following these methods would greatly benefit the FM community; Yin's<sup>16</sup> and Wohlin et al.'s procedures provide welcome guidance. Specific guidelines will effectively aid researchers in conducting evaluation research, writing up results, and performing peer reviews in a repeatable, standardised, and fair manner. The principles of the manifesto (Section 4) may serve as an initial template for such guidelines.

<sup>&</sup>lt;sup>16</sup>I.e. plan, design, prepare, collect, analyse, and share.

Implications of the Manifesto on Future Formal Method Teaching. It is important to have good case studies that are relevant to students. They must be able to recognise the problem being solved. They should have realistic case studies for every important concept in the course. This is particularly important for industrial courses, where it helps if the presenter has good industrial experience using the formal method. Robust tools are important. There must be parsers and type checkers. Model checkers are attractive, but can disappoint if newcomers have difficulty in scaling their use. Theorem provers have a higher entry barrier but their success can be inspiring. A successful course teaches not just one formal method, but families of formal methods: students like to see the connections between different formal methods. Industrial courses should show how formal methods fit into software management processes and popular methodologies. This includes combining formal methods with testing strategies and their role in formal domain engineering as part of requirements engineering.

Impact on the Evaluation of Future Formal Method Research. We expect the manifesto to motivate researchers to carry out comparative method and tool evaluations (e.g., [19]), realistic case studies and goal-directed action research, and controlled method experiments improving over previous lessons learnt [52, 57]. For example, in the ABZ community there are ongoing activities to create a case study library for such purposes. Another example is the VerifyThis collaborative long-term verification challenge bringing together FM researchers to show "that deductive program verification can produce relevant results for real systems with acceptable effort". 18

The manifesto has the potential to create new lines and formats of research funding specifically shaped to the needs of formal method evaluation and tool development, such as funding for experiments and entrepreneurship funding for spin-offs. Comparative method experiments and usable tool interfaces require resources going beyond PhD projects or beyond the pure response to scientific questions. Only appropriately funded research projects will create convincing evidence.

Impact on the Further Development of the Formal Methods Community. The manifesto could reduce the current fragmentation of the formal methods community by subsequently integrating selective sub-communities, for example, communities working on common semantic frameworks (e.g., the UTP community<sup>19</sup>) or formal method integration (e.g., the sub-communities around the "Formal Methods in Industrial Critical Systems (FMICS)", "Integrated Formal Methods (iFM)", "NASA Formal Methods (NFM)", and "Software Engineering and Formal Methods (SEFM)" conference series<sup>20</sup>). Moreover, the man-

<sup>17</sup>https://abz2021.uni-ulm.de/case-study

<sup>18</sup>https://verifythis.github.io

<sup>19</sup>https://www.cs.york.ac.uk/circus/utp2019

<sup>20</sup>http://fmics.inria.fr, http://www.ifmconference.org, https://shemesh.larc.nasa.gov/nfm2021, https://sefm-conference.github.io

ifesto could inspire new actions of researchers to work towards a collection of formal methods that follow the proposed principles.

Impact on Software Engineering as a Legally Recognised Profession.

In his Turing Award acceptance speech about 40 years ago, Tony Hoare reviewed type safety precautions in programming languages and concluded: "In any respectable branch of engineering, failure to observe such elementary precautions would have long been against the law" [32]. In this regard, for example, U.S. law still does not recognise computing (including software engineering) as a profession [14], opposing ACM's self-perception [13]. This is mainly because software practitioners' work is not subject to malpractice claims based on a legal concept known as "customary care". Customary care defines (i.e., standardises) best practice more stringently<sup>21</sup> than the notion of "reasonable care" applied to any occupation or business. From a computing standpoint, ongoing juristic debates about which other occupations<sup>22</sup> should be treated as professions could be advanced by this manifesto, corroborate codes such as ACM's Code of Ethics and Professional Conduct,<sup>23</sup> and help to standardise results from the formal methods community as credible best practices underpinning such codes.

In Denmark, 51% of the developers hired by the IT companies developing software do not have a BSc/MSc degree in computing.<sup>24</sup> It is to be expected that this situation can be generalised to other European countries and, to a smaller degree, also to critical application domains. Hence, this manifesto could aid in the expansion of existing software engineering professionalism<sup>25</sup> within such domains.

#### 7 A Life Without the Manifesto

Above, we summarised actions and expected outcomes of a successful implementation of the manifesto. However, some negative long-term consequences of not following an agenda implied by the manifesto are to be foreseen.

First, the progress of formal method research might be further threatened by missing scalability, vacuous proofs, lack of user education and training, poor tool integration, lack of researcher engagement and, thus, research funding [25, pp. 117:23,29].

Secondly, formal methods might be wiped out by opportunistic trends or powerful convenience technologies (e.g., relying too much on search- or AI-based software engineering) that can make the highlighted problems worse. It can be observed that software solutions constructed through automatic search may require significant further investments into the reverse engineering of these so-

 $<sup>^{21}</sup>$ Taking the state of the art including recent scientific results as a reference.

 $<sup>^{22}\,\</sup>mathrm{``[E]}$  very court to consider this question has refused to recognize software developers as professionals' [14, p. 23].

<sup>&</sup>lt;sup>23</sup>Version 2018: https://www.acm.org/code-of-ethics

<sup>&</sup>lt;sup>24</sup>https://www.prosa.dk/artikel/nu-er-der-over-100000-it-professionelle

<sup>&</sup>lt;sup>25</sup>https://en.wikipedia.org/wiki/Software\_engineering\_professionalism

lutions in order to verify them. This may happen frequently in cases where not all critical properties to be verified can be encoded into the search criteria.

Ultimately, decreasing global coordination among formal method researchers can lead to an extinction of the formal methods community, which is currently rather fragmented. It is difficult for the community to maintain too many notations and too many tools and make fast progress. This situation seems quite unique among related or other scientific disciplines (i.e., STEM<sup>26</sup>). Also, there is a proliferation of formal method conferences and workshops that are competing for the same resources (i.e., papers, reviewers, etc.). Ideally, a representative, coordinated approach could lead to an authoritative voice towards the scientific, governmental, and industrial communities.

## 8 Conclusions and Outlook

The manifesto for applicable formal methods expresses aims and intentions and shall help formal methods researchers to implement a modern research agenda for developing formal methods that can arguably be used for critical software engineering research but, even more importantly, in the practical engineering of systems and software whose functioning is critical and whose failure would have unacceptable consequences. Rather than exercising criticism of past developments, the manifesto strives to foster progress of a currently dissatisfying situation found in the science of formal methods.

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<sup>&</sup>lt;sup>26</sup>Science, Technology, Engineering, Mathematics

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Table 1: The manifesto and its ten principles at a glance

Motivation	
Success stories	FMs aim at applicability and were shown to be effective.
Visible demand	Practitioners are interested in using FMs more fre-
	quently.
But: Scarce use	FMs are far less applied than expected, particularly, in
	critical domains.

#### Diagnostic Finding

Formal methods (still) seem not to be applicable enough (or ready) for their intended use.

Ten Principles / Precepts / Commitments	
Scope	Clearly define the scope of applicability
Methodology	Provide concepts, tools, and procedural guidance (for
	scalability)
Integration	Integrate with methods, modelling techniques, and
	prog. languages
Explainability	Allow established claims to be communicated precisely
	and clearly
Automation	Provide automated abstractions (for scalability)
Scalability	Be applicable to the size/complexity of systems oper-
	ated in practice
Transfer	Provide teaching and training strategies
Usefulness	Provide evidence on effectiveness (for a good
	cost/benefit ratio)
Ease of Use	Provide evidence on efficiency (for a good cost/benefit
	ratio)
Evaluation	Demonstrate applicability in a credible way

#### Aims, Actions, and Expected Impacts

- $\bullet$   $\mathbf{Provide}$   $\mathbf{guidance}$  for performing, writing, and reviewing formal method  $\mathbf{research}$
- $\bullet$   $\mathbf{Drive}$  the selection of relevant unsolved (benchmark or fundamental)  $\mathbf{chal}$  lenges and  $\mathbf{stimulate}$   $\mathbf{research}$   $\mathbf{proposals}$
- Foster interactions between academia and industry
- Establish connections between formal method developers and users (through explainability) and customers (through economical arguments)