

Formal Methods in the Field (FMitF)

PROGRAM SOLICITATION

NSF 18-536



National Science Foundation

Directorate for Computer & Information Science & Engineering
Division of Computing and Communication Foundations
Division of Computer and Network Systems
Division of Information & Intelligent Systems

Full Proposal Deadline(s) (due by 5 p.m. submitter's local time):

May 08, 2018

IMPORTANT INFORMATION AND REVISION NOTES

Any proposal submitted in response to this solicitation should be submitted in accordance with the revised *NSF Proposal & Award Policies & Procedures Guide* (PAPPG) (NSF 18-1), which is effective for proposals submitted, or due, on or after January 29, 2018.

SUMMARY OF PROGRAM REQUIREMENTS

General Information

Program Title:

Formal Methods in the Field (FMitF)

Synopsis of Program:

The Formal Methods in the Field (FMitF) program aims to bring together researchers in formal methods with researchers in other areas of computer and information science and engineering to jointly develop rigorous and reproducible methodologies for designing and implementing correct-by-construction systems and applications with provable guarantees. FMitF encourages close collaboration between two groups of researchers. The first group consists of researchers in the area of formal methods, which, for the purposes of this solicitation, is broadly defined as principled approaches based on mathematics and logic, including modeling, specification, design, program analysis, verification, synthesis, and programming language-based approaches. The second group consists of researchers in the "field," which, for the purposes of this solicitation, is defined as a subset of areas within computer and information science and engineering that currently do not benefit from having established communities already developing and applying formal methods in their research. Initially the program will limit the field to these four areas that stand to directly benefit from a grounding in formal methods: computer networks, cyber-human systems, machine learning, and operating/distributed systems. However other field(s) may emerge as priority areas for the program in future years, subject to the availability of funds.

Each proposal must have at least one Principal Investigator (PI) or co-PI with expertise in formal methods and at least one with expertise in one or more of these fields: computer networks, cyber-human systems, machine learning, and operating/distributed systems. Proposals are expected to address the fundamental contributions to both formal methods and the respective field(s), and should include a proof of concept in the field along with a detailed evaluation plan that discusses intended scope of applicability, trade-offs and limitations. All proposals are expected to contain a detailed collaboration plan that clearly highlights and justifies the complementary expertise of the PIs in the designated areas, and describes the mechanisms for continuous bi-directional interaction.

Cognizant Program Officer(s):

Please note that the following information is current at the time of publishing. See program website for any updates to the points of contact.

- Nina Amla, Program Director, telephone: (703) 292-7991, email: namla@nsf.gov
- Anindya Banerjee, Program Director, telephone: (703) 292-7885, email: abanerje@nsf.gov
- Dan R. Cosley, Program Director, telephone: (703) 292-8491, email: dcosley@nsf.gov
- Darleen L. Fisher, Program Director, telephone: (703) 292-8950, email: dlfisher@nsf.gov

- Sol Greenspan, Program Director, telephone: (703) 292-8910, email: sgreensp@nsf.gov
- Samee Khan, Program Director, telephone: (703) 292-8061, email: skhan@nsf.gov
- Weng-Keen Wong, Program Director, telephone: (703) 292-7129, email: wwong@nsf.gov

Applicable Catalog of Federal Domestic Assistance (CFDA) Number(s):

- 47.070 --- Computer and Information Science and Engineering

Award Information

Anticipated Type of Award: Standard Grant or Continuing Grant

Estimated Number of Awards: 8

Approximately 8 awards of up to \$1,000,000 per award with durations up to 4 years per award are anticipated, subject to availability of funds.

Anticipated Funding Amount: \$8,000,000

Subject to availability of funds.

Eligibility Information

Who May Submit Proposals:

Proposals may only be submitted by the following:

- Institutions of Higher Education (IHEs) - Two- and four-year IHEs (including community colleges) accredited in, and having a campus located in the US, acting on behalf of their faculty members. Special Instructions for International Branch Campuses of US IHEs: If the proposal includes funding to be provided to an international branch campus of a US institution of higher education (including through use of subawards and consultant arrangements), the proposer must explain the benefit(s) to the project of performance at the international branch campus, and justify why the project activities cannot be performed at the US campus.
- Non-profit, non-academic organizations: Independent museums, observatories, research labs, professional societies and similar organizations in the U.S. associated with educational or research activities.

Who May Serve as PI:

PIs, co-PIs or other senior project personnel must hold primary and full-time paid appointments in research or teaching positions at US-based campuses/offices of eligible organizations.

Each proposal must have at least one (co)-PI focusing on formal methods and at least one focusing on one or more of the field(s) named herein: computer networks, cyber-human systems, machine learning, and operating/distributed systems.

Limit on Number of Proposals per Organization:

There are no restrictions or limits.

Limit on Number of Proposals per PI or Co-PI: 1

An investigator may participate as PI, co-PI, or senior personnel in no more than one proposal submitted in response to this solicitation.

These eligibility constraints will be strictly enforced in order to treat everyone fairly and consistently. In the event that an individual exceeds this limit, only the first submitted proposal received before the deadline will be accepted. **No exceptions will be made.**

Proposals submitted in response to this solicitation may not duplicate or be substantially similar to other proposals concurrently under consideration by NSF.

Proposal Preparation and Submission Instructions

A. Proposal Preparation Instructions

- **Letters of Intent:** Not required
- **Preliminary Proposal Submission:** Not required
- **Full Proposals:**
 - Full Proposals submitted via FastLane: *NSF Proposal and Award Policies and Procedures Guide (PAPPG)* guidelines apply. The complete text of the PAPPG is available electronically on the NSF website at:

- https://www.nsf.gov/publications/pub_summ.jsp?ods_key=pappg.
- o Full Proposals submitted via Grants.gov: *NSF Grants.gov Application Guide: A Guide for the Preparation and Submission of NSF Applications via Grants.gov* guidelines apply (Note: The *NSF Grants.gov Application Guide* is available on the Grants.gov website and on the NSF website at: https://www.nsf.gov/publications/pub_summ.jsp?ods_key=grantsgovguide).

B. Budgetary Information

- **Cost Sharing Requirements:**

Inclusion of voluntary committed cost sharing is prohibited.

- **Indirect Cost (F&A) Limitations:**

Not Applicable

- **Other Budgetary Limitations:**

Not Applicable

C. Due Dates

- **Full Proposal Deadline(s)** (due by 5 p.m. submitter's local time):

May 08, 2018

Proposal Review Information Criteria

Merit Review Criteria:

National Science Board approved criteria. Additional merit review considerations apply. Please see the full text of this solicitation for further information.

Award Administration Information

Award Conditions:

Standard NSF award conditions apply.

Reporting Requirements:

Standard NSF reporting requirements apply.

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I. INTRODUCTION

Computational and communication networks and systems impact all aspects of our daily lives from our economic and societal infrastructure to national security. These networks and systems are complex and notoriously hard to design and analyze, and they often come with significant performance expectations and challenging physical limitations. To complicate matters further, many critical applications that run on these systems and networks are increasingly dependent on machine learning to make important data-driven predictions or decisions, and may require humans to be “in the loop.” It is not surprising that this complex computing ecosystem leads to error-prone systems, networks and applications that lack critical correctness and safety guarantees. There is therefore an urgent need to move the needle on ensuring the reliability and resilience at all levels of the computing and information environment.

Formal methods are mathematically- or logically-based techniques for the specification, modeling, development, verification, and synthesis of systems, networks, and applications, which serve as the foundation for all aspects of information and communication technologies. While formal methods have been used successfully in areas like hardware, cyber physical systems, software development and robotics, there remain many other research areas that could benefit from using them. Two NSF workshops brought together researchers from academia, industry, and government to discuss the important role of formal methods in ensuring the security and reliability of the systems, networks and applications. The [report](#) from the workshop [1] held in 2012 concluded that strong, coordinated and strategically chosen priorities in formal methods can significantly influence current trends in computing for the better, allowing society to continue to reap benefits from computing technology, while helping to build a foundation for a safer, more secure and more dependable future. The [report](#) from the second workshop [2] held in 2015 emphasized that rigorous formal methods are essential for systematic, secure system design, and recommended both foundational scientific work and more applied engineering as foci for improving cybersecurity via formal methods.

The objective of the Formal Methods in the Field (FMITF) program – which is strongly aligned with two of NSF’s Big Ideas for Future Investment, namely Harnessing the Data Revolution for 21st-Century Science and Engineering (HDR) and the Future of Work at the Human-Technology Frontier (FW-HTF) – is to build a community of researchers who will work symbiotically on integrating formal methods into the design and development of critical systems to enable correctness by construction. Inspired by [Robin Milner’s double thesis](#) [3] that “the design of computing systems can only properly succeed if it is well grounded in theory, and that the important concepts in a theory can only emerge through protracted exposure to application,” the FMITF program aims to bring together researchers in formal methods with those in other areas of computer and information science and engineering to jointly develop rigorous and reproducible methodologies for designing and implementing systems and applications with provable correctness guarantees.

[1] NSF Workshop on Formal Methods: Future Directions & Its Transition To Practice, Ranjit Jhala & Rupak Majumdar (Eds.), Dec 2012

[2] NSF Workshop on Formal Methods for Security, Stephen Chong & Joshua Guttman (Eds.), Dec 2015

[3] Inaugural lecture on “Is Computing an Experimental Science?”, Robin Milner, 1986

II. PROGRAM DESCRIPTION

FMITF posits the need for close and continuous collaboration between two groups of researchers. The first group consists of researchers in the area of formal methods, which, for the purposes of this solicitation, is broadly defined as principled approaches based on mathematics and logic, including modeling, specification, design, program analysis, verification, synthesis, and programming language-based approaches. The second group consists of researchers in the “field,” which, for the purposes of this solicitation, is defined as a subset of areas within computer and information science and engineering that currently do not benefit from having established communities already developing and applying formal methods in their research. Initially the program will limit the field to these four areas that stand to directly benefit from a grounding in formal methods: computer networks, cyber-human systems, machine learning, and operating and distributed systems. However other field(s) may emerge as priority areas for the program in future years, subject to the availability of funds.

Today, these two groups of researchers operate largely independently of one another, leading to a significant gap between theory and practice. Many practical systems are constructed without clear design principles and often lack basic safety and correctness guarantees. At the same time, many formal methods are based on assumptions that do not correspond to any realistic system or application. The development of new formal methods, or adaptation of existing ones to address the variety of practical problems that arise in the design and implementation of complex systems necessitates partnerships and collaborations that are often not in place. On the other hand, adequate solutions of the practical problems could present new opportunities and challenges for the formal methods communities, and spur the development of novel theories and abstractions. This bi-directional fertilization envisioned by the FMITF program can lead to new fields of study on both sides, as well as to cutting-edge theories, tools, and experiments inspired by challenges faced in the field.

The premise is that, by working jointly, researchers from these different communities will continually inform each other and collaboratively forge new formal methods that are inspired by practical problems, or find novel, unanticipated applications of existing formal methods that can be validated in the field. The vision in the long run is that mathematical structuring principles realized through protracted exposure to applications will lead to design principles, abstractions, and methodologies for implementing complex systems and applications that are correct by construction.

Specific details of the various areas “in the field” are as follows:

Computer Networks: The goal for this area is to explore the use of formal methods to create high-confidence networks. New technologies that are rapidly becoming part of today's networking environments result in increasing complexity, heterogeneity, and programmability, which in turn produce new challenges to achieving this goal. These technologies include, for example, software-defined networks, programmable packet processors, network functions virtualization, software-defined radios, cloud-based radio access networks, heterogeneous networks and power-constrained endpoints (such as those seen in an Internet-of-Things ecosystem). The use of formal methods in specification, design, synthesis, configuration and management at one or more of the layers of the network (e.g. physical, medium access, network and transport) may enable high-confidence heterogeneous networks and ideally provide provable end-to-end network service assurance.

Cyber-Human Systems: Ensuring desirable properties in human computation systems where humans and computers closely interact is important, and challenging because of the need to account for variability in human abilities, behavior, context, and motivations. Formal methods can help address these challenges. Topics of interest include novel formal techniques to model and reason about correctness and social benefit in deployed information networks and human computation systems like crowdsourcing and citizen science; formal methods for interface specification that could improve efficiency, correctness, and user satisfaction in real-world, safety-critical interfaces; and new program synthesis techniques that could dramatically improve end user programming or improve trust in and outcomes of adaptive agents such as recommender systems and intelligent tutors.

Machine Learning: The sheer complexity of machine learning algorithms and their applications makes it hard to ensure correctness. Exploration of new formal methods can be used to characterize boundaries of behavior, and may bring much needed rigor to machine learning algorithms and applications. These techniques could range from novel programming languages and compilers for more robust machine learning to formal verification techniques for machine learning systems that could provide assurances of safety, correctness, and fairness. The interplay between program synthesis and machine learning offers many interesting possibilities to both improve machine learning and formal techniques.

Operating/Distributed Systems: Operating Systems (OS) and Distributed Systems (DS) are highly complex systems that provide many important services on which most applications depend. Given such a vital role, it is crucial to consider the formal correctness of operating systems and their interfaces – especially in the face of concurrency and shared memory – and distributed systems that need to consider synchronous and asynchronous control, and decentralized, data storage and computation. A few key considerations for both OS and DS are modularity and abstraction – which are essential to avoid reasoning about the entire system at once – and interoperability which entails reasoning about basic system functionalities, as well as multiple interface specifications and libraries. Topics of interest include formal specification of real-world system behaviors and interfaces; new language-based models and techniques; and methods to prove functional correctness and various resource and performance guarantees that evolve with changing systems dynamics, specifications, and requirements.

FMitF solicits proposals that advance general theories, principles and methodologies that go beyond specific problem instances. FMitF seeks to support proposals that have the potential to make **strong** advances in both the area of formal methods and in the application area to which the formal methods are being deployed; an ideal proposal will integrate both formal methods and field components and argue the potential for lasting impact on both sides. Proposals that make strong advances primarily on one side of this relationship are not in scope. Proposals that seek to apply existing formal methods without theoretical advances that leverage characteristics of the underlying application domain are also not in scope. Finally, proposals that only explore theoretical advances without strong connection to the application domain, or those that do not target a realistic problem in the field, are not in scope as well. Proposals focused on areas in the field that are not listed above are considered to be out of scope for this solicitation. All proposals that are deemed to be out of scope will be returned without review.

Proposals are expected to clearly address the fundamental contributions to formal methods and the respective field(s), and should (if appropriate) include a plan for developing a proof of concept in the field along with a detailed evaluation plan that discusses the scope of applicability, trade-offs and limitations. This discussion should be in a separate section titled "Contributions to Formal Methods and the Field". All proposals are expected to contain a detailed collaboration plan that clearly highlights and justifies the complementary expertise of the PIs in the designated areas, and describes the mechanisms for continuous bi-directional collaboration.

FMitF PI Meeting

The FMitF program is aiming to grow a new research community. In this spirit, the program plans to host a PI meeting in 2020 to be held in the U.S., with participation from funded PIs (at least one collaborating PI focusing on formal methods and at least one PI focusing on field per award, and their students), along with other representatives from the research community, government and industry.

BROADENING PARTICIPATION

CISE is committed to enhancing the community's awareness of and overcoming barriers to Broadening Participation in Computing (BPC), and to providing information and resources to PIs so that they can develop interest, skills, and activities in support of BPC at all levels of the CISE community (K-12, undergraduate, graduate, and postgraduate). All PIs are strongly encouraged to include meaningful BPC plans in the Broader Impacts sections of their submitted proposals, and to include such plans in future proposal submissions. More information, including examples of meaningful BPC activities and metrics, can be found on the CISE BPC webpage: <https://www.nsf.gov/cise/bpc>.

III. AWARD INFORMATION

Anticipated Type of Award: Continuing Grant or Standard Grant

Estimated Number of Awards: 8

Approximately 8 awards of up to \$1,000,000 per award with durations up to 4 years per award are anticipated, subject to availability of funds.

Anticipated Funding Amount: \$8,000,000, subject to availability of funds.

Estimated program budget, number of awards and average award size/duration are subject to the availability of funds.

IV. ELIGIBILITY INFORMATION

Who May Submit Proposals:

Proposals may only be submitted by the following:

- Institutions of Higher Education (IHEs) - Two- and four-year IHEs (including community colleges) accredited in, and having a campus located in the US, acting on behalf of their faculty members. Special Instructions for International Branch Campuses of US IHEs: If the proposal includes funding to be provided to an international branch campus of a US institution of higher education (including through use of subawards and consultant arrangements), the proposer must explain the benefit(s) to the project of performance at the international branch campus, and justify why the project activities cannot be performed at the US campus.
- Non-profit, non-academic organizations: Independent museums, observatories, research labs, professional societies and similar organizations in the U.S. associated with educational or research activities.

Who May Serve as PI:

PIs, co-PIs or other senior project personnel must hold primary and full-time paid appointments in research or teaching positions at US-based campuses/offices of eligible organizations.

Each proposal must have at least one (co)-PI focusing on formal methods and at least one focusing on one or more of the field(s) named herein: computer networks, cyber-human systems, machine learning, and operating/distributed systems.

Limit on Number of Proposals per Organization:

There are no restrictions or limits.

Limit on Number of Proposals per PI or Co-PI: 1

An investigator may participate as PI, co-PI, or senior personnel in no more than one proposal submitted in response to this solicitation.

These eligibility constraints will be strictly enforced in order to treat everyone fairly and consistently. In the event that an individual exceeds this limit, only the first submitted proposal received before the deadline will be accepted. **No exceptions will be made.**

Proposals submitted in response to this solicitation may not duplicate or be substantially similar to other proposals concurrently under consideration by NSF.

Additional Eligibility Info:

For US institutions of higher education, and non-profit, non-academic organizations with overseas campuses/offices, this solicitation restricts eligibility to research activities using the facilities, equipment, and other resources of the campuses/offices located in the US only.

Further, subawards are not permitted to overseas campuses/offices of US-based proposing organizations.

V. PROPOSAL PREPARATION AND SUBMISSION INSTRUCTIONS

A. Proposal Preparation Instructions

Full Proposal Preparation Instructions: Proposers may opt to submit proposals in response to this Program Solicitation via Grants.gov or via the NSF FastLane system.

- Full proposals submitted via FastLane: Proposals submitted in response to this program solicitation should be prepared and submitted in accordance with the general guidelines contained in the *NSF Proposal & Award Policies & Procedures Guide* (PAPPG). The complete text of the PAPPG is available electronically on the NSF website at: https://www.nsf.gov/publications/pub_summ.jsp?ods_key=pappg. Paper copies of the PAPPG may be obtained from the NSF Publications Clearinghouse, telephone (703) 292-7827 or by e-mail from nsfpubs@nsf.gov. Proposers are reminded to identify this program solicitation number in the program solicitation block on the NSF Cover Sheet For Proposal to the National Science Foundation. Compliance with this requirement is critical to determining the relevant proposal processing guidelines. Failure to submit this information may delay processing.
- Full proposals submitted via Grants.gov: Proposals submitted in response to this program solicitation via Grants.gov should be prepared and submitted in accordance with the *NSF Grants.gov Application Guide: A Guide for the Preparation and*

Submission of NSF Applications via Grants.gov. The complete text of the *NSF Grants.gov Application Guide* is available on the Grants.gov website and on the NSF website at: (https://www.nsf.gov/publications/pub_summ.jsp?ods_key=grantsgovguide). To obtain copies of the Application Guide and Application Forms Package, click on the Apply tab on the Grants.gov site, then click on the Apply Step 1: Download a Grant Application Package and Application Instructions link and enter the funding opportunity number, (the program solicitation number without the NSF prefix) and press the Download Package button. Paper copies of the Grants.gov Application Guide also may be obtained from the NSF Publications Clearinghouse, telephone (703) 292-7827 or by e-mail from nsfpubs@nsf.gov.

In determining which method to utilize in the electronic preparation and submission of the proposal, please note the following:

Collaborative Proposals. All collaborative proposals submitted as separate submissions from multiple organizations must be submitted via the NSF FastLane system. PAPPG Chapter II.D.3 provides additional information on collaborative proposals.

See PAPPG Chapter II.C.2 for guidance on the required sections of a full research proposal submitted to NSF. Please note that the proposal preparation instructions provided in this program solicitation may deviate from the PAPPG instructions.

Titles:

Proposal titles must indicate the **FMitF** program, followed by a colon, followed by the title of the project. For a collaborative proposal (that is, one submitted as separate submissions from multiple organizations), all participating institutions should use the same title, which should also include the phrase **Collaborative Research** followed by a colon. Thus, a single-institution proposal would have a title of the form **FMitF: Title**, and a collaborative proposal would use the form **FMitF: Collaborative Research: Title**.

Project Summary:

All proposals must include one or more of the following four keywords describing the field area(s) of the proposal: Computer Networks, Cyber Human Systems, Machine Learning, and Operating/Distributed Systems.

Budget:

Each proposal must include the costs of attending a FMitF PI meeting as part of the budget for the second year of the project. The budget should cover participation by the PIs, co-PIs, and their students, as described above under "FMitF PI Meeting".

Supplementary Documents:

1) **Collaboration Plan:** Each project is required to include a Collaboration Plan submitted by the lead institution as a separate supplementary document (limited to 3 pages or less). This plan must describe the distinct expertise provided by the PIs as required above under "Who May Serve as PI" as well as plans for working together to advance knowledge in both formal methods and at least one "field" area. Joint supervision of students and postdoctoral researchers is strongly encouraged. The collaboration plan must also describe clear measures of success for both the formal method and "field" aspects of the project and a plan for evaluating success. **Projects without this document will be returned without review.**

2) **Data Management Plan:** Each proposal is required to include a Data Management Plan as a separate supplementary document (limited to 2 pages or less). This plan must address the dissemination of the algorithmic contributions and resulting applications, tools, languages, compilers, libraries, architectures, systems, software, architectures, data, etc. Open source release of these artifacts is strongly encouraged. **Proposals without this document will not be accepted or will be returned without review.**

Single Copy Documents:

Collaborators and Other Affiliations Information: Proposers should follow the guidance specified in [Chapter II.C.1.e](#) of the NSF PAPPG. *Grants.gov Users:* The COA information must be provided through use of the COA template and uploaded as a PDF attachment.

B. Budgetary Information

Cost Sharing:

Inclusion of voluntary committed cost sharing is prohibited.

Budget Preparation Instructions:

Budgets for all projects must include funding for travel for the collaborating PIs [at least one collaborating PI focusing on formal methods and at least one PI focusing on the field(s) per award, and their students to attend the FMitF PI Meeting in 2020. For budget preparation purposes, PIs may assume these meetings will be held in the Washington, DC, area.

C. Due Dates

- **Full Proposal Deadline(s)** (due by 5 p.m. submitter's local time):

May 08, 2018

D. FastLane/Grants.gov Requirements

For Proposals Submitted Via FastLane:

To prepare and submit a proposal via FastLane, see detailed technical instructions available at: <https://www.fastlane.nsf.gov/a1/newstan.htm>. For FastLane user support, call the FastLane Help Desk at 1-800-673-6188 or e-mail fastlane@nsf.gov. The FastLane Help Desk answers general technical questions related to the use of

the FastLane system. Specific questions related to this program solicitation should be referred to the NSF program staff contact(s) listed in Section VIII of this funding opportunity.

For Proposals Submitted Via Grants.gov:

Before using Grants.gov for the first time, each organization must register to create an institutional profile. Once registered, the applicant's organization can then apply for any federal grant on the Grants.gov website. Comprehensive information about using Grants.gov is available on the Grants.gov Applicant Resources webpage: <http://www.grants.gov/web/grants/applicants.html>. In addition, the NSF Grants.gov Application Guide (see link in Section V.A) provides instructions regarding the technical preparation of proposals via Grants.gov. For Grants.gov user support, contact the Grants.gov Contact Center at 1-800-518-4726 or by email: support@grants.gov. The Grants.gov Contact Center answers general technical questions related to the use of Grants.gov. Specific questions related to this program solicitation should be referred to the NSF program staff contact(s) listed in Section VIII of this solicitation.

Submitting the Proposal: Once all documents have been completed, the Authorized Organizational Representative (AOR) must submit the application to Grants.gov and verify the desired funding opportunity and agency to which the application is submitted. The AOR must then sign and submit the application to Grants.gov. The completed application will be transferred to the NSF FastLane system for further processing.

Proposers that submitted via FastLane are strongly encouraged to use FastLane to verify the status of their submission to NSF. For proposers that submitted via Grants.gov, until an application has been received and validated by NSF, the Authorized Organizational Representative may check the status of an application on Grants.gov. After proposers have received an e-mail notification from NSF, Research.gov should be used to check the status of an application.

VI. NSF PROPOSAL PROCESSING AND REVIEW PROCEDURES

Proposals received by NSF are assigned to the appropriate NSF program for acknowledgement and, if they meet NSF requirements, for review. All proposals are carefully reviewed by a scientist, engineer, or educator serving as an NSF Program Officer, and usually by three to ten other persons outside NSF either as *ad hoc* reviewers, panelists, or both, who are experts in the particular fields represented by the proposal. These reviewers are selected by Program Officers charged with oversight of the review process. Proposers are invited to suggest names of persons they believe are especially well qualified to review the proposal and/or persons they would prefer not review the proposal. These suggestions may serve as one source in the reviewer selection process at the Program Officer's discretion. Submission of such names, however, is optional. Care is taken to ensure that reviewers have no conflicts of interest with the proposal. In addition, Program Officers may obtain comments from site visits before recommending final action on proposals. Senior NSF staff further review recommendations for awards. A flowchart that depicts the entire NSF proposal and award process (and associated timeline) is included in PAPPG Exhibit III-1.

A comprehensive description of the Foundation's merit review process is available on the NSF website at: https://www.nsf.gov/bfa/dias/policy/merit_review/.

Proposers should also be aware of core strategies that are essential to the fulfillment of NSF's mission, as articulated in *Investing in Science, Engineering, and Education for the Nation's Future: NSF Strategic Plan for 2014-2018*. These strategies are integrated in the program planning and implementation process, of which proposal review is one part. NSF's mission is particularly well-implemented through the integration of research and education and broadening participation in NSF programs, projects, and activities.

One of the strategic objectives in support of NSF's mission is to foster integration of research and education through the programs, projects, and activities it supports at academic and research institutions. These institutions must recruit, train, and prepare a diverse STEM workforce to advance the frontiers of science and participate in the U.S. technology-based economy. NSF's contribution to the national innovation ecosystem is to provide cutting-edge research under the guidance of the Nation's most creative scientists and engineers. NSF also supports development of a strong science, technology, engineering, and mathematics (STEM) workforce by investing in building the knowledge that informs improvements in STEM teaching and learning.

NSF's mission calls for the broadening of opportunities and expanding participation of groups, institutions, and geographic regions that are underrepresented in STEM disciplines, which is essential to the health and vitality of science and engineering. NSF is committed to this principle of diversity and deems it central to the programs, projects, and activities it considers and supports.

A. Merit Review Principles and Criteria

The National Science Foundation strives to invest in a robust and diverse portfolio of projects that creates new knowledge and enables breakthroughs in understanding across all areas of science and engineering research and education. To identify which projects to support, NSF relies on a merit review process that incorporates consideration of both the technical aspects of a proposed project and its potential to contribute more broadly to advancing NSF's mission "to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense; and for other purposes." NSF makes every effort to conduct a fair, competitive, transparent merit review process for the selection of projects.

1. Merit Review Principles

These principles are to be given due diligence by PIs and organizations when preparing proposals and managing projects, by reviewers when reading and evaluating proposals, and by NSF program staff when determining whether or not to recommend proposals for funding and while overseeing awards. Given that NSF is the primary federal agency charged with nurturing and supporting excellence in basic research and education, the following three principles apply:

- All NSF projects should be of the highest quality and have the potential to advance, if not transform, the frontiers of knowledge.
- NSF projects, in the aggregate, should contribute more broadly to achieving societal goals. These "Broader Impacts" may be accomplished through the research itself, through activities that are directly related to specific research projects, or through activities that are supported by, but are complementary to, the project. The project activities may be based on previously established and/or innovative methods and approaches, but in either case must be well justified.
- Meaningful assessment and evaluation of NSF funded projects should be based on appropriate metrics, keeping in mind the likely correlation between the effect of broader impacts and the resources provided to implement projects. If the size of the activity is limited, evaluation of that activity in isolation is not likely to be meaningful. Thus, assessing the effectiveness of these activities may best be done at a higher, more aggregated, level than the individual project.

With respect to the third principle, even if assessment of Broader Impacts outcomes for particular projects is done at an aggregated level, PIs are expected to be accountable for carrying out the activities described in the funded project. Thus, individual projects should include clearly stated goals, specific descriptions of the activities that the PI intends to do, and a plan in place to document the outputs of those activities.

These three merit review principles provide the basis for the merit review criteria, as well as a context within which the users of the criteria can better understand their intent.

2. Merit Review Criteria

All NSF proposals are evaluated through use of the two National Science Board approved merit review criteria. In some instances, however, NSF will employ additional criteria as required to highlight the specific objectives of certain programs and activities.

The two merit review criteria are listed below. **Both** criteria are to be given **full consideration** during the review and decision-making processes; each criterion is necessary but neither, by itself, is sufficient. Therefore, proposers must fully address both criteria. (PAPPG Chapter II.C.2.d(i). contains additional information for use by proposers in development of the Project Description section of the proposal). Reviewers are strongly encouraged to review the criteria, including PAPPG Chapter II.C.2.d(i), prior to the review of a proposal.

When evaluating NSF proposals, reviewers will be asked to consider what the proposers want to do, why they want to do it, how they plan to do it, how they will know if they succeed, and what benefits could accrue if the project is successful. These issues apply both to the technical aspects of the proposal and the way in which the project may make broader contributions. To that end, reviewers will be asked to evaluate all proposals against two criteria:

- **Intellectual Merit:** The Intellectual Merit criterion encompasses the potential to advance knowledge; and
- **Broader Impacts:** The Broader Impacts criterion encompasses the potential to benefit society and contribute to the achievement of specific, desired societal outcomes.

The following elements should be considered in the review for both criteria:

1. What is the potential for the proposed activity to
 - a. Advance knowledge and understanding within its own field or across different fields (Intellectual Merit); and
 - b. Benefit society or advance desired societal outcomes (Broader Impacts)?
2. To what extent do the proposed activities suggest and explore creative, original, or potentially transformative concepts?
3. Is the plan for carrying out the proposed activities well-reasoned, well-organized, and based on a sound rationale? Does the plan incorporate a mechanism to assess success?
4. How well qualified is the individual, team, or organization to conduct the proposed activities?
5. Are there adequate resources available to the PI (either at the home organization or through collaborations) to carry out the proposed activities?

Broader impacts may be accomplished through the research itself, through the activities that are directly related to specific research projects, or through activities that are supported by, but are complementary to, the project. NSF values the advancement of scientific knowledge and activities that contribute to achievement of societally relevant outcomes. Such outcomes include, but are not limited to: full participation of women, persons with disabilities, and underrepresented minorities in science, technology, engineering, and mathematics (STEM); improved STEM education and educator development at any level; increased public scientific literacy and public engagement with science and technology; improved well-being of individuals in society; development of a diverse, globally competitive STEM workforce; increased partnerships between academia, industry, and others; improved national security; increased economic competitiveness of the United States; and enhanced infrastructure for research and education.

Proposers are reminded that reviewers will also be asked to review the Data Management Plan and the Postdoctoral Researcher Mentoring Plan, as appropriate.

Additional Solicitation Specific Review Criteria

Proposals will be evaluated on the basis of the following solicitation-specific review criteria: (1) the extent to which the proposal addresses one or more of the four field areas; (2) the extent to which fundamental contributions to both formal methods and the field area are a likely outcome of this project; and (3) the extent to which the collaboration plan meets the criteria identified in the solicitation.

B. Review and Selection Process

Proposals submitted in response to this program solicitation will be reviewed by Ad hoc Review and/or Panel Review.

Reviewers will be asked to evaluate proposals using two National Science Board approved merit review criteria and, if applicable, additional program specific criteria. A summary rating and accompanying narrative will generally be completed and submitted by each reviewer and/or panel. The Program Officer assigned to manage the proposal's review will consider the advice of reviewers and will formulate a recommendation.

After scientific, technical and programmatic review and consideration of appropriate factors, the NSF Program Officer recommends to the cognizant Division Director whether the proposal should be declined or recommended for award. NSF strives to be able to tell applicants whether their proposals have been declined or recommended for funding within six months. Large or particularly complex proposals or proposals from new awardees may require additional review and processing time. The time interval begins on the deadline or target date, or receipt date, whichever is later. The interval ends when the Division Director acts upon the Program Officer's recommendation.

After programmatic approval has been obtained, the proposals recommended for funding will be forwarded to the Division of Grants and Agreements for review of business, financial, and policy implications. After an administrative review has occurred, Grants and Agreements Officers perform the processing and issuance of a grant or other agreement. Proposers are cautioned that only a Grants and Agreements Officer may make commitments, obligations or awards on behalf of NSF or authorize the expenditure of funds. No commitment on the part of NSF should be inferred from technical or budgetary discussions with a NSF Program Officer. A Principal Investigator or organization that makes financial or personnel commitments in the absence of a grant or cooperative agreement signed by the NSF Grants and Agreements Officer does so at their own risk.

Once an award or declination decision has been made, Principal Investigators are provided feedback about their proposals. In all cases, reviews are treated as confidential documents. Verbatim copies of reviews, excluding the names of the reviewers or any reviewer-identifying information, are sent to the Principal Investigator/Project Director by the Program Officer. In addition, the proposer will receive an explanation of the decision to award or decline funding.

VII. AWARD ADMINISTRATION INFORMATION

A. Notification of the Award

Notification of the award is made to *the submitting organization* by a Grants Officer in the Division of Grants and Agreements. Organizations whose proposals are declined will be advised as promptly as possible by the cognizant NSF Program administering the program. Verbatim copies of reviews, not including the identity of the reviewer, will be provided automatically to the Principal Investigator. (See Section VI.B. for additional information on the review process.)

B. Award Conditions

An NSF award consists of: (1) the award notice, which includes any special provisions applicable to the award and any numbered amendments thereto; (2) the budget, which indicates the amounts, by categories of expense, on which NSF has based its support (or otherwise communicates any specific approvals or disapprovals of proposed expenditures); (3) the proposal referenced in the award notice; (4) the applicable award conditions, such as Grant General Conditions (GC-1)*; or Research Terms and Conditions* and (5) any announcement or other NSF issuance that may be incorporated by reference in the award notice. Cooperative agreements also are administered in accordance with NSF Cooperative Agreement Financial and Administrative Terms and Conditions (CA-FATC) and the applicable Programmatic Terms and Conditions. NSF awards are electronically signed by an NSF Grants and Agreements Officer and transmitted electronically to the organization via e-mail.

*These documents may be accessed electronically on NSF's Website at https://www.nsf.gov/awards/managing/award_conditions.jsp?org=NSF. Paper copies may be obtained from the NSF Publications Clearinghouse, telephone (703) 292-7827 or by e-mail from nsfpubs@nsf.gov.

More comprehensive information on NSF Award Conditions and other important information on the administration of NSF awards is contained in the *NSF Proposal & Award Policies & Procedures Guide* (PAPPG) Chapter VII, available electronically on the NSF Website at https://www.nsf.gov/publications/pub_summ.jsp?ods_key=papppg.

C. Reporting Requirements

For all multi-year grants (including both standard and continuing grants), the Principal Investigator must submit an annual project report to the cognizant Program Officer no later than 90 days prior to the end of the current budget period. (Some programs or awards require submission of more frequent project reports). No later than 120 days following expiration of a grant, the PI also is required to submit a final project report, and a project outcomes report for the general public.

Failure to provide the required annual or final project reports, or the project outcomes report, will delay NSF review and processing of any future funding increments as well as any pending proposals for all identified PIs and co-PIs on a given award. PIs should examine the formats of the required reports in advance to assure availability of required data.

PIs are required to use NSF's electronic project-reporting system, available through Research.gov, for preparation and submission of annual and final project reports. Such reports provide information on accomplishments, project participants (individual and organizational), publications, and other specific products and impacts of the project. Submission of the report via Research.gov constitutes certification by the PI that the contents of the report are accurate and complete. The project outcomes report also must be prepared and submitted using Research.gov. This report serves as a brief summary, prepared specifically for the public, of the nature and outcomes of the project. This report will be posted on the NSF website exactly as it is submitted by the PI.

More comprehensive information on NSF Reporting Requirements and other important information on the administration of NSF awards is contained in the *NSF Proposal & Award Policies & Procedures Guide* (PAPPG) Chapter VII, available electronically on the NSF Website at https://www.nsf.gov/publications/pub_summ.jsp?ods_key=papppg.

VIII. AGENCY CONTACTS

Please note that the program contact information is current at the time of publishing. See program website for any updates to the points of contact.

General inquiries regarding this program should be made to:

- Nina Amla, Program Director, telephone: (703) 292-7991, email: namla@nsf.gov
- Anindya Banerjee, Program Director, telephone: (703) 292-7885, email: abanerje@nsf.gov
- Dan R. Cosley, Program Director, telephone: (703) 292-8491, email: dcosley@nsf.gov
- Darleen L. Fisher, Program Director, telephone: (703) 292-8950, email: dlfisher@nsf.gov
- Sol Greenspan, Program Director, telephone: (703) 292-8910, email: sgreensp@nsf.gov
- Samee Khan, Program Director, telephone: (703) 292-8061, email: skhan@nsf.gov
- Weng-Keen Wong, Program Director, telephone: (703) 292-7129, email: wwong@nsf.gov

For questions related to the use of FastLane, contact:

- FastLane Help Desk, telephone: 1-800-673-6188; e-mail: fastlane@nsf.gov.

For questions relating to Grants.gov contact:

- Grants.gov Contact Center: If the Authorized Organizational Representatives (AOR) has not received a confirmation message from Grants.gov within 48 hours of submission of application, please contact via telephone: 1-800-518-4726; e-mail: support@grants.gov.

IX. OTHER INFORMATION

The NSF website provides the most comprehensive source of information on NSF Directorates (including contact information), programs and funding opportunities. Use of this website by potential proposers is strongly encouraged. In addition, "NSF Update" is an information-delivery system designed to keep potential proposers and other interested parties apprised of new NSF funding opportunities and publications, important changes in proposal and award policies and procedures, and upcoming NSF [Grants Conferences](#). Subscribers are informed through e-mail or the user's Web browser each time new publications are issued that match their identified interests. "NSF Update" also is available on [NSF's website](#).

Grants.gov provides an additional electronic capability to search for Federal government-wide grant opportunities. NSF funding opportunities may be accessed via this mechanism. Further information on Grants.gov may be obtained at <http://www.grants.gov>.

ABOUT THE NATIONAL SCIENCE FOUNDATION

The National Science Foundation (NSF) is an independent Federal agency created by the National Science Foundation Act of 1950, as amended (42 USC 1861-75). The Act states the purpose of the NSF is "to promote the progress of science; [and] to advance the national health, prosperity, and welfare by supporting research and education in all fields of science and engineering."

NSF funds research and education in most fields of science and engineering. It does this through grants and cooperative agreements to more than 2,000 colleges, universities, K-12 school systems, businesses, informal science organizations and other research organizations throughout the US. The Foundation accounts for about one-fourth of Federal support to academic institutions for basic research.

NSF receives approximately 55,000 proposals each year for research, education and training projects, of which approximately 11,000 are funded. In addition, the Foundation receives several thousand applications for graduate and postdoctoral fellowships. The agency operates no laboratories itself but does support National Research Centers, user facilities, certain oceanographic vessels and Arctic and Antarctic research stations. The Foundation also supports cooperative research between universities and industry, US participation in international scientific and engineering efforts, and educational activities at every academic level.

Facilitation Awards for Scientists and Engineers with Disabilities (FASSED) provide funding for special assistance or equipment to enable persons with disabilities to work on NSF-supported projects. See the *NSF Proposal & Award Policies & Procedures Guide* Chapter II.E.6 for instructions regarding preparation of these types of proposals.

The National Science Foundation has Telephonic Device for the Deaf (TDD) and Federal Information Relay Service (FIRS) capabilities that enable individuals with hearing impairments to communicate with the Foundation about NSF programs, employment or general information. TDD may be accessed at (703) 292-5090 and (800) 281-8749, FIRS at (800) 877-8339.

The National Science Foundation Information Center may be reached at (703) 292-5111.

The National Science Foundation promotes and advances scientific progress in the United States by competitively awarding grants and cooperative agreements for research and education in the sciences, mathematics, and engineering.

To get the latest information about program deadlines, to download copies of NSF publications, and to access abstracts of awards, visit the NSF Website at <https://www.nsf.gov>

- **Location:** 2415 Eisenhower Avenue, Alexandria, VA 22314
- **For General Information** (NSF Information Center): (703) 292-5111
- **TDD (for the hearing-impaired):** (703) 292-5090
- **To Order Publications or Forms:**
 - Send an e-mail to: nsfpubs@nsf.gov
 - or telephone: (703) 292-7827
- **To Locate NSF Employees:** (703) 292-5111

PRIVACY ACT AND PUBLIC BURDEN STATEMENTS

The information requested on proposal forms and project reports is solicited under the authority of the National Science Foundation Act of 1950, as amended. The information on proposal forms will be used in connection with the selection of qualified proposals; and project reports submitted by awardees will be used for program evaluation and reporting within the Executive Branch and to Congress. The information requested may be disclosed to qualified reviewers and staff assistants as part of the proposal review process; to proposer institutions/grantees to provide or obtain data regarding the proposal review process, award decisions, or the administration of awards; to government contractors, experts, volunteers and researchers and educators as necessary to complete assigned work; to other government agencies or other entities needing information regarding applicants or nominees as part of a joint application review process, or in order to coordinate programs or policy; and to another Federal agency, court, or party in a court or Federal administrative proceeding if the government is a party. Information about Principal Investigators may be added to the Reviewer file and used to select potential candidates to serve as peer reviewers or advisory committee members. See Systems of Records, [NSF-50](#), "Principal Investigator/Proposal File and Associated Records," 69 Federal Register 26410 (May 12, 2004), and [NSF-51](#), "Reviewer/Proposal File and Associated Records," 69 Federal Register 26410 (May 12, 2004). Submission of the information is voluntary. Failure to provide full and complete information, however, may reduce the possibility of receiving an award.

An agency may not conduct or sponsor, and a person is not required to respond to, an information collection unless it displays a valid Office of Management and Budget (OMB) control number. The OMB control number for this collection is 3145-0058. Public reporting burden for this collection of information is estimated to average 120 hours per response, including the time for reviewing instructions. Send comments regarding the burden estimate and any other aspect of this collection of information, including suggestions for reducing this burden, to:

Suzanne H. Plimpton
Reports Clearance Officer
Office of the General Counsel
National Science Foundation
Alexandria, VA 22314

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