U.S. DEPARTMENT OF ENERGY | Office of Science

Office of Science Graduate Student Research

2021 Solicitation 1 - Application for: Alexey Voronin

APPLICANT PROFILE

General Applicant Information	
First Name:	Alexey
Middle Name:	
Last Name:	Voronin
Previous Last Name(s):	
Primary Email Address:	voronin2@illinois.edu
Alternate Email Address 1:	5lexey.voronin@gmail.com
Alternate Email Address 2:	
Current Address	
Country:	United States
Address:	406 W Clark St
City:	Champaign
State/Province/Territory:	IL
Zip Code:	61820-4660
Primary Phone Number:	650-391-4296
Alternate Phone Number:	
Permanent Address	
Country:	United States
Address:	406 W Clark St
City:	Champaign
State/Province/Territory:	IL
Zip Code:	61820-4660
Citizenship / Eligibility Information	
I will be 18 years of age or older by the time the internship begins:	Yes
Are you a U.S. Citizen?	Yes

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EDUCATIONAL BACKGROUND

Undergraduate Education

College/University Country:	United States and U.S. Territories
College/University State/Province/Territory:	California
College/University Name:	University of California-San Diego
College/University Department:	Mathematics
College/University Address:	9500 Gilman Dr
College/University City:	La Jolla
College/University Zip Code:	92093-5003
Major:	Mathematics
Graduation Date:	06 / 2015
Degree:	B.S.
Cumulative GPA (on a 4.0 scale):	3.40
College/University Country:	United States and U.S. Territories
College/University State/Province/Territory:	California
College/University Name:	University of California-San Diego
College/University Department:	Physics
College/University Address:	9500 Gilman Dr
College/University City:	La Jolla
College/University Zip Code:	92093-5003
Major:	Physical Sciences - Physics
Graduation Date:	06 / 2015
Degree:	B.S.
Cumulative GPA (on a 4.0 scale):	3.50

Graduate Education Status

Are you currently enrolled as a full-time graduate student in a Ph.D. program?	Yes
Do you plan to be enrolled as a full-time graduate student during the proposed research project period?	Yes
Current Status in Ph.D. Program:	Year 3

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Current Graduate Institution

Have you obtained your Ph.D. candidacy at your current graduate institution?	Yes
Does your Official Graduate Transcript explicitly indicate your Ph.D. candidacy?	No
Alternative Official Ph.D. Candidacy Documentation Upload:	PhD Candidacy Letter Alexey Voronin.pdf
College/University Country:	United States and U.S. Territories
College/University State/Province/Territory:	Illinois
College/University Name:	University of Illinois at Urbana-Champaign
College/University Address:	901 W Illinois St
Department Name:	Computer Science
Start Date of Enrollment:	08 / 2018
End Date of Enrollment:	06 / 2023
Field of Study:	Scientific Computing
Credit Type:	Semester
Credit Hours Enrolled/Completed:	60.00
Transcript:	AV_UIUC_transcript.pdf

Additional Graduate Education

None entered

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Primary Graduate Thesis Advisor

Is your primary graduate thesis advisor at your current graduate institution?	Yes
College/University Country:	United States and U.S. Territories
College/University State/Province/Territory:	Illinois
College/University Name:	University of Illinois at Urbana-Champaign
College/University Address:	901 W Illinois St
College/University City:	Champaign
College/University Zip Code:	61820-5711
First Name:	Luke
Last Name:	Olson
Department Name:	Computer Science
Position Title:	Director of Computational Science and Engineering@UIUC
Office Country:	United States
Office Street Address:	201 N. Goodwin Ave.
Office City:	Urbana
Office State/Province/Territory:	Illinois
Office Zip Code:	61801
Office Phone:	650-391-4296
Office Email:	lukeo@illinois.edu

Graduate Thesis Abstract

Title of Graduate Thesis (or Working Title): Robust Algebraic Multigrid Preconditioners for Saddle-Point Systems

Abstract:

AMG methods are popular and effective preconditioners for systems of linear equations that arise from discretized scalar partial differential equations(PDEs). While they have been successfully applied to a broad class of problems, their successful application to saddle-point systems presents some unique challenges that have yet to be addressed in a robust fashion.

Application of AMG to PDE systems is problematic when the discretization techniques employ different types of basis functions for different fields. For example, certain mixed finite element representations are known to yield inf-sup stable discretizations when applied to the incompressible Navier-Stokes (N-S) equations. This desirable property may not be maintained throughout the AMG hierarchy when traditional automatic coarsening methods are used. Unfortunately, this potential instability can lead to significant performance degradation in terms of AMG's convergence rate and overall robustness.

To address the AMG challenges associated with high order discretizations, we instead apply AMG to low order inf-sup stable mixed discretizations that are used within a preconditioner for the original high order system. To address challenges associated with the use of different basis function types, we consider a novel correlated coarsening scheme that roughly mirrors the relationship between the different basis function types on coarse levels. In this way, inf-sup stability can be better maintained on the automatically generated coarse level representations.

The resulting monolithic AMG schemes will be verified for grid-size independent convergence for both model benchmarks and application-specific problems. For example, we will verify these schemes on real-world problems with complex mesh geometries and poor element aspect ratios, such as those arising from N-S equations. Additionally, we aim to generalize these methods to other saddle-point systems, such as those arising in resistive magnetohydrodynamics simulations.

PROFESSIONAL BACKGROUND

Prior Scientific Research Experience

Experience #1: Lawrence Livermore National Laboratory (LLNL), 06/2015 - 07/2018

- Job Title: High Performance Computing (HPC) Scientist
- Divisions: ASQ (Applications, Simulations and Quality), CASC (Center for Applied Scientific Computing)
- I worked on a number of multi-physics and engineering applications improving the performance of parallel codes, preparing them for the current GPU-based systems.
    - Improved load-balancing and parallel scaling of hybrid MPI-3/OpenMP particle-in-cell code used by LLNL's plasma physics groups.
    - Worked on extending the functionality of finite-elements-based codes (e.g. MFEM, LiDO) to emerging supercomputer architectures.
- My employment at LLNL gave me the necessary background in scientific computing to pursue graduate work in the field, as well as, inspired my interest in numerical linear solvers.

Experience #2: Sandia National Laboratories, Livermore, Summer 2020

- Job Title: Summer Intern
- Advisor: Raymond Tuminaro
- We experimentally explored monolithic multi-level preconditioners for saddle-point systems arising from the finite-element discretization of Stokes equations. We focused on the development of practical and theoretical guidance into different algebraic multigrid preconditioning approaches.
- This research project served as the primer for my proposed thesis. Part of my internship work required an extensive literature review, where I noticed a lack of research on algebraic multigrid solvers for systems of partial differential equations. The foundational knowledge acquired from this internship, as well as, the identification of gaps in this research area, lead to the design of the multiple projects outlined in my thesis proposal.

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Scientific Publications and Presentations

Publication Type:	Archival Publication - Peer Reviewed Scientific or Technical Journal Article
Article Title:	AMG for Mixed Finite Element Representations of Systems of PDEs
Author(s):	Alexey Voronin, Raymond Tuminaro, Luke Olson, Scott MacLachlan
Journal Name:	Computer Science Research Institute Summer Proceedings 2020
Publication Volume:	SAND#: SAND2020-12580 R
Publication Issue Number:	
Publication Page Numbers:	127-137
Publication Publisher:	2020
Publication Type:	Archival Publication - Peer Reviewed Scientific or Technical Journal Article
Article Title:	Low-order preconditioning of the Stokes equations
Author(s):	Alexey Voronin, Yunhui He, Scott MacLachlan, Luke N. Olson, Raymond Tuminaro
Journal Name:	Numerical Linear Algebra with Applications
Publication Volume:	submitted and under review
Publication Issue Number:	
Publication Page Numbers:	1-17
Publication Publisher:	2021
Publication Type:	Presentation - Conference, Workshop, or Symposium
Title of Talk:	Analysis of low-order preconditioners for the Stokes equations
Author(s):	Alexey Voronin, Yunhui He, Scott MacLachlan, Luke N. Olson, Ray Tuminaro
Conference, Workshop, or Symposium Name:	SIAM Conference on Computational Science and Engineering
Presentation Type:	Oral Presentation
Conference, Workshop, or Symposium Location:	online
Conference, Workshop, or Symposium Date:	3/1/2021

Academic Awards & Honors

None entered

PROGRAM INFORMATION

Eligibility

Are you currently conducting research at a DOE Laboratory? **OR** **Have you conducted graduate level research at a DOE Laboratory for an accumulative duration of 3 or more months in the past?**	No

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Association with DOE Office of Science

Research Area:	ASCR - Applied Mathematics
Current Status:	I am a graduate student pursuing thesis research that is significantly well aligned with an Office of Science Research program, but not currently in a university group funded by the Office of Science, and proposing to do thesis research in collaboration with a DOE laboratory scientist in a priority research area.

Current Graduate Support

Type of Support:	Teaching Assistantship
Support Level:	$2,522

Previous Participation

None entered

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RESEARCH PROPOSAL

Host DOE Laboratory and Collaborating DOE Laboratory Scientist

Proposed Host DOE Laboratory:	Sandia National Laboratory (SNL)
Collaborating Scientist First Name:	Raymond
Collaborating Scientist Last Name:	Tuminaro
Collaborating Scientist Division/Department:	Center for Computing Research
Collaborating Scientist Position Title:	Research Scientist
Collaborating Scientist Email:	rstumin@sandia.gov
Collaborating Scientist Phone:	945510-969
Collaborating Scientist State:	California

Proposed Research Project

Title of SCGSR Research Proposal	AMG for Multi-Physics Flow Problems
SCGSR Research Proposal Abstract:	Magnetohydrodynamics (MHD) equations describe the dynamics of a charged fluid under the influence of an electromagnetic field. Effective time integration of these equations requires fully implicit time-stepping algorithms, resulting in stiff linear systems whose solution time typically dominates the total execution time of an application. Monolithic multigrid methods provide a computationally optimal and scalable preconditioning approach for these linear systems, however, most of these methods are geometric multigrid (GMG) methods. This creates difficulties because GMG is not easily applicable to problems with anisotropic flow and non-uniform meshes which are the key characteristics in solutions of Navier-Stokes (N-S) and MHD equations. The algebraic multigrid (AMG) framework allows for more flexible integration into many scalar PDE applications, but there are few monolithic AMG approaches for coupled multi-physics problems. The Ph.D. thesis aims to address the lack of available methods by creating a robust AMG framework that automatically constructs lower-resolution grids for the mixed finite-element (MFE) discretizations arising in multi-variable simulations. The proposed SCGSR research aims to address additional challenges that arise in building monolithic AMG methods for N-S and resistive MHD applications through collaboration with DOE scientists whose current capabilities are limited due to the lack of a robust AMG framework for MFE discretized systems.
Research Proposal:	alexeyvoronin.pdf

Additional Project Information

Proposed Project Period Start Date:	1/10/2022
Proposed Project Period End Date:	12/16/2022
Will any Office of Science scientfic user facilities be used in your project?	No

Anticipated Graduate Training

Graduate Training and Research Skills:	My interest in numerical solvers stems from my passion for physical modeling. As a natural extension of this interest, I would like to partake in SCGSR at Sandia National Lab. The staff and facilities at Sandia provide a wide range of learning opportunities well-suited to my research goals and career aspirations. I look forward to working closely with application scientists from different backgrounds (physics, engineering, applied mathematics) and learning about the specific challenges and bottlenecks that they encounter. With their guidance, I hope to acquire interdisciplinary problem-solving skills that I would otherwise not develop when performing research solely in a university setting. In addition, the knowledge I gain from working with lead scientists will help guide my development of more robust multi-level solvers, while also providing me a platform for applying the learned theory to real-life problems (the key to ensuring that my research contributes meaningfully to science.)

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Relevance of Proposed Research Project to the DOE Office of Science Mission Areas

Proposed SCGSR Research Project Alignment with ASCR - Applied Mathematics:

Computer models and simulations have become a leading tool for scientific explorations, supplementing and sometimes replacing physical experimentation. Increased reliance on higher resolution simulations spurred the need for more sophisticated discretization, meshing, and time-stepping algorithms, which in turn rendered many numerical linear solvers less effective.

To meet these science needs, we seek to address the lack of robust linear solvers for the Navier-Stokes and resistive MHD models. Solutions of linear systems that arise from finite element discretization and linearization of these systems usually dominates the total execution time of the above-mentioned applications.

We aim to design scalable algebraic multigrid (AMG) linear solvers for mixed finite element (MFE) representation of PDE systems, targeting the mentioned performance bottleneck. In order to achieve this, we team up with DOE scientists with both MHD and AMG expertise whose current capabilities are limited by the lack of a robust AMG capability for MFE discretized systems.

LETTERS OF SUPPORT

Letter of Support 1:

First Name: Luke
Last Name: Olson
Email: lukeo@illinois.edu
Type: Primary Graduate Thesis Advisor
Status: Received 5/4/2021

Letter of Support 2:

First Name: Raymond
Last Name: Tuminaro
Email: rstumin@sandia.gov
Type: Collaborating DOE Laboratory Scientist
Status: Received 5/4/2021