SINBAD Consortium

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To whom it may concern,

Summary

UBC-Seismic Laboratory for Imaging and Modeling (SLIM) conducts research in exploration seismology with support from the oil & gas industry. The main focus of SLIM is to leverage insights from recent developments in compressive sensing— spanning mathematics, computer science, and electrical engineering—towards the design and implementation of an imaging technology for severely sub-sampled data. The main outcome of this approach will be a new model for seismic imaging where the costs of acquisition and processing are no longer determined by overly pessimistic sampling criteria. Instead, the costs will depend on transform-domain sparsity of the final image and will therefore no longer grow uncontrollably with the dimensionality of the imaging problem.

SINBAD Consortium's core team consists of three dynamic faculty members from the Department of Earth & Ocean Sciences, Computer Science, and Mathematics including their students and post-docs. Research is disseminated through reproducible reports, annual Consortium meetings, Software releases, the SLIM web site and through coordinated internships.

Outcomes of SINBAD I

The SINBAD project made important contributions that have sparked wide-spread interest from industry, judged by multiple calls for commercialization, and academia, resulting in numerous invitations for presentations at conferences. Our techniques remove the "curse of dimensionality" and allow us to create images that would otherwise require acquisition and processing of infeasibly large amounts of data. Companies are competing to take advantage of this technology. Other highlights include: 37 students and postdocs supervised; calls from industry for commercialization; being featured as a "nugget" by the Institute of Pure and Applied Mathematics, which included a plenary talk at the NSF workshop "Cyber-Enabled Discovery and Innovation: Knowledge Extraction"; the EAGE Arie Van Weelden Award for our recent PhD graduate Gilles Hennenfent; and the plenary talk "Sub-Nyquist sampling and sparsity: getting more information from fewer samples" presented by me during the "Recent Advances and Road Ahead Session" at last year's Society for Exploration Geophysicists Meeting. Amongst our major contributions we count our random sub-sampling scheme for curvelet-based recovery; our large-scale one-norm solvers; our primary-multiple separation method, based on a combination of curvelet-domain matching and sparsity promotion; and our recent simultaneous acquisition design. We achieved these successes by developing a deep understanding of sparsity promotion, nonlinear optimization, and phase-space methods. With SINBAD Consortium, we plan to continue this line of research, and blend a deep theoretical understanding with real applications.

Research topics of SINBAD Consortium[1]

With the current surge in demand for oil and gas exploration, and the need for sustainable production, the seismic industry is struggling with two important questions: *How to cope with the increasing demand for seismic data, and the increasing data volumes that need to be processed? How to obtain more information from the observed waveforms?* As part of SINBAD Consortium, we plan to tackle these important questions by completely redesigning seismic methods using the principles of CS. Our approach will follow two complementary design philosophies: the classical approach where seismic data is subjected to a number of processing steps; and the "holistic" approach of full-wave form inversion. Our main strengths lie in (i) our ability to take deep results in computational harmonic analysis and turn them into practicable and concrete ground-breaking solutions to vital problems in seismic exploration; (ii) our results on sparse recovery and simultaneous source modeling to full-waveform inversion using adjoint-state methods that solve a compressively-sampled and sparsity-promoting PDE constrained optimization problem; and (iii) our ability to compare the redesigned processing flow with the "all-at-once" full-waveform methodology. These efforts will proceed in tandem with the following research topics.

Compressive acquisition and sparse recovery: The monetary costs and turn-around times of seismic processing are crucial factors in modern-day exploration seismology. We will continue to leverage and adapt findings from CS towards a complete redesign of seismic acquisition and subsequent processing. In particular, we plan to improve on current acquisition design by incorporating our work on jitter sampling and simultaneous-shot simulation. We also plan to improve on sparse recovery, through selection and adaptation of multiscale and multi-directional transforms including wave-equation based techniques, and the design and implementation of large-scale solvers that promote joint sparsity. **Outcome:** *A new methodology for exploration seismology where the costs of acquisition and processing are no longer dominated by the size of the survey area, but instead by the sparsity exhibited by seismic data volumes.*

Free-surface removal: The presence of the free surface and a difficult to control source function represent two formidable challenges impeding the success of linearized seismic imaging. Failure to handle these challenges has detrimental effects on migration and migration velocity analysis. Therefore, we will continue to develop techniques that exploit transform-domain sparsity and phase-space adaptation to improve the removal of surface-related coherent noise components. Our activities will also include joint primary-impulse response prediction and source-function estimation based on separable least squares and sparsity promotion. Our methodology will be applied to multiple and ground roll removal. **Outcome:** *Wave-equation driven wavefield separation methodology that limits removal of primary energy through improved prediction, matching, and separation.*

Compressive modeling for imaging and inversion: Access to a fast, parallel, and scalable modeling capability is key to the design of imaging technology, through linearization, and full-waveform inversion, through partial-differential-equation (PDE) constrained optimization. Because imaging and inversion both rely on correlations of the time history, we will further develop our implicit time-harmonic Helmholtz solver, including a parallel implementation for large models with $N \sim 1000^3$ grid points. We will include density-variations

[1] The DNOISE II proposal serves as the detailed research plan for SINBAD Consortium and is available upon request.

and extend our solver to elastic media. For scalability, we will generalize our preconditioned iterative solver to handle large numbers of shots (i.e., right-hand sides). This modeling capability will also include our recent work on simultaneous-source simulation where the solution is subsampled deliberately according to the principles of CS. **Outcome:** A new implicit scalable time-harmonic full-waveform modeling utility with a numerical complexity comparable to time-domain finite differences, and additional cost reductions commensurate with the transform-domain sparsity of the solution.

Compressive wave-equation based imaging and inversion: The success of imaging and full-waveform inversion hinges on our ability to mitigate three key impediments, namely (i) the presence of (nonlinear) effects of the free surface and the source function, which either violate assumptions underlying linearized imaging, or lead to additional nonlinearities and calibration issues in inversion, (ii) the increasing size of seismic data volumes that call for increasing computational resources in a time where Moore's Law is under strain, and finally (iii) the non-uniqueness associated with the full-waveform inversion problem that is known to be multimodal. We tackle the first two challenges by integrating our free-surface removal technology, which extends and benefits from compressive sensing, into to-be-developed sparsity-promoting formulations for imaging and inversion. We plan to address the uniqueness problem of full-waveform inversion through a combination of continuation methods that sweep from coarse to fine scales and focusing through mixed (1,2)-norm minimization. **Outcome:** *A imaging and full-waveform technology that leverages our contributions on simultaneous acquisition design, Helmholtz solvers, sparsity promotion for prestack migration, and a solver for PDE-constrained optimization.*

Parallel development environment: The development and implementation of imaging and full-waveform inversion algorithms in 3D is a challenging task within an academic research environment. To meet this challenge, we plan to combine the development of a parallel version of our object-oriented toolbox for sparse reconstruction, using the Matlab's Parallel Toolbox, with selective low-level implementations of our wave solvers. We will also continue to work with the development of our reproducible research environment. **Outcome:** *An environment that allows us to disseminate our research findings and evaluate our algorithms on real data.*

The research is carried out by a diverse research team at the University of British Columbia:

> Dr. Felix J. Herrmann (director of SLIM and principal investigator), Seismic Laboratory for Imaging and Modeling (SLIM), Department of Earth and Ocean Sciences;
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> Dr. Michael P. Friedlander (co-principal investigator), Scientific Computing Laboratory, Department of Computer Science;
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> Dr. Özgür Yılmaz, (co-principal investigator), Department of Mathematics.

These researchers will, with input from industry, determine the research objectives, budget and overall organization of the project. The research and administration of this research project will be conducted in accordance with the rules and regulations of the Department of Earth and Ocean Sciences under its head Dr. Greg Dipple, and the terms and regulations of the University of British Columbia. As outlined in the DNOISE II proposal, this project will support a large number of graduate students (6-9) and postdoctoral fellows (2-3).

Why join SINBAD Consortium?

The SINBAD Consortium is built around a young dynamic and ambitious research team consisting of three faculty members, several post-docs, and students with various backgrounds and expertise across a wide-range of disciplines, including Electrical Engineering, Engineering Physics, Earth & Ocean Sciences, Computer Science, and Mathematics. This diversity makes the SINBAD Consortium unique for the following reasons:

- our ability to give you a fresh perspective on open problems in exploration seismology by leveraging our cross-disciplinary backgrounds;
- our ability to push the envelope and to conduct transformative research by implementing our deep theoretical understanding to solve applied problems;
- our ability to be a conduit for new developments in compressive sampling and apply these to solve problems in exploration seismology;
- our ability to implement and test our algorithms on real problems involving real data;
- our ability to spark world-wide interest from industry and academia in seismic applications of CS, which enables us to attract the best graduate students.

The unique composition of our team has resulted in fundamental contributions in sparse-recovery with practical applications such as seismic regularization, multiple removal, and simultaneous-source acquisition designed to reduce acquisition and processing related costs. We successfully used this latter methodology to speed up simulations with our preconditioned time-harmonic Helmholtz solver. Since its inception in 2005, SINBAD has resulted in eleven journal publications (five in review) and more than fifty (C)SEG/EAGE talks. By becoming a sponsor, your organization will receive the following:

- early access to our publications, including theses, technical reports, publication preprints, and slides of presentations;
- access to our software releases and reproducible-research documents;
- access to basic assistance with the installation and use of our software;
- access to specialized assistance for our software at additional costs;
- invitations to our annual Consortium Meetings where we present our latest research;
- access to our coordinated graduate internship program to get to know our graduate students and to embark on projects to evaluate our technology.

Terms & Conditions

UBC does not permit secrecy in research. The director of SLIM determines the research direction and will seek advice from the Advisory Committee, which consists of representatives of all SINBAD Consortium member companies. There will be procedures in place for industry visitors. UBC's intellectual property (IP) policies apply to research conducted as part of SINBAD Consortium. The membership fees are inclusive of all costs, including all licenses to use the technology commercially, including third party intellectual property rights. The membership fees also include all overhead (25 %) and access fees. In addition, members will gain access to all background and foreground IP for the duration of the Consortium and will have the option to buy a perpetual royalty-free license. The UBC Liaison Office (UILO) has drawn up a detailed research agreement, which is available upon request from Mario Kasapi (mario.kasapi@uilo.ubc.ca) UILO.

Financial structure

SINBAD CONSORTIUM is financed by the industrial member companies. The funding of these companies is matched dollar-for-dollar by the Collaborative Research and Development Grant: DNOISE II. This matching is subject to the guidelines the Natural Sciences and Engineering Research Council of Canada (NSERC) and only becomes available after timely submission of letters of support and forms 183As.

New sponsors will gain access to the IP and software that were developed as part of SINBAD I and available at the SLIM web site. All sponsors have representation in the Advisory committee. Subject to the University's compliance with the terms of this Agreement, the Participant shall pay the University funds in accordance with the schedule below (all funds in Canadian dollars):

OIL COMPANIES that were SINBAD I Member: $72,500 per annum due on the Effective Date and on each anniversary of the effective date until termination.

OR NON-SINBAD I Member (oil company): $78,500 per annum due on the Effective Date and on each anniversary of the Effective Date for the first four years (i.e. five payments of $78,500), and $72,500 per annum thereafter until termination. OR NON-SINBAD I Member (oil company): $72,500 per annum due on the Effective Date and on each anniversary of the effective date until termination, and a one-time fee of $25,000 due on the Effective Date.

SERVICE PROVIDERS: $83,500 per annum due on the Effective Date and on each anniversary of the effective date until termination.

Late Entry Fee AND $36,250 one-time late entry fee due on or before the Effective Date. These fees are waived for companies that timely (before July 10th 2010) submit their letters of support and form 183A. For questions regarding the fee structure, please contact Mario Kasapi (mario.kasapi@uilo.ubc.ca) of the UILO.

If you have questions please feel free to contact me or Harry Dosanjh (mailto:slim-assist@eos.ubc.ca), phone 1 (604) 822-5674).

Sincerely,

Felix J. Herrmann
Director UBC-Seismic Laboratory for Imaging and Modeling
Department of Earth and Ocean Sciences