Overview & Future Plans SINBAD Consortium

Felix J. Herrmann
Hosts of the 2017 SINBAD Consortium Meeting
Guest wifi

**Network:** dugeoguest  
**Password:** GuestsRgr8!
Outline

Mission & highlights

Move to the Georgia Institute of Technology

Research Overview
Our mission

Fast & agile development of next-generation of seismic data acquisition, processing, wave-equation based imaging & inversion technology

Dissemination of research findings to spark innovations

Training of the next-generation of computational problem solvers

- undergraduate
- graduate, and
- post-graduate level
**Processing**

- Includes randomized SVD and hierarchical matrices
  - Can be dimensionality reduced using

- EPSI (Estimation of Primaries via Sparse Inversion)
  - Can be speeded up by
  - Can mitigate local minima using
  - Ocean bottom data extension

- Robust EPSI via one-norm minimization

- Multilevel acceleration of REPSI

- REPSI w/ primary wavefield autoconvolution

- Up/down wavefield decomposition by sparse inversion
Matrix square root-based wavefield extrapolation

includes

CARP-CG

includes

uses

Preconditioning of the Helmholtz equation via row-projections

includes

includes

A parallel matrix-free framework for frequency-domain seismic modeling in Matlab
The team...

Total of 15 (under)graduate students, PDFs, visitors, faculty, & staff...
Sponsors

Total of 10 sponsors

BG GROUP

Chevron

Petrobras

Schlumberger

ConocoPhillips

HESS

Woodside
Sponsors

Total of 10 sponsors

BG GROUP

Chevron

DownUnder GeoSolutions

Schlumberger

ConocoPhillips

Hess

TOTAL

ExxonMobil

Interests....

SINOPEC

SUB SALT SOLUTIONS

woodside

Wednesday, October 4, 2017
Guests

- Bill Curry (ExxonMobil)
- Ramesh Neelamani (ExxonMobil)
- Partha Routh (ExxonMobil)
- Anatoly Baumstein (ExxonMobil)
- Min Zhou (Sinopec)
- Changhua Zhang (Sinopec)
- Shiyong Xu (Sinopec)
- Mingqiu Luo (Sinopec)
- Scott Morton
Moving on ...

Haneet Wason — August
“Simultaneous-source seismic data acquisition & processing with compressive sensing”

Rajiv Kumar — August
“Enabling large-scale seismic data acquisition, processing & waveform-inversion via rank-minimization”

Felix Oghenekohwo — July
“Economic time-lapse seismic acquisition and imaging — Reaping the benefits of randomized sampling with distributed Compressive Sensing”

Curt Da Silva — August
“Large-scale optimization algorithms for missing data completion and inverse problems”
Moving on …..

Rongrong Wang, PhD.

Assistant Professor, Department of Computational Mathematics, Science and Engineering

Michigan State University (Fall 2017 to present)

Post-Doctoral Fellow, UBC SLIM (2013 to 2017)

Submitted

1 Curt Da Silva and Felix J. Herrmann, “A unified 2D/3D large scale software environment for nonlinear inverse problems”, 2017. Abstract BibTex

2 Emmanouil Daskalakis, Rachel Kuske, and Felix J. Herrmann, "Developments in the direction of solving extremely large problems in Geophysics", in SEG Technical Program Expanded Abstracts, 2017. Abstract BibTex


4 Shashin Sharan, Rongrong Wang, and Felix J. Herrmann, "High resolution fast microseismic source collocation and source time function estimation", in SEG Technical Program Expanded Abstracts, 2017. Abstract BibTex


7 Michael Lange, Navjot Kukreja, Fabio Luporini, Mathias Louboutin, Charles Yount, Jan (Hückelheim), and Gerard Gorman, "Optimised finite difference computation from symbolic equations", in Python in Science Conference Proceedings, 2017, p. 89–96. Abstract BibTex


9 Rajiv Kumar, Nick Moldoveanu, and Felix J. Herrmann, "Denoising high-amplitude cross-flow noise using curvelet-based stable principle component pursuit", in EAGE Annual Conference Proceedings, 2017. Abstract BibTex

10 Mathias Louboutin and Felix J. Herrmann, "Extending the search space of time-domain adjoint-state FWI with randomized implicit time shifts", in EAGE Annual Conference Proceedings, 2017. Abstract BibTex

11 Felix Oghenekohwo and Felix J. Herrmann, "Improved time-lapse data repeatability with randomized sampling and distributed compressive sensing", in EAGE Annual Conference Proceedings, 2017. Abstract BibTex

12 Ali M. Alfaraj, Rajiv Kumar, and Felix J. Herrmann, "Shear wave reconstruction from low cost randomized acquisition", in EAGE Annual Conference Proceedings, 2017. Abstract BibTex
1 Philipp A. Witte, Mengmeng Yang, and Felix J. Herrmann, “Sparsity-promoting least-squares migration with the linearized inverse scattering imaging condition”, in EAGE Annual Conference Proceedings, 2017. Abstract BibTex


Recent software releases – February

1 **Devito**: Fast Finite Difference Computations. (slim branch) Devito is a new Python tool for performing optimised Finite Difference (FD) computation from high-level symbolic problem definitions. Devito performs automated code generation and Just-In-time (JIT) compilation based on symbolic equations defined in SymPy to create and execute highly optimised Finite Difference kernels on multiple computer platforms. For questions contact Mathias Louboutin. ([GitHub](https://github.com/))

2 **JOLI — Julia Operators LIbrary.** (master branch) Julia framework for constructing matrix-free linear operators and applying them in basic algebraic matrix-vector operations. It is a Julia implementation of our MATLAB-based SPOT. For questions contact Henryk Modzelewski. ([GitHub](https://github.com/))

3 **Julia interface for Devito.** (master branch) This Julia package is a large-scale seismic modeling workflow and provides a framework for wave-equation based inversion methods, such as full waveform inversion or least squares migration. The framework is based on the Devito. The flexible workflow is based on abstract matrix-free linear operators (JOLI) and enables developers to write code that closely resembles the underlying math, while at the same time leveraging highly optimized wave equation solvers, allowing us to solve large-scale three-dimensional inverse problems. For questions contact Mathias Louboutin. ([GitHub](https://github.com/))

4 **Time-domain seismic modeling.** (master branch) This application demonstrates application of our Julia framework for 2D and 3D seismic modeling and inversion in the time domain. The underlying Julia module offers functions for solving the forward and adjoint acoustic wave equation as well as the linearized acoustic wave equation (Born modeling). This module is also based on JOLI abstract matrix-free linear operators, which allow easy formulation of algorithms for PDE-constrained optimization problems, such as least squares migration (LSRTM) and full waveform inversion (FWI). We use Devito (via our Julia interface for Devito) for solving wave equations. For questions contact Philipp Witte. ([Read more](https://github.com/))

5 **Time-domain seismic imaging.** (master branch) This application demonstrates our Julia tools for reverse time migration (RTM) and least squares RTM (LSRTM) with and without sparsity constraints. Furthermore the underlying Julia module contains several pre-conditioners for LSRTM, namely model- and data-space topmutes, depth scaling and data scaling. For questions contact Philipp Witte. ([Read more](https://github.com/))
1 Residual Constrained Alternating Minimization (RCAM) (new on master branch) A Julia factorization-based alternating minimization scheme for large scale matrix completion on parallel computing architectures. For questions contact Rajiv Kumar. [GitHub]

2 GenSPGL (new on master branch) A Julia solver for large scale minimization problems using any provided norm. GenSPGL supports implicit arrays(JOLI), explicit arrays, and functions as modelling operators A. For questions contact Rajiv Kumar. [GitHub]

3 SeisIO (new on master branch) A Julia package for reading and writing SEGY Rev 1 files. In addition to providing tools for reading/writing entire files, SeisIO provides a scanner that turns SEGY volumes into an object with direct out-of-core access to the underlying data. For questions contact Keegan Lensink. [GitHub]

4 Devito: Fast Finite Difference Computation. (updates to master branch) Devito is a Python tool for performing optimized Finite Difference (FD) computation from high-level symbolic problem definitions. Multiple updates improving performance and stability of the package. For questions contact Mathias Louboutin. [GitHub]

5 Julia interface for Devito. (updates to master branch) A Devito-based large-scale seismic modeling workflow and provides a framework for wave-equation based inversion methods, like full waveform inversion or least squares migration. Updates to use our SeisIO package for SEGY input/output, out-off-core functionality, and performance improvements. For questions contact Mathias Louboutin. [GitHub]

6 Time-domain seismic imaging. (updates to master branch) This application demonstrates our Julia tools for reverse time migration (RTM) and least squares RTM (LSRTM) with and without sparsity constraints. Added examples for 2D least-square RTM. For questions contact Philipp Witte. [GitHub]

7 Time-domain FWI. (new on master branch) This application demonstrates using software to perform full-waveform inversion. Includes example for 2D-Overthrust model. For questions contact Philipp Witte. [GitHub]

8 3D time-domain FWI. (new on developer branch) This prototype application (in script fwi_overthrust_3D.jl) demonstrates using software to perform full-waveform inversion, but for 3D synthetic data (including script generate_data_overthrust.jl to generate data). For questions contact Philipp Witte. [GitHub]

9 JOLI - Julia Operators Library. (updates to master branch) Julia framework for constructing matrix-free linear operators and applying them in basic algebraic matrix-vector operations. Added numerous new operators. For questions contact Henryk Modzelewski. [GitHub]
“Sterke wiskunde voor toepassingen in de geofysica”

Clarence Karcher Award voor Tristan van Leeuwen

Tristan van Leeuwen ontvangt de Clarence Karcher Award van SEG President Bill Abriel
Collaborators

Mike Warner & Gerard Gorman (Imperial College London)

Rongrong Wang (Michigan State)

Ben Recht (Berkeley)

Tristan van Leeuwen (Utrecht University)

Sasha Aravkin (UoW)
Impact

Curvelet-based processing:
- noise removal, multiple elimination, sparse inversions, e.g. SRME & EPSI
- incorporated by Chevron & others leading to major improvements

Randomized (timelapse) acquisition / Compressive Sensing:
- validated & practiced by ConocoPhilips & SLB
- major (5–10 X) improvements in production & environmental imprint

Structure-promoting inversion by (convex) optimization:
- enabler of high-quality recovery from severe undersamplings
- randomized time-lapse surveys will be shot
Impact

Randomized sampling in FWI:
- \((4 - 8 \times)\) reduction in computational costs
- makes WEI’s computationally & economically feasible
- allowed Schlumberger to develop FWI into a viable service

FWI with extensions & convex constraints:
- removal of sensitivity to starting models
- EAGE distinguished lecture series
- constraints instead of penalties
CAI – Compressive time-lapse Acquisition & Imaging

Grant proposal submitted:
- to ITF’s call IMPROVED RESERVOIR IMAGING 2016 in the UK in collaboration w/ Gerard Gorman
- budget: 2,524,000 GPB
- duration: 36 months

Personnel:
- 6 FTEs for post-doctoral fellows
- 3 FTEs research faculty/associate
- 1.5 FTEs of a software support person
- 3 FTEs of student research time
CAI – objectives

Form & analyze high-amplitude fidelity full-subsurface pre-stack image volumes for target-oriented reservoir delineation, characterization & monitoring

Create 3D artifact-free highly repeatable high-resolution time-lapse images from data with multiples in (shallow) marine settings

Create an agile 3D imaging framework that will enable rapid at scale deployment

Minimize cost of acquiring 3D time-lapse seismic data without impacting 4D repeatability

Make developed acquisition and imaging technology available in the cloud

Interest from:
- Exxonmobil
- Total
Research themes & outcomes

**Scalable low-rank representations:**
- recovery & on-the-fly shot generation
- handle full subsurface offset image volumes w/ probing & randomized linear algebra

**Economic time-lapse seismic w/ joint-recovery model:**
- exploit information shared amongst the vintages
- stable w.r.t. calibration errors obtain high degrees repeatability w/o in-field replication

**High-performant automatic code generation & abstractions:**
- verifiable high-performance time-stepping code w/ domain-specific language (Devito)
- agile wave-equation based inversion framework
Research themes & outcomes

Large-scale optimization with constraints:
- (accelerated) imaging & microseismic w/ sparsity promotion
- novel (dual) formulations for WRI & FWI

Multiple imaging modalities:
- physics based imaging technology for sensor networks
- medical imaging, radar, and nondestructive testing

Machine learning for inversion:
- incorporate generative deep convolutional networks in data completion problems
- alternative formulations for wave-equation based inversion
October 1st — Started cross-appointments at CSE, EE & Earth Sciences
- connect w/ very strong engineering school
- use GT’s extensive corporate ties w/ industry & access to federal funding
- leverage machine learning PhD program

First- & second semester next academic year — move my research team to GT
- easier access to the US job market
- ability to connect to strong faculty

By Spring 2018
- start new diversified research program
- move our activities to the cloud
By Jan 2018 turn SINBAD into two-tier gift/project program:

- perpetual industry affiliate program w/o explicit deliverables
- simplifies IP structure & avoids overhead
- second-tier periodic proprietary projects w/ deliverables
- w/ separate tailored IP arrangements that carry overhead

New funding model:

- spearheading sustainable computational experiment lab in the cloud @GT
- drive innovations by developing at scale services in the cloud
- public private partnership between academia, cloud providers, and industry affiliates possibly partnering w/ startup companies (Osokey & juliacomp)
Main activities

Training of graduate students
- in theoretical & computational aspects
- to incorporate ideas from mathematics & computers science (compressive sensing and machine learning)
- prototype development

Bespoke solutions for individual projects that include at-scale technology validation (NEW)

Development and delivery of our innovative solutions in the cloud (NEW).
First-tier membership

Opportunity to work with us on bespoke solutions addressing particular research questions and needs

Delivery of project-based research outcomes according to agreed upon milestones

Arrangements for access to IP

Benefits of second-tier membership
Second-tier membership

Preprints of publications, our newsletter, attendance to Consortium meetings

Access to

- basic support of our public-domain source code w/ proofs-of-principle implementations
- our students and other members of the SINBAD research team;
- our coordinated graduate internship program to get to know our graduate students.
Status of research group

Bas, Zhilong, Yimeng, Ali, and Marie will stay at UBC

Henryk and Diana will continue to offer support

Mathias, Philipp, Mengmeng, Shashin, Ali, and Rajiv (PDF) will move to Gatech
This meeting

Impact of Compressive Sensing on Seismic Data Acquisition & Processing — boosting the economics & time-lapse repeatability from fewer non-replicated data

› Field Case studies & Multicomponent data
› Full-azimuth processing
› Time-lapse seismic
› At scale matrix factorization
This meeting (cont’ed)

Wave-equation based Imaging, Inversion, and Uncertainty Quantification — tackling artifacts, noise, lack of convergence speed & parasitic minima

- Compressive imaging w/ multiples & source estimation
- Microseismic source collocation
- Novel formulations &
- Inversions w/ constraints
This meeting (cont’ed)

Extreme-scale matrix factorizations — making the impossible possible w/ randomized probing

- low-rank data compression & recovery w/ on-the-fly data generation
- full-subsurface image volumes from low-rank data representations
- scenario testing in radatuming
- probing of image volumes revisited
This meeting (cont’ed)

Extreme performant at-scale Wave Equation-Based Inversion — managing complexity while increasing performance

- Latest developments in Devito — a domain-specific language and compiler for stencil-based finite-difference computations
- Performance & capabilities review
- Time-domain Wave-equation based Inversion & Imaging in Julia
- The road ahead to the Cloud
<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
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<tbody>
<tr>
<td>08:00—08:30 AM</td>
<td>Registration and coffee &amp; pastries</td>
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<tr>
<td>08:30—09:00 AM</td>
<td>Felix J. Herrmann: Welcome &amp; overview of the meeting</td>
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<tr>
<td>09:00—09:30 AM</td>
<td>Chuck Mosher: Impact of Compressive Sensing on Seismic Data Acquisition &amp; Processing — boosting the economics &amp; time-lapse repeatability from fewer non-replicated data (Chair: Rajiv Kumar)</td>
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<tr>
<td>09:30—10:00 AM</td>
<td>Oscar Lopez: A Guide for Successful Low-Rank Matrix Recovery in Seismic Applications</td>
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<td>Ali M. Alfaraj: Reconstruction of S-waves from low-cost randomized acquisition</td>
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<tr>
<td>10:45—11:15 AM</td>
<td>Chengbo Li: Alternating Direction Method and its role in CSI technology</td>
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<tr>
<td>11:15—11:45 AM</td>
<td>Rajiv Kumar: Full azimuth seismic data processing with coil acquisition</td>
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<tr>
<td>11:45—12:15 PM</td>
<td>Felix J. Herrmann: Highly repeatable 3D compressive full azimuth towed streamer time lapse acquisition — a numerical feasibility study at scale</td>
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<tr>
<td>12:15—12:30 AM</td>
<td>Discussion</td>
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<td>12:30—01:30 PM</td>
<td>Lunch</td>
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<tr>
<td>01:30—02:15 PM</td>
<td>Oscar Lopez: Extreme-scale matrix factorizations — making the impossible possible with randomized probing (Chair: Marie Graff)</td>
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<tr>
<td>02:15—02:45 PM</td>
<td>Yiming Zhang: Matrix Completion in Parallel Architectures: Julia Implementation</td>
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<td>02:45—03:15 PM</td>
<td>Ali Siahkoohi: Seismic data interpolation with Generative Adversarial Networks</td>
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<tr>
<td>03:30—04:00 PM</td>
<td>Rajiv Kumar: Multi-domain target-oriented imaging using extreme-scale matrix factorization</td>
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<tr>
<td>04:00—04:30 PM</td>
<td>Marie Graff: Low-rank representation of omnidirectional subsurface extended image volumes</td>
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<td>Discussion</td>
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<td>Mathias Louboutin: Data driven Gradient Sampling for seismic inversion</td>
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<td>Zhilong Fang: PDE-free Gauss-Newton Hessian for Wavefield Reconstruction Inversion</td>
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<td>Shashin Sharan: Tracking the spatial-temporal evolution of fractures by microseismic source collocation</td>
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<tr>
<td>06:30—08:30 PM</td>
<td>Dinner, Caracol Restaurant, 2200 Post Oak Blvd</td>
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