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PI/PD Name: Thomas L Henyey

Gender: ☒ Male ☐ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☒ Not Hispanic or Latino

Race:
(Select one or more)
- ☐ American Indian or Alaska Native
- ☐ Asian
- ☐ Black or African American
- ☐ Native Hawaiian or Other Pacific Islander
- ☒ White

Disability Status:
(Select one or more)
- ☐ Hearing Impairment
- ☐ Visual Impairment
- ☐ Mobility/Orthopedic Impairment
- ☐ Other ______________________
- ☒ None

Citizenship: (Choose one) ☒ U.S. Citizen ☐ Permanent Resident ☐ Other non-U.S. Citizen

Check here if you do not wish to provide any or all of the above information (excluding PI/PD name): ☐

REQUIRED: Check here if you are currently serving (or have previously served) as a PI, co-PI or PD on any federally funded project ☒

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PI/PD Name: Geoffrey C Fox

Gender: ☒ Male ☐ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☒ Not Hispanic or Latino

Race:
(Select one or more)
- ☐ American Indian or Alaska Native
- ☐ Asian
- ☐ Black or African American
- ☐ Native Hawaiian or Other Pacific Islander
- ☒ White

Disability Status:
(Select one or more)
- ☐ Hearing Impairment
- ☐ Visual Impairment
- ☐ Mobility/Orthopedic Impairment
- ☐ Other ____________
- ☐ None

Citizenship: (Choose one) ☒ U.S. Citizen ☐ Permanent Resident ☐ Other non-U.S. Citizen

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PI/PD Name: David D Jackson

Gender: ☒ Male ☐ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☒ Not Hispanic or Latino

Race:
(Select one or more)
- ☐ American Indian or Alaska Native
- ☐ Asian
- ☐ Black or African American
- ☐ Native Hawaiian or Other Pacific Islander
- ☒ White

Disability Status:
(Select one or more)
- ☐ Hearing Impairment
- ☐ Visual Impairment
- ☐ Mobility/Orthopedic Impairment
- ☐ Other ________________
- ☒ None

Citizenship: (Choose one) ☒ U.S. Citizen ☐ Permanent Resident ☐ Other non-U.S. Citizen

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PI/PD Name: Thomas H Jordan

Gender: ☒ Male ☐ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☒ Not Hispanic or Latino

Race:
(Select one or more)
- ☐ American Indian or Alaska Native
- ☐ Asian
- ☐ Black or African American
- ☐ Native Hawaiian or Other Pacific Islander
- ☒ White

Disability Status:
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PI/PD Name: John B Rundle

Gender: ☒ Male ☐ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☒ Not Hispanic or Latino

Race:
(Select one or more)
☐ American Indian or Alaska Native
☐ Asian
☐ Black or African American
☐ Native Hawaiian or Other Pacific Islander
☒ White

Disability Status:
(Select one or more)
☐ Hearing Impairment
☐ Visual Impairment
☐ Mobility/Orthopedic Impairment
☐ Other ____________
☒ None

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COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 99-2	FOR NSF USE ONLY
99-29 02/01/99	NSF PROPOSAL NUMBER
FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.)	**9975591**

DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION
				072933393	

EMPLOYER IDENTIFICATION NUMBER (EIN) OR TAXPAYER IDENTIFICATION NUMBER (TIN)	SHOW PREVIOUS AWARD NO. IF THIS IS	IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY?
951642394	☐ A RENEWAL ☐ AN ACCOMPLISHMENT-BASED RENEWAL	YES ☐ NO ☒ IF YES, LIST ACRONYMS(S)

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE	ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE
University of Southern California	Department of Contracts and Grants University Park Los Angeles, CA. 900891147
AWARDEE ORGANIZATION CODE (IF KNOWN): 0013284000	
NAME OF PERFORMING ORGANIZATION, IF DIFFERENT FROM ABOVE	ADDRESS OF PERFORMING ORGANIZATION, IF DIFFERENT, INCLUDING 9 DIGIT ZIP CODE
PERFORMING ORGANIZATION CODE (IF KNOWN)	

IS AWARDEE ORGANIZATION (Check All That Apply) (See GPG II.D.1 For Definitions) ☐ FOR-PROFIT ORGANIZATION ☐ SMALL BUSINESS ☐ MINORITY BUSINESS ☐ WOMAN-OWNED BUSINESS

TITLE OF PROPOSED PROJECT **General Earthquake Models: A New Computational Challenge**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PREPROPOSAL NO., IF APPLICABLE
$ 2,899,999	36 months	09/01/99	

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW

- ☐ BEGINNING INVESTIGATOR (GPG 1.A.3)
- ☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.D.1)
- ☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG II.D.10)
- ☐ NATIONAL ENVIRONMENTAL POLICY ACT (GPG II.D.10)
- ☐ HISTORIC PLACES (GPG II.D.10)
- ☐ SMALL GRANT FOR EXPLOR. RESEARCH (SGER) (GPG II.D.12)
- ☐ GROUP PROPOSAL (GPG II.D.12)
- ☐ VERTEBRATE ANIMALS (GPG II.D.12) IACUC App. Date ________
- ☐ HUMAN SUBJECTS (GPG II.D.12)
  Exemption Subsection ________ or IRB App. Date ________
- ☐ INTERNATIONAL COOPERATIVE ACTIVITIES: COUNTRY/COUNTRIES ________
- ☐ FACILITATION FOR SCIENTISTS/ENGINEERS WITH DISABILITIES (GPG V.G.)
- ☐ RESEARCH OPPORTUNITY AWARD (GPG V.H)

PI/PD DEPARTMENT	PI/PD POSTAL ADDRESS
Department of Earth Sciences	University Park Los Angeles, CA 900890740 United States
PI/PD FAX NUMBER: 213-740-0011	

NAMES (TYPED)	High Degree	Yr of Degree	Telephone Number	Electronic Mail Address
PI/PD NAME: Thomas L Henyey	PH.D	1968	213-740-5832	henyey@earth.usc.edu
CO-PI/PD: Geoffrey C Fox	Ph.D.	1967	315-443-2163	gcf@cs.fsu.edu
CO-PI/PD: David D Jackson	PH.D.	1969	310-825-0421	djackson@ucla.edu
CO-PI/PD: Thomas H Jordan	PhD	1972	617-253-3589	thj@quake.mit.edu
CO-PI/PD: John B Rundle	Ph.D.	1976	303-492-5642	rundle@fractal.colorado.edu

CERTIFICATION PAGE

Certification for Principal Investigators and Co-Principal Investigators:

I certify to the best of my knowledge that:

(1) the statements herein (excluding scientific hypotheses and scientific opinions) are true and complete, and
(2) the text and graphics herein as well as any accompanying publications or other documents, unless otherwise indicated, are the original work of the signatories or individuals working under their supervision. I agree to accept responsibility for the scientific conduct of the project and to provide the required progress reports if an award is made as a result of this application.

I understand that the willful provision of false information or concealing a material fact in this proposal or any other communication submitted to NSF is a criminal offense (U.S.Code, Title 18, Section 1001).

Name (Typed)	Signature	Social Security No.*	Date
PI/PD **Thomas L Henyey**		SSNs are confidential and are not displayed *ON FASTLANE SUBMISSIONS*	
Co-PI/PD **Geoffrey C Fox**			
Co-PI/PD **David D Jackson**			
Co-PI/PD **Thomas H Jordan**			
Co-PI/PD **John B Rundle**			

Certification for Authorized Organizational Representative or Individual Applicant:

By signing and submitting this proposal, the individual applicant or the authorized official of the applicant institution is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding Federal debt status, debarment and suspension, drug-free workplace, and lobbying activities (see below), as set forth in Grant Proposal Guide (GPG), NSF 99-2. Willful provision of false information in this application and its supporting documents or in reports required under an ensuring award is a criminal offense (U. S. Code, Title 18, Section 1001).

In addition, if the applicant institution employs more than fifty persons, the authorized official of the applicant institution is certifying that the institution has implemented a written and enforced conflict of interest policy that is consistent with the provisions of Grant Policy Manual Section 510; that to the best of his/her knowledge, all financial disclosures required by that conflict of interest policy have been made; and that all identified conflicts of interest will have been satisfactorily managed, reduced or eliminated prior to the institution's expenditure of any funds under the award, in accordance with the institution's conflict of interest policy. Conflict which cannot be satisfactorily managed, reduced or eliminated must be disclosed to NSF.

Debt and Debarment Certifications

(If answer "yes" to either, please provide explanation.)

Is the organization delinquent on any Federal debt? Yes ☐ No ☒

Is the organization or its principals presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency? Yes ☐ No ☒

Certification Regarding Lobbying

This certification is required for an award of a Federal contract, grant, or cooperative agreement exceeding $100,000 and for an award of a Federal loan or a commitment providing for the United States to insure or guarantee a loan exceeding $150,000.

Certification for Contracts, Grants, Loans and Cooperative Agreements

The undersigned certifies, to the best of his or her knowledge and belief, that:

(1) No federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.

(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, ''Disclosure Form to Report Lobbying,'' in accordance with its instructions.

(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
NAME/TITLE (TYPED) **Lloyd Armstrong, Jr./Provost**		**01/28/99**

TELEPHONE NUMBER	ELECTRONIC MAIL ADDRESS	FAX NUMBER
213-740-7762	**nbennett@mizar.usc.edu**	**213-740-6070**

*SUBMISSION OF SOCIAL SECURITY NUMBERS IS VOLUNTARY AND WILL NOT AFFECT THE ORGANIZATION'S ELIGIBILITY FOR AN AWARD. HOWEVER, THEY ARE AN INTEGRAL PART OF THE INFORMATION SYSTEM AND ASSIST IN PROCESSING THE PROPOSAL. SSN SOLICITED UNDER NSF ACT OF 1950, AS AMENDED.

Scientific Research Problem: Earthquakes are devastating natural events whose economic and human costs can be enormous. At the present time, the physics underlying the processes on these complex, scale invariant fault systems is obscure. Significant progress is stymied by the fact that the conduct of earthquake science has historically been primarily observational, rather than experimental. As an example, there exist no currently known, successful techniques to forecast or predict earthquakes. However, recent advances in understanding the physics of other complex, scale-invariant systems through modeling and simulation indicates that the development of "experimental numerical earthquake laboratories" offers great promise for rapid and significant progress on the earthquake problem. We therefore propose a Pilot Project to develop many of the important scientific and computational capabilities necessary to carry out large-scale numerical simulation of the physics of earthquakes on scale-invariant fault systems in California. Together with new scientific approaches, our state-of-the-art problem solving environment will facilitate the construction of numerical and computational algorithms, together with the specific environment(s) needed to carry out large-scale simulations over a geographically widely distributed, heterogeneous computing network.

Scientific Foci: Our proposed Pilot Project will be based upon currently available, workstation-scale simulation codes for the San Andreas fault system as starting points. The planned adaptation of the hugely successful astrophysical N-body algorithm known as the Fast Multipole (FM) Method to the implementation of stress Green's functions on to these scale-invariant interacting fault systems will represent a major advance. We will use pattern identification methods based upon discrete Karhunen-Loeve expansions, "data mining" and other feature extraction technologies to identify previously unknown space-time pattern correlation structures in both simulation and field data. We will also adapt data assimilation and "model steering" techniques developed elsewhere to actively integrate existing observational data into the simulations.

Computational Foci: We will focus on developing and demonstrating the capability to carry out large scale simulations of complex, scale-invariant, interacting fault systems using a software environment adapted for rapid prototyping of new phenomenological models. The problem-solving environment (PSE) will be based on emerging distributed object-based systems, and will leverage state-of-the-art national HPCC activities in simulation of continuum, cellular automata, and large-scale particle systems. It will require the development of algorithms for solving computationally difficult nonlinear problems involving ("discontinuous") thresholds and nucleation events in a networked parallel (super) computing environment. The PSE will also require the adaptation of existing modern Web and other commodity technologies to allow researchers to rapidly integrate and assimilate simulation data with field and laboratory data (visually and quantitatively).

Potential Outcomes: The GEM approach will allow the physics of large, scale-invariant networks of earthquake faults to be analyzed, interpreted, and understood within a general theoretical framework for the first time. For the first time, it will be possible to interrelate, reconcile, and understand previously disjoint, diverse data sets, and to extrapolate results to predict new data by a "model-based inference" process. Through the use of Karhunen-Loeve and other pattern analysis and "pattern dynamics" methods, GEM models and simulations may lead to earthquake forecast methodologies similar to the successful El Nino-Southern Oscillation forecasts. The computational techniques developed by the project will have important applications to many other computationally hard problems, including statistical physics approaches to random field spin systems, and simulating nonlinear threshold systems including such as large neural networks with learning and cognition, magnetic depinning transitions in superconductors, and charge density wave systems.

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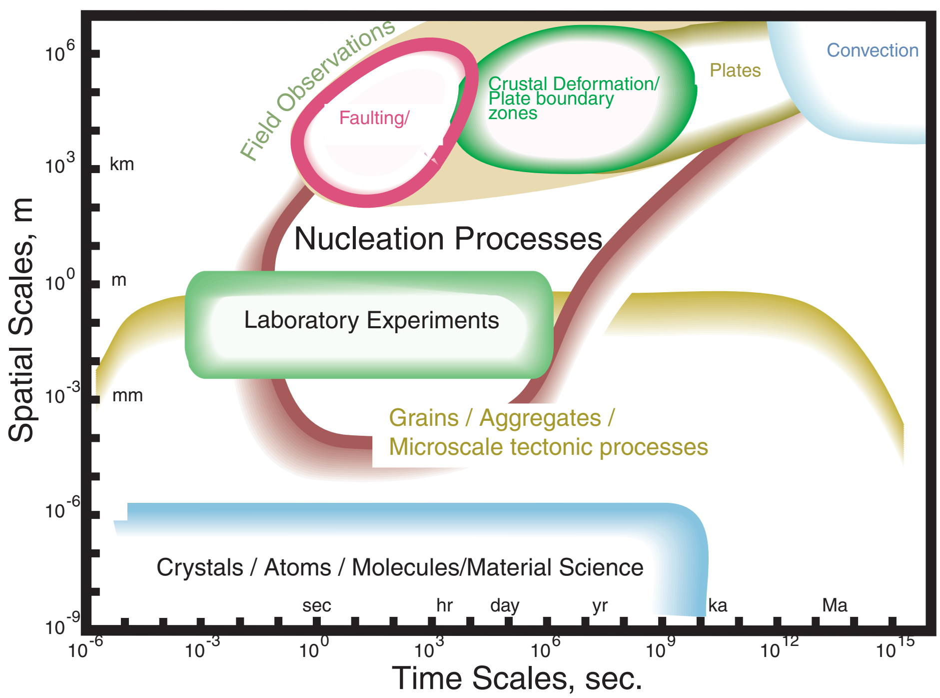
*Proposers may select any numbering mechanism for the proposal, however, the entire proposal must be paginated. Complete both columns only if the proposal is numbered consecutively.

Introduction and Impact: Earthquakes in urban centers are capable of causing enormous damage. The recent January 16, 1995 Kobe, Japan earthquake was only a magnitude 6.9 event and yet produced an estimated $200 billion loss. Despite an active earthquake prediction program in Japan, this event was a complete surprise. Similar scenarios are possible in Los Angeles, San Francisco, Seattle, and other urban centers around the Pacific plate boundary.

The development of forecast or prediction methodologies has been complicated by the fact that large events responsible for the greatest damage repeat at irregular intervals of hundreds to thousands of years,a limited historical record that has frustrated phenomenological studies. An alternative approach, proposed here, is to develop and analyze realistic earthquake simulations that generate arbitrarily long seismicity catalogs. This approach provides a "numerical laboratory" in which the physics of earthquakes can be investigated from a systems viewpoint. Physical processes on a wide range of spatio-temporal scales such as friction, fluid flow and the branching and interaction of fractures can be integrated into a common theoretical framework. "Model based inference" is then possible in which seemingly diverse data sets taken at different scales can be interrelated, reconciled, with predictions extrapolated to motivate and guide further observational studies. The impact of this new simulation technology on earthquake science will be to allow hypothesis testing and data integration on a scale not heretofore possible.

Nature of Earthquake Physics -- Space and Time Scales: Complex, nonlinear fault systems exhibit a wealth of emergent, dynamical phenomena over a large range of spatial and temporal scales, including space-time clustering of events, self-organization and scaling. Examples of the latter include the Gutenberg-Richter magnitude-frequency relation, and the Omori law for aftershocks (and foreshocks). The physical processes associated with earthquakes also occur on a wide range of spatial and temporal scales (Figure 1).



Frictional processes, the primary nonlinearity associated with earthquakes, are known to be physically significant from the molecular scale, on time intervals of less than 10^{-8} seconds and lengths of Angstroms (Å), to plate motion scales, on time intervals of 10^{6} years and lengths in excess of 1000 km. The physical processes directly associated with faulting and seismology, including nucleation and quasistatic crustal deformation, occur over time intervals of fractions of seconds to thousands of years, and lengths of meters to a hundreds of km. By contrast, experiments on frictional sliding of rock samples are usually carried out over laboratory bench-top scales extending over typical time intervals of 10^{-3} seconds to days, and over length scales of cm to m. Figure 1 indicates that the length scales associated with processes of faulting, seismology and crustal deformations are as far removed from laboratory experiments on rock samples as the laboratory processes are from those on the molecular scale.

Some of the spatial scales for physical fault geometries include:

The microscopic scale (~ 10^{-6} m to 10^{-1} m) associated with static and dynamic friction (the primary nonlinearities associated with the earthquake process).

The fault-zone scale (~ 10^{-1} m to 10^{2} m) that features complex structures containing multiple fractures and crushed rock.

The fault-system scale (10^{2} m to 10^{4} m), in which faults are seen to be neither straight nor simply connected, but in which bends, offsetting jogs and sub-parallel strands are common and known to have important mechanical consequences during fault slip.

The regional fault-network scale (10^{4} m to 10^{5} m), where seismicity on an individual fault cannot be understood in isolation from the seismicity on the entire regional network of surrounding faults, and where concepts such as "correlation length" and "critical state" borrowed from statistical physics have led to new approaches to understanding regional seismicity.

The tectonic plate-boundary scale (10^{5} m to 10^{7} m), at which Planetary Scale boundaries between plates can be approximated as thin shear zones and the motion is uniform at long time scales.

Broad Scientific and Computational Objectives: GEM models and simulations are needed to address fundamental questions related to earthquakes that can be understood by no other means. The types of broad scientific objectives that a GEM-type approach can ultimately address include:

Cataloging and understanding the nature and configurations of space-time patterns of earthquakes, and examining whether these are scale-dependent or scale-invariant in space and time. Certain characteristic patterns may indicate that a given event is a candidate foreshock of a future, larger event.

Developing and testing potential earthquake forecast algorithms, based primarily upon the use of space-time patterns in the fault system of interest.

Understanding the physical conditions that allow space-time coarse-graining of sub-grid scale processes, and whether these processes can be represented as noise.

Developing the theoretical framework to integrate diverse data and extrapolate existing data in space and time so that model predictions can be tested with new observations (Model-Based Inference).

Developing an understanding of hardware, software and algorithmic issues in computational support for multi-scale science and engineering simulations which are of pervasive importance in many fields.

These objectives underscore the need for models and simulations that mirror the wide range of space and time scales of the underlying processes.

Implications of Multi-Scale Physics: Past earthquake research has focused on problems that display only a limited range of spatial and temporal scales. Examples include laboratory studies of friction at the bench-top scale and crustal deformation at the plate boundary scale. However, the Gutenberg-Richter and Omori scaling laws, the scale-invariant physical structure of fault zones, and observations that seismic events cluster at all space and time scales investigated, all imply that multi-scale processes are at work, similar to those observed in many other areas of physics. Other complex nonlinear systems that exhibit qualitatively and quantitatively similar multi-scale features include the earth's weather and climate, neural networks with learning and cognition, superconductors and charge density wave systems that exhibit magnetic depinning transitions, liquid crystals undergoing smectic or nematic transitions, and ferromagnets and thin films in which magnetized domains evolve.

Large-scale computing approaches have had a significant and lasting impact in many areas of science where the underlying phenomena span significant ranges in spatial and temporaal scales. Therefore it is highly likely that a computational approach to the earthquake problem will produce a similarly successful outcome, provided that the major focus of the work is understanding the origins and implications of the fundamentally multi-scale phenomena that are observed in many seemingly disparate systems.

Classes of Earthquake Problems: **W**ithin the region of spatial and temporal scales in Figure 1 describing earthquakes (denoted "faulting and seismology"), there exist a sub-hierarchy of processes roughly defined by current research activity within the scientific community. These include:

1. ***Deterministic prediction of rupture on a single planar fault*** (Time Scales: 10^{-1} sec to 10^{2} sec; Length Scales: 10^{-1} km to 10^{2} km).
2. ***Prediction of stress transfer and seismic triggering of multiple earthquakes on several faults*** (Time Scales: 10^{4} sec to 10^{8} sec; Length Scales: 10^{1} km to 10^{3} km).
3. ***Space-time patterns and emergent structures in large populations of earthquakes on multi-scale fault systems*** (Time Scales: 10^{2} sec to 10^{12} sec; Length Scales: 10^{-2} km to 10^{4} km).
4. ***Geologic structure and evolution of faults and fault zones including the roles of fragmentation, fluids, and thermomechanics*** (Time Scales: 10^{3} to 10^{8} years; Length Scales: 10^{-6}km to 10 km).

Research over the last two decades has demonstrated that the significant physical processes associated with problems 1 and 2 occur over a narrow range of scales. For these problems, a classical "reductionist" approach continues to produce new results. However, progress on problems 3 and 4 has been limited, precisely because few methods have been available to earthquake scientists that allow physical processes to be linked across large ranges in scale. Because our interests lie directly in the area of understanding and learning to forecast large and damaging earthquakes, we propose a Pilot Project to address some of the important facets of problem 3. The remainder of this pre-proposal describes this Pilot Project.

Pilot Project: The purpose of the proposed work is to develop the modeling and analysis technologies that will be needed to implement large GEM simulations. We have chosen to focus on Problem 3 above because it directly addresses issues of scale in earthquake physics and because uncertainty in the details of friction and rupture processes is relatively unimportant at these time scales. The spatial and temporal details of the rupture process will be coarse-grained in the dynamical equations. Only differences between the coarse-grained pre- and post-earthquake physical states are relevant, and the statistical evolution of the stress correlation that these imply. For these models, simple scale-invariant Coulomb friction will suffice.

Over the past decade, several members of the GEM Team (Rundle, Ward, and Ben-Zion) have demonstrated the workstation-level feasibility of fault system computations of the kind contemplated. Typically, these computations involve about 100 to 1000 individual fault elements, usually of roughly similar size and having Coulomb-type friction laws. Interactions of faults on different scales have generally not been addressed. Computations, data assimilation, pattern analysis, and other interpretation techniques have been severely limited by available computational resources, although a preliminary parallel version has been developed by the collaboration for one code. The ability to include realistic fault geometry and rheology has been limited. Moreover, existing code is often neither portable nor transparent to other users. Significant progress on this critical problem requires a major leap forward in modeling, simulation, analysis, and software technology.

Models: A centerpiece of early development will be a newly constructed, variable-scale fault-interaction model, to be built by a team of earthquake scientists and experts in parallel-computation using modern distributed object and component paradigms. Specifically, the proposed Pilot Project will consist of a set of N coupled, nonlinear boundary value problems that are obtained by formulating the balance of forces on each site $\mathbf{x}$ at time t of all of the faults in the model. Space-time evolution of the fault slip $s(\mathbf{x},t)$ is a function both of the nonlinear friction on the fault surface, and of the stress $\Delta\sigma_{ij}(\mathbf{x},t)$ transferred to the site at $\mathbf{x}$ at time t from slip at the site $\mathbf{x}'$ at the earlier time t'. Stress transfer is characterized by a stress Green's function tensor $T_{ij}^{kl}(\mathbf{x}-\mathbf{x}',t-t')$. Coulomb friction leads to a problem characterized by a sharp failure stress threshold: No slip occurs until the total shear stress $\sigma_S(\mathbf{x},t)$ exceeds a value proportional to the total normal stress $\sigma_N(\mathbf{x},t)$. Other friction laws, of either the slip-weakening, or rate and state type, lead to equations of evolution for $s(\mathbf{x},t)$ that do not have such sharp thresholds. For these types of friction laws, recent research has led to efficient algorithms for solving these problems on workstations for small numbers of faults.

The planned adaptation of the highly successful astrophysical N-body algorithm known as the *Fast Multipole Method* to the implementation of the stress Green's functions $T_{ij}^{kl}(\mathbf{x}-\mathbf{x}',t-t')$ for interacting fault systems will represent a major advance, which when completed will provide a unique capability for modeling complex crustal dynamics. The expected computer requirements will eventually exceed 1 teraflop. This capability will become available over the duration of the project. Our approach will ensure that these resources are well used, since the N-body algorithm is both accurate and efficient. The primary friction model(s) used for the GEM pilot project will be of the scale-invariant Coulomb-type. However, the code and software will be constructed so that other friction laws, including the well-known slip-weakening and rate-and-state models, can be tested.

Pattern Analysis: Observations accumulated over many years clearly indicate the existence of recognizable space-time patterns in seismicity data. The exact nature of these patterns has been the subject of considerable debate. As part of the project, computational tools will be developed to analyze the information content of both real and simulated earthquake distributions using new ideas about pattern analysis and pattern reconstruction in complex systems. These include methods based upon the discrete Karhunen-Loeve expansion, scatter matrices and separability criteria, Bhattacharyya distance, correlation dimension, and "log-periodic" techniques.

Computations: The current computing environment is exemplified by isolated research groups using in-house software. The move to new, more fruitful collaborations marked by shared resources will take advantage of the emerging web-based object technology to create an environment where computing platforms, software, data and researchers will easily communicate. Early in the collaboration, agreement will be reached on a standard computational framework, consisting of a web-server object broker system and web-browser-based development environment, together with data-flow and visualization tools. Components of the framework will be acquired by the collaborating institutions. Because this is a rapidly evolving field, we defer the choice of tools to the initial phase of the work, and expect it to evolve as the collaboration proceeds. Promising technologies are described in "Building Distributed Systems for the Pragmatic Object Web" (see www.npac.syr.edu/users/shrideep/book), and prototypes have been studied at JPL and NPAC.

Data Assimilation and Model Validation: GEM will build and test modules that will allow comparison to observational data. First, models will be tested for self-consistency. Then data assimilation capabilities will be added so that the models can be calibrated and initialized using real data. Data assimilation techniques have been developed by the climate and ocean modeling community that start with a given model code from which the "adjoint model" is calculated. The adjoint can be run backward in time, beginning with current data, to predict the initial and boundary conditions that led to the current conditions. This computational procedure allows a subset of model variables to be adjusted so that initial conditions, historical observations, and current data can be optimally matched. Field observations of interest include GPS, InSAR, seismicity, and paleoseismic data all of which are readily available in computerized databases.

Multidisciplinary Aspects, HPC/NCC and Relation to KDI: The proposed Pilot Project in the GEM New Computational Challenge involves further development and use of a variety of technologies from other fields. These technologies, which have never been contemplated for use in earthquake-related problems include:

Fast Multipole Methods that have been used extensively in gravitational N-body problems and computational fluid mechanics.

Karhunen-Loeve Expansions and other pattern recognition, feature extraction, mode shaping and "data mining" techniques that have been developed for the study of electronic systems, weather forecasting and oceanographic analysis.

Data Assimilation Methodologies that have been developed to perform "model steering" feedback in ocean and climate simulations.

Analysis Techniques from theoretical analysis of random field systems for use in understanding the impacts of random properties, un-modeled sub-grid scale physics, and space and time coarse graining.

Computational, Web-Based, Multi-user Interactive Software that will use modern web-based technologies allowing large groups of scientists to interact meaningfully on difficult computational problems.

Current evidence suggests that forecasting earthquakes of magnitude ~6 and greater will depend upon understanding the space-time patterns displayed by smaller events; i.e., the magnitude 3's, 4's and 5's. With at least 40,000 km^2 of fault area in southern California, as many as 10^8 grid sites will be needed to accommodate events down to magnitude 3. Extrapolations based upon existing calculations indicate that using time steps of ~100 sec implies that ~10^8 time steps will be required to simulate several earthquake cycles. Using current computational technology, run-time estimates of several months for this problem can be documented.

It should be emphasized that the technologies described above for the Pilot Project involve considerations of both scale and structure, as well as successfully addressing issues related to the interplay between computations and data. Development of a working forecast technology demands that human interaction with the computational simulation must be real-time. Thus, the space and time scales of this complex system, together with the novel multidisciplinary and human interaction aspects, clearly place GEM into the category of KDI/NCC problems.

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D. Some Recent Publications

Li, Y.G., T.L. Teng, and T.L. Henyey, Shear Wave Splitting Observations and Implications for the Stress Regime in the Los Angeles Basin, Southern California, Bull. Seis. Soc. Amer., 84, 307-323, 1994.

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Kagan, Y. Y., and D. D. Jackson. Long-term probabilistic forecasting of earthquakes. *J. Geophys. Res*., *99*, 13685-13700, 1994.

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John B. Rundle has been a Professor of Physics at the University of Colorado since 1993. Since 1996 he has been Director of the Colorado Center for Chaos and Complexity. He received his BSE degree (1972) from Princeton University and his MS (1973) and PhD (1976) degrees from UCLA in Geophysics and Space Physics. He was employed as a Research Geophysicist at Sandia National Laboratories (1977-1990), and as a Physicist in the Earth Sciences Department of the Lawrence Livermore National Laboratory (1990-1993). He has been a Visiting Associate at the California Institute of Technology, and a Visiting Scholar at the Department of Physics of Boston University, and is currently a Distinguished Visiting Scientist at the Jet Propulsion Laboratory.

He has served as chairman of the Committee on Geodesy of the National Research Council; is currently a member of the ESSAAC committee advisory to the Associate Administrator of NASA for Mission to Planet Earth; he is past chair of the Advisory Council to the Southern California Earthquake Center; and he currently chairs the Committee on Nonlinear Geophysics of the American Geophysical Union. Recently, he was appointed Association Lectureer at the 27th General Assembly of the IASPEI held in Wellington, New Zealand. Professor Rundle is a member of the American Geophysical Union, the Seismological Society of America, and the American Physical Society. His current interests include earthquake physics, modeling and simulations, nucleation phenomena, friction and fracture mechanics, geodetic modeling of Global Positioning System and Synthetic Aperature Radar data, and pattern analysis and pattern dynamics of seismicity data.

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Selected List of Publications

1. Fox, G.C., Johnson, M.A., Lyzenga, G.A., Otto, S.W., Salmon, J.K., Walker, D.W., Solving Problems on Concurrent Processors, Vol. 1, Prentice-Hall, Inc. 1988; Vol. 2, 1990.
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Scientific Publications

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1993 Ihmlé, P. F., P. Harabaglia, and T. H. Jordan, Teleseismic detection of a slow precursor to the great 1989 Macquarie Ridge earthquake, *Science*, **261**, 177-183.
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Ben-Zion, Y., K. Dahmen, V. Lyakhovsky, D. Ertas and A. Agnon, Self-Driven Mode Switching of Earthquake Activity on a Fault System, submitted to *Earth Planet. Sci. Lett.*, 1998.

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  My dissertation research investigated the role of fluids in seismic phenomena using computer simulation tools that I designed and wrote (using C++, linpack, Diffpack). This code employed a finite element discretization to solve fully-coupled, implicit poroelastic equations. I am continuing development of the object-oriented library that I developed for this work and hope to develop a framework for a general geodynamics modeling package.

  My computational investigations also included a lattice Boltzmann code for a pore-scale investigation of porosity-permeability relationships under various diagenetic schemes. I am supervising the transfer of my lattice Boltzmann code to another graduate students in the department for continuing research.

- *Computational Scientist,* Center for Applied Scientific Computing, Lawrence Livermore National Laboratory (LLNL), March 1992 to present.

  Before my sabbatical leave, I was project leader for the ParFlow project, a parallel groundwater and contaminant transport simulation effort. (See http://www.llnl.gov/casc/projects/parflow). I developed parallel geostatistical routines and conceptual model building algorithms, and implemented numerical algorithms (polynomial preconditioned conjugate gradient solver). As the project geoscientist, I was also involved with customer interactions and site simulations. Target computers were large, distributed memory machines.

  A new groundwater modeling project was recently funded that will replace the ParFlow effort. The new project will target fluid flow, heat transport, mechanical deformation and contaminant transport problems connected with the Yucca Mountain nuclear waste repository effort. Upon returning to LLNL, I will be responsible for fluid-mechanical coupling and its effect on permeability in fractured environments.

Journal Articles, Technical Reports, Conference Proceedings

Bosl, W. J., and A. Nur, "Numerical Simulation of Postseismic Deformation Due to Pore Fluid Diffusion". In J.-F. Thimus, et al., *Poromechanics: A Tribute to Maurice A. Biot*, pages 23-28. Balkema: Rotterdam, 1998.

Bosl, W. J., J. Dvorkin, and A. Nur, 1998. "A Study of Porosity and Permeability Using a Lattice Boltzmann Simulation", *Geophysical Research Letters*, **25**, pp. 1475-1478.

Tompson, A. F. B., R. D. Falgout, S. G. Smith, W. J. Bosl, S. F. Ashby, 1998. "Analysis of Subsurface Contaminant Migration and Remediation Using High Performance Computing", *Advances in Water Resources*, **22**, pp. 203-221. Also available as LLNL Technical Report UCRL-JC-124650

Falgout, R., S. Ashby, W. Bosl, S. Smith, A. Tompson, T. Williams, "A Numerical Simulation of Groundwater and Contaminant Transport on the Cray T3D Supercomputer", *The International Journal of High Performance Computer Applications*, in press.

Bosl, William J., "Modeling Groundwater Flow and Contaminant Transport on Massively Parallel Computers" in Koniges, Alice, editor, *Parallel Computing for Industrial and Scientific Applications*, to be published by Morgan Kaufmann; expected to be available in spring 1999.

Andrea Donnellan

Current Position

Research Scientist, Satellite Geodesy and Geodynamics Systems Group, Jet Propulsion Laboratory (1993–present)

Education

Ph.D., Geophysics, California Institute of Technology (1991)
M.S., Geophysics, California Institute of Technology (1988)
B. S., Geology, Ohio State University, *with honors and distinction in geology* (1986)

Postgraduate Professional History

Research Scientist (1997–present), Member of Technical Staff (1993–1997), Satellite Geodesy and Geodynamics Systems Group, Jet Propulsion Laboratory
Visiting Associate, Seismological Laboratory, California Institute of Technology, (1995–1996)
National Research Council Resident Research Associate, NASA Goddard Space Flight Center (1991–1993)
Graduate Research Assistant, California Institute of Technology (1986–1991)
Research Assistant, Institute of Polar Studies, Ohio State University (1983–1986)
Geochemistry Group, Sohio Research and Development (1985)
Thin Section Laboratory Technician, Ohio State University (1983)

Recent Honors

Southern California Earthquake Center Outreach award for Education (1998)
Presidential Early Career Award for Scientists and Engineers (1996)
National Research Council Postdoctoral Fellowship (1991–1993)

Relevant Experience

SCEC Crustal Deformation Working Group (1993–present)
S. Cal. Integrated GPS Network (SCIGN) Coordinating Committee and related sub-committees (1994–1998)
UNAVCO Field Operations Working Group, Chair (1995–1997)

Developing a fully three-dimensional viscoelastic finite element code for studying fault interactions. In collaboration with Worcester Polytechnic Institute, UC Davis, and other JPL researchers.

Collect and model GPS data from the Northridge earthquake region, Ventura basin and Antarctica.

Collection and interpretation of GPS data to study crustal deformation and the earthquake cycle.

Five Related References

Donnellan, A. and G. A. Lyzenga, Fault afterslip and upper crustal relaxation following the Northridge earthquake, *J. Geophys. Res.*, **103**, 21,285–21,297.

Donnellan, A. and F.H. Webb, Geodetic observations of the M 5.1 January 29, 1994 Northridge aftershock, *Geophys. Res. Lett.*, **25**, 667–670, 1998.

Heflin, M.B., D. Dauger, D. Dong, A. Donnellan, K. Hurst, D. Jefferson, G. Lyzenga, M. Watkins, F. Webb, J. Zumberge, Rate change observed at JPLM after the Northridge earthquake, *Geophys. Res. Lett.*, **25**, 93–96, 1998.

Bawden, G., A. Donnellan, L. Kellogg, D. Dong, J. Rundle, Geodetic measurements of seven decades of hortizontal strain near the White Wolf fault, Kern County California: I. Observations, *J. Geophys. Res.*, **102**, 4957–4976, 1997.

Hudnut, K. W. , Z. Shen, M. Murray, S. McClusky, R. King, T. Herring, B. Hager, Y. Feng, P. Fang, A. Donnellan and Y. Bock, Co-Seismic Displacements of the 1994 Northridge, California, Earthquake, *Bull. Seism. Soc. Am.*, **86**, S19–S36, 1996.

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Professional Employment

1985-Present	Associate Professor (tenured), Department of Electrical, Computer and Systems Engineering, College of Engineering, Boston University.
1979-1985	Assistant Professor, Department of Physics and Center for Theoretical Physics, Massachusetts Institute of Technology
1976-1978	Post-Doctoral Fellow, Center for Theoretical Physics, Massachusetts Institute of Technology.
1975-1976	Post-Doctoral Fellow, Theoretical Physics Group, Stanford Linear Accelerator Center (SLAC)

Education

Ph.D.,	Physics	Stanford University, 1975
M.S.,	Physics	Stanford University, 1973
B.A. Honors,	Physics	University of Chicago, 1970

Professional Activities

Team Leader for Education, Outreach, & Training Partnership for Advanced Computational Infrastructure (http://www.eot.org) , National Computational Science Alliance Executive Committee, 1997-present.
Member, National Research Council NIST Assessment Board, Panel for Information Technology (NIST), 1997-present
Member, NSF-EHR Special Emphasis Panel on Evaluation, 1997-present
Member, Advisory Committee, DOE Computational Science and Engineering Graduate Fellowships Program, 1996-present
Deputy Director, Center for Computational Science, 1992–present.
Member, External Advisory Committee, NSF/ARPA Graphics and Visualization Center, 1996-present
Member, Boston Public Schools Technology Planning Committee Advisory Board, 1995-present
Member, Boston Museum of Science Program Advisory Committee, 1995-Present
Co-Chair for SC97 Education Program, SC97 Conference Executive Committee, 1995-97.
Member, Board of Directors, Fayerweather Street School, 1988-1995
Associate Chairman, Department of Electrical, Computer, and Systems Engineering, Boston University, 1993-1995.
Advisory Board Member, Computational Science Education Project, 1994-1995
Member, Organizing Committee for "Workshop on Increasing the Participation of Minorities in Computing Disciplines", 1995.
Member, American Physical Society
Member, Sigma Xi
Member, Phi Beta Kappa
Member, Society for Industrial and Applied Mathematics

Selected Publications

Daniel Reed, Roscoe Giles, Charles Catlett. "Distributed Data and Immersive Collaboration", Comm. ACM. **40**, p 39, 1997.

Elizabeth R. Jessup, Roscoe C. Giles, "Teach Computing in Context," Computational Science & Engineering, **3**, Fall 1996, p54.

Beazley, Lomhdal, Gronbech-Jensen, Giles, and Tamayo, "Parallel Algorithms for Short Range Molecular Dynamics," Annual Reviews in Computational Phyiscs, **3**, 1995.

H. Fu, R. Giles, M. Mansuripur, "Coercivity Mechanisms in Magneto-Optical Recording Media," Computers in Physics, 8, 80 (1994).

R. Giles, P.S. Alexopoulos, and M. Mansuripur, “Micromagnetics of Thin Film Cobalt-Based Media for Magnetic Recording,” Computers in Physics, 6, 53 (1992).

HIROO KANAMORI

Born - 17 October 1936
Japan (Japanese citizen)

Address:
Seismological Laboratory, California Institute of Technology, Pasadena California 91125
Telephone: (626) 395 6914, FAX: (626) 564-0715, E-mail: hiroo@gps.caltech.edu

Education:
B. S. (Physics), Tokyo University, 1959
M. S. (Geophysics), Tokyo University, 1961
Ph.D. (Geophysics), Tokyo University, 1964

Professional Experience:
Research Associate, Geophysics Institute, Tokyo University, 1962-65
Research Fellow, California Institute of Technology, 1965-66
Associate Professor, Earthquake Research Institute, Tokyo University, 1966-69
Visiting Associate Professor, Massachusetts Institute of Technology, 1969
Professor, Earthquake Research Institute, Tokyo University, 1970-72
Professor, California Institute of Technology, 1972-89
John E. and Hazel S. Smits Professorship of Geophysics, 1989-
Director, Seismological Laboratory, California Institute of Technology, 1990-April, 1998

Awards
Medal of the Seismological Society of America, 1992
Arthur L. Day Prize and Lectureship, U.S. National Academy of Science, 1993
California Scientist of the Year Award, 1993
The Asahi Prize, 1993.
Walter H. Bucher Medal, American Geophysical Union, 1996.

Relevant Publications
Kanamori, H., and M. Kikuchi, The 1992 Nicaragua Earthquake: a slow tsunami earthquake associated with subducted sediments, Nature, 361, 714-716, 1993.

Kanamori, H., J. Mori, E. Hauksson, T. H. Heaton, L. K. Hutton and L. M. Jones, 1993, Determination of Earthquake Energy Release and ML Using TERRAscope, Bull. Seismol. Soc. Am., 83, 330-346, 1993.

Mori, J., and H. Kanamori, Initial rupture of earthquakes in the 1955 Ridgecrest, California sequence, Geophys. Res. Lett., 23, 2437-2440, 1996.

Sturtevant, B., H. Kanamori, and E. Brodsky, Seismic triggering by rectified diffusion in geothermal systems, J. Geophys. Res., submitted 1996.

Kanamori, H., D. L. Anderson, and T. H. Heaton, Frictional Melting During Faulting, Science, 279, 839-842, 1998.

WILLIAM KLEIN

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Department of Physics
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PERSONAL
Born, April 1, 1943, Philadelphia, Pa. ; married, two children.

EDUCATION
Ph.D., Temple University 1972, Physics
B.A., Temple University 1965, Physics

RECENT POSITIONS
Professor of Physics, Boston University, Sept. 1984-
Professor, College of Engineering, Boston University, January, 1992 --
External Researcher, Santa Fe Institute, January, 1996--
Visiting Scientist, Lawrence Livermore Laboratory, Sept. 1,1990 –July, 1993
Visiting Professor, McGill University, January 1, 1987--December 31, 1989

PUBLICATIONS
[1] J. Rundle and W. Klein, ``Scaling and Critical Phenomena in a Class of Burridge-Knopoff Models for Earthquakes'', J. Stat. Phys., 72} 405 (1993).

[2] J. B. Rundle and W. Klein, ``Dynamical Segmentation and Rupture Patterns in a `Toy' Slider Block Model for Earthquakes'', Non-Linear Proc. in Geophys., 2, 61 (1995).

[3] W. Klein, J. B. Rundle and C. D. Ferguson, ``Critical Phenomena and Metastability in Models of Earthquake Faults'', Phys. Rev. Lett., 78, 3793 (1997).

[4] J. B. Rundle, E. Preston, S. McGinnis and W. Klein, ``Why Earthquakes Stop: Growth and Arrest in Stochastic Fields'', Phys. Rev. Lett., 80, 5698 (1998).

[5] C. F. Ferguson, W. Klein and J. R. Rundle ``Spinodals, Scaling and Ergodicity in a Model of an Earthquake Fault with Long-Range Stress Transfer'', Phys. Rev., (submitted for publication).

Biographical Sketch: Jean-Bernard Minster

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1994-Present: Professor of Geophysics, Director, Systemwide, Institute of Geophysics and Planetary Physics
1995-present: Member, Committee on Environmental and Geophysical Data, National Research Council.
1993-present: Member, National Research Council Board on Earth Sciences and Resources
1990-present: Member, Board of Directors, Southern California Earthquake Center

Professional Associations & Memberships: American Geophysical Union, European Geophysical Union, Royal Astronomical Society, Seismological Society of America, Society of Exploration Geophysicists, European Geophysical Society, American Association for the Advancement of Science

Education
Ph.D., Geophysics, California Institute of Technology, 1974
Doctorat d'État : Géophysique, Université de Paris VII, 1974

5 Publications Related to the Proposed Project:

Baker, G.E., J.B. Minster, G. Zandt, and H. Gurrola, Constraints on crustal structure and complex Moho topography beneath Piñon Flat, California, from teleseismic receiver functions, *Bull. Seismol. Soc. Amer.*, 86, 1830-1844, 1996.
Shkoller, S. and J. B. Minster, Reduction of Dietrich-Ruina attractors to unimodal maps, *Nonlinear Processes in Geophysics*, **4**, 63-69, 1997.
Xu, H., S. M. Day and J. B. Minster, Model for nonlinear wave propagation derived from rock hysteresis measurements, *J. Geophys. Res.*, **submitted**, 1998.
Hofton, M. A., J. B. Blair, J.-B. Minster, J. R. Ridgway, N. P. Williams, J. L. Bufton and D. L. Rabine, An airborne topographic survey of Long Valley Caldera, CA, 1995, using scanning laser altimetry, *Int. J. Remote Sensing*, **submitted**, 1998.
Calais, E. and J.-B. Minster, GPS, earthquakes, the ionosphere, and the space shuttle, *Physics of the Earth and Planetary Interiors*, **105**, 167-181, 1998.

John K. Salmon

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Education

Ph.D. Physics: California Institute of Technology, 1991
M.S. Physics: U.C. Berkeley, 1983
B.S. Physics: Massachusetts Institute of Technology, 1981
B.S. EECS: Massachusetts Institute of Technology, 1981

Experience

Senior Scientist, Center for Advanced Computing Research, California Institute of Technology,
1994 to present
Visiting Fellow, Australian National University, 1994-1995
Post-doctoral Research Fellow, California Institute of Technology, 1991-1994

Fellowships and Awards

Gordon Bell Prize for Achievement in Large Scale Scientific Computing, 1998
Two Gordon Bell Prizes for Achievement in Large Scale Scientific Computing, 1997
Intel Grand Challenge Computing Award, 1992
Gordon Bell Prize for Achievement in Large Scale Scientific Computing, 1992

Related publications

1. John K. Salmon and Michael S. Warren. Parallel out-of-core mtehods for N-body simulation. In Michael Heath, Virginia Torczon, et al., editors, *Eighth SIAM Conference on Parallel Processing for Scientific Computing*. SIAM, 1997.
2. Gregoire S. Winckelmans, John K. Salmon, Anthony Leonard, and Michael S. Warren. Three-dimensional vortex particle and panel methods: fast tree-code solvers with active error control for arbitrary distributions/geometrics. In *Forum on Vortex Methods for Engineering Applications*, pages 23-43, 1995.
3. Michael S. Warren and John K. Salmon. A portable parallel particle program. *Computer Physics Communications*, 87, 1995. Special issue on particle methods.
4. Michael S. Warren and John K. Salmon. A parallel hashed oct-tree N-body algorithm. In *Supercomputing '93*, pages 12-21, Los Alamitos, 1993. IEEE Comp. Soc.
5. John K. Salmon and Michael S. Warren. Skeletons from the tree-code closet. Journal of Computational Physics, 111 (1): 136:155, 1994.

Charles G. Sammis

Present Position: Professor of Geological and Materials Sciences, University of Southern California

Visiting Professor, University College London

Born: 1944, Huntington, New York

Education:

Brown University, Sc. B. (Cum Laude, with honors in Physics) 1965
California Institute of Technology, M.S. (Geophysics) 1968
California Institute of Technology, Ph.D., 1971

Previous Positions:

N.A.T.O. Postdoctoral Fellow in the School of Theoretical Chemistry at the University of Bristol, 1971-72
Assistant Professor of Geophysics, Department of Geosciences, The Pennsylvania State University, 1972-75
Associate Professor of Geophysics, Department of Geosciences, The Pennsylvania State University, 1975-77
Associate Professor of Geophysics, Department of Geological Sciences, University of Southern California, 1977-1987
Professor, Department of Geological Sciences, University of Southern California, 1987-

Academic Awards:

United Aircraft Scholarship, Brown University, 1961-1965.
Title IV Fellowship, Caltech, 1966-1970.
N.E.R.C. Visiting Scientist Fellowship, Cambridge, 1983-1984.
Burlington Resources Foundation Faculty Research Award, 1991.
USC Associates Award for Excellence in Teaching, 1994.

Recent Related Publications

Huang, Y., H. Saleur, C. Sammis, and D. Sornette, Precursors, aftershocks, criticality and self-organized criticality, Europhys. Letters , 41, 43-48, 1998.

Bowman, D.D., G. Ouillon, C.G. Sammis, A. Sornette, and D. Sornette, An observational test of the critical earthquake concept, J.Geophys. Res., in press, 1998.

Sammis, C.G., R.M. Nadeau, and L.R. Johnson, How strong is an asperity?, submitted to J. Geophys Res., 1998.

Saleur, H., C.G. Sammis, and D. Sornette, Discrete scale invariance, complex fractal dimensions, and log-periodic fluctuations in seismicity, J. Geophys. Res., 101, 17,661-17,677, 1996.

Robertson, M.C., C.G. Sammis, M. Sahimi, and A. Martin, The 3-D spatial distribution of earthquakes in southern California with a percolation theory interpretation, J. Geophys. Res., 100, 609-620, 1995.

BRUCE E. SHAW

Lamont-Doherty Earth Observatory of Columbia University
Palisades, NY 10965
914 365-8380
shaw@ldeo.columbia.edu

Bruce E. Shaw received his A.B. in Physics from the University of California Berkeley in 1984. Awards there included a UC Berkeley Alumni Scholarship from 1980-84, a Summer Research Fellowship in Geology and Geophysics at Yale University in 1983, with a graduation at Magna Cum Laude with Phi Beta Kappa honors. He received his Ph.D. in Physics from the University of Chicago in 1989 under the supervision of Prof. Leo P. Kadanoff. His thesis, "Universality in Selection with Local Perturbations in the Saffman-Taylor Problem" [B. E. Shaw, Physical Review A, 40, 5875-5895, 1989], was a problem in the field of pattern formation. His general research area was Nonlinear Dynamics. In 1989 he joined the Institute for Theoretical Physics at the University of California Santa Barbara as a Postdoctoral Fellow. There, he began working on problems involving the dynamics of earthquakes with Prof. James S. Langer. In 1993 he moved to the Lamont-Doherty Earth Observatory of Columbia University to pursue his interests in the Earth Sciences. He began there as a Postdoctoral Research Scientist, and was appointed an Associate Research Scientist beginning in 1995. He was awarded the Storke-Doherty Lectureship by the Department of Geological Sciences and Lamont in 1995. He is currently acting as a research advisor to Chrysanthe Spyropolous; she is a fourth-year graduate student in Professor Chris Scholz's group. His collaborators in the past 48 months are: G. C. Beroza, J. M. Carlson, C. R. Myers, J. S. Langer, S. L. Pepke, and D. P. Schaff.

Five Most Relevant Publications:

Bruce E.Shaw, Jean M. Carlson, and James S. Langer, Patterns of Seismic Activity Preceding Large Earthquakes, Journal of Geophysical Research, 97, 479-88, 1992.

Bruce E. Shaw, Moment Spectra in a Simple Model of an Earthquake Fault, Geophysical Research Letters, 30, 643, 1993a.

Bruce E. Shaw, Generalized Omori Law for Aftershocks and Foreshocks from a Simple Dynamics, Geophysical Research Letters, 30, 907, 1993b.

Bruce E. Shaw, Frictional Weakening and Slip Complexity on Earthquake Faults, Journal of Geophysical Research, 100, 18239, 1995.

Bruce E. Shaw, Modelquakes in the two dimensional wave equation, Journal of Geophysical Research, 102, 27367, 1997.

Donald L. Turcotte

Donald L. Turcotte is the Maxwell Upson Professor of Engineering in the Department of Geological Sciences, Cornell University, Ithaca, New York. He received B.S. and Ph. D. degrees from Caltech in 1954 and 1958 respectively and has been on the Faculty of Cornell University since 1959. He is author or co-author of 4 books and 251 papers. He is a member of the National Academy of Sciences and the American Academy of Arts and Sciences and has received the Day Medal of the Geological Society of America, the Wegener Medal of European Union of Geosciences, the Whitten Medal of the American Geophysical Union, and the Regents (New York State) Medal of Excellence.

Turcotte has actively worked on fractals, chaos, self-organized criticality, and related topics for 15 years. His book (D.L. Turcotte, Fractals and Chaos in Geology and Geophysics, 2nd ed., Cambridge University Press, 1997) is the primary textbook and reference work in this area in the earth sciences. Recently he has also applied concepts of complexity to a variety of natural hazards including earthquakes, floods, forest fires, and landslides.

Five related publications:

B. Barriere and D.L. Turcotte, Seismicity and self-organized criticality, Phys. Rev. E49, 1151-1160, (1994).

W.I. Newman, D.L. Turcotte, and A.M. Gabrielov, Log-periodic behavior of a hierarchical failure model with applications to precursory seismic activation, Phys. Rev. E52, 4827-4835, (1995).

D.L. Turcotte, Eathquakes, fracture, complexity, in Nonlinear Analysis of Fracture, J.R. Willis, ed., Pp. 163-175, Kluwer, Dordecht, 1997.

J.D. Morgan, D.L. Turcotte, and J.R. Ockendon, Models for earthquake rupture propagation, Tectonophys., 277, 209-217 (1997).

G. Morein, D.L. Turcotte, and A. Gabrielov, Statistical mechanics of distributed seismicity, Geophys. J. Int.., 131, 552-558 (1997).

Steven Neal Ward

Present Position:

Research Geophysicist
Institute of Tectonics
University of California
Santa Cruz, CA 95064
(831) 459-2480: FAX- (831) 459-3074: email- ward@uplift.ucsc.edu

Education:

B.S.,	Physics, 1974	Bucknell University, Lewisburg, Pennsylvania
M.A.,	Geophysics, 1976	Princeton University, Princeton, New Jersey
Ph.D.,	Geophysics, 1978	Princeton University, Princeton, New Jersey

Recent Experience:

7/86-Present	Research Geophysicist
1/84-6/86	Associate Research Geophysicist, University of California, Santa Cruz

Publications (5 most relevant to GEM):

Ward, S. N., 1994. A Multidisciplinary Approach to Seismic Hazard in Southern California, *Bull. Seism. Soc. Am., 84*, 1293-1309.

Ward, S. N., 1996. A synthetic seismicity model for southern California: Cycles, Probabilities, Hazards, *J. Geophys. Res., 101*, 22,393-22,418.

Ward, S. N., 1997. Dogtails versus Rainbows: Synthetic earthquake rupture models as an aid in interpreting geological data, *Bull. Seism. Soc. Am.*, *87*, 1422-1441.

Ward, S. N., 1998. On the consistency of earthquake rates, geological fault data, and space geodetic strain: The United States, *Geophys. Jour. Int.*, *134* , 172-186.

Ward, S. N., 1998. San Francisco Bay Area Earthquake Simulations: A step toward a Standard Physical Earthquake Model, *Bull. Seism. Soc. Am.*, submitted.

Bryant York

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Education:
Ph.D. University of Massachusetts - Amherst, Computer Science
M.S. University of Massachusetts - Amherst, Computer Science
S.M. Sloan School of Management, M.I.T., Management
A.B. Brandeis University, Waltham, MA, Mathematics

Professional Experience:
9/91--Present: Associate Professor and Research Director, College of Computer Science, Northeastern University,Boston, MA
9/90--9/91: Program Director, CISE/CDA, National Science Foundation, Washington, DC 20550
9/90--8/91: Visiting Research Scientist, Center for Computing and Applied Mathematics National Institute of Standards and Technology, Gaithersburg, MD 20899
1/86--8/91: Associate Professor (on leave 1990-91),Computer Science Department, Boston University, Boston, MA
6/84--1/86 Consulting Software Engineer, AI Technology Group, Digital Equipment Corporation, Hudson, MA
2/83--6/84 Principal Software Engineer, AI Technology Group, Digital Equipment Corporation, Hudson, MA
6/79--2/83 Research Staff member, Computer Science Dept,IBM Research Labs, San Jose, CA

Professional Societies: ACM, IEEE-CS, AAAI, AAAS, SIAM

Five Relevant Publications:

``The Ab-Initio Crystal Structure Solution of Proteins by Direct Methods. VI. Complete phasing up to derivative resolution.", C. Giacovazzo, D. Siliqi, J. Platas, H-J. Hecht, G. Zanotti, B. W. York, Acta Cryst., (1996). D 52. 813-825.

``On the Scalability of Parallel Triplet Generation for Protein Crystallography, S. Ramamurthy, B. W. York, and C. Giacovazzo, in Proc. of 1996 ACM Symposium on Experimental Computing and Applications Development (SAC 96), pp. 344-352, February 1996, Philadelphia.

``Constructing Permutation Representations for Matrix Groups", G. Cooperman, L. Finkelstein, M. Tselman, and B. W. York, Journal of Symbolic Computation, (1997), 24, 471-488.

``Matrix Inversion in O(log n) on a Scan-Enhanced Reconfigurable Mesh Computer", A. Moreira and B. W. York, in Proc. of 24th Annual ACM Computer Science Conference, pp. 67-75, February 1996, Philadelphia.

``A Parallel Multi-Grid Algorithm for Percolation Clusters", R. Brower, P. Tamayo, and B. York, Journal of Statistical Physics, vol. 63, no 1/2, pp. 73-88, April 1991.

SUMMARY PROPOSAL BUDGET

YEAR 1

ORGANIZATION				FOR NSF USE ONLY	
University of Southern California				PROPOSAL NO.	DURATION (months): Proposed / Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR				AWARD NO.	
Thomas L Henyey					

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Thomas L Henyey - none	0.00	0.00	0.00	$ 0	$
2. Yehuda Ben-Zion - Assistant Professor	0.00	0.00	3.00	18,000	
3. Geoffrey C Fox - none	0.00	0.00	0.00	0	
4. David D Jackson - none	0.00	0.00	0.00	0	
5. Thomas H Jordan - none	0.00	0.00	0.00	0	
6. (2) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	1.50	15,000	
7. (7) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	4.50	33,000	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (1) POST DOCTORAL ASSOCIATES	18.00	0.00	0.00	60,000	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (2) GRADUATE STUDENTS				120,000	
4. (3) UNDERGRADUATE STUDENTS				12,000	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (1) OTHER				36,000	
TOTAL SALARIES AND WAGES (A + B)				261,000	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				36,249	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				297,249	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				33,000	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 50,000 3. SUBSISTENCE 75,000 4. OTHER 25,000					
(100) TOTAL PARTICIPANT COSTS				150,000	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				5,072	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				20,000	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				30,000	
5. SUBAWARDS				2,120,000	
6. OTHER				0	
TOTAL OTHER DIRECT COSTS				2,175,072	
H. TOTAL DIRECT COSTS (A THROUGH G)				2,655,321	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) 63.5% of MTDC (Rate: 63.5000, Base: 385321)					
TOTAL INDIRECT COSTS (F&A)				244,678	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				2,899,999	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 2,899,999	$

M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $			
PI / PD TYPED NAME & SIGNATURE* Thomas L Henyey	DATE	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked	Date Of Rate Sheet	Initials - ORG

 *SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.B)

SUMMARY PROPOSAL BUDGET COMMENTS - Year 1

Other Senior Personnel

Name - Title	Cal	Acad	Sumr	Funds Requested
Rundle, John B - none	0.00	0.00	0.00	0
Sammis, Charles G - Professor	0.00	0.00	1.50	15000

SUMMARY PROPOSAL BUDGET — Cumulative

ORGANIZATION: **University of Southern California**			FOR NSF USE ONLY: PROPOSAL NO.	DURATION (months) Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR: **Thomas L Henyey**			AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Thomas L Henyey - none	0.00	0.00	0.00	$ 0	$
2. Yehuda Ben-Zion - Assistant Professor	0.00	0.00	3.00	18,000	
3. Geoffrey C Fox - none	0.00	0.00	0.00	0	
4. David D Jackson - none	0.00	0.00	0.00	0	
5. Thomas H Jordan - none	0.00	0.00	0.00	0	
6. (2) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	1.50	15,000	
7. (7) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	4.50	33,000	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (1) POST DOCTORAL ASSOCIATES	18.00	0.00	0.00	60,000	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (2) GRADUATE STUDENTS				120,000	
4. (3) UNDERGRADUATE STUDENTS				12,000	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (1) OTHER				36,000	
TOTAL SALARIES AND WAGES (A + B)				261,000	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				36,249	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				297,249	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				33,000	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ 0					
2. TRAVEL 50,000					
3. SUBSISTENCE 75,000					
4. OTHER 25,000					
(100) TOTAL PARTICIPANT COSTS				150,000	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				5,072	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				20,000	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				30,000	
5. SUBAWARDS				2,120,000	
6. OTHER				0	
TOTAL OTHER DIRECT COSTS				2,175,072	
H. TOTAL DIRECT COSTS (A THROUGH G)				2,655,321	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				244,678	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				2,899,999	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 2,899,999	$

M. COST SHARING PROPOSED LEVEL $ 0 AGREED LEVEL IF DIFFERENT $

PI / PD TYPED NAME & SIGNATURE*: **Thomas L Henyey**	DATE	FOR NSF USE ONLY — INDIRECT COST RATE VERIFICATION
ORG. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked / Date Of Rate Sheet / Initials - ORG

Budget Justification Page

This project will be managed by the Southern California Earthquake Center at the University of Southern California. Thomas L. Henyey, Director of SCEC, and David D. Jackson, Science Director of SCEC, will be Co-Principal Investigators along with John Rundle of the University of Colorado (head of the Modeling Group), Thomas Jordan of MIT (head of the Data Validation Group), and Geoffrey Fox of Syracuse (head of the Computational Methods Group).

The modeling group will include Rundle, Don Turcotte of Cornell, Yehuda Ben-Zion of USC, Steve Ward of UC-Santa Cruz, Bill Klein of Boston University, and Bruce Shaw of Columbia University.

The data validation group will include Jordan, Charles Sammis of USC, Andrea Donnellan of JPL/USC, and Hiroo Kanamori of Caltech.

The computational methods group will include Fox, Roscoe Giles of Boston College, York of Northeastern University, J. Bernard Minster of UC-San Diego, Bosl of Los Alamos National Laboratory, and John Salmon of Caltech.

USC will manage this project and conduct the workshops. USC participants will be assisted by a half-time post-doc, 2 graduate students, and 3 undergraduate assistants. The support of Ben-Zion, Sammis, Turcotte, Donnellan, Giles, and Bosl are included in the USC budget.

USC will subcontract to Colorado ($320K), UC-Santa Cruz ($150K), Boston College ($150K), Columbia ($150K), MIT ($300K), Caltech ($330K), Syracuse ($300K), Northeastern ($180K), and UC-San Diego ($240K).

At Colorado, MIT, UC-San Diego, and Syracuse, the PI's will be assisted by post-docs and graduate students. At UC-Santa Cruz and Columbia, the PI's will conduct most of the research. At Boston College, Caltech, and Northeastern, the PI's will be assisted mainly by graduate students.