Urgent Earthquake Insights

Philip Maechling
SCEC IT Architect
Urgent Computing Workshop
25 April 2007
Southern California Earthquake Center

- Involves 500+ scientists at 55 institutions worldwide
- Focuses on earthquake system science using Southern California as a natural laboratory
- Translates basic research into practical products for earthquake risk reduction
- Collaboration with IT Organizations accelerating SCEC science
**SCEC Member Institutions**  
*(October 1, 2005)*

### Core Institutions (15)

- California Institute of Technology
- Columbia University
- Harvard University
- Massachusetts Institute of Technology
- San Diego State University
- Stanford University
- U.S. Geological Survey, Golden
- U.S. Geological Survey, Menlo Park
- U.S. Geological Survey, Pasadena
- University of California, Los Angeles
- University of California, Riverside
- University of California, San Diego
- University of California, Santa Barbara
- University of Nevada, Reno
- University of Southern California (lead)

### Participating Institutions (40)

- Arizona State University
- Boston University
- Brown University
- Cal-State, Fullerton
- Cal-State, Northridge
- Cal-State, San Bernardino
- California Geological Survey
- Carnegie Mellon University
- Case Western Reserve University
- Central Washington University
- CICESE (Mexico)
- ETH (Switzerland)
- Institute of Earth Sciences of Academia Sinica (Taiwan)
- Institute of Geological and Nuclear Sciences (New Zealand)
- Jet Propulsion Laboratory
- Lawrence Livermore National Laboratory
- National Chung Cheng University (Taiwan)
- National Taiwan University (Taiwan)
- National Central University (Taiwan)
- Oregon State University
- Pennsylvania State University
- Rensselaer Polytechnic University
- Rice University
- SUNY Stony Brook
- Texas A&M University
- UC Berkeley
- UC, Davis
- UC, Irvine
- UC, Santa Cruz
- University of Colorado
- University of Kentucky
- University of Massachusetts
- University of New Mexico
- University of Oregon
- University of Utah
- University of Western Ontario (Canada)
- URS Corporation
- Utah State University
- Whittier College
- Woods Hole Oceanographic Institution

Foreign institutions highlighted in blue.
SCEC PetaSHA Project

Goal: Develop a petascale cyberfacility for physics-based seismic hazard analysis

Support: 2-yr project funded by the NSF-EAR


http://scecdatab.usc.edu/petasha
PetaSHA Geoscience Goals

Status:

• Grid resolution has restricted Pathway 2 simulations to low frequencies (< 0.5 Hz) and physical domains that are too small to model the largest ruptures

PetaSHA objectives:

1. Extend the upper frequency bound of ground-motion simulations from the current value of 0.5 Hz to 3 Hz
   • Investigate the upper frequency limit of deterministic ground-motion prediction by comparing the simulations with seismic data from Southern California earthquakes.

2. Extend the outer grid dimensions to 800 km x 400 km x 100 km
   • Investigate very large rupture scenarios, including “wall-to-wall” events on the southern San Andreas fault

3. Incorporate additional geologic complications; e.g., surface topography, non-planar faults, and nonlinear wave propagation effects
PetaSHA Milestone Simulations

Simulation Volumes

- **V1** Northridge domain
- **V2** PSHA site volume
- **V3** regional M7.7 domain
- **V4** regional M8.1 domain

<table>
<thead>
<tr>
<th>Milestone</th>
<th>Pathway</th>
<th>Outer Scale</th>
<th>Inner Scale</th>
<th>Complexity</th>
<th>Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1a</td>
<td>2</td>
<td>V1</td>
<td>3 Hz, 200 m/s</td>
<td>-</td>
<td>NV, D/S</td>
</tr>
<tr>
<td>M1b</td>
<td>2</td>
<td>V1</td>
<td>3 Hz, 200 m/s</td>
<td>T</td>
<td>NV, D/S, topographic effects</td>
</tr>
<tr>
<td>M2</td>
<td>3</td>
<td>M6.9</td>
<td>25 m</td>
<td>DF</td>
<td>NV, D/S, PD, DW</td>
</tr>
<tr>
<td>M3</td>
<td>2</td>
<td>V3</td>
<td>1 Hz, 200 m/s</td>
<td>-</td>
<td>Large-event hazard</td>
</tr>
<tr>
<td>M4</td>
<td>2</td>
<td>V2</td>
<td>0.5 Hz, 500 m/s</td>
<td>-</td>
<td>Los Angeles hazard map for NSHMP-2002</td>
</tr>
<tr>
<td>M5</td>
<td>3</td>
<td>M7.7</td>
<td>25 m</td>
<td>NP</td>
<td>Fault-system interactions, PD, DW</td>
</tr>
<tr>
<td>M6</td>
<td>2</td>
<td>V2</td>
<td>2 Hz, 200 m/s</td>
<td>-</td>
<td>Precarious-rock validation</td>
</tr>
<tr>
<td>M7</td>
<td>3</td>
<td>M7.7</td>
<td>10 m</td>
<td>-</td>
<td>DW</td>
</tr>
<tr>
<td>M8</td>
<td>2</td>
<td>V4</td>
<td>2 Hz, 200 m/s</td>
<td>T, NP</td>
<td>Large-event hazard</td>
</tr>
<tr>
<td>M9</td>
<td>2</td>
<td>V2</td>
<td>1 Hz, 200 m/s</td>
<td>T, NP</td>
<td>Los Angeles hazard map for WGCEP-2007</td>
</tr>
</tbody>
</table>

T=topography, DF=dipping fault, NP=non-planar faults, NV=Northridge validation, D/S= deterministic/stochastic transition, PD=pseudo-dynamic parameterization, DW=dynamic weakening
PetaSHA Milestone Simulations

<table>
<thead>
<tr>
<th>Simulation</th>
<th>Sustained Performance (TFLOP/s)</th>
<th>System Memory (TB)</th>
<th>Mass Storage (TB)</th>
<th>Number of Repetitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>TeraShake-1</td>
<td>0.04</td>
<td>0.25</td>
<td>43</td>
<td>4</td>
</tr>
<tr>
<td>Quake</td>
<td>1.2</td>
<td>2.5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>TeraShake-2</td>
<td>0.3</td>
<td>3.41</td>
<td>40</td>
<td>1</td>
</tr>
<tr>
<td>CyberShake</td>
<td>0.03</td>
<td>0.14</td>
<td>0.25</td>
<td>10</td>
</tr>
<tr>
<td>M1a</td>
<td>1.1</td>
<td>2.75</td>
<td>16,875</td>
<td>1</td>
</tr>
<tr>
<td>M1B</td>
<td>0.09</td>
<td>0.3</td>
<td>288</td>
<td>1</td>
</tr>
<tr>
<td>M2</td>
<td>0.22</td>
<td>0.8</td>
<td>4,600</td>
<td>1</td>
</tr>
<tr>
<td>M3</td>
<td>14.3</td>
<td>30.6</td>
<td>20,480</td>
<td>1</td>
</tr>
<tr>
<td>M4</td>
<td>0.09</td>
<td>0.14</td>
<td>1.25</td>
<td>1000</td>
</tr>
<tr>
<td>M5</td>
<td>22.8</td>
<td>24.5</td>
<td>4,000</td>
<td>1</td>
</tr>
<tr>
<td>M6</td>
<td>91.5</td>
<td>18.4</td>
<td>200</td>
<td>10</td>
</tr>
<tr>
<td>M7</td>
<td>365</td>
<td>19.6</td>
<td>32,000</td>
<td>1</td>
</tr>
<tr>
<td>M8</td>
<td>609</td>
<td>54.4</td>
<td>106,666</td>
<td>1</td>
</tr>
<tr>
<td>M9</td>
<td>5.72</td>
<td>17.6</td>
<td>12.8</td>
<td>1000</td>
</tr>
</tbody>
</table>
One Week of Earthquakes in California

SCEC research program is active regardless of Calif. Seismicity.

Urgent Computing could improve the information SCEC provides after the next large California Earthquake
Earthquake research makes key distinction between emergency response and urgent insights.

Earthquake emergency response is responsibility of seismic network operators (California Integrated Seismic Network (UCB, Caltech, USGS), ANSS, NEIC. They must answer to California Office of Emergency Services and FEMA (24x7x365 – etc)

Urgent Earthquake Insights are open to any research group and are in great demand after a significant event.
Example of “Not my Job….”
I believe TeraGrid Urgent Computing is better suited for serving the needs of researchers, such as SCEC, that produce urgent earthquake insights rather than earthquake emergency response groups.

SCEC Urgent Computing needs are not emergency response calculations.
Information about an Earthquake should improve with time.

**Seconds**

0 – Earthquake Starts  
20 – Earthquake location  
45 – preliminary magnitude  
60 – Radio and Television discussing earthquake  
120 – Publicly released magnitude  
360 – preliminary shaking map (ShakeMap)

**Hours**

0.5 - Television repeating available information and images  
1 – Fault identified  
1 – Stable magnitude  
6 – Improved ShakeMap  
12 – Slip distribution on fault
Summary of SCEC Urgent Computing Needs

1. Identification of the earthquake fault, source mechanism, and extended source description.

2. Simulation-based ground motion maps to augment the observations from the seismic networks,

3. Provide detailed scientific and public information when interest is high right after a large event.
Observed Areas of Strong Ground Motion

CISN Rapid Instrumental Intensity Map
Epicenter: 5.6 mi ESE of Anza, CA
Sun Jun 12, 2005 08:41:46 AM PDT
M 5.2, N 33.53, W 115.58, Depth: 14.1 km
ID: 14151344

Processed: Mon Jun 13, 2005 04:03:26 PM PDT
### Earthworks Science Gateway

#### SCEC Earthworks Science Gateway Portal for Configuring a Pathway 2 Simulation (Joanna Muench, Hunter Francoeur, David Okaya et al)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epicenter Latitude</td>
<td>34.3033</td>
</tr>
<tr>
<td>Epicenter Longitude</td>
<td>-118.577</td>
</tr>
<tr>
<td>Epicenter Depth (km)</td>
<td>4.0</td>
</tr>
<tr>
<td>Event Magnitude</td>
<td>5.1</td>
</tr>
<tr>
<td>Event Strike</td>
<td>330.0</td>
</tr>
<tr>
<td>Event Dip</td>
<td>80.0</td>
</tr>
<tr>
<td>Event Rake</td>
<td>-20.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Region Origin Latitude</td>
<td>34.25</td>
</tr>
<tr>
<td>Region Origin Longitude</td>
<td>-118.6</td>
</tr>
<tr>
<td>Region Depth Shallow</td>
<td>0.0</td>
</tr>
<tr>
<td>Region Depth Deep</td>
<td>5000.0</td>
</tr>
<tr>
<td>Region Length East</td>
<td>10.0</td>
</tr>
<tr>
<td>Region Length North</td>
<td>10.0</td>
</tr>
<tr>
<td>Surface Definition</td>
<td>bykm</td>
</tr>
<tr>
<td>Velocity Model</td>
<td>cvm3.0</td>
</tr>
</tbody>
</table>
SCEC Earthworks Science Gateway Portal for Configuring a Pathway 2 Simulation (Joanna Muench, Hunter Francoeur, David Okaya et al)
Earthworks Point Source Simulation

Hollywood EQ
Mw 4.23, 6.98 depth
24x24x12 km region
(160x160x80 nodes)
~2M mesh points
(Δx=150 m)

CVM 3.0
Conceptual SCEC Urgent Computing Workflow

- Retrieve Data
- Slip Calculation
- Wave Propagation
- High Frequencies
- Synthetic Seismograms
- Structure Models
- Visualization
- Maps/Movies
- N=50
- N=1
- N=100
- N=100K
Frequency of Simulations – Duplicating ShakeMaps

While the number of events can be highly variable (especially if a large event occurs), we will use an approximate average of 40 events as our estimate of the number of earthquake – (79 in 1999, 29 in 2000, 18 in 2001, 24 in 2001, 27 in 2003, 21 in 2004, 34 in 2005).

SU estimates for small scale Wave Propagation simulation is: 1500 x 750 x 200 (225 million points) mesh with 12000 time steps (2 minutes rupture time) per simulation. (300km x 150km x 40km) = 1500 SU
SCEC Urgent Earthquake Insights Computational Scenario

1. Trigger on Mag 4.0 or larger Southern California Earthquake
2. Combine observed seismograms with pre-calculated Receiver Green Tensors. Determine a fault plane and magnitude and slip distribution (due in 10 minutes)
3. Use Source Description to calculate a wave propagation simulation (due in 30 minutes)
4. Output synthetic ShakeMap and simple animation (due in 1 hour)
5. Calculate stochastic high frequencies for seismograms (due in 2 hours)
6. Calculate structural response using observed and synthetics seismograms (due in 3 hours)
7. Create “broadband” maps and detailed animations (due in 6 hours)
Urgent Earthquake Insights Computational Scenario

Goal: Combine observed seismograms with pre-calculated Receiver Green Tensors. Determine a fault plane and magnitude and slip distribution.

1. Retrieve observed seismograms from data center (available 10 minutes after event) (~10MB).
2. Select RGT’s for 10 closest stations and move onto a TeraGrid accessible disk. (Each RGT is approximately 100 GB for 1 TB total out of 100TB total archive)
3. Run short parameter sweep simulations for each site (1 SU per site for total 10 SUs).
4. Output is 1M ASCII file.
Urgently Needed Insight is Specification of Earthquake Rupture
Urgently Needed Insight is Specification of Earthquake Rupture

- Isotropic Point Source (IPS)
- Centroid Moment Tensor (CMT)
- Finite Moment Tensor (FMT)
- Fault Slip Distribution (FSD)

Number of parameters:
- IPS: (5)
- CMT: (8-10)
- FMT: (14-20)
- FSD: (>100)
Earthquake Slip on Fault Distribution
Urgent Earthquake Insights Computational Scenario

Goal: Use Source Description to calculate a wave propagation simulation (~30 minutes)

- Generate a 225M mesh point velocity Mesh (100 SU (0.5 Hz) soon 800 SU’s (1.0Hz))
- Configure and run a 300km x 150km x 40km wave propagation simulation using source calculated earlier (Currently 1500 SU’s (0.5Hz) soon 24000 SU’s (1.0Hz))
- Output data sets (surface data only) - 100 GB (0.5Hz) soon 800GB (1.0Hz)
CMU Hercules TeraShake ~1Hz

Displacement

Velocity

65s

100s

150s

David O'Hallaron et al (CMU) Etree Mesh Representation
Jacobo Bielak et al (CMU) AWM
Goal: Output synthetic shakemap and simple animation (~1 hour). Synthetic ShakeMap could augment observed ShakeMap particularly if data sets were merged.

1. Once Seismograms are calculated, verification of synthetics is done (short jobs)
2. Maps are made (visualization Jobs)
Observed Red – Simulated Black
Synthetic Shakemap versus Observed (bottom)
Automated Maps and Visualization Techniques

TeraShake 1 Spectral Acceleration at 10 Seconds with Bump Mapping
(Amit Chourasia, Steve Cutchin, Kim Olsen)
Automated Animations and Map Visualization Techniques

Surface Cumulative Peak Velocity Magnitude (153 sec)

Simulation 2 (NW-SE)

Simulation 3 (SE-NW)

TeraShake 1 PGV (Amit Chourasia, Steve Cutchin, Kim Olsen)
Goal: Calculate stochastic high frequencies for seismograms (~2 hours)

- Requires 100K very short, independent jobs to add stochastic high frequencies to seismograms.
- Output is 100K binary files (10MB Total)
Puente Hills Simulation 10Hz
Puente Hills Simulation
Low Frequency – Point Source Simulation

Animation Credit: ShakeMovie - Caltech
Broadband Frequency – Extended Source Simulation

Animation Credit: Amit Chourasia – SDSC
Robert Graves – URS Corp
Urgent Earthquake Insights Computational Scenario

Goal Calculate structural response using observed and synthetics seismograms (~3 hours)

Idea is to use a Standard building and run seismograms into this building, capture response, and use the images for further animations.

- Processing requirements are something like 10K small standalone jobs with small data sets output (1MB each).
Animation Credit: Swami Krishnan - Caltech
Urgent Earthquake Insights Computational Scenario

Goal: Create “broadband” maps and detailed animations (~6 hours)

• Detailed, constructed animation for public release.
• Estimates of visualization processing are:
Integrated Visualizations
High Quality Visualization

Approximately 2000 SU’s per animation
TeraShake 2 Dynamic Rupture and Wave Propagation

Experimental Cross Sectional Viz for Terashake 2.1

Sliprate on vertical fault plane of 16 km scaled 4 times and surface velocity magnitude every 100th timestep (3600)

TeraShake 2 Animation with Narration showing Dynamic Rupture and Wave Propagation (Amit Chourasia, Kim Olsen, Yifeng Cui et al)
M_w 7.8 ‘ShakeOut’ Scenario  (Nov. 2008)

- San Andreas ‘Really Big One’ simulated earthquake
- Initiation near Bombay Beach (unilateral rupture to the NW)
- Slip of 4.5 meters at Cajon Pass (I-15); disruption of critical lifeline infrastructure (freeway, internet, power and gas lines)
- Basic description sent out via OES statewide and announced at SoSAFE workshop Jan. 9, 2007
- Developments needed:
  - Earthquake Early Warning
    - Zipper array along fault
    - Lifeline crossings
  - Building Damage Assessment
    - DamageMap

Credit: Nitin Gupta, OpenSHA & Ned Field, USGS
TeraShake Code Strong Scaling on IBM Blue Gene at Watson
2048^3-100m, PS-150m (5312x2656x520), and PS-100m (8000x4000x1000)

Number of processors vs. Wall clock time (sec) per time step

Yifeng Cui, SDSC
F’06 AGU

32,000 processors
Urgent Earthquake Insights Computational Scenario

Future Directions - Large Scale 1Hz Simulation in Large Region (Summer 2007):

- 600K SUs per simulation
- 100 TB output data