Rupture Dynamics Code Validation 2009 Workshop
(SCEC Project 09154)
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Final Report
Submitted by Ruth Harris to SCEC
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The 2009 SCEC Code Validation workshop was held at the Kellogg West Conference Center in Pomona, California on November 20, 2009. Thirty-six people attended, including ten graduate students, seven postdoctoral researchers, and outstanding SCEC meeting planner, Tran Huynh (see Table 1). Approximately one-third of the attendees were students or junior researchers who are new to, or who have just recently joined, our group and workshops. There were six invited speakers (Table 2 shows the agenda). We started our invited research presentations with a senior, world-famous scientist discussing Extreme Ground motion simulations, and ended our invited research presentations with a graduate student pointing us to new directions in which we hope to travel in 2010. By the end of the day, it appeared that everyone had benefited from the range of expertise and ease of discussion and learning afforded by this SCEC workshop setting.

The workshop started with an overview of our efforts, then led into presentations and discussions of the 2009 rupture dynamics code comparison benchmarks (please see our website http://scecdata.usc.edu/cvws for the exact details of the benchmarks and results), The Problems Version 12 and 13, and 205 and 210. TPV12 and 13 were designed to show whether or not Joe Andrews simulations of Extreme Ground Motion at the proposed Yucca Mountain Nuclear Waste Repository, that Joe published in the paper Andrews, Hanks, and Whitney, BSSA, 2007, were repeatable. TPV12 and 13 were simplifications of the Andrews et al. (2007) simulations, but still retained many of the main characteristics, including supershear, complete stress-drop events, that maximize ground motion. TPV12 was a warm-up simulation for TPV13, in that TPV12 was the elastic case, whereas TPV13 invoked plastic yielding. Both benchmarks were conducted by modelers in both 2D and 3D, so as to fully include cases where codes could handle just one, or both situations. The original Andrews et al. (2007) simulations were conducted in 2D, so for TPV12 and TPV13, Joe Andrews also just performed the 2D simulations.

Overall, there was good agreement among many codes. Joe showed that the 2D simulations generally produce larger ground motions than the 3D simulations. He also showed that dynamic rupture simulations that include plastic yielding reduce the ground motions compared to simulations that assume dynamic rupture in an elastic halfspace. Readers of this report who are interested in more details of the TPV12 and TPV13 simulations are referred to our website http://scecdata.usc.edu/cvws. **Figure 1** shows the setting of the repository (from Andrews et al., 2007), and a sketch of our TPV12 and TPV13 fault models**. Figure 2** shows a comparison of the (filtered) vertical ground motion at a repository station in a) the 2D model and b) the 3D model, for elastic benchmark TPV12; **Figure 3** shows a comparison of the (filtered) vertical ground motion at a repository station in a) the 2D model and b) the 3D model, for plastic (inelastic) benchmark TPV13. The 3D elastic model (TPV12b) and the 2D and 3D inelastic yielding models (TPV13a,b) produce lower ground motions than those produced by the 2D elastic model (TPV12a) at the repository site, with the minimum produced by the inelastic 3D simulation.

Figure 1.
Top) Geological setting of the repository region (figure 7 from Andrews et al., 2007), with the dashed area indicated the repository site.
Bottom) a sketch of the fault model that we used for our 3D TPV12 and TPV13 benchmarks. Our 2D simulations used the centerline of the fault.

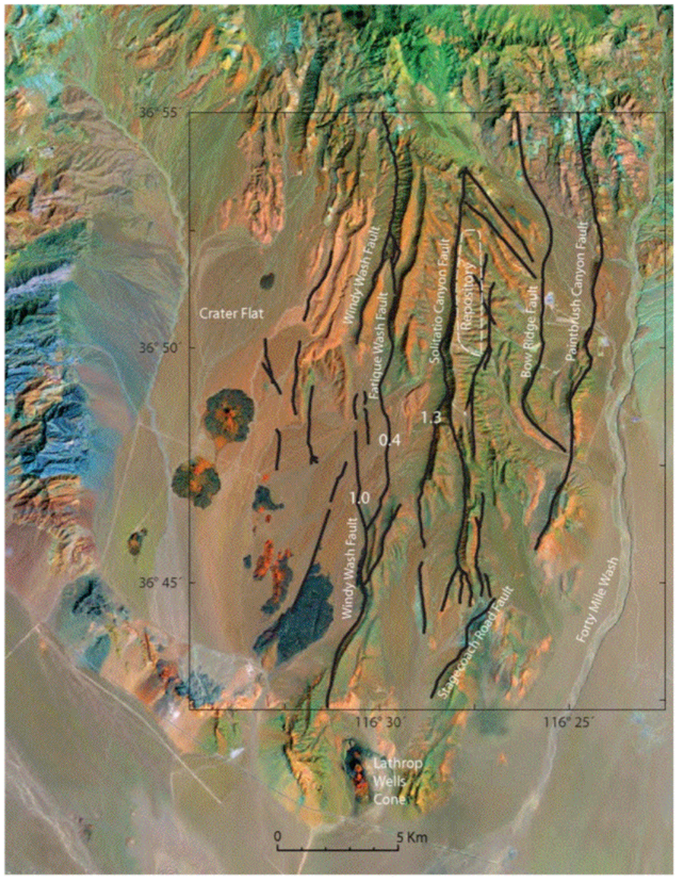

Figure 7. Color orthophoto map of the Yucca Mountain area with surface fault traces from figure 2 of Whitney, Taylor, and Menges, 2004 shown in the smaller boxed area. Numbers show locations of observed maximum-slip values of 1.3 m on the Solitario Canyon fault, 0.4 m on the Fatigue Wash fault, and 1.0 m on the Windy Wash fault at the time of the Lathrop Wells eruption. The footprint of the proposed repository is approximate.

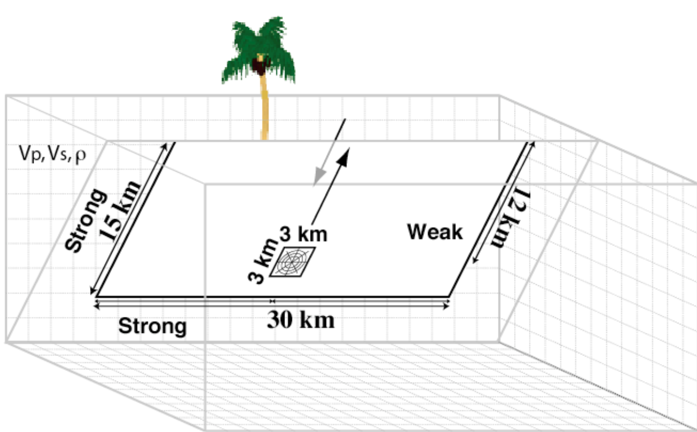

Figure 2.   Benchmark results - TPV12.
Elastic simulation, repository location (0 km along- strike, -1 km off-fault, 0.3 km deep).
100-m element size on the fault, lowpass Butterworth filter (2 poles, 2 passes) applied at 3 Hz.

Benchmark: tpv12-2d (2D Version of TPV12)

File: body-010st000dp003 (body -1.0 km, strike 0.0 km, depth 0.3 km)

Field: v-vel (vertical velocity)

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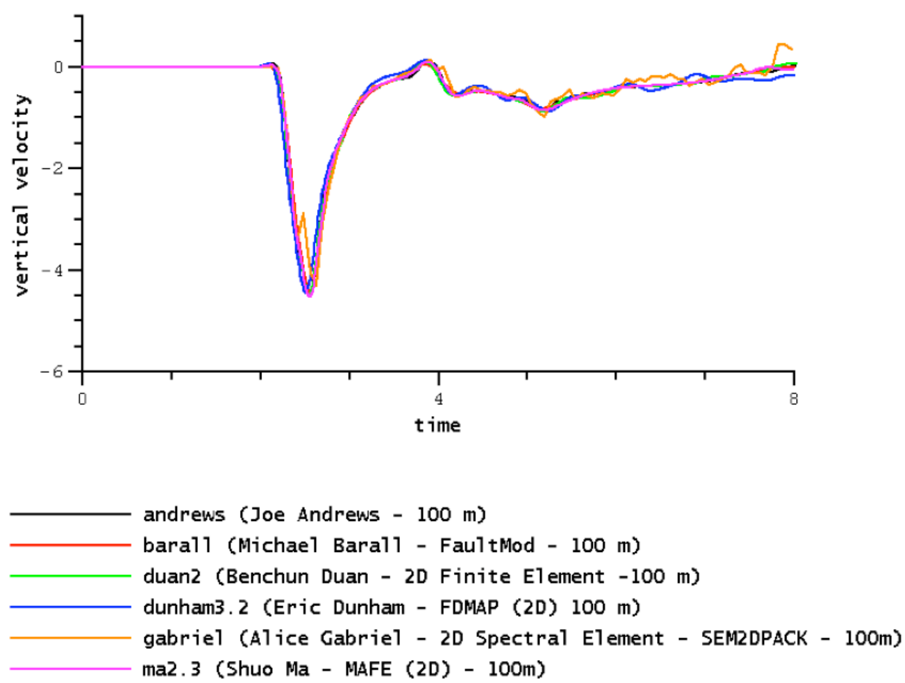

a) **2D** TPV12 - Elastic benchmark: Vertical velocity (m/s) vs. time (seconds)

Figure 2, continued.

Benchmark: tpv12 (The Problem, Version 12)

File: body-010st000dp003 (body -1.0 km, strike 0.0 km, depth 0.3 km)

Field: v-vel (vertical velocity)

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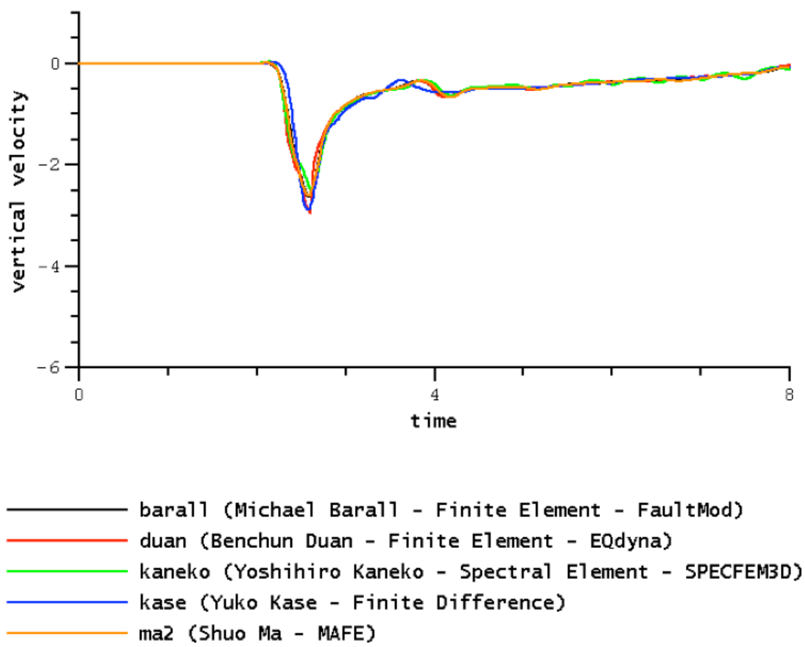
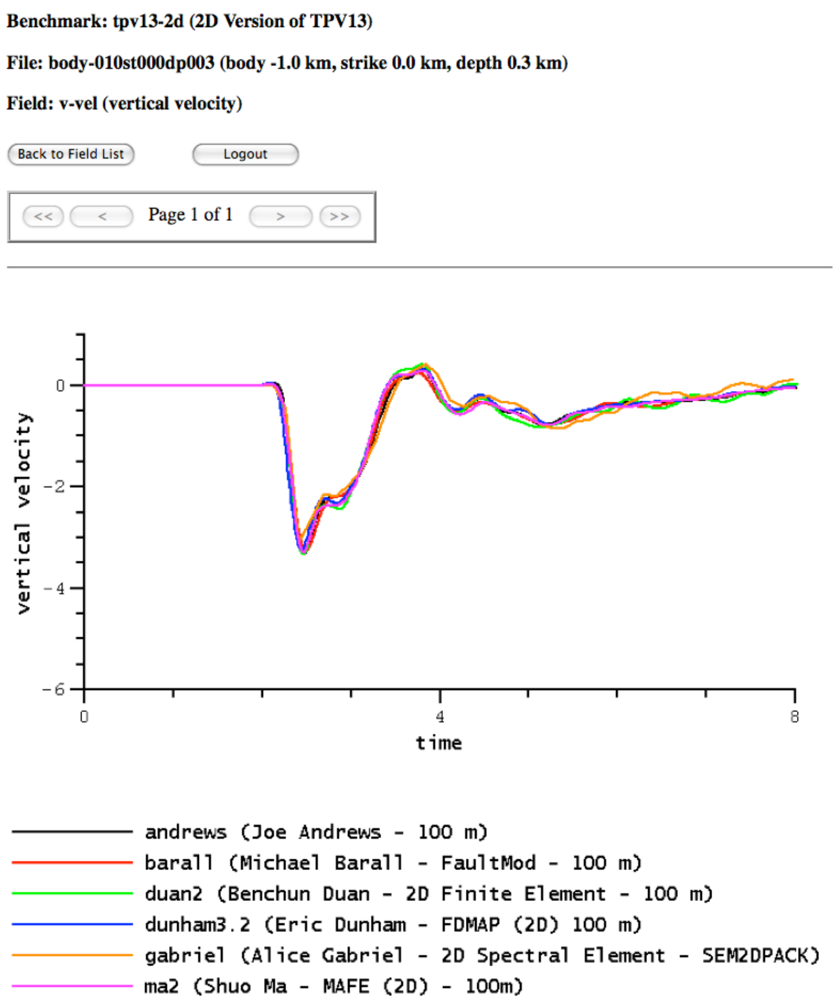


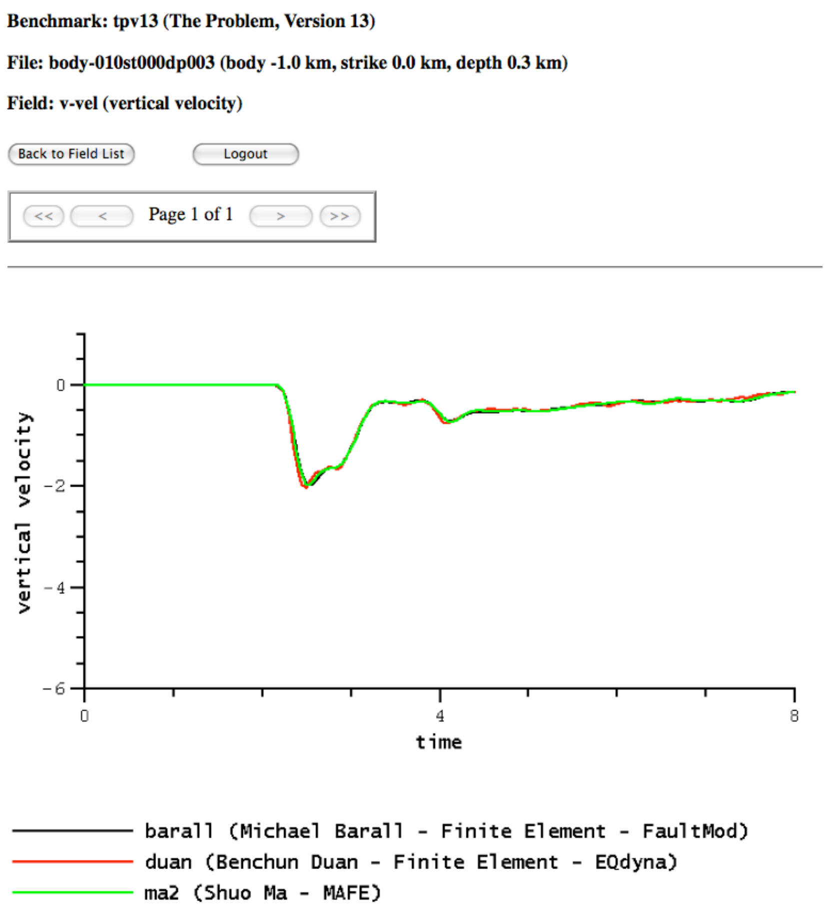
b) **3D** TPV12 - Elastic benchmark: Vertical velocity (m/s) vs. time (seconds)

Figure 3. Benchmark results - TPV13
Inelastic simulation, repository location (0 km along- strike, -1 km off-fault, 0.3 km deep)
100-m element size on the fault, lowpass Butterworth filter applied at 3 Hz.



a) **2D** TPV13 - Inelastic benchmark: Vertical velocity (m/s) vs. time (seconds)

Figure 3, continued.



b) **3D** TPV13 - Inelastic benchmark: Vertical velocity (m/s) vs. time (seconds)

The second set of 2009 benchmarks, TPV205/210, were presented by Eric Dunham. The goals of these benchmarks were to test the convergence of the codes, that is, to test the effects of using different element-sizes (or node-spacings) in the simulations. TPV205 revisited our 'classic' TPV5 vertical strike-slip-fault benchmark, but at multiple element-sizes, and TPV210 revisited TPV10, our dipping fault, dip-slip benchmark, again at multiple element sizes. Eric showed that to achieve perfection, the benchmarks likely need to be conducted at element sizes that are much smaller than the 100-m element-sizes that we usually use, perhaps on the order of 10m. On the other hand, some of the modelers in the room noted that this decision would likely be frequency dependent. I.e., if one just wanted synthetic ground motion simulations at up to 1-3 hz, then 100-m might be fine.

In the afternoon of the workshop, we heard two talks about quantitative misfit metrics. To date our code comparison exercise has primarily concentrated on qualitative assessment, but some have desired a quantitative metric also. Kim Olsen presented work by his recent M.S. student at SDSU, showing metrics for quantitative comparisons between synthetic and observed ground motion data, including an example for the 2008 Chino Hills earthquake. Following Kim's talk it was discussed how some of his methods might be adapted to quantifying the comparisons among modelers' rupture-front contour plots. Our group has found, over the past few years, that rupture-front contour plots are a diagnostic tool that help explain the differences and similarities among synthetic seismograms produced by the different codes. Following Kim's talk, Brad Aagaard presented a talk about a tool used by the CIG group to compare modeling results throughout a 3D medium. To date this has mostly been applied to understanding earth-science simulations that were conducted by CIG researchers who used finite-element methods.

In addition to our longer-running group comparison exercise, SCEC is now home to other collaborative comparison efforts. The most recent, the Source Inversion Exercise (SIV) is being led by Martin Mai, Morgan Page, and Danijel Schorlemmer. Invited speaker Morgan Page presented the background and plans for this collaborative exercise. From Morgan's presentation, we quickly saw how the SIV effort has many more scientific challenges than our group's does, since we are working with the forward problem that has one solution, whereas SIV is conducting an inverse problem, that has an infinite number of solutions. An idea that was presented at the last SIV workshop, held in September in Palm Springs, was that at least one of SIV's inverse cases could start with one of our forward spontaneous rupture simulations, so as to produce a physically consistent source, and thereby, ground motion data. A member of our dynamic rupture code group, Yoshi Kaneko, has volunteered to work on this scenario with the SIV group.

Our final invited talk of the day was a presentation by Nora DeDontney who introduced the science of dynamic rupture on branched faults. To date our exercise has concentrated on benchmarks that involve complexities such as bimaterials, heterogeneous stress, and rate-state friction, but the fault geometry has remained a simple planar feature. Because it is observed in nature that faults are rarely simple planar features, and some SCEC and USGS researchers do perform simulations assuming non-planar fault geometry, it is desirable for us to also test our codes with more complicated geometries. One example of non-planar geometry is the fault branch, a geometry that we have proposed to work with for our 2010 group efforts (if we receive 2010 funds). Nora introduced us to the field and laboratory observations that have been conducted in the arena of fault branches, and also described the findings from 7 years of researchers' numerical simulation studies. Following Nora's talk we had an extensive question and answer session, and discussions about how to best conduct our fault-branch numerical simulations. We did not finish the discussion, but we did come to a better understanding of the range of complexity that we will need to agree upon before we define the fault branch rupture scenarios. Among the most important is how we define the behavior at the intersections of faults, and whether or not we include plastic yielding. One aspect that will be new to us is that most, although not all, of the dynamic rupture community's previous detailed numerical work on fault branches has been conducted in 2D, so we will need to consider the best way to extend this work to 3D.

Following the invited talks and related discussions, we talked about what our group should do next. The list of potential activities was ambitious, and included creating, then adopting numerous quantitative metrics and implementing them on our SCEC dynamic rupture website, modifying the codes so as to perform thermal pressurization benchmarks in 2010, inclusion of multiple fault-geometry benchmarks in 2010, implementation of the convergence testing methodology, and creation of a suite of canonical benchmarks that modelers could go to anytime a new code was developed or an old one was modified. This list is likely more ambitious than the funding that we might receive in 2010 (unless we all receive 3-year full-time funding), so we will need to choose just one or two of these activities for 2010. On the other hand, the discussions clearly demonstrated that our group is very motivated to continue as a cohesive SCEC unit, and that there is considerable scientific advantage to continuing these interactions.

We ended our workshop with a thoughtful presentation by Tom Hanks about Extreme Ground motion and Yucca Mountain. Tom pointed out that the numerical simulations of extreme ground motion, such as those in Andrews et al. (BSSA, 2007), and in TPV12 and TPV13, were unlikely-impossible events, based on geologic evidence in the Yucca Mountain region, but that these extreme-event numerical simulations were necessary so as to be able to put an upper limit to expectations at the proposed repository site in Nevada. Indeed the work of Joe Andrews alone had decreased the maximum expected ground-velocity by a factor of three compared to previous estimates by some other workers. Tom also mentioned that when we move forward into 2010, we will instead be conducting multiple realizations of more reasonable events.

With this we ended the workshop.

Funding for this workshop was provided by SCEC and PG&E.

<u>Reference</u>:

Andrews, D.J., T.C. Hanks, and J.W. Whitney (2007), Physical limits on ground motion at Yucca Mountain, Bull. Seism. Soc. Am., Vol. 97, No. 6, pp. 1771–1792, December 2007, doi: 10.1785/0120070014.

Table 1. List of Workshop Attendees and Affiliations

Brad Aagaard (USGS)
Jean-Paul Ampuero (Caltech)
Joe Andrews (USGS)
Ralph Archuleta (UCSB)
Michael Barall (Invisible Software)
Nora DeDontney (Harvard)*
Ben Duan (TAMU)
Eric Dunham (Stanford)
Alice Gabriel (ETH, Switzerland)*
Tom Hanks (USGS)
Ruth Harris (USGS)
Steve Day (SDSU)
Brittany Erickson (UCSB)*
Tran Huynh (USC)
Yoshi Kaneko (UCSD)**
Yuko Kase (GSJ, Japan)
Jeremy Kozdon (Stanford)**
Daniel Lavallee (UCSB)
Qiming Liu (UCSB)*
Zaifeng Liu (TAMU)*
Julian Lozos (UCR)*
Shuo Ma (SDSU)
Hiro Noda (Caltech)**
David Oglesby (UCR)
Kim Olsen (SDSU)
Morgan Page (USGS)**
Arben Pitarka (QTSI)
Daniel Roten (SDSU)**
Kenny Ryan (UCR)*
Surendra Somala (Caltech)*
Jingqian Kang (TAMU)*
Zheqiang Shi (SDSU)**
Seok Goo Song (URS)
Katie Wooddell (PG&E)
Tomoko Yano (UCSB)*
Jinquan Zhong (TAMU)**

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*=grad student
**=postdoc

Table 2. The Workshop Agenda

Rupture Dynamics Code Validation 2009 SCEC Workshop

Nov. 20, 2009
Kellogg West Conference Center
Pomona, California

Conveners: Ruth Harris and Ralph Archuleta

		Speaker & Discussion Leader
09:00	Introduction to the Workshop	*Ruth Harris*
09:30	Extreme Ground Motion Benchmarks TPV12/13	*Joe Andrews*
10:45	Break	
11:00	Convergence Benchmarks TPV205/210	*Eric Dunham*
12:15	Lunch	
13:15	Misfit Metrics	*Kim Olsen*
14:00	CIG Benchmark Tool	*Brad Aagaard*
14:15	The Source Inversion Validation Exercise	*Morgan Page*
14:40	Break	
15:00	Rupture Propagation on Branching faults	*Nora DeDontney*
16:00	Group Discussion of Future Plans	*Everyone*
17:00	Adjourn	