Antelope Overview

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CTO, Boulder Real Time Technologies, Inc. June, 2023, Vienna, Austria



Boulder Real Time Technologies, Inc.

- Founded 1996
- Based in Boulder, Colorado, USA
- Makers of the Antelope Environmental Monitoring System







Antelope: Enterprise-grade Software for Earth Monitoring Operations

- "Enterprise" = Created to serve a clearly-defined mission
 - All further decisions made in subservience to that mission
 - Hardware, operating system, mission software, configuration etc.
 - Usually licensed, offers upgrades and support, "someone to call"
 - Supports virtualization and cloud computing
- "Operations" = 24/7 functioning with specific, quantitative requirements
 - Up-time, Output speed, Data completeness, Processing completeness, Downtime service windows, Possible hot-swap failover, etc.
- Turn-key operation on standard system



Enterprise software creation

- Forces
 - Hardware technology advances to meet growing user compute needs
 - Large corporate entities move according to macro economics, not small scientific software companies. We're the
 passenger, not the driver.
 - Advances in hardware and user market needs drive Operating System advances
 - Computer science advances drive language change, compiler change, component-package changes
 - Hardware purchased for network operations ages, breaks, and gets decommissioned, requiring updates to hardware, thus OS, thus software
 - Continual improvement of application software drives updates, on newer OS's; can't run on older OS's. Limited ability to support older versions due to hardware aging and irreplaceability of old machines.
 - "Software Rusts" Danny Harvey
 - Software at its best: codified explanation of how to do monitoring task, in every detail, to both the humans and the machines. This understanding advances in sophistication. [N.B. 'Spaghetti code' loses the 'explain to humans' part]
 - Research-purposed software has to adapt to varied ecosystems, impacting robustness and adding admin work.
 - Enterprise software aiming for *mission support*. Install it and it runs out-of-the-box. Tremendous amount of work to create this effect with sophisticated applications.



What is Antelope

- Software platform for earthquake, geophysical, and structural health monitoring
 - Data Acquisition
 - State-of-health monitoring
 - Centralized Command and Control
 - Automated and manual processing
 - Research

- Scalable and Extensible
 - Used at most of the largest seismic networks and data centers, down to the smallest research and monitoring networks
- Dual mission:
 - The monitoring mission
 - The network operations
 - mission





Data Acquisition: q3302orb

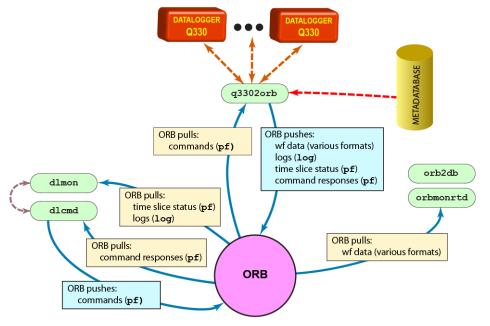
q3302orb

Over 2 years at USArray:

• 1166 dataloggers



- 10,292 physical data channels at multiple sample rates
- ~40,000 channels of SOH waveform data
- 8760 instance-days of software running
- 16 Terasamples of end user data collected (not including SOH)



- **0 downtime, 0 lost data** due to acquisition software failures
- 1 FTE to manage data center O&M
- 99.5% data completeness





Data Acquisition: q8



BRTT Boulder Real Time Technologies, Inc.

orb2orb

Dataflow SOH Monitoring

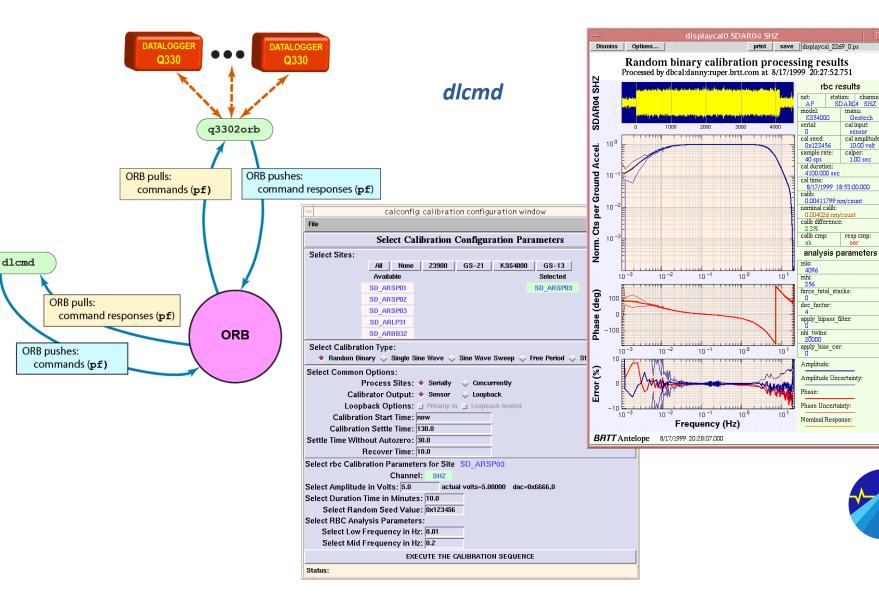
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Robust Software Sophisticated SOH Monitoring



Datalogger Command and Control





station: channel:

SDARC4 SHZ

Geotech

cal input:

sensor

calper: 1.00 sec

resp cmp:

cal amplitude

10.00 volt

manu:

Station Metadata Management

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dbbuild

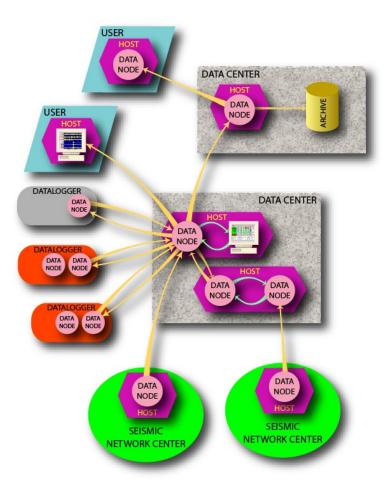
- Program for building the "metadata" part of a Datascope database (*site, sitechan, sensor, instrument, calibration, stage* tables plus external instrument response files)
- Can operate in either interactive or batch mode.
- Can run from a master configuration file
- Based on well-documented ASCII files
- User-configurable single-stage response files
- set of parameter files that describe standard dataloggers, pre-amps and sensors



Data Transport Backbone

orbserver

- orbserver / orb protocol
- Network transparent
- Data-neutral
- Data-driven
- Extremely reliable
- Short-haul Inter-process communication
- Long-haul, low latency data transport
- Extension to standard networking stack:
 - IP = packet transport
 - TCP = reliable transport of bytes
 - Orb = reliable transport of monitoring-data packets





Embedded Relational Database

Datascope

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23	-3.4497	152.8790	548,0665	5/27/13 (147) 11 5/27/13 (147) 11		57446	57410	2013147	16	13	190	15 M		4	5.32					ocsat:iasp91	OtDblMbMwp OtDblMwpMb
24	52.3370	160.4000	44.6325	5/27/13 (147) 17		57447	57447	2013147	10	11	219	19 M		f	4.86					ocsat:iasp91	OtDb1MbMsMwp
25	52.3114	159.9761	53.5337	5/27/13 (147) 20		57448	57412	2013147	14	14	219	19 M		f	5.92		5.66			ocsat:iasp91	OtDb1MbMwpMs
26	52.2806	159,9952	45.9726	5/27/13 (147) 20		57449	57412	2013147	34	28	219	19 M		f	5.74		5.54			ocsat:iasp91	OtDb1MbMsMwp
27	43.2105	41.5780	0.0000	5/28/13 (148) 00		57450	57430	2013148	27	26	362	30 M		f	5.30		5.02			ocsat:iasp91	OtDblMbMsMwp
28	-46.9599	33.4798	10.0500	5/29/13 (149) 14		57451	57451	2013149	0	95		v			5.10	3874					USGS:us
29	54.2008	153,4378	620.3754	5/28/13 (148) 08		57453	57453	2013148	21	18	663	41 M		f	4.89				1	ocsat:iasp91	OtDb1MbMwp
30	-21.1488	-177.7830	372.4145	5/28/13 (148) 08		57454	57415	2013148	20	14	181	13 M		f	5.13					ocsat:iasp91	OtDb1MwpMb
31	53.4219	159.8032	78.0098	5/28/13 (148) 16	:25:34.86331 UTC	57456	57421	2013148	30	25	218	19 M		f	5.25		4.33		1	ocsat:iasp91	OtDb1MbMsMwp
32	34.0430	141.1570	0.0000	5/28/13 (148) 19		57457	57423	2013148	14	14	229	19 M		f	5.10		4.61		1	ocsat:iasp91	OtDb1MbMsMwp
33	52.7069	159.0924	70.6694	5/28/13 (148) 19		57458	57458	2013148	7	7	219	19 M		f	5.23				1	ocsat:iasp91	OtDb1MbMsMwp
34	52.4627	159.4598	62.4572	5/28/13 (148) 19		57459	57459	2013148	17	16	219	19 M		f	5.21		4.64			ocsat:iasp91	OtDb1MbMsMwp
35	53.0641	157.5260	0.0000	5/28/13 (148) 19		57460	57458	2013148	13	12	217	19 M		f	5.44					ocsat:iasp91	OtDb1MbMsMwp
6	33.9787	141.0686	0.0000	5/28/13 (148) 19		57461	57423	2013148	10	10	229	19 M		t	4.99		4.52			ocsat:iasp91	OtDb1MbMsMwp
37 38	-4.8560	102.4168	234.5506	5/29/13 (149) 04		57462 57463	57462 57463	2013149	14	11	274	24 M		f	4.81					ocsat:iasp91	OtDb1MbMwp
38	34.4990 -46.6177	-119.7787 33.2593	0.0000	5/29/13 (149) 14		57463	57463	2013149	12	9	43 431	3 M		f	5.02					ocsat:iasp91	OtDb1MbMsMwp
10	-46.6177 34.4125	-119,9260	8.0000	5/29/13 (149) 14 5/29/13 (149) 14		57464	57451	2013149 2013149	8	31	+31			T						ocsat:iasp91	OtDblMbMwp USGS:ci
11	-9.3435	107.4365	5.0800	5/27/13 (149) 14		57465	57403	2013149	13	55		y v			4.90	3890					USGS:ct USGS:us
2	-9.5455	-71.2581	101.0900	5/27/13 (147) 00		57475	57435	2013147	7	55		y			4.90	3890					USGS:us
3	39,1901	141.6693	94.2900	5/27/13 (147) 09		57480	57441	2013147	9	36		y			4.50	3892					USGS:us
4	54.2411	153.3947	627.1400	5/28/13 (148) 08		57483	57453	2013148	18	59		ý			4.40	3893					USGS:us
15	-5.1139	102.1242	34.1700	5/29/13 (149) 04		57492	57462	2013149	11	41		ý			4.90	3894					USGS:us
46	52.7396	158.8913	77.8400	5/28/13 (148) 19		57504	57458	2013148	12	190		ý			4.70	3895					USGS:us
47	55.3879	163.1770	70.9454	5/29/13 (149) 18		57506	57506	2013149	10	10	219	19 M		f	4.79				1	ocsat:iasp91	OtDblMbMwpMs
48	55 4117	163 1343	78 8576	5/20/13 (1/0) 18		57510	57506	20131/0	13	13	210	10 0		¢	4 78					occation01	0+Dh1MbMapMc



Real-time System

- Unix building-block design
 - Hundreds of small, well-designed programs, each with a clear job
 - Shared-object libraries of generic and specialized tools
- Framework to customize solutions
- Scalable
- Network-transparent
 - Allows local deployments
 - Allows distributed processing
- Demonstration system based on GSN
 - Learning and Testing
 - Augment small networks with global processing for context
 - Basis for rapid configuration of larger operations





Real-time Executive

rtexec

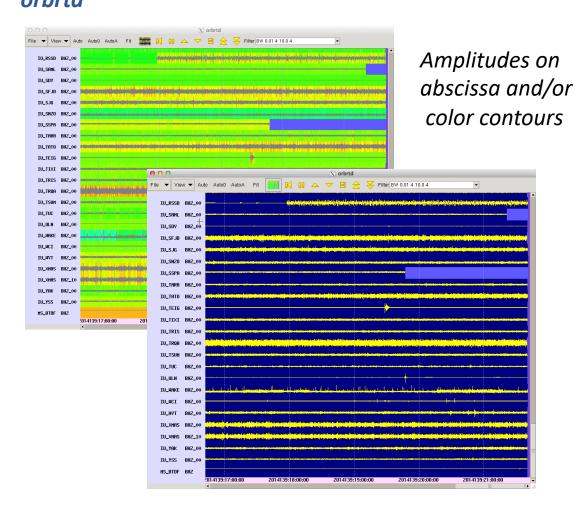
rtm

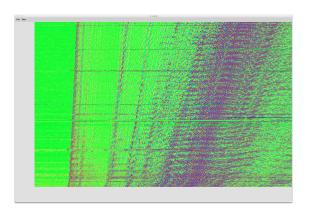
• • •						XG	SN				
File <u>E</u> dit <u>V</u> iew <u>R</u> ef	resh					Ante	lope 5.4				2015-272 19:33
Start System is up Stop			oad Average 1min 2.34 5min 2.51 15min 2.41	C C C	Cpu Usage (4 cp pu#0 pu#1 pu#2 pu#3 pu#3 pu#3 procession processio		Memory Usa ram sw 8192 Mb 4096	rap ro	Disk Usage ot	Orb Ring Buffer Status : pkts/s 17 connect In 17.620 Out 53.153	
						Processin	g Tasks				
ask	Pid	cpu	cpu	rss	rss	To Orb	To Orb	From Orb	From Orb	Latency	Latency
texec	95	0.00	10.0		500.0						
orbserver	246	0.10	10.0	50.0	500.0						
orbserver_mime	248	0.00	10.0	127.0	500.0						
orb2wf	249	0.00	10.0	0.4	500.0	0.0 bps	20.00	17.6 Kbps	20.00	33:01 minutes	5000
orb2dbt	255	0.00	10.0		500.0	0.0 bps	20.00	0.0 bps	20.00	3:04 minutes	5000
orbdetect	332	0.40	10,0	14.0	500.0	0.0 bps	20.00	17.6 Kbps	20.00	33:01 minutes	5000
orbassoc	356	0.00	10.0	210.1	500.0	0.0 bps	20.00	0.0 bps	20.00	3:04 minutes	5000
nagnitude	395	0.00	10.0	51.0	500.0	0.0 bps	20.00	0.0 bps	20.00	3:04 minutes	5000
GSNimport	487	0.00	10.0	0	500.0	17.6 Kbps	20.00	0.0 bps	20.00	33:01 minutes	5000
JSGSimport	509	0.00	10.0	L7.0	500.0	0.0 bps	20.00	0.0 bps	20.00	7:44 minutes	5000
tcache	546	0.10	10.0	-10.12	500.0						
twebserver	639	0.00	10.0	1.6	500.0						
Cron Job Status			patches				compress			rtdbclean	
						Network C	peration				
processes		0	rbstat	ORI	3_Data	DB_data	ι [Event_Map	Grid_M	ap Stati	ons_Map

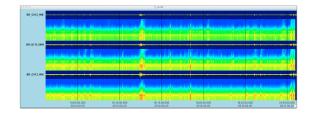
- System Command-and-control
- Run-time monitoring
- System State-Of-Health
- Comprehensive logging
- Alerting on hardware infrastructure, RT system, and process-status
- Headless, enterprise server operation with optional graphical front-end
- Turnkey reboot capability
- Cooperates with advanced deployments high availability, redundant failover networking etc.



Streaming Time-series Display









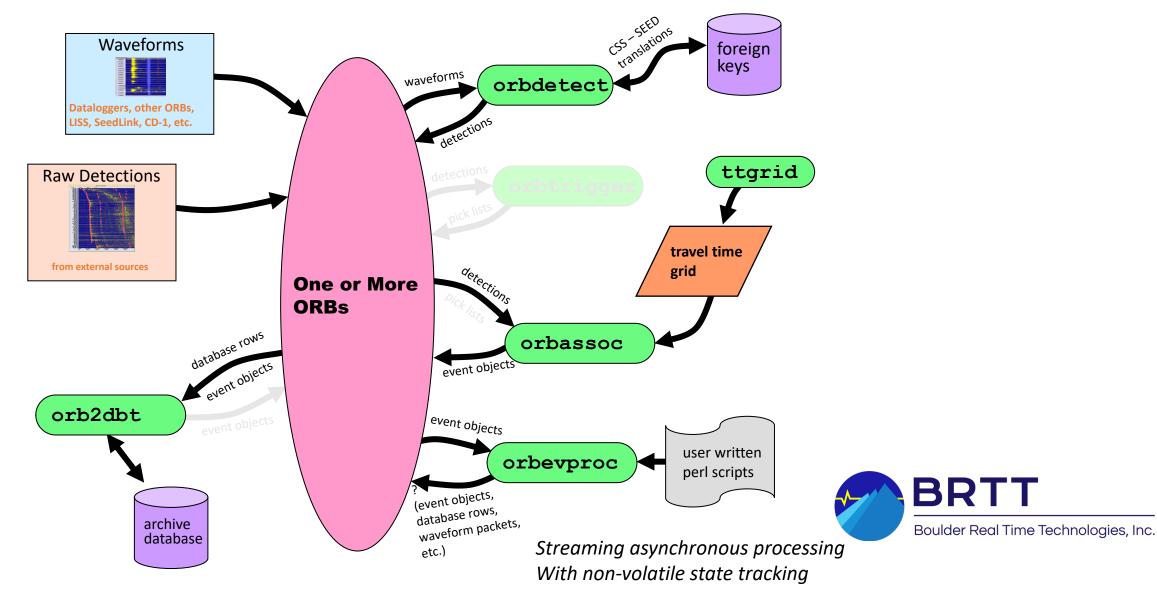
Continuous Waveform Archiving

orb2wf

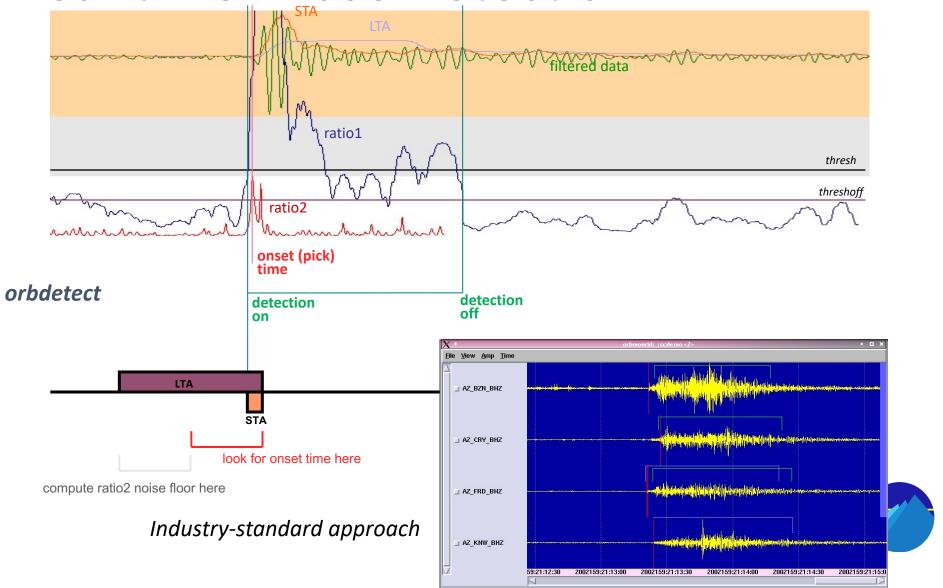
- orb2wf writes waveform data from ORB ring buffer to continuous database
- Efficiently handles gaps and out-of-order data with automatic healing
- Dynamically handles anomalies such as sample rate changes, calibration changes for channel
- Vets data for unstuffing and timing errors
- Optionally morphs data SEED codes
- Configurable output format



Antelope Automated Event Processing



Real-time Phase Detection



BRTT Boulder Real Time Technologies, Inc.

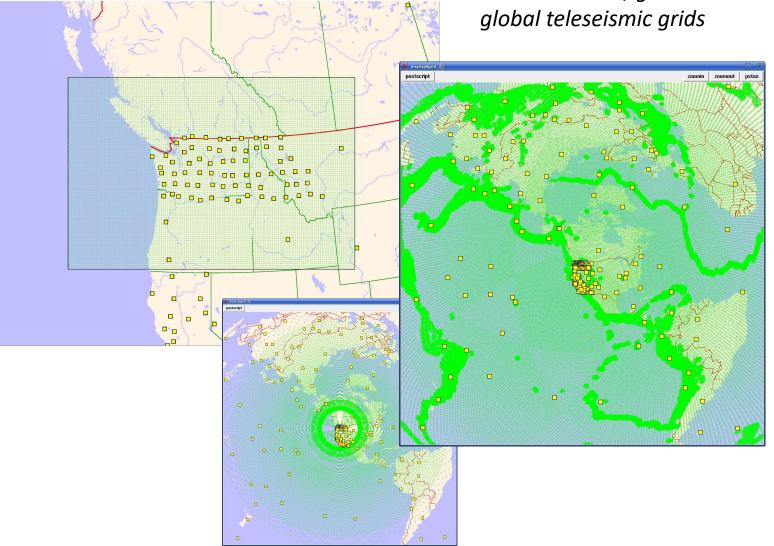
Real-time event locator

- *orbassoc* State-of-the-art, sophisticated grid-based associator
- Tunable all the way from Earthquake Early Warning to Catalog Production
- Multiple simultaneous grids: local; regional; universal teleseismic (more dense around PDE seismicity)
- Engineered in close coordination with multi-band detector
- Works for small networks, volcanoes, volcano chains, regional networks, global events, tsunamigenic quakes, aftershock sequences
- Four main revisions, through 2007; operations-hardened on many different network sizes and types around the planet
- Many sophisticated parameters available to tune for your network geometry and application

orbassoc



Travel-time Grids



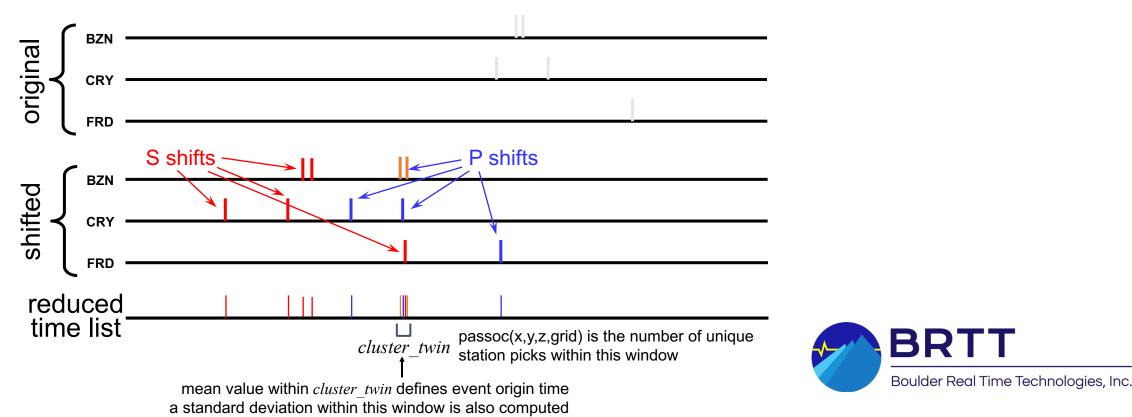
Local cartesian, global slowness, and global teleseismic grids



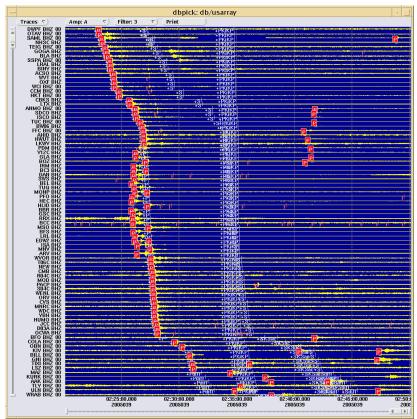
P-wave Processing

For each grid-source location node:

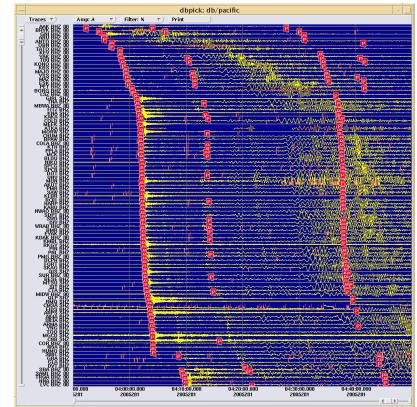
- 1. All of the times in the pick list are reduced by the phase travel times to an equivalent origin time.
- 2. These reduced pick times for each travel time phase are put into a reduced time list for subsequent time-clustering analysis:



Recursive Pick Processing



Best-fit identification of overlapping events

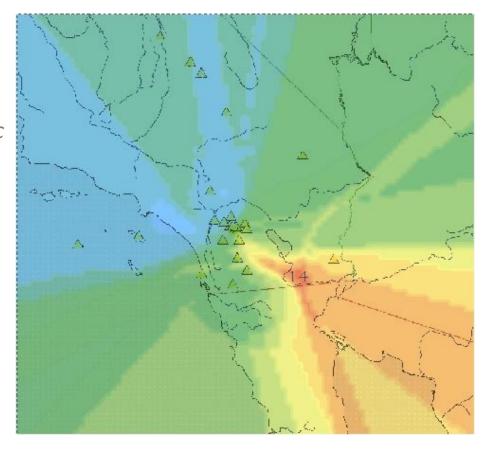




Location Grid in Action

orbassoc

- Peak grid point chosen as earthquake location
- Latest version of orbassoc allows Geiger-method refinement (dbgenloc)



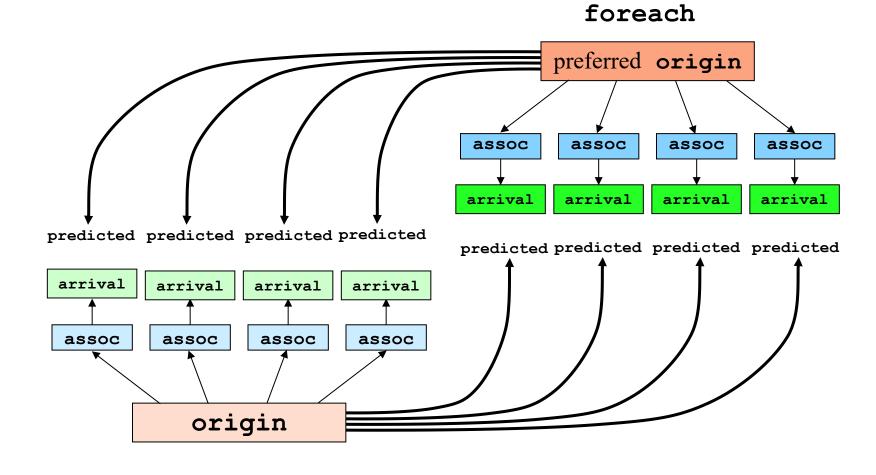


"Smart" Event Association

From event object

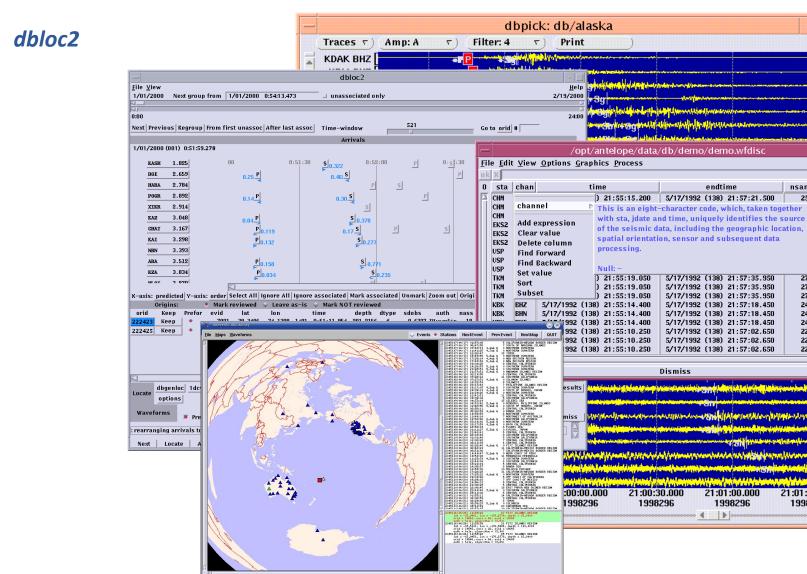
From archive database

orb2dbt



BRTT Boulder Real Time Technologies, Inc.

Analyst Event Location and Review



Status: Time: 2005117(04/27) 09:57:35 Gmt, 00:02:51 since last update, 18:23:58 since last even



<u>H</u>elp

| ← | →

samprate

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2249 20.000000

nsamp

2527

2739

2739

2739

2482

2482

2482

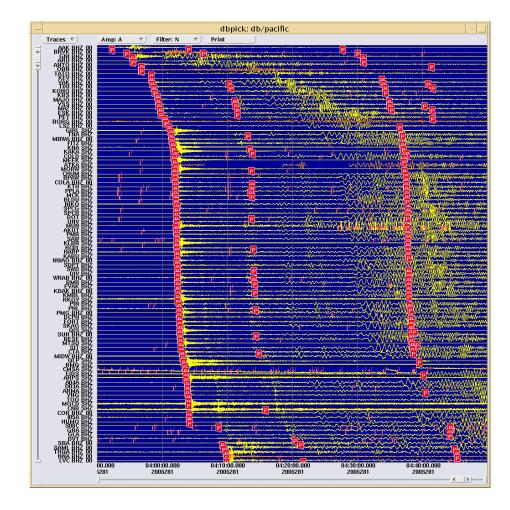
21:01:30.000

1998296

Waveform viewing and phase picking

Dbpick and traceview

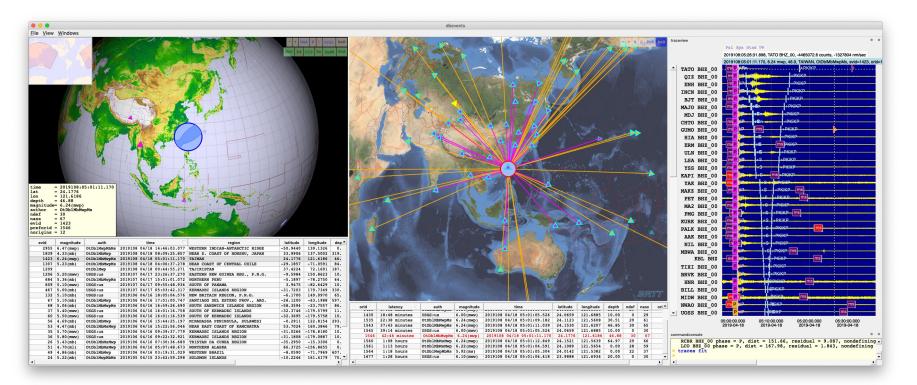
- Runs locally or over ssh connection
- Customizable filtering
- Configurable phase naming
- Amplitude measurement
- Small networks or hundreds of station deployments





Event Display

dbevents





Generic Stream Processing Framework

Framework for arbitrary waveform computations

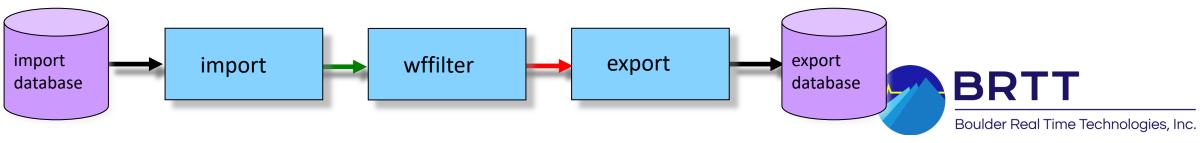
orbwfproc

- Open-source C code program *orbwfproc*Configurable 'tasks': building-block construction of processing chains
- BRTT provides multiple algorithms, filtering, etc.
- Extensible with client-written algorithms
- Streaming (orbwfproc) and Batch (dbwfproc) mode

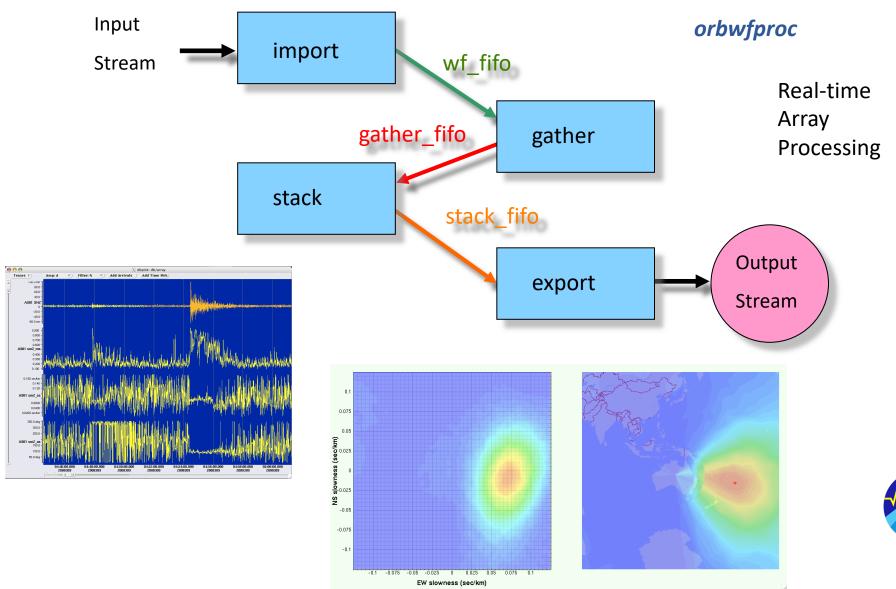
Heal waveforms (data out of time order, overlapping data, gaps, etc) Create defragmented export database:



Resample or filter waveform data (e.g. change SEED codes):



Generic Stream Processing Framework

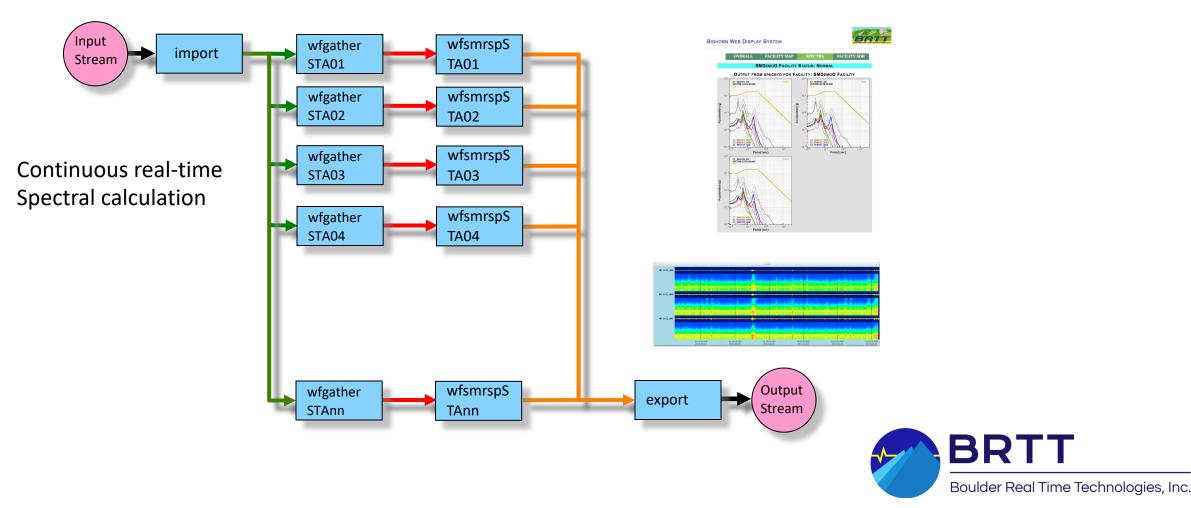


BRTT

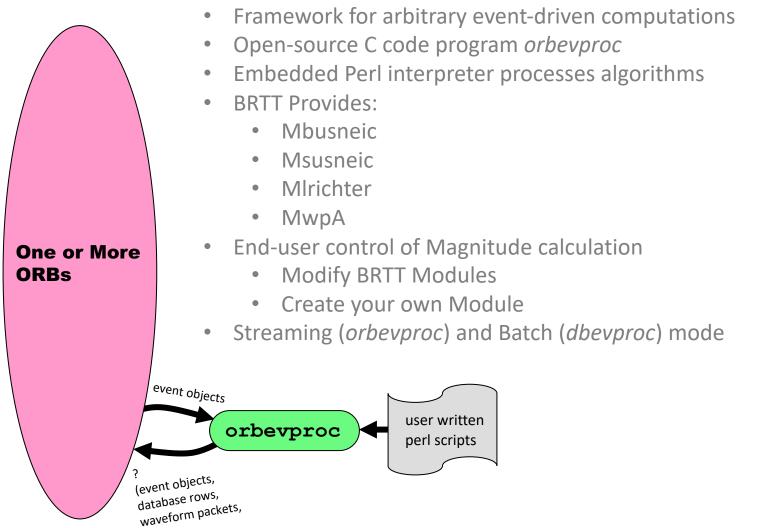
Boulder Real Time Technologies, Inc.

Generic Stream Processing Framework

orbwfproc



Generic Event Processing Framework

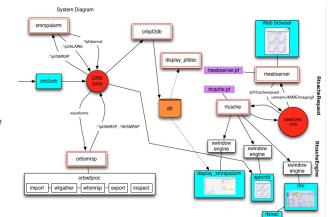


etc.)



Structural Health Monitoring: Bighorn

- Alarms based on exceedence of Operating Basis Earthquake (OBE)
- Building-block nature of Antelope/Bighorn system and open-architecture APIs allow construction of wide variety of systems for Structural-Health Nowcasting, Earthquake Early Warning, and Post-Earthquake Response (e.g. Aramco/APEAS Facility alert / Alarm Acknowledgment system)









Bighorn

Main Features

- *Now-casting* of wavefield spectral content
- Real-time, continuous response spectra exceedence
- Immediate results tailored for response team
- Automatic alarms against engineered criteria (Structural Health Monitoring)
- Independent of Earthquake Location
 - No need to wait for location
 - Applicable for non-earthquake sources
 - Very close to Earthquake Early Warning
- Quantitative, *critical decision support*





State-of-Health Monitoring



Facility Monitoring

Bundled into Antelope



Bighorn

- Method vetted by Nuclear Regulatory Commission
- Faithful translation from
 - After-the-fact event-based review; to

BR Q113 HH

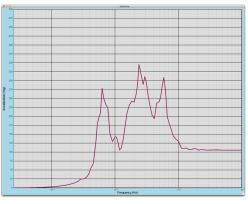
BR Q113 H

RR 0119

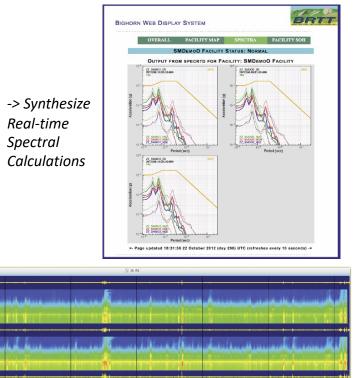
19:05:00.000

19:10:00.000

• Streaming, real-time, continuous now-casting

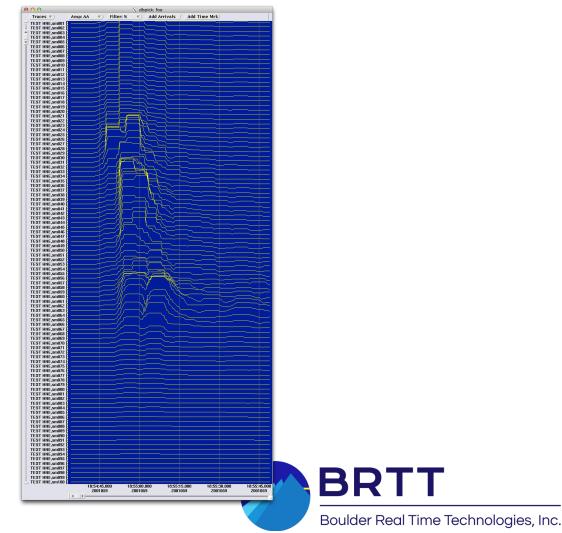


Blue: Traditional post-processing Red: Streaming real-time processing (or vice versa...)



19:20:00.000 2012-02-20

Multiple Time-domain filters Of incoming wavefield



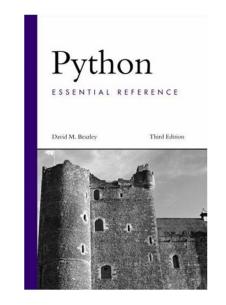
Extensive Development Environment

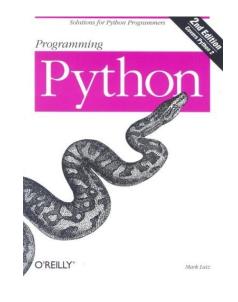
- Fully developed command-line build tools
- Extensive man-pages, web documentation, online reference guide
- Compiled language interfaces
 - C
 - C++
 - Fortran
- Scripted language interfaces
 - Shell
 - Perl
 - TCL/Tk
 - Python
 - (PHP)
 - MATLAB
- Powerful interactive capabilities
 - Command-line tools
 - Interactive Python
 - MATLAB



Python

- Python: Object-oriented scripting language
 - <u>http://www.python.org</u>
 - Dynamic
 - Powerful
 - Extensible
 - Fast







Open-source Community

- <u>http://www.antelopeusersgroup.com</u>
- http://www.github.com/antelopeusersgroup
- Advances
 - Custom earthquake alarms
 - Alarm-response tools
 - Enhancements to Antelope utilites dbpick etc.
 - S-wave and polarization detection
 - Moment-tensor computation
 - Real-time gridded moment-tensors
 - Cross-correlation tools



Antelope Key Points

- Complete software package for traditional seismic network operations and SHM
- Extensible Middleware Framework for interconnecting data sources with data processing to create custom earth monitoring systems
- Store-and-forward packet system enables reliable transport, processing, dissemination
- Embedded relational database system
- Core utilities available for both streaming and batch-mode processing
- Has been applied to numerous environmental monitoring domains
 - seismic, tsunami, volcano, strong-motion, sensor-web, structural health
- Open architecture, with both closed and open-source components
- High performance and reliability
- High scalability
- High interoperability
- Minimum processing and communications latencies (early warning)
- Productive development environment for new/extended functionality
- Coherent engineering throughout creates highly robust, highly functional, low cost-ofownership system – only available from commercial code



Obtaining Antelope

- Evaluation copies, subscriptions or upgrades to Antelope 5.13:
 - Contact Kinemetrics, Inc.:
 - <u>sales@kmi.com</u>
- Technical questions about Antelope:
 - Contact BRTT:

• <u>support@brtt.com</u>



Thank You

support@brtt.com

