

# 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



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# 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



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# 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.



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# 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



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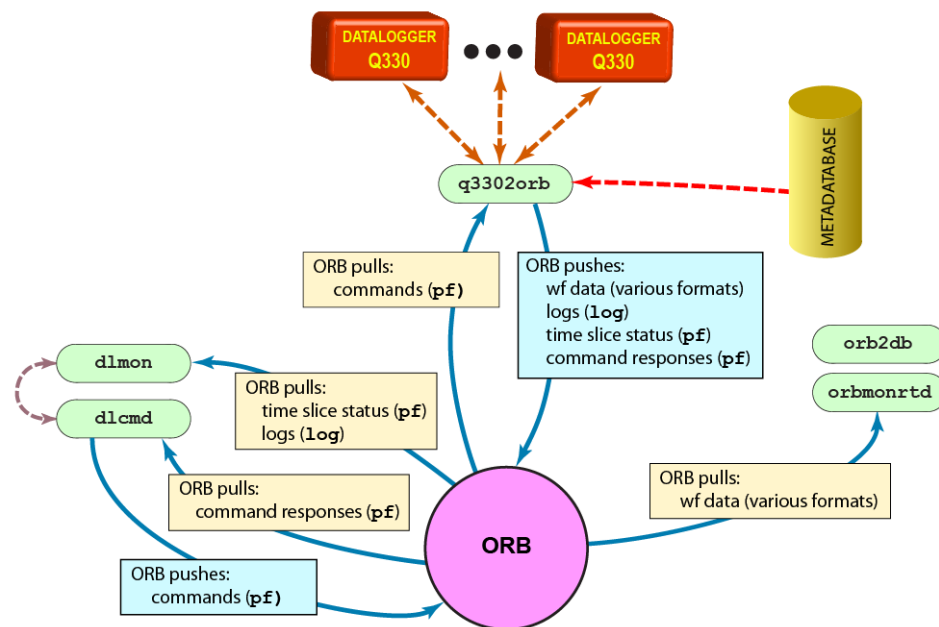
# Data Acquisition: q3302orb

## 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**



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# Data Acquisition: q8

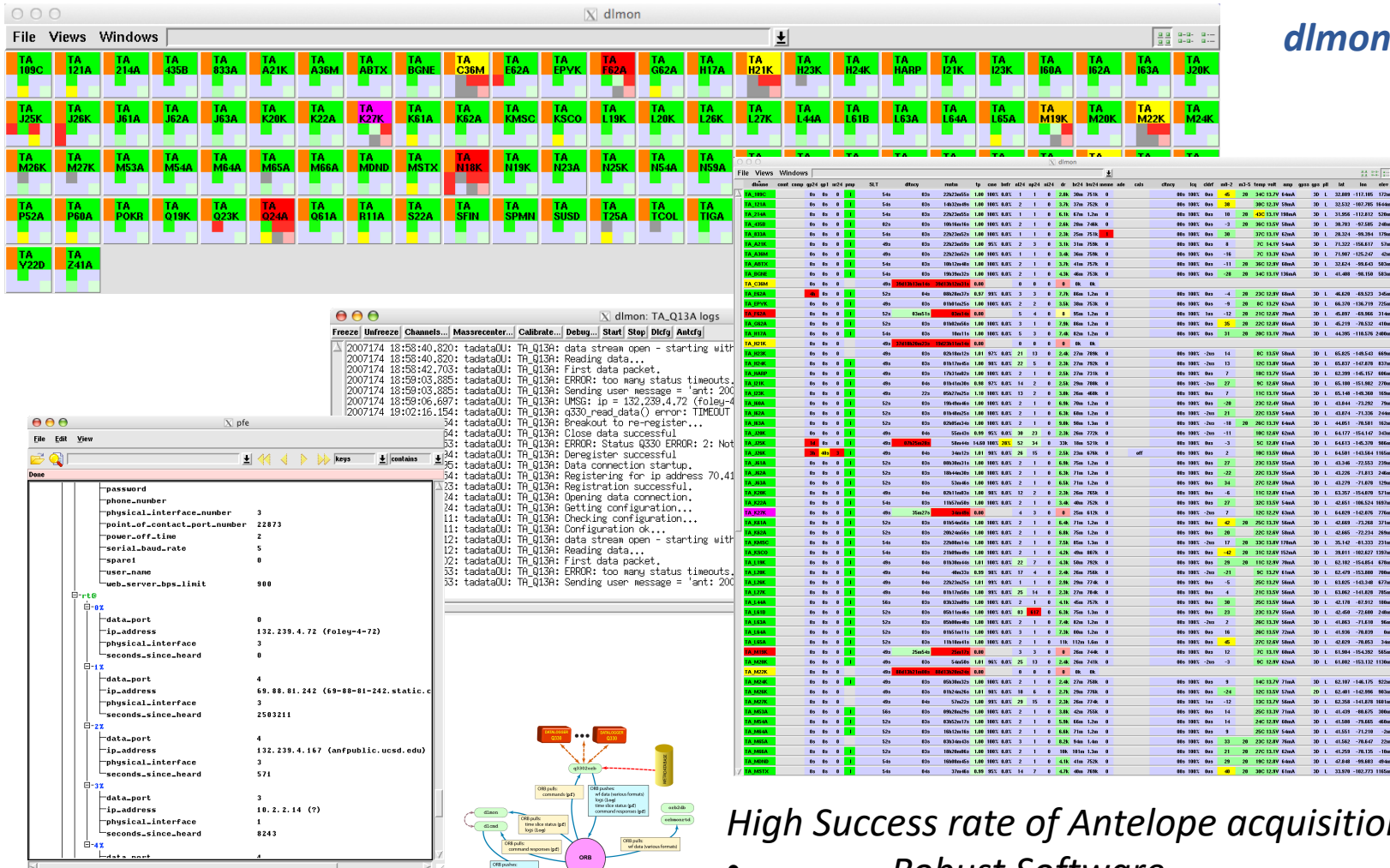
*orb2orb*



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# Dataflow SOH Monitoring



*High Success rate of Antelope acquisition:*

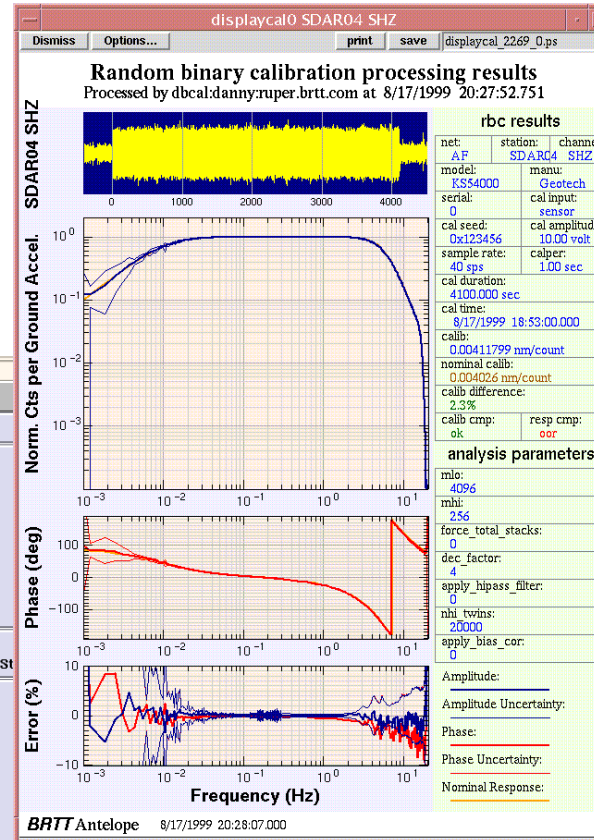
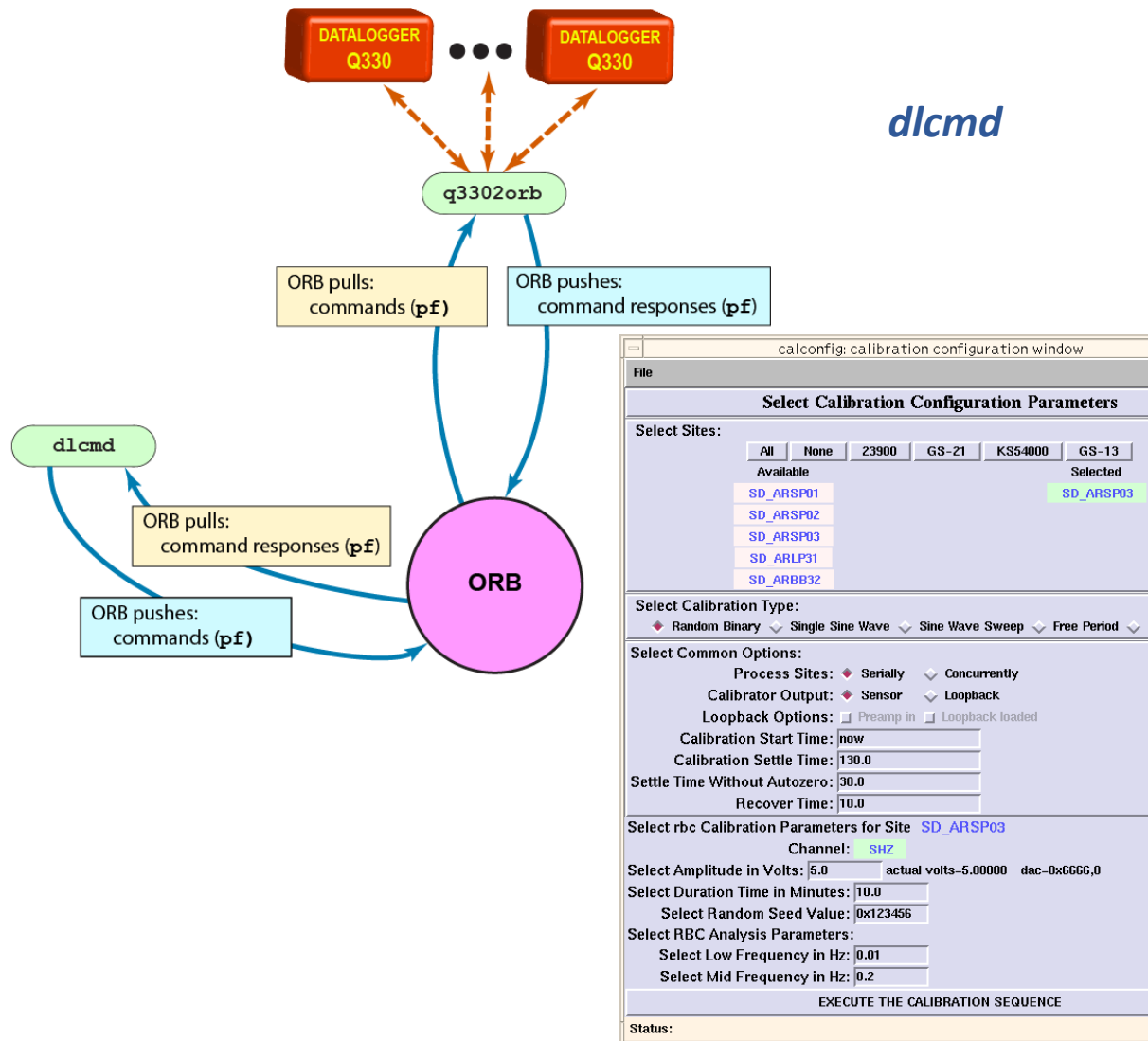
- *Robust Software*
- *Sophisticated SOH Monitoring*



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# Datalogger Command and Control



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# Station Metadata Management

The screenshot shows the 'Master Database Construction' window with the following configuration details:

- Database Configuration:** Configuration time: 4/1/2004. Comment: (empty).
- Network:** net: XT, network name: SECARIB - Pascual Broadband Experiment.
- Station:** sta: ZUPC, latitude: 8.3597, longitude: -65.1951, elevation: 0.0960, station name: Zuata.
- Datalogger:** Reftek 130 Datalogger. Model: rt130. Serial number: 123. Dist: (empty).
- Sensor:** Episensor 200 Hz 10 Volt FS 2g. Model: episensor\_2g\_10vfs. Serial number: 456. Edepth: 0.0. Band: s. Rsp type: A. Loc code: (empty).

axis	hang	vang	sensor gain	lead	preamp gain	preamp stage
Z	0	0	5.1e-10			
N	0	90	5.1e-10			
E	90	90	5.1e-10			

Sample rate: 250sps. On/Off checkboxes for channels: HGZ, HGN, HGE.

*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



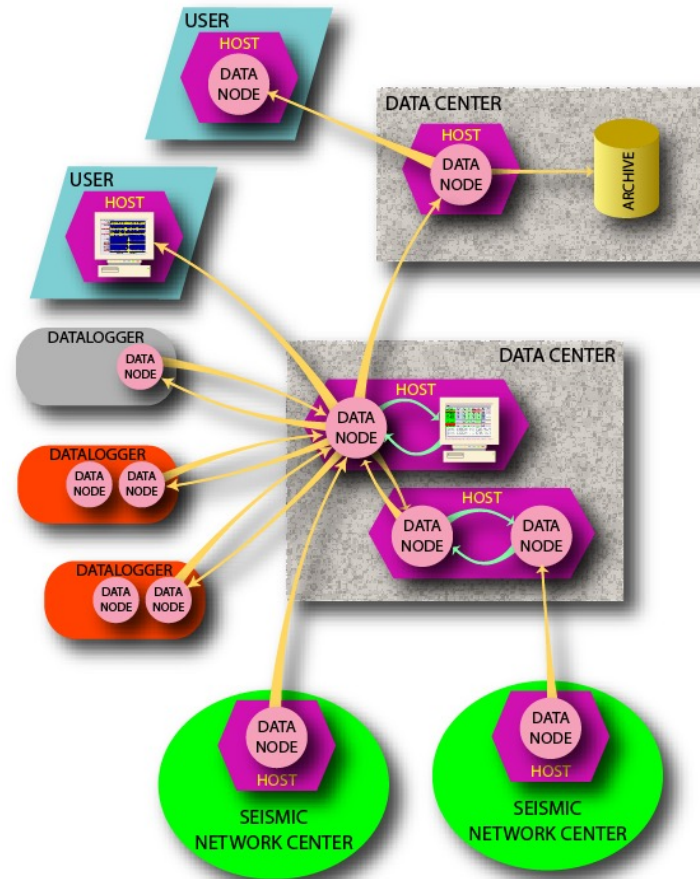
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# Data Transport Backbone

## *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



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# Embedded Relational Database

Datascope

dbs_pre: /opt/antelope/dev/src/lib/qt/buplotqt/testdb/gsn																									
File Edit View Options Graphics Help																									
Su So G U J O L N T Sv Sp Tables New Window																									
arrival	assoc	calibration	event	instrument	lastid	mt	netmag	network	origerr	origin	schancloc	sensor	site	sitechan	snetsta	specdisc	stamag	wfdisc	wfmeas						
lat	lon	depth	time	orid	evid	idate	nass	ndef	grn	srn	review	dtype	mb	mbid	ms	ml	mid	algorithm	auth						
0	-3.3227	138.4008	57.3215	5/26/13 (146)	13:04:31.55641 UTC		57394	57394	2013146	0	6	201	16	M		f	4.86	5.32	4.00	14524	locsat:issp91	01db1MbMap			
1	-2.0053	100.0038	43.7600	5/26/13 (146)	11:20:00.53000 UTC		57396	57396	2013146	0	44			Y			5.00		3840		USGS:us				
2	-3.3804	138.4390	73.9500	5/26/13 (146)	13:04:32.09000 UTC		57398	57394	2013146	0	36			Y			4.70		3841		USGS:us				
3	36.7162	5.2484	14.6200	5/26/13 (146)	16:00:55.83000 UTC		57400	57400	2013146	0	124			Y			5.00		3842		USGS:us				
4	-3.5649	152.5107	466.6200	5/27/13 (147)	11:29:28.66000 UTC		57410	57410	2013147	0	69			Y			5.20		3843		USGS:us				
5	52.2416	160.1957	13.2300	5/27/13 (147)	20:22:00.17000 UTC		57412	57412	2013147	0	115			Y			5.30		3844		USGS:us				
6	-21.3691	-177.8298	400.3500	5/28/13 (148)	08:45:53.28000 UTC		57415	57415	2013148	0	68			Y			5.00		3845		USGS:us				
7	53.4469	159.7921	71.6500	5/28/13 (148)	16:25:33.05000 UTC		57421	57421	2013148	0	530			Y			5.30		3846		USGS:us				
8	14.5928	53.8331	9.7000	5/27/13 (147)	03:36:31.30000 UTC		57422	57422	2013147	0	59			Y							USGS:us				
9	34.1491	140.7115	35.7800	5/28/13 (148)	19:24:25.66000 UTC		57423	57423	2013148	0	69						5.00		3848		USGS:us				
10	9.3873	-82.6475	11.2600	5/27/13 (147)	09:41:14.80000 UTC		57427	57427	2013147	0	82			Y			5.60		3849		USGS:us				
11	43.2238	41.6083	9.8200	5/28/13 (148)	00:09:54.28000 UTC		57430	57430	2013148	0	65			Y			5.40		3850		USGS:us				
12	-46.9497	33.4567	9.9700	5/29/13 (149)	14:47:32.92000 UTC		57431	57431	2013149	0	74			Y			5.20		3851		USGS:us				
13	36.7956	5.3154	0.0000	5/26/13 (146)	16:00:55.07494 UTC		57434	57400	2013146	21	20	396	31	M		f	5.25				locsat:issp91	01db1MbMap			
14	-9.5071	107.2935	35.4034	5/27/13 (147)	00:06:13.00972 UTC		57435	57435	2013147	16	13	282	24	M		f	5.36				locsat:issp91	01db1MbMap			
15	-9.4667	107.3132	36.0432	5/27/13 (147)	00:06:13.44697 UTC		57436	57435	2013147	15	13	282	24	M		f	5.36				locsat:issp91	01db1MbMap			
16	14.4762	53.3950	68.9483	5/27/13 (147)	03:36:40.67242 UTC		57437	57422	2013147	18	14	417	33	M		f	5.48		5.27		locsat:issp91	01db1MbMap			
17	14.4337	53.2797	87.3250	5/27/13 (147)	03:36:42.99708 UTC		57438	57422	2013147	18	14	417	33	M		f	5.41		5.27		locsat:issp91	01db1MbMap			
18	-35.6809	-68.8468	198.0046	5/27/13 (147)	05:21:15.48960 UTC		57439	57439	2013147	8	7	139	8	M		f					locsat:issp91	01db1MbMap			
19	-35.6640	-68.8559	203.5245	5/27/13 (147)	05:21:15.91666 UTC		57440	57439	2013147	9	7	139	8	M		f					locsat:issp91	01db1MbMap			
20	39.2928	141.6161	90.1195	5/27/13 (147)	09:16:38.11038 UTC		57441	57441	2013147	9	9	227	19	M		f	4.72				locsat:issp91	01db1MbMap			
21	9.4250	-82.6093	38.6423	5/27/13 (147)	09:41:18.38839 UTC		57444	57427	2013147	19	17	80	6	M		f	5.75		5.31		locsat:issp91	01db1MbMap			
22	-3.5205	152.6179	468.3788	5/27/13 (147)	11:29:28.57514 UTC		57445	57410	2013147	31	27	190	15	M		f	5.45				locsat:issp91	01db1MbMap			
23	-3.4497	152.8790	548.0665	5/27/13 (147)	11:29:35.64043 UTC		57446	57410	2013147	16	13	190	15	M		f	5.32				locsat:issp91	01db1MbMap			
24	52.3370	160.4000	44.6325	5/27/13 (147)	17:13:32.28110 UTC		57447	57447	2013147	11	11	219	19	M		f	4.87				locsat:issp91	01db1MbMap			
25	52.3114	159.9761	53.5337	5/27/13 (147)	20:22:06.71880 UTC		57448	57412	2013147	14	14	219	19	M		f	5.92		5.66		locsat:issp91	01db1MbMap			
26	52.2806	159.9952	45.9726	5/27/13 (147)	20:22:06.08574 UTC		57449	57412	2013147	34	28	219	19	M		f	5.74		5.54		locsat:issp91	01db1MbMap			
27	43.2105	41.5780	0.0000	5/28/13 (148)	00:09:53.51977 UTC		57450	57430	2013148	27	26	362	30	M		f	5.30		5.02		locsat:issp91	01db1MbMap			
28	-46.9599	33.4798	10.0500	5/29/13 (149)	14:47:33.62000 UTC		57451	57451	2013149	0	95			Y			5.10		3874		USGS:us				
29	54.2008	153.4378	620.3754	5/28/13 (148)	08:58:40.16980 UTC		57453	57453	2013148	21	18	663	41	M		f	4.89				locsat:issp91	01db1MbMap			
30	-21.1488	-177.7830	372.4145	5/28/13 (148)	08:45:50.10883 UTC		57454	57415	2013148	20	14	181	13	M		f	5.13				locsat:issp91	01db1MbMap			
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		locsat:issp91	01db1MbMap			
32	34.0430	141.1570	0.0000	5/28/13 (148)	19:24:18.85773 UTC		57457	57423	2013148	14	14	229	19	M		f	5.10		4.61		locsat:issp91	01db1MbMap			
33	52.7069	159.0924	70.6694	5/28/13 (148)	19:24:44.13972 UTC		57458	57458	2013148	7	7	219	19	M		f	5.23				locsat:issp91	01db1MbMap			
34	52.4627	159.4598	62.4572	5/28/13 (148)	19:37:20.43642 UTC		57459	57459	2013148	17	16	219	19	M		f	5.21		4.64		locsat:issp91	01db1MbMap			
35	53.0641	157.5260	0.0000	5/28/13 (148)	19:24:42.27123 UTC		57460	57458	2013148	13	12	217	19	M		f	5.44				locsat:issp91	01db1MbMap			
36	33.9787	141.0666	0.0000	5/28/13 (148)	19:24:19.13573 UTC		57461	57423	2013148	10	10	229	19	M		f	4.99		4.52		locsat:issp91	01db1MbMap			
37	-4.8560	102.4168	234.5506	5/29/13 (149)	04:35:39.30521 UTC		57462	57462	2013149	14	11	274	24	M		f	4.81				locsat:issp91	01db1MbMap			
38	34.4990	-119.7787	0.0000	5/29/13 (149)	14:38:03.10871 UTC		57463	57463	2013149	12	9	43	3	M		f	5.02				locsat:issp91	01db1MbMap			
39	-46.6177	33.2593	650.0000	5/29/13 (149)	14:48:26.46440 UTC		57464	57451	2013149	8	6	431	33	M		f					locsat:issp91	01db1MbMap			
40	34.4125	-119.9260	0.0000	5/29/13 (149)	14:38:03.20000 UTC		57465	57463	2013149	9	31			Y							USGS:ci				
41	-9.3435	107.4365	5.0800	5/27/13 (147)	00:06:10.09000 UTC		57473	57435	2013147	13	55			Y			4.90		3890		USGS:us				
42	-36.0174	-71.2581	101.0900	5/27/13 (147)	05:21:06.74000 UTC		57477	57439	2013147	7	66			Y			4.80		3891		USGS:us				
43	39.1901	141.6693	94.2000	5/27/13 (147)	09:16:36.99000 UTC		57480	57441	2013147	9	36			Y			4.50		3892		USGS:us				
44	54.2411	153.3947	627.1400	5/28/13 (148)	08:58:39.17000 UTC		57483	57453	2013148	18	59			Y			4.40		3893		USGS:us				
45	-5.1139	102.1242	34.1700	5/29/13 (149)	04:35:18.47000 UTC		57492	57462	2013149	11	41			Y			4.90		3894		USGS:us				
46	52.7396	158.8913	77.8400	5/28/13 (148)	19:24:43.72000 UTC		57504	57458	2013148	12	190			Y			4.70		3895		USGS:us				
47	59.3879	163.1770	70.9454	5/29/13 (149)	18:21:54.29727 UTC		57506	57506	2013149	10	10	219	19	M		f	4.79				locsat:issp91	01db1MbMap			
48	66.4112	163.1543	78.8576	6/20/13 (140)	18:21:54.2																				

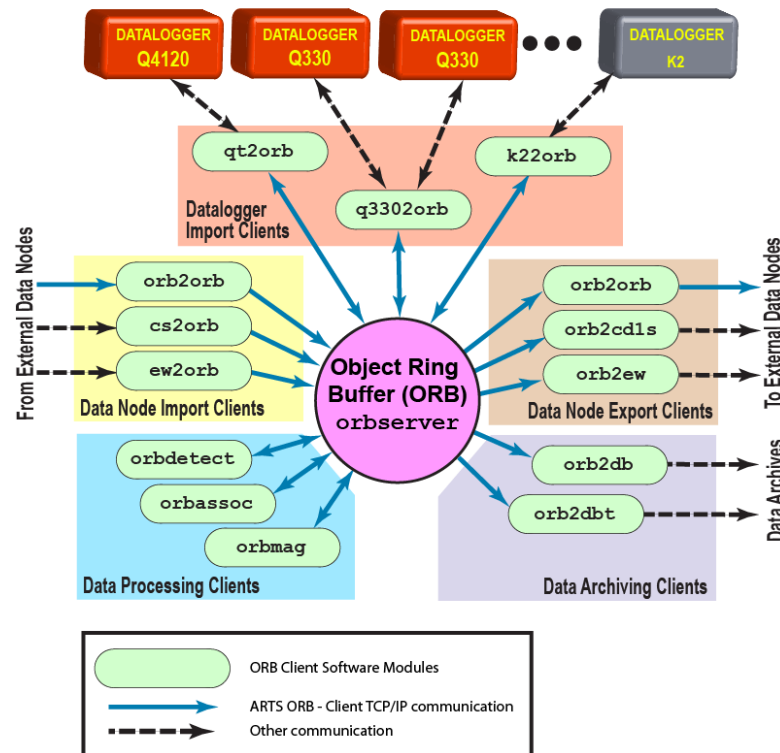
21,477 Rows

Table 'origin' updated: 11/28/14 (332) 01:03:41.00000 UTC (241 days 15.8 hours ago)

dbs\_pre updated: 7/27/15 (208) 16:52:45.02126 UTC

# 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

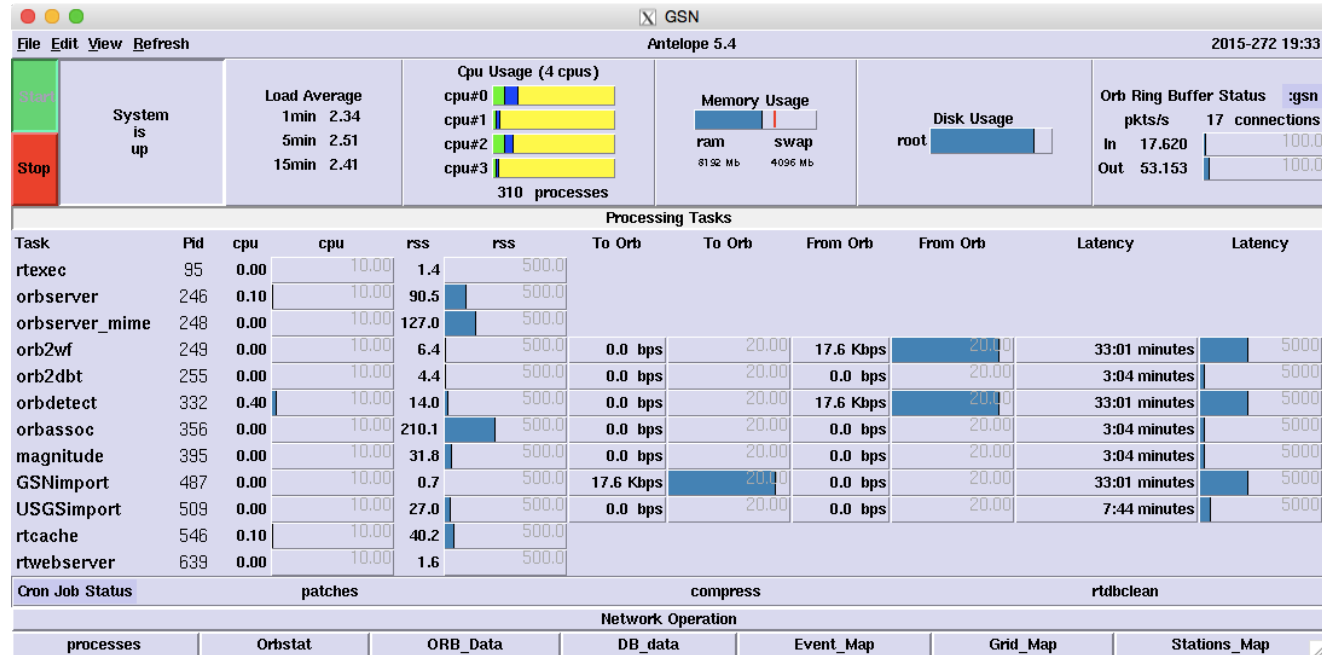


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# Real-time Executive

*rtexec*  
*rtm*



- 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.

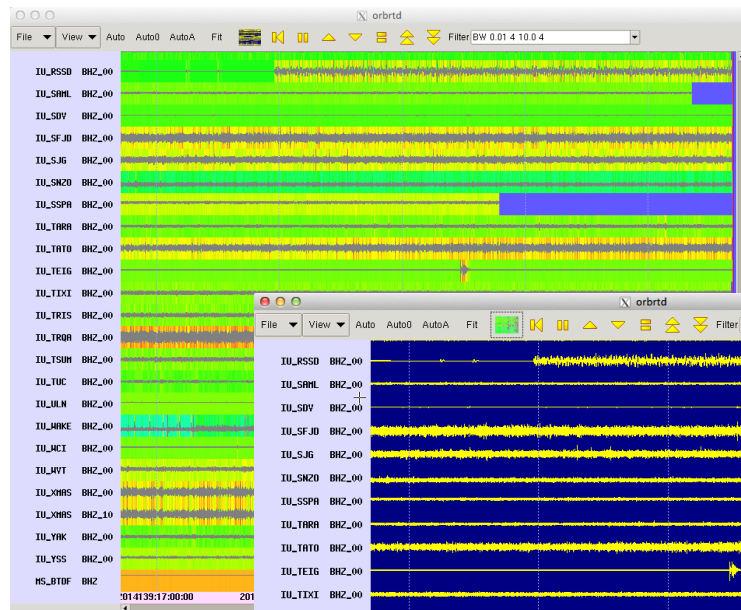


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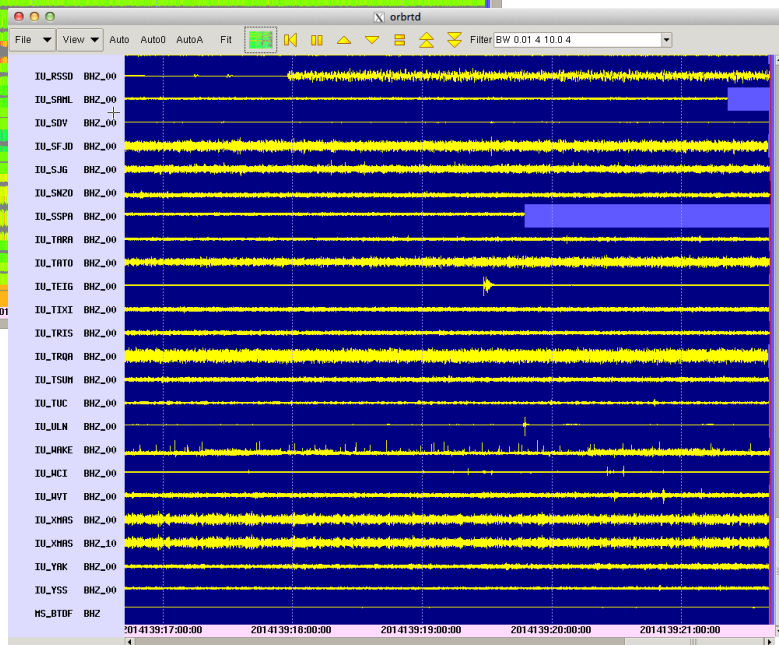
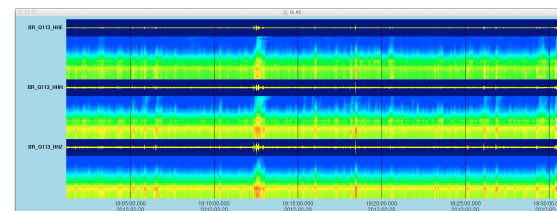
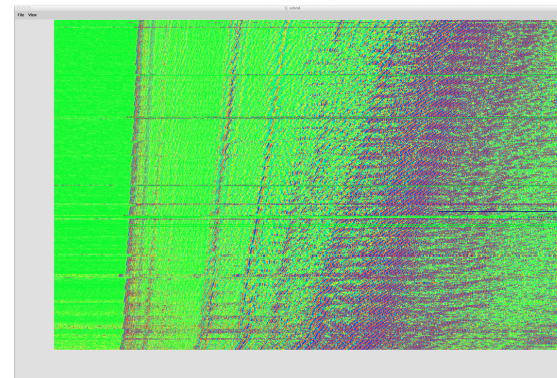
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# Streaming Time-series Display

orbrtd



*Amplitudes on  
abscissa and/or  
color contours*



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# Continuous Waveform Archiving

*orb2wf*

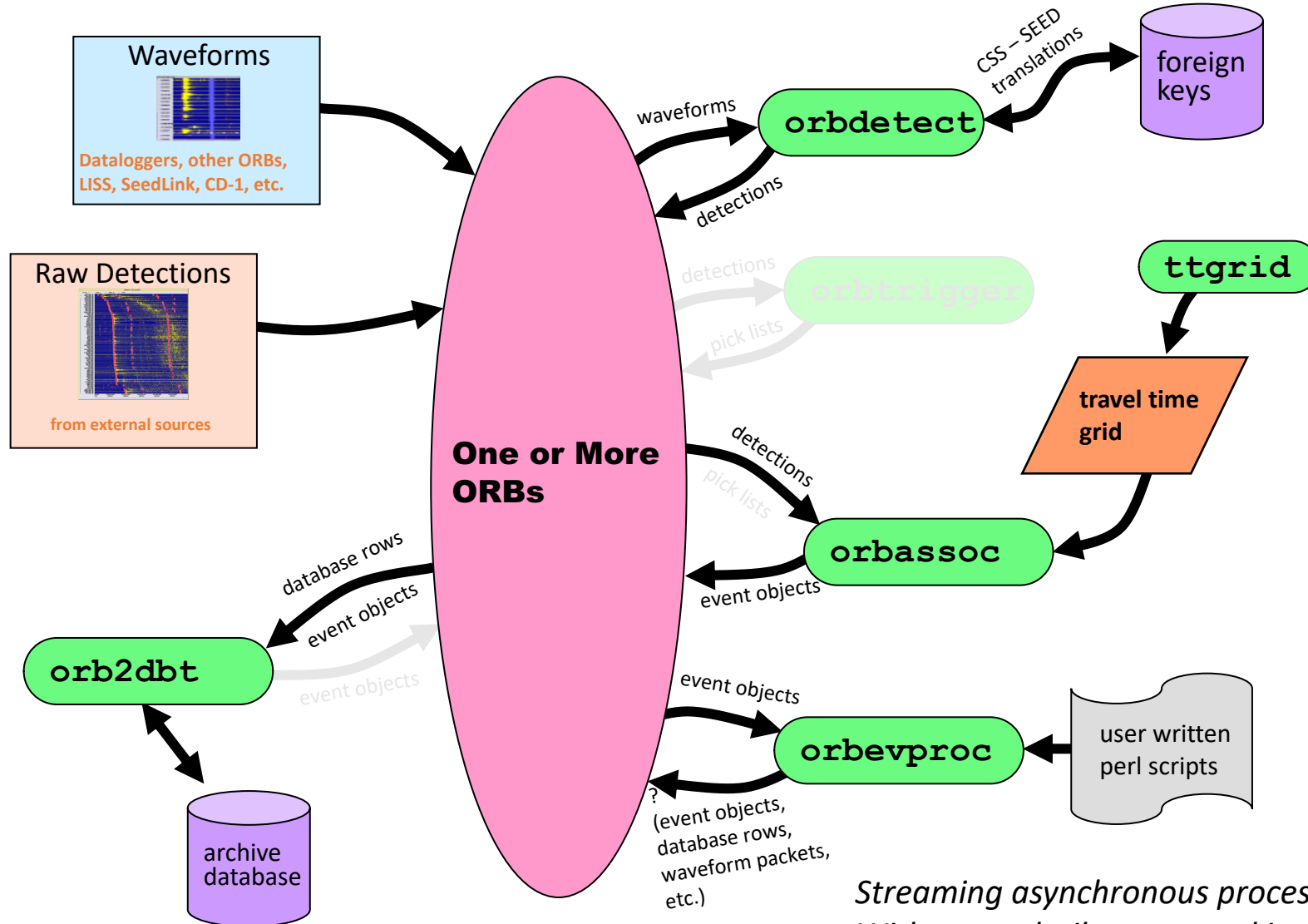
- *orb2wf* writes waveform data from ORB ring buffer to continuous database
- Efficiently handles gaps and out-of-order data with automatic healing
- Dynamically handles anomalies such as sample rate changes, calibration changes for channel
- Vets data for unstuffing and timing errors
- Optionally morphs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



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# Antelope Automated Event Processing



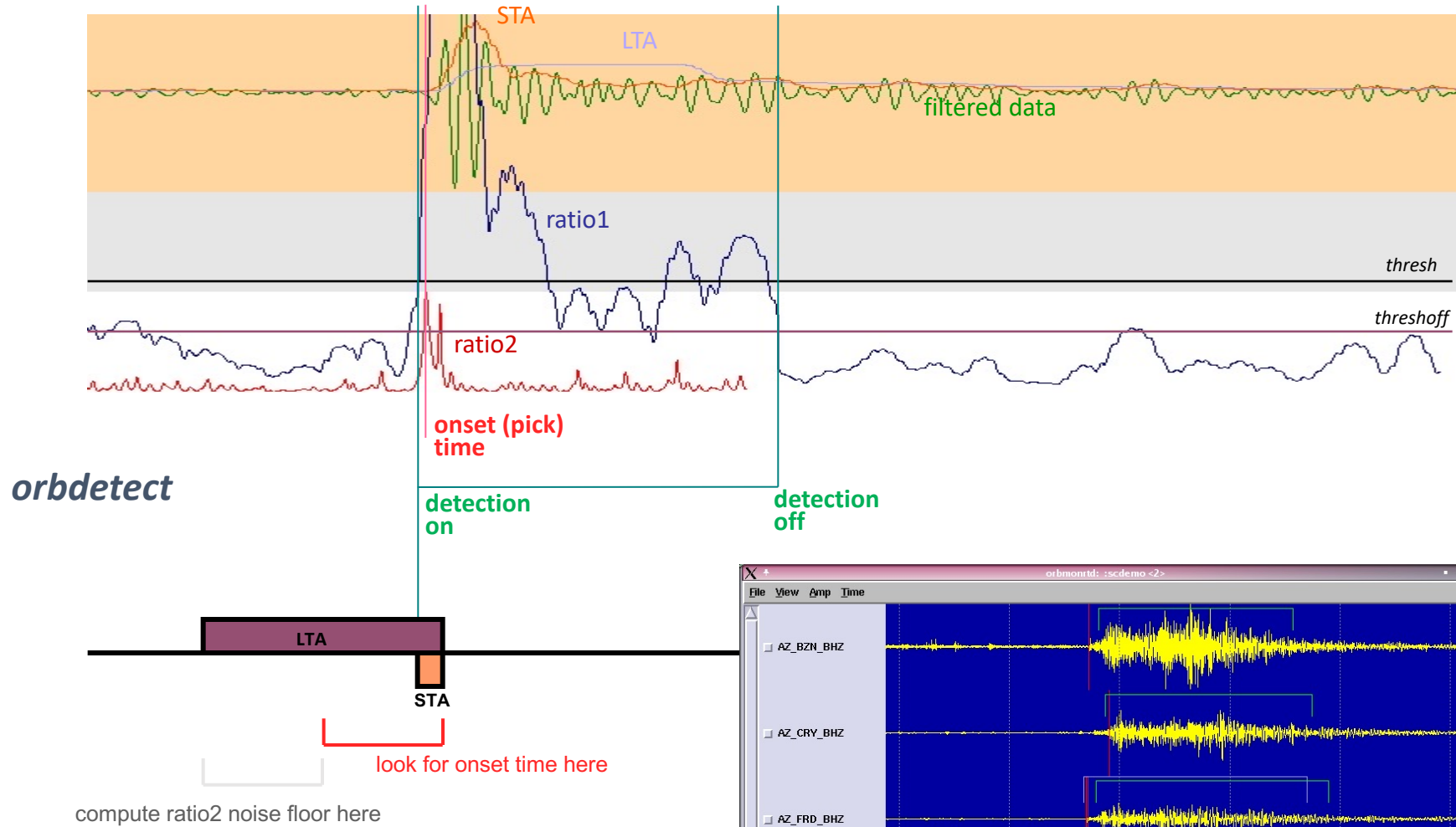
*Streaming asynchronous processing  
With non-volatile state tracking*



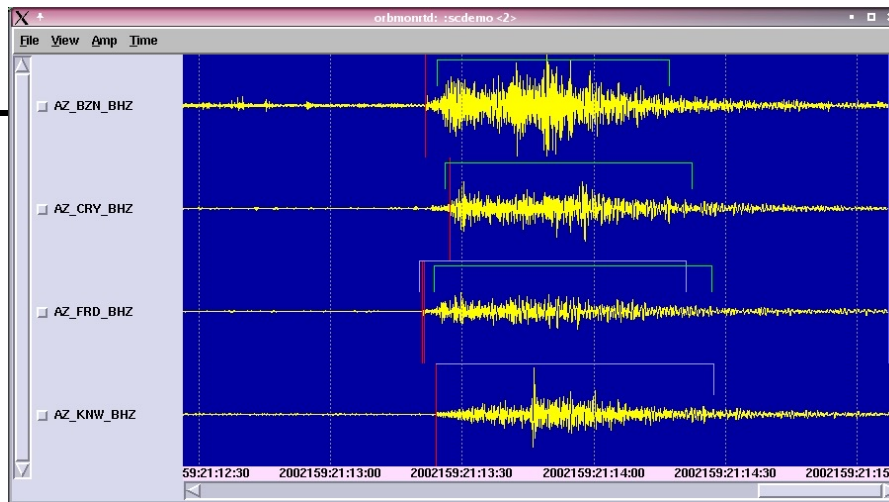
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# Real-time Phase Detection



*Industry-standard approach*



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# 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*

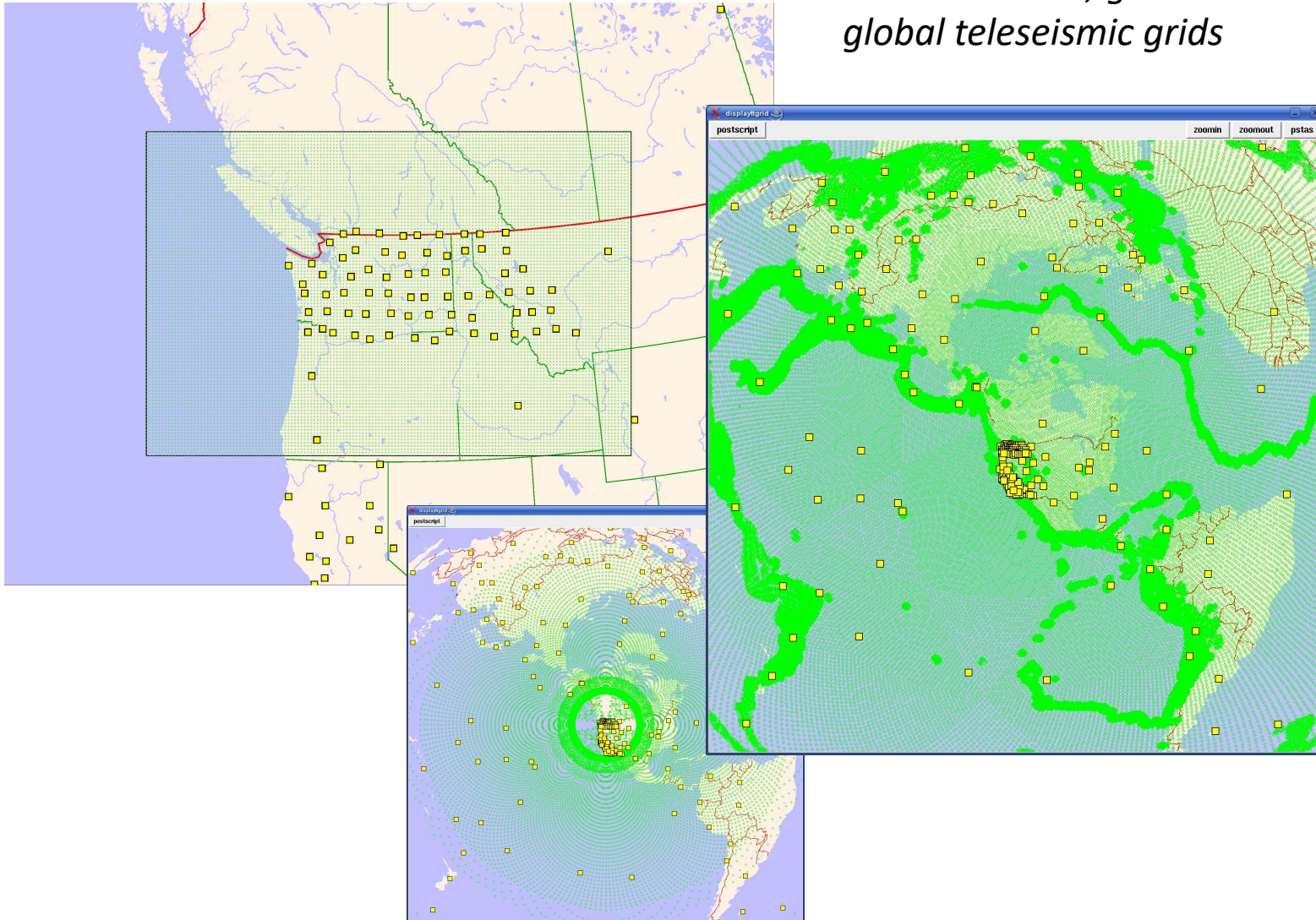


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# Travel-time Grids

*Local cartesian, global slowness, and  
global teleseismic grids*



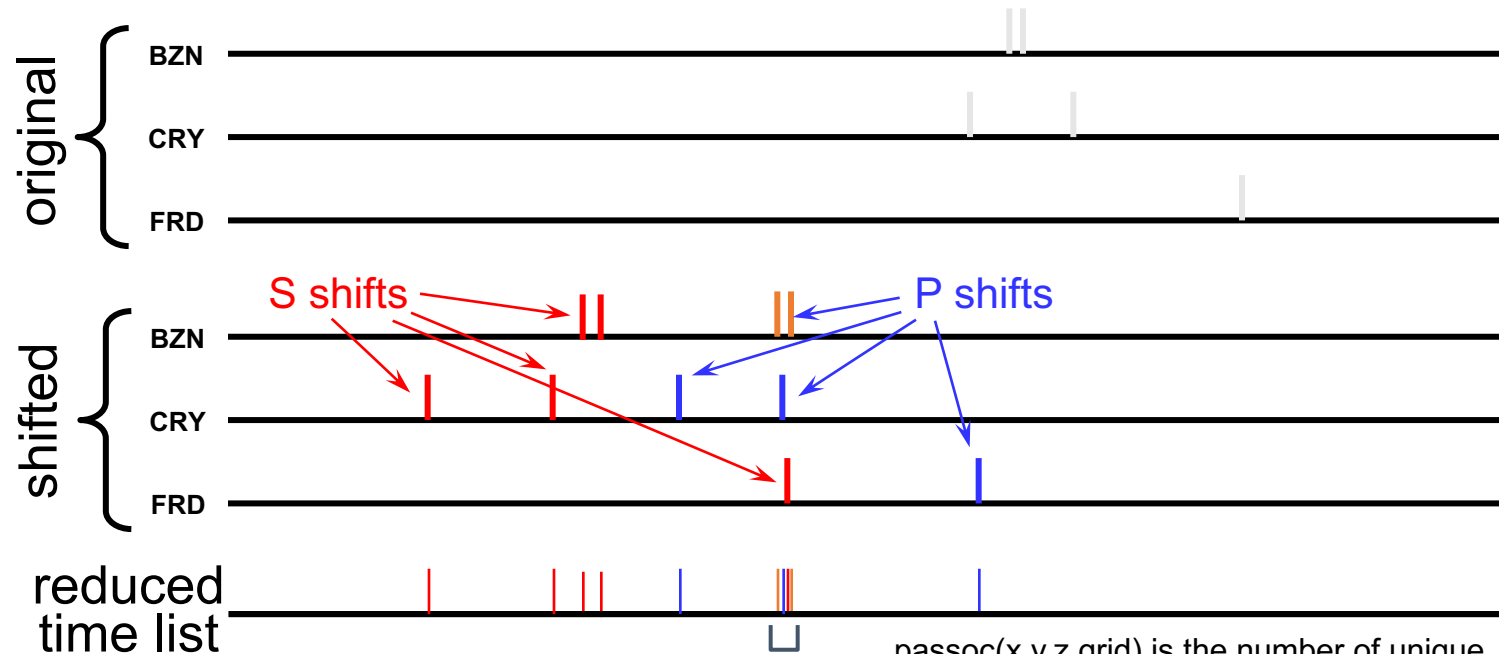
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# P-wave Processing

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:



$cluster\_twin$  passoc(x,y,z,grid) is the number of unique station picks within this window

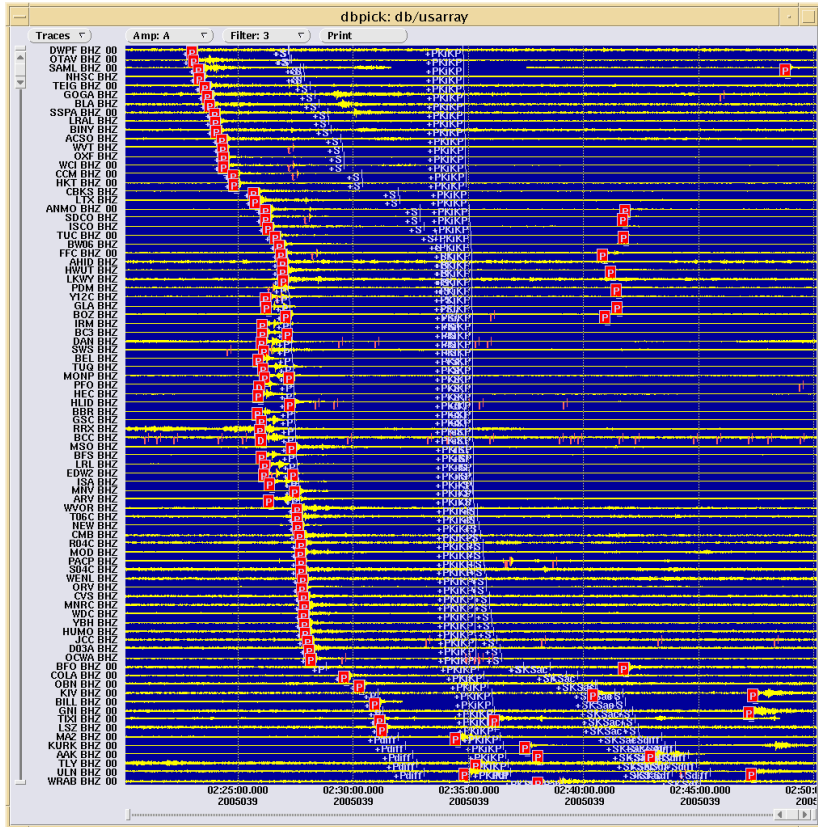
mean value within  $cluster\_twin$  defines event origin time  
a standard deviation within this window is also computed



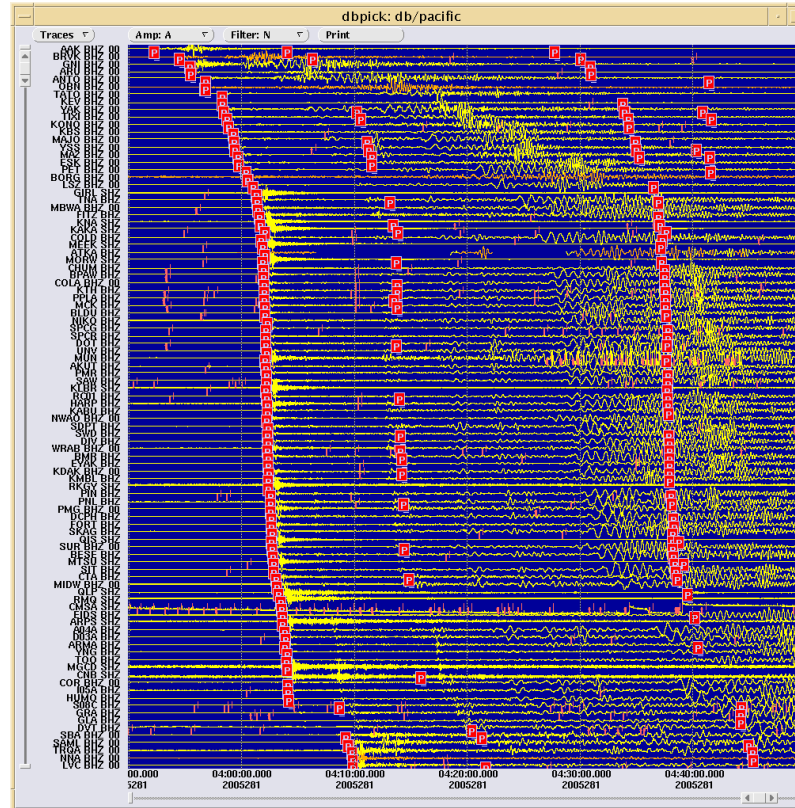
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# Recursive Pick Processing



### Best-fit identification of overlapping events

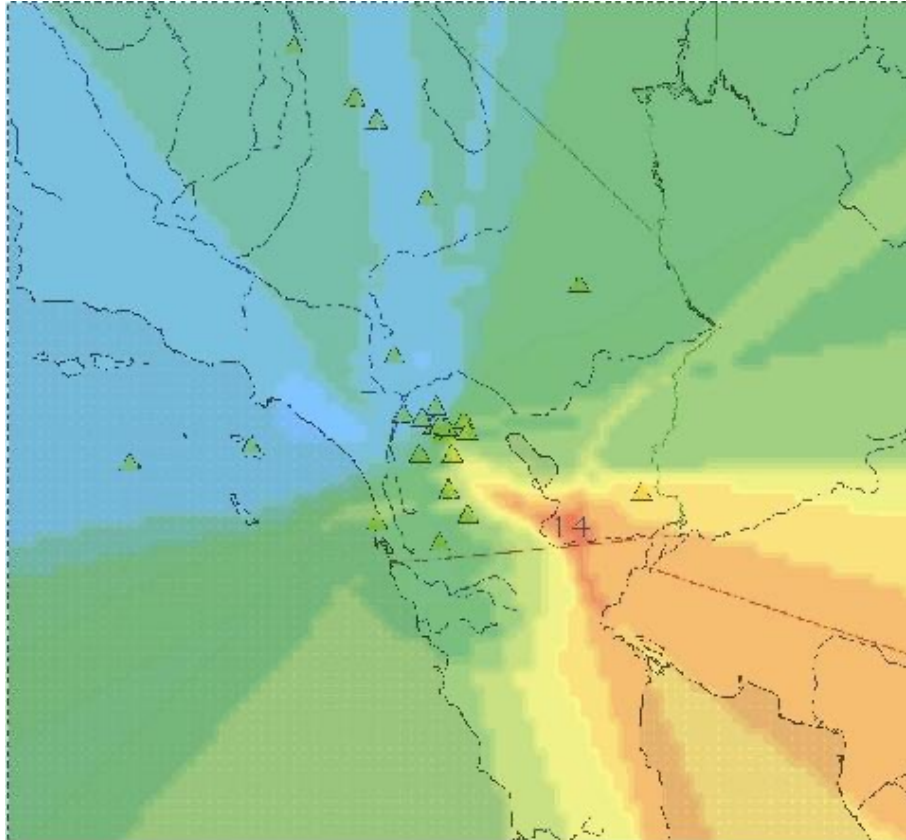


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# Location Grid in Action

*orbassoc*

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



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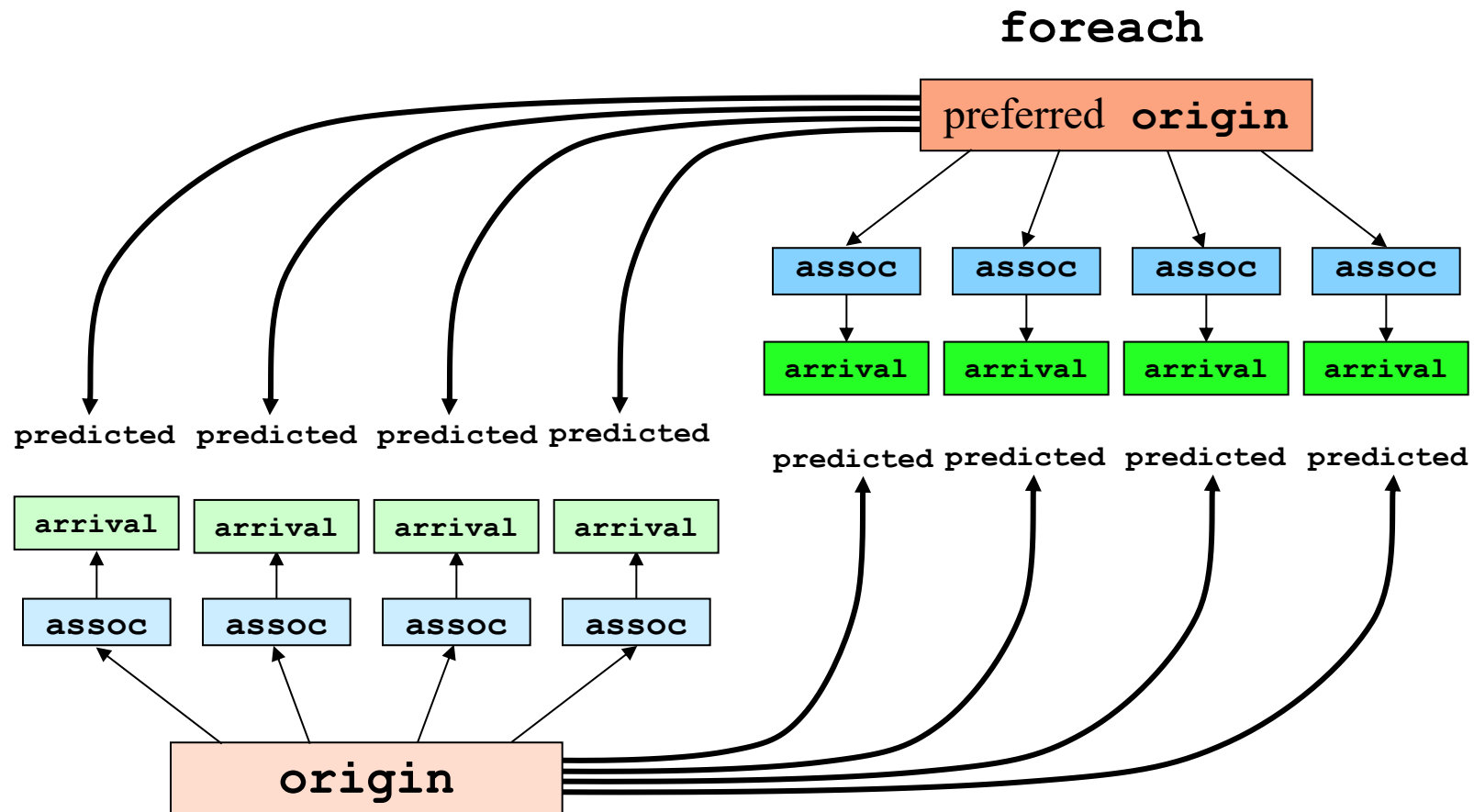
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# “Smart” Event Association

From event object

From archive database

*orb2dbt*

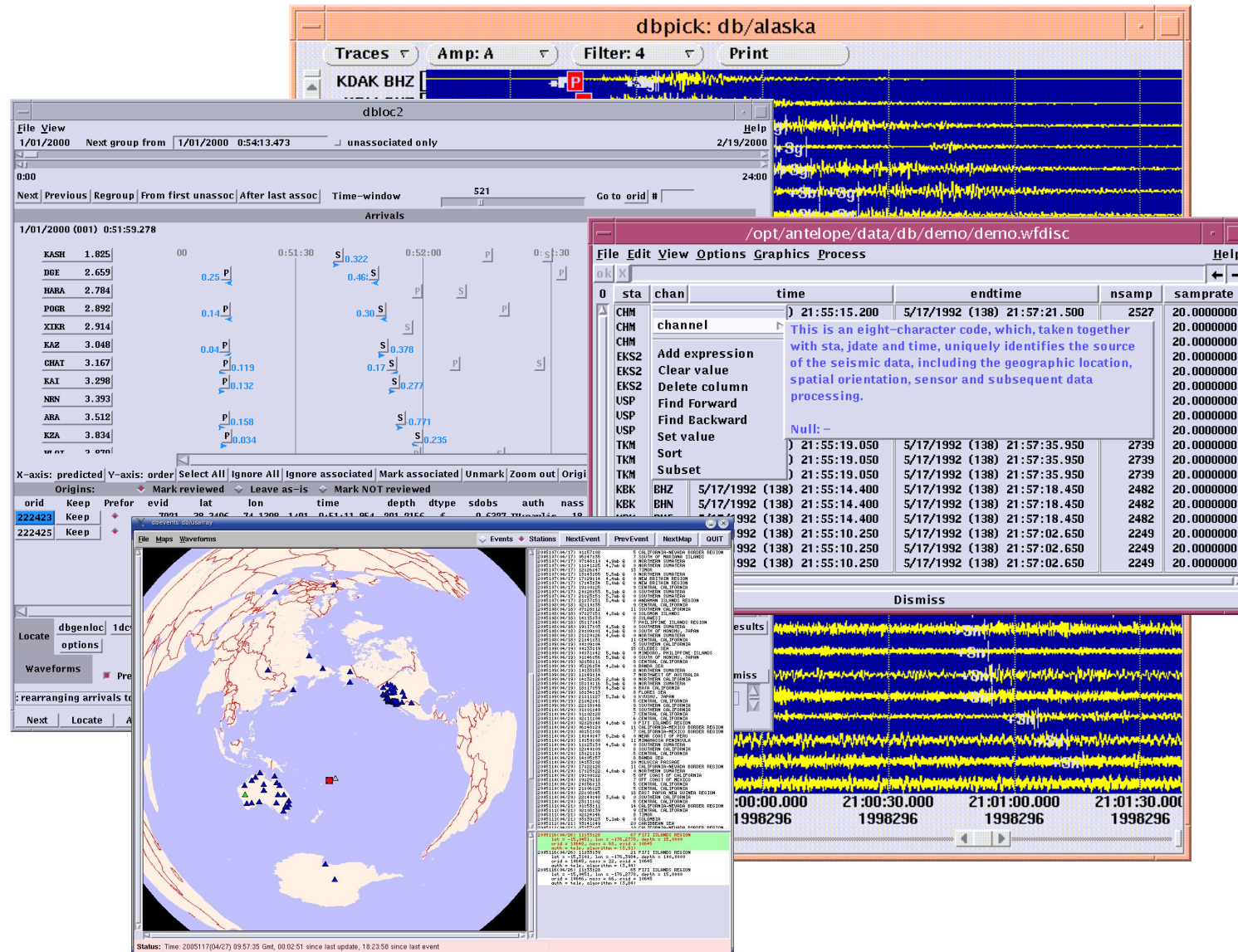


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# Analyst Event Location and Review

dbloc2



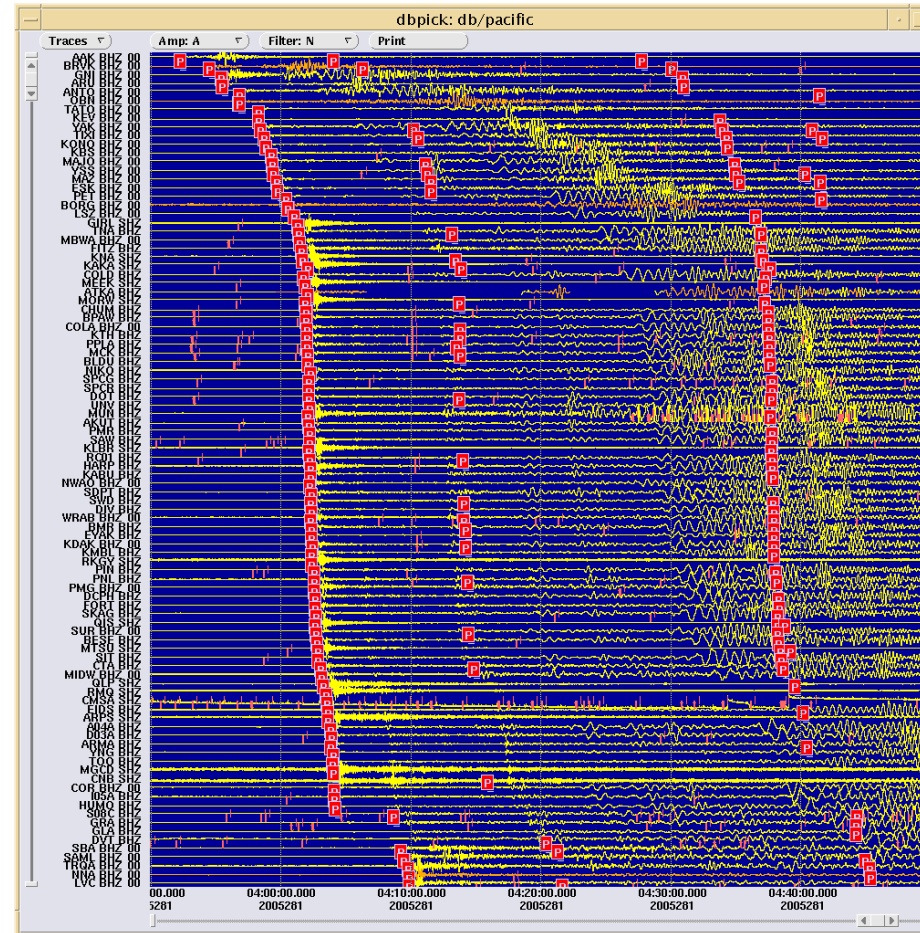
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# Waveform viewing and phase picking

## *Dbpick and traceview*

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

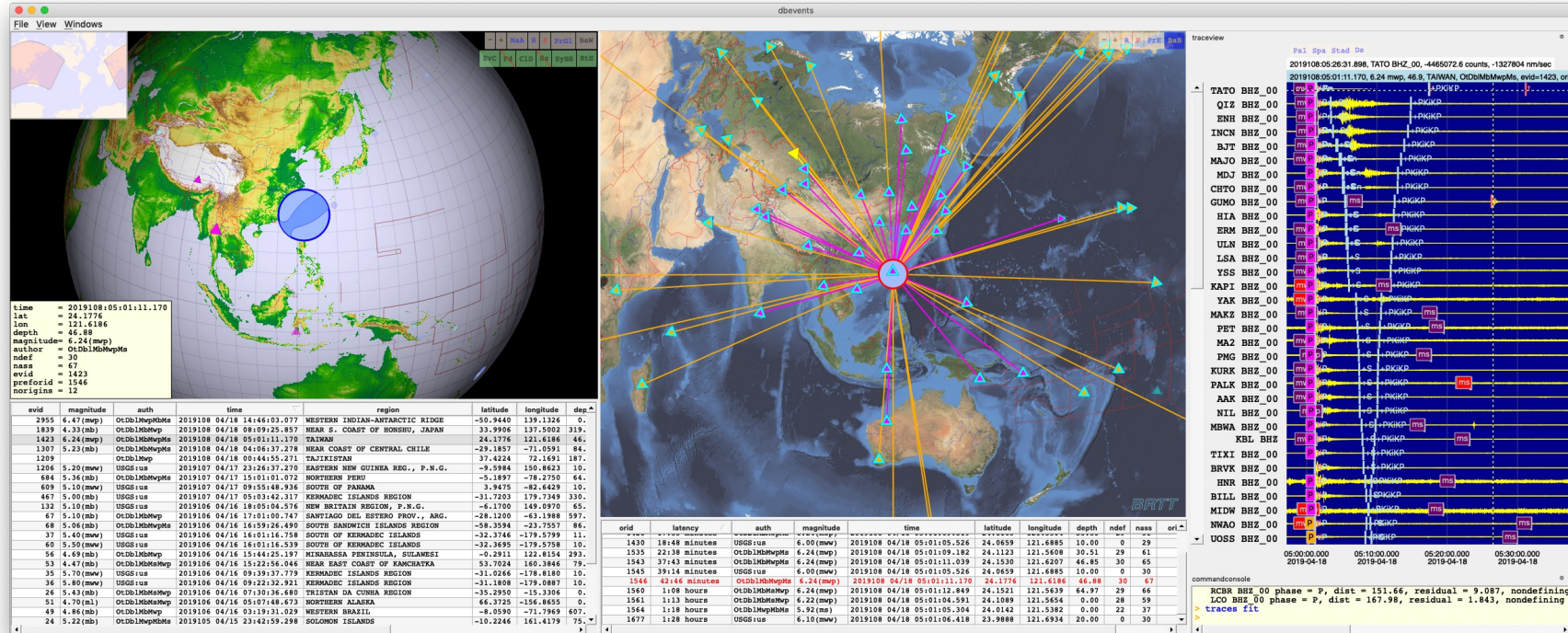


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# Event Display

dbevents



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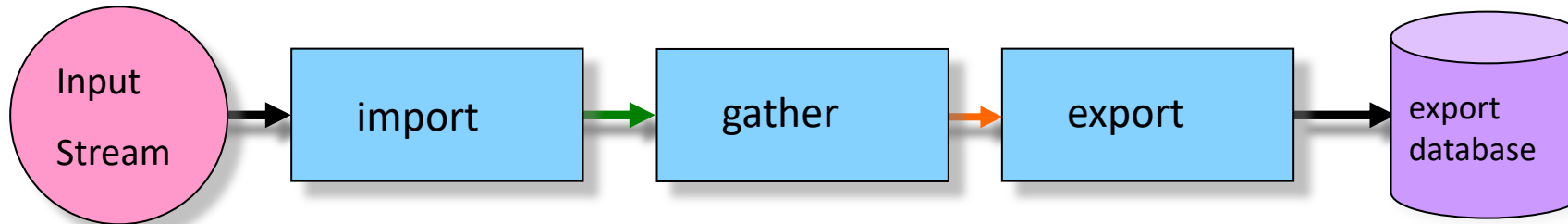
# Generic Stream Processing Framework

- Framework for arbitrary waveform computations
- 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

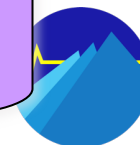
*orbwfproc*

*Heal waveforms (data out of time order, overlapping data, gaps, etc)*

*Create defragmented export database:*



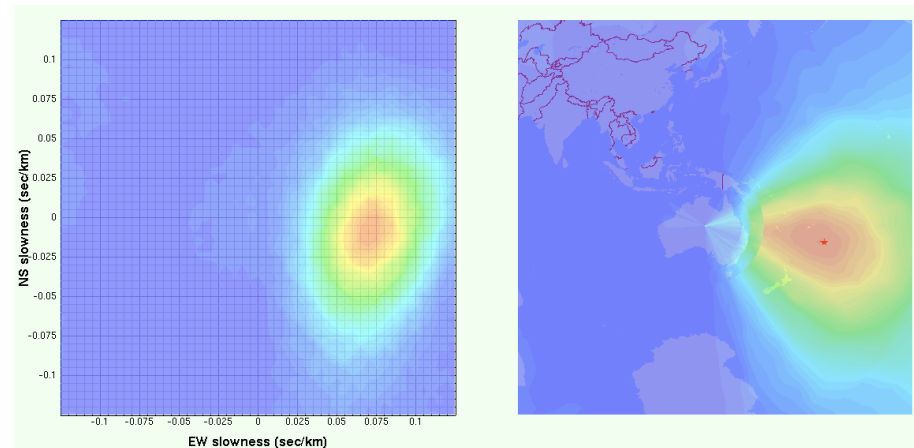
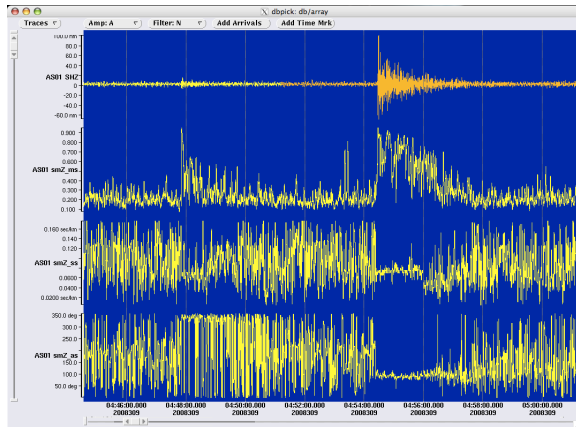
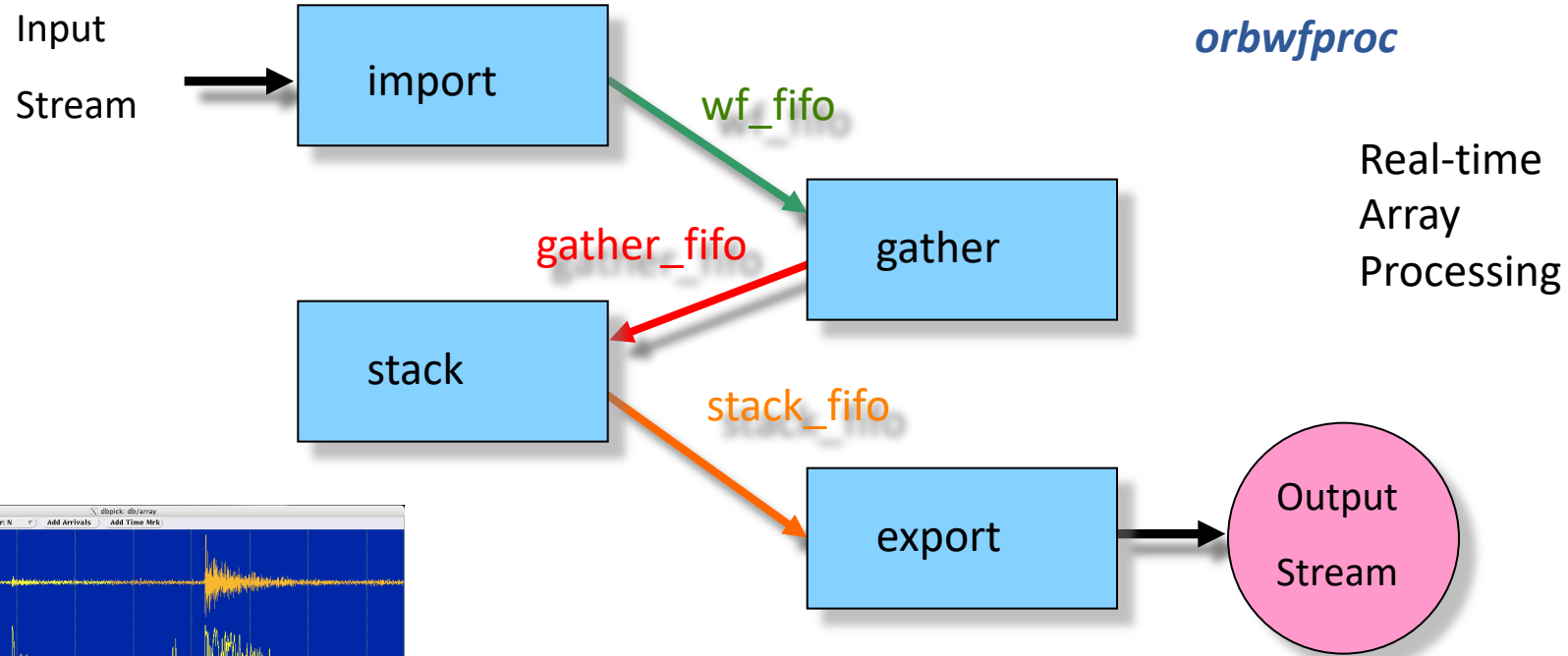
*Resample or filter waveform data (e.g. change SEED codes):*



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# Generic Stream Processing Framework

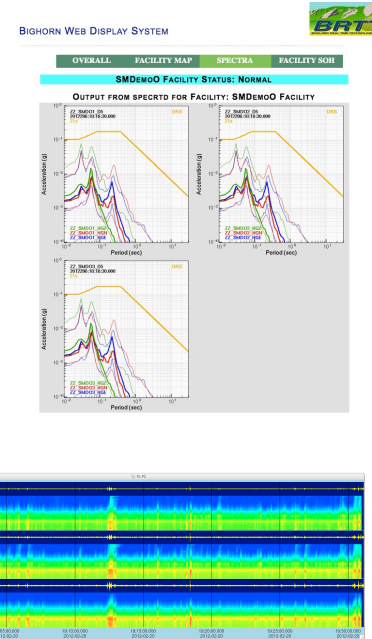
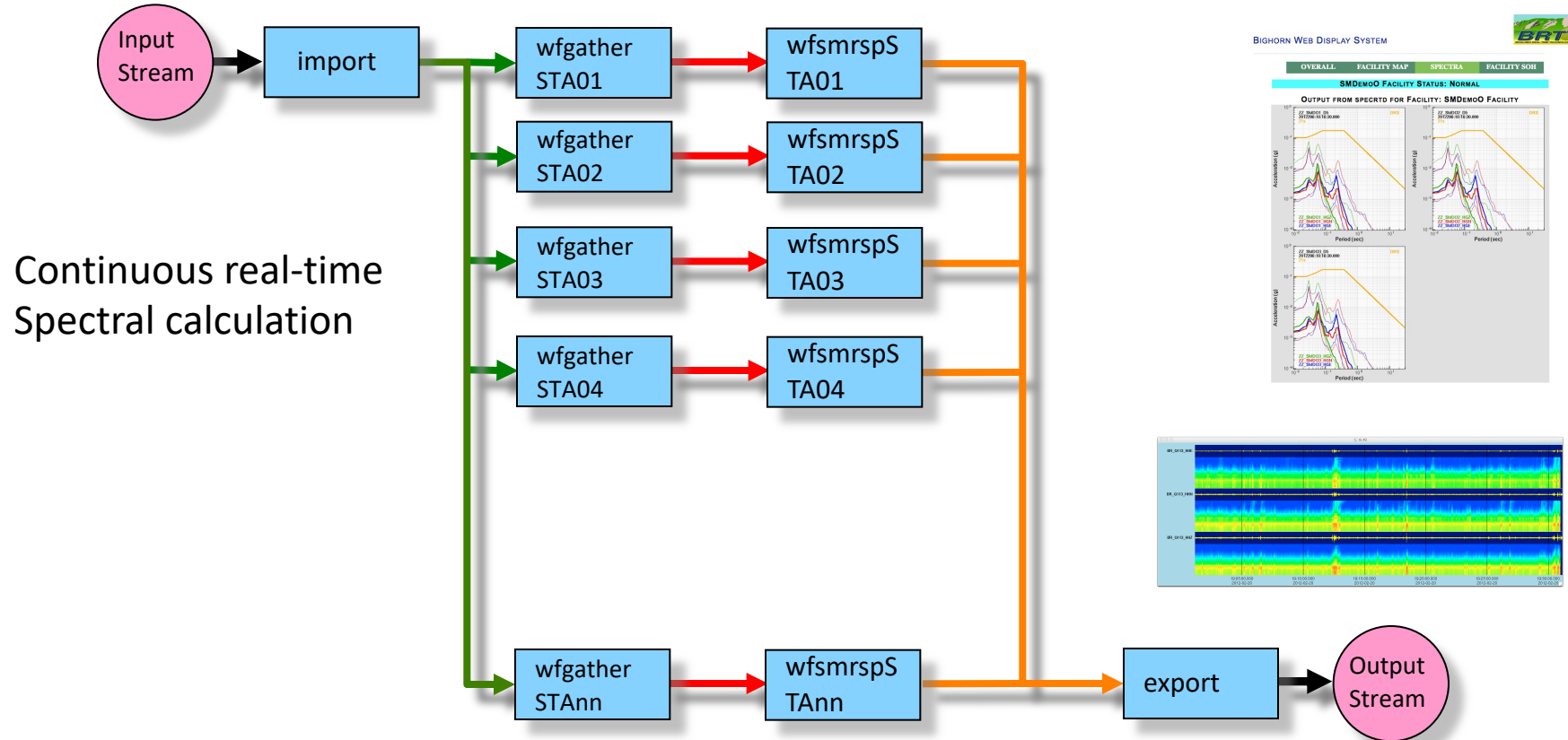


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# Generic Stream Processing Framework

*orbwfproc*

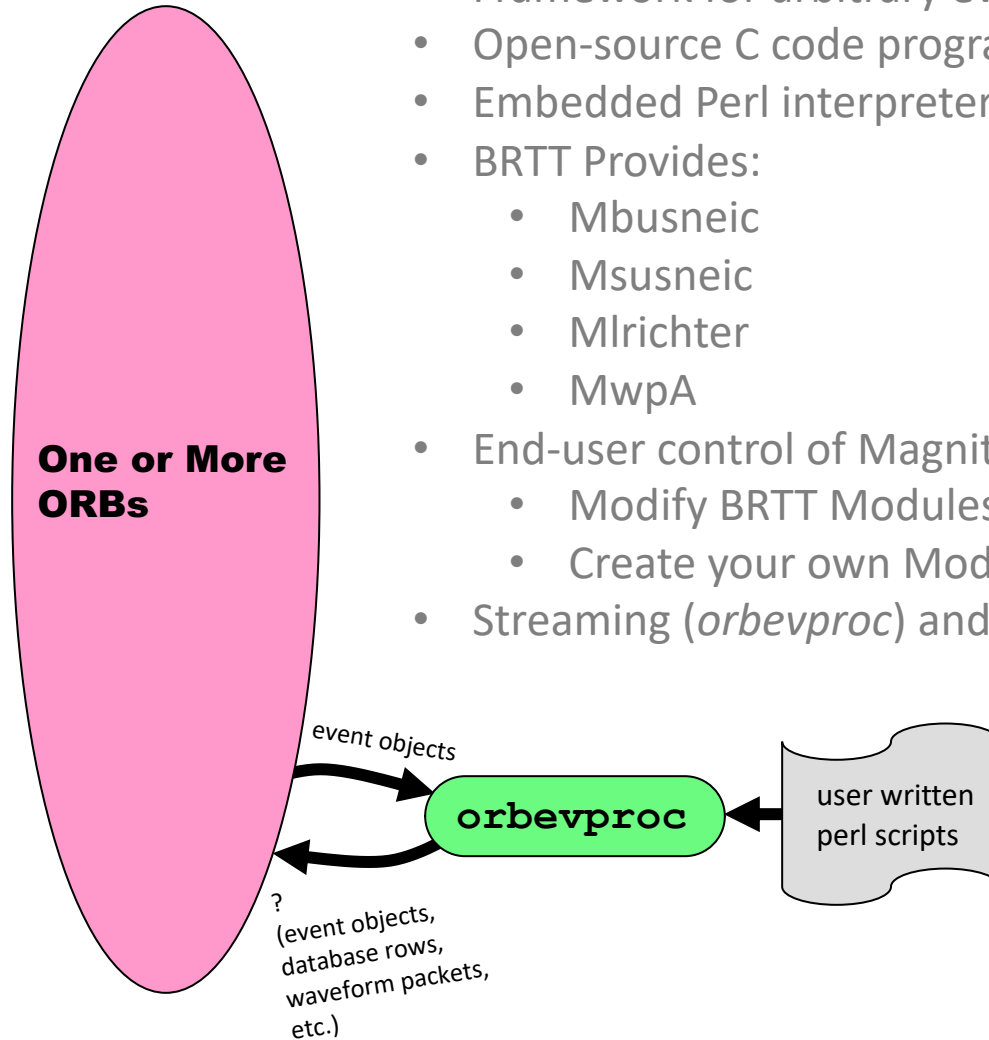


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# Generic Event Processing Framework

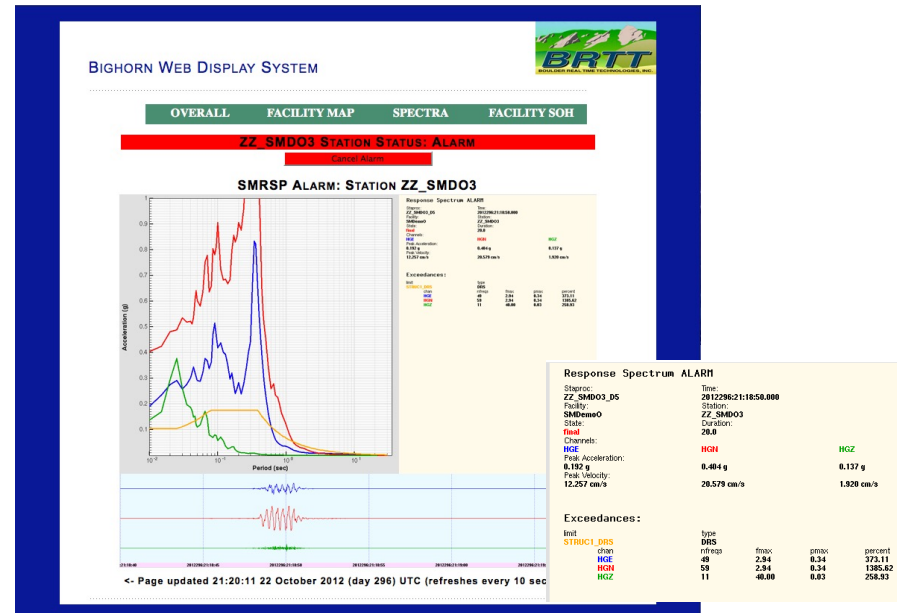
- Framework for arbitrary event-driven computations
- Open-source C code program *orbevproc*
- Embedded Perl interpreter processes algorithms
- BRTT Provides:
  - Mbusneic
  - Msusneic
  - Mlrichter
  - MwpA
- End-user control of Magnitude calculation
  - Modify BRTT Modules
  - Create your own Module
- Streaming (*orbevproc*) and Batch (*dbevproc*) mode



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- [illegible]



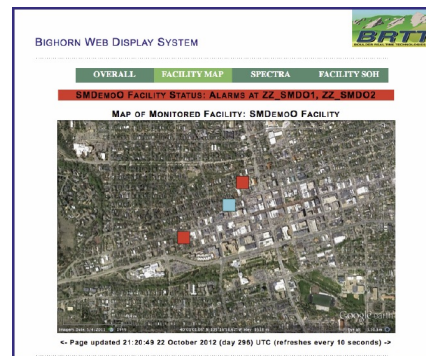
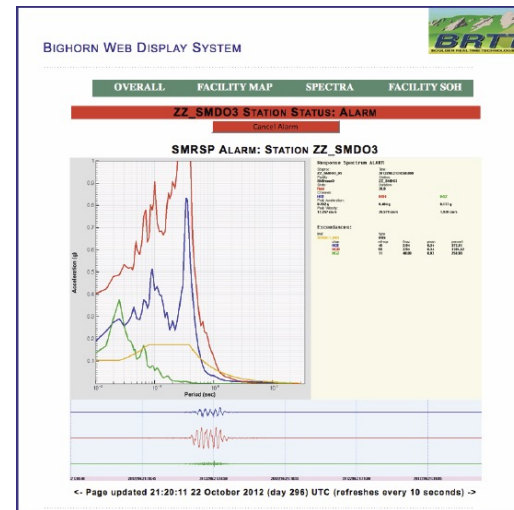
# Bighorn

## 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***

*Facility  
Monitoring*

***Bundled into Antelope***



***State-of-Health  
Monitoring***

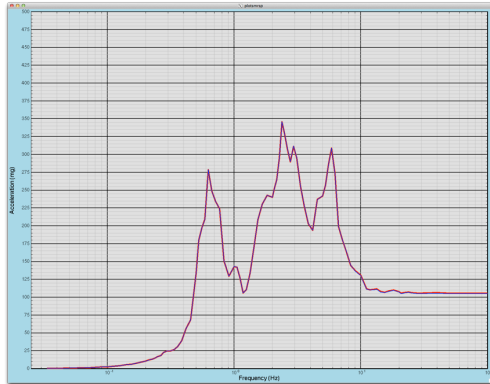


**BRTT**

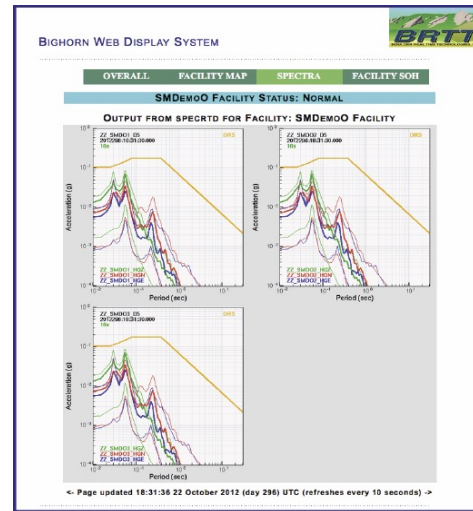
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# Bighorn

- Method vetted by Nuclear Regulatory Commission
- Faithful translation from
  - After-the-fact event-based review; to
  - Streaming, real-time, continuous now-casting



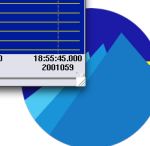
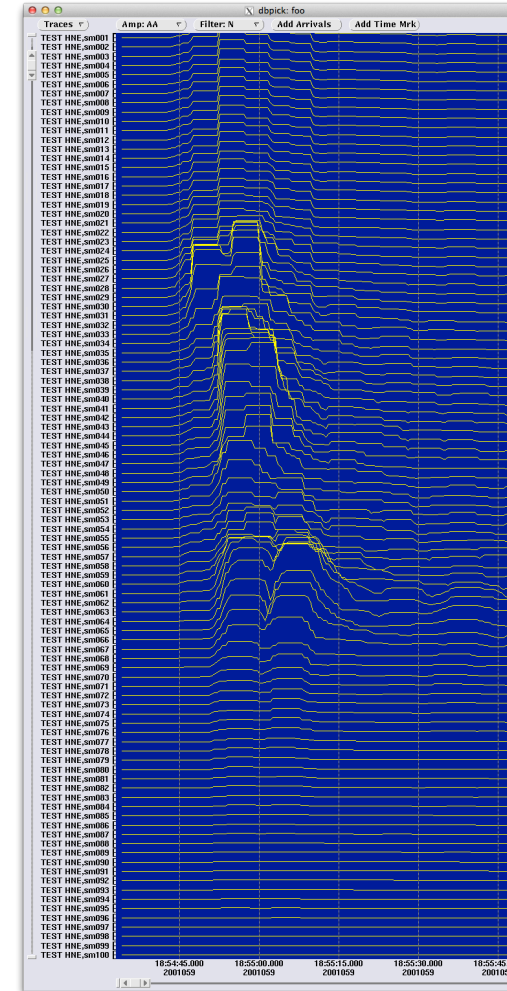
-> Synthesize  
Real-time  
Spectral  
Calculations



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



Multiple  
Time-domain filters  
Of incoming wavefield



## BRTT

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# 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



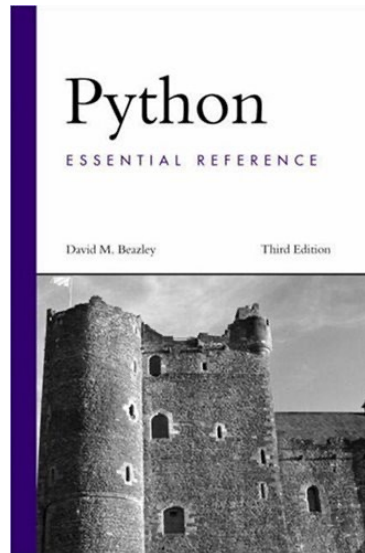
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# Python

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



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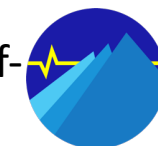
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# Open-source Community

- <http://www.antelopeusersgroup.com>
- <http://www.github.com/antelopeusersgroup>
- Advances
  - Custom earthquake alarms
  - Alarm-response tools
  - Enhancements to Antelope utilities – 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-of-ownership system – only available from commercial code



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# Obtaining Antelope

- Evaluation copies, subscriptions or upgrades to Antelope 5.13:
  - Contact Kinemetrics, Inc.:
    - [sales@kmi.com](mailto:sales@kmi.com)
- Technical questions about Antelope:
  - Contact BRTT:
    - [support@brtt.com](mailto:support@brtt.com)

Thank You

***support@brtt.com***



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