

**MATSEIS AND THE GNEM R&E REGIONAL SEISMIC ANALYSIS TOOLS**

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**ABSTRACT**

To improve the nuclear event monitoring capability of the United States (US), the National Nuclear Security Administration (NNSA) Ground-based Nuclear Explosion Monitoring Research & Engineering (GNEM R&E) program has been developing a collection of products known as the Knowledge Base (KB). Though much of the focus for the KB has been on the development of calibration data, we have also developed numerous software tools for various purposes. The Matlab-based MatSeis package and the associated suite of regional seismic analysis tools were developed to aid in the testing and evaluation of some Knowledge Base products for which existing applications were either not available or ill-suited. This presentation will highlight new features in this year's versions of MatSeis and the regional analysis tools.

New MatSeis features include: support for the United States National Data Center (USNDC) 2003 database schema, backwards compatibility with the previous database schema, a full-featured locator written entirely in Matlab code (compiled libraries not required), an interface to LocOO (a new Object-Oriented locator written in C++), communication with KBNavigator (a new Knowledge Base GIS application), and an updated user's manual with expanded feature descriptions and tutorials.

The Regional Seismic Tools include CodaMag Tool, EventID Tool, PhaseMatch Tool, and Dendro Tool. New CodaMag Tool features include: more informative output records and the use of kriged correction surfaces. New EventID Tool features include: a plot of  $M_s$  vs  $m_b$  and processing parameters obtained from the database. New PhaseMatch Tool features include an interface to display a dispersion curve for any desired path. New Dendro Tool features include: expanded capabilities to automatically add/re-pick arrivals based on the picked arrivals for similar events; integrated use of Measure Tool to manually adjust arrival times; expanded multi-window processing parameters (filter banks, different sized windows and filters); and Principle Component Analysis/Factor Analysis capabilities.

## **OBJECTIVE**

MatSeis continues to provide an excellent prototyping environment in which promising seismic analysis techniques can be implemented and evaluated quickly and with relatively little effort. Sandia has used the package to build a set of prototypes for various regional analysis tasks: PhaseMatch Tool for phase match filtering, CodaMag Tool for regional magnitude calculations, EventID Tool for phase ratio discrimination, and Dendro Tool for event clustering using waveform correlation. These products are now all fairly mature, but development on them continues in response to the research results from our co-workers at LANL and LLNL and to feedback from our users at AFTAC. In addition to the changes to the tools, we also continue to make changes to MatSeis itself, particularly in fixing bugs and adding in missing basic features.

## **RESEARCH ACCOMPLISHED**

The following sections describe the latest versions (1.7) of MatSeis, and the four regional seismic analysis tools. The important new features are highlighted for each.

### **MatSeis**

The main MatSeis graphical window is a standard time vs. epicentral distance plot that can display waveforms, arrivals, origins, and travel time curves. The user can interact with this display by clicking directly on the displayed objects, by using the buttons along the bottom, by using the menus along the top, or by typing commands at the Matlab prompt. MatSeis is predominantly written as Matlab m-file functions, which are organized in a set of directories according to the general purpose of each. However, the package also includes a set of compiled C functions linked to the m-files via the Matlab cmex utility. Typically the C functions are introduced where performance of an m-file is too slow (e.g. FK calculations).

### **Data IO**

MatSeis can read US NDC format data from either an Oracle database, or flatfiles. Output is restricted to flatfiles only. The number of tables used by MatSeis has steadily expanded and now includes: *affiliation, amplitude, arrival, assoc, event, instrument, nextid, netmag, network, origerr, origin, remark, sensor, site, sitechan, stamag, wfdisc, and wftag*. In Version 1.7, flatfile data reads have been greatly sped up, making it practical to work with larger data sets than has been the case in the past. In order to allow the user to better control the data read into MatSeis, Version 1.7 has an extensive set of filters for both origins (*lat, lon, magnitude, etype, auth*) and arrivals (*sta, chan, phase, auth, orid*). These filters have been expanded to support querying for lists of several parameters (i.e. multiple station names). In the origin read popup, *evid* is now displayed, which makes it more convenient to work with multiple origins for the same event. The origins across the top of the main MatSeis window are now displayed with both *orid* and *evid*.

### **Location**

MatSeis-1.7 includes two new options for performing locations. The first option is a fully-featured locator written entirely in Matlab (Figure 1). The advantage of this new locator is that there are no binaries to compile or proprietary libraries to reference. So, this locator will be able to run on any platform that is supported by Matlab.

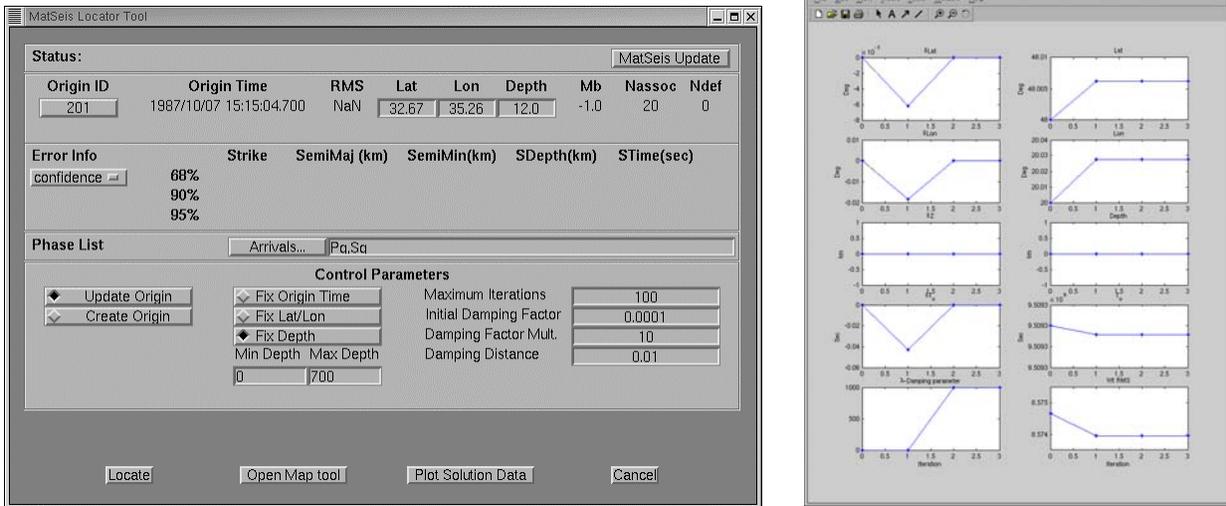


Figure 1. The MatSeis Locator (left) is written entirely in Matlab. The iterative solution data is also shown (right).

The second new locator option (not included in the standard release) is a MatSeis interface to LocOO (Figure 2). LocOO is an extensible Object Oriented locator written in C++ that provides the capability for developers to add their own solvers (Ballard, 2002). The interface allows the user to review and edit various control parameters, locate the event, and then review the results.

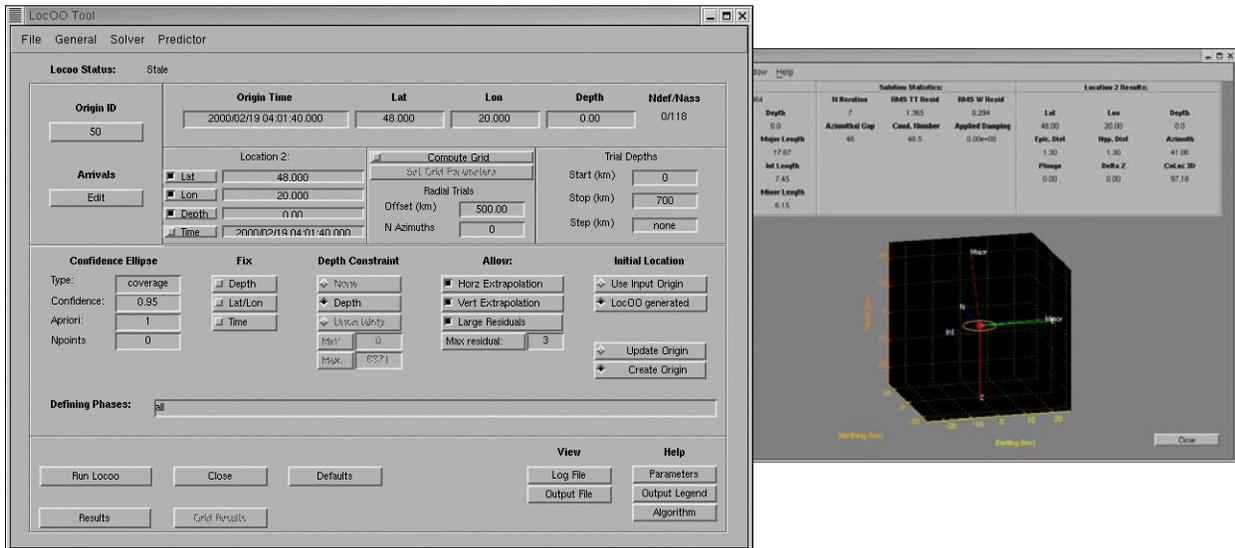


Figure 2. The MatSeis interface to LocOO (left) and the 3D location results (right).

In addition to graphical controls for the various parameters needed to run LocOO, the interface also provides innovative graphical presentations of the solution location and the calculated uncertainties which can aid in interpreting the event.

## Regional Seismic Analysis Tools

### Phase Match Tool

PhaseMatch Tool is a waveform analysis interface launched from MatSeis that allows the user to calculate the predicted surface wave dispersion for a given source to receiver path by ray tracing through a model, and then use the model dispersion to generate and apply a matched filter (Herrin and Goforth, 1977). The tool allows the user to view the observed waveform, the model dispersion, the predicted waveform, the cross-correlation of the predicted and observed waveforms, and the match-filtered waveform. The user can control the frequency range of the model dispersion used, as well as the time limit of the portion of the cross-correlated waveform from which the match-filtered waveform is taken. Once a satisfactory filtering has been achieved, the user can send either the observed waveform or the filtered waveform to Measure Tool to measure surface wave amplitudes, which can then be used to determine event magnitude.

The new feature for Version 1.7 is an option to display a dispersion curve for any desired path by entering the start and end points of the path (Figure 3).

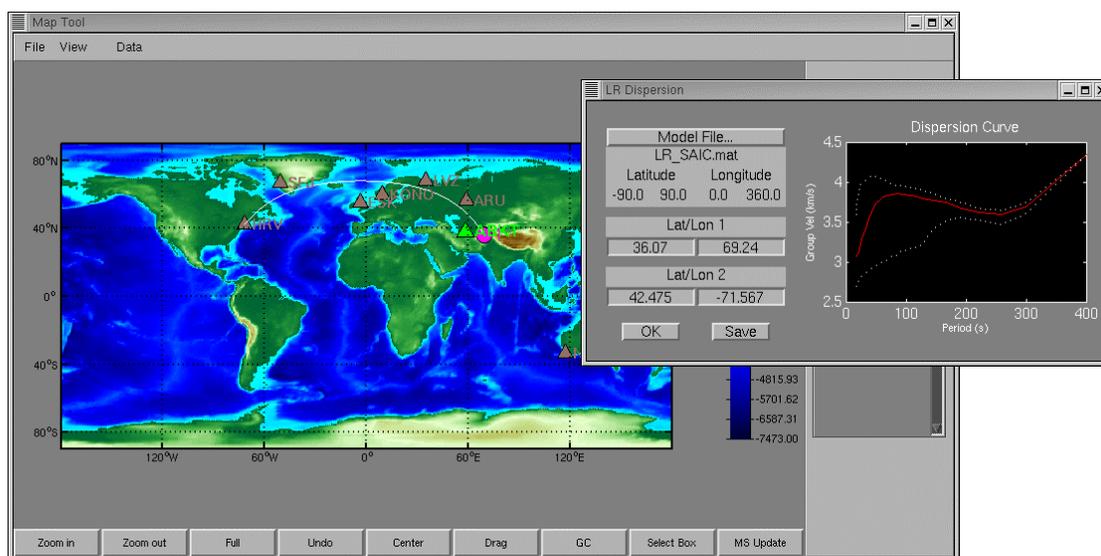


Figure 3. Phase Match Tool now allows the user to compute a dispersion curve for any path.

### Coda Magnitude Tool

CodaMag Tool is a waveform analysis interface launched from MatSeis that allows the user to calculate magnitudes and source spectra for an event of interest by fitting empirical decay functions to narrow-band coda envelopes of a given phase (currently Lg). The technique was developed by Mayeda and has been described in detail in several papers (Mayeda, 1993; Mayeda and Walter, 1996; Mayeda, et al., 1999). The tool consists of two displays. The main one shows the calculated moment spectrum and the derived magnitudes. The second display shows how the spectrum was derived. The user can adjust the Lg arrival window, examine the fit between the observed and synthetic envelopes, and control which frequency bands are used for the magnitude calculations. The various required parameters (frequency bands, groups velocity windows, decay curves, etc.) are read from parameter files unique to each station.

Important new features in Version 1.7 include more informative output data records and the ability to make use of kriged correction surfaces.

### Event Identification Tool

EventID Tool is a waveform analysis interface launched from MatSeis that allows the user to identify an event of interest (i.e. explosion or earthquake) using spectral ratios of standard regional arrivals (see Hartse et al., 1997; Walter et al., 1999). The tool consists of three displays. The main display plots the phase ratio for the current event against a backdrop of the same ratio for archived events that have already been identified. The user can choose different phases and/or frequency bands to ratio to try to improve the separation of the earthquake and explosion

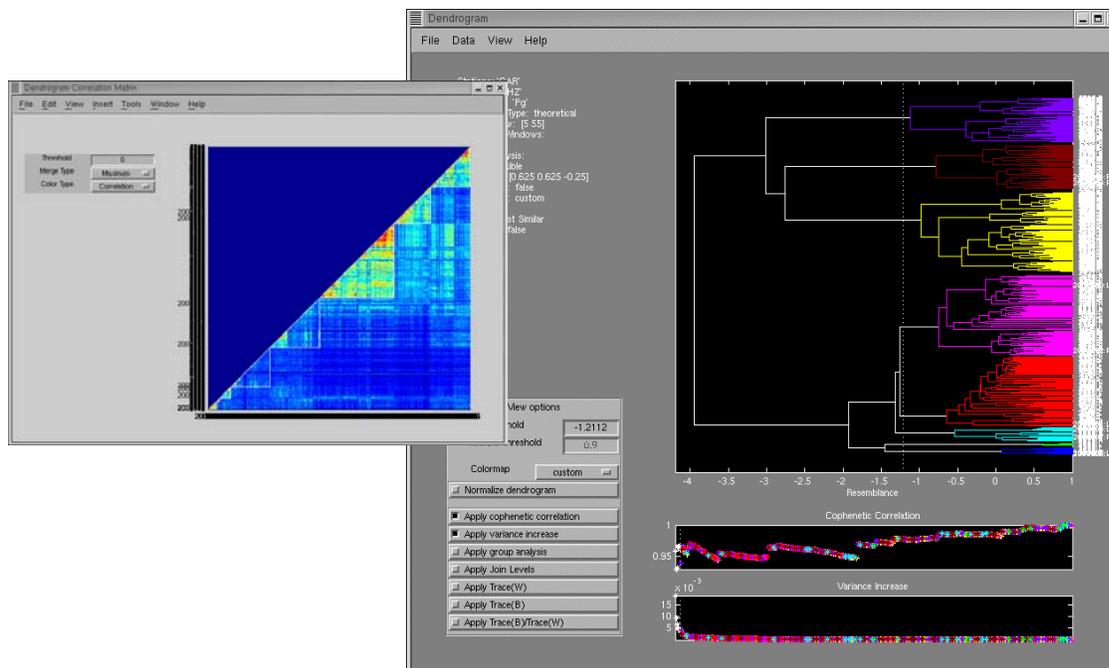
populations, and the display will immediately update. A second display shows the user a plot of an “MDACogram” (i.e. the MDAC corrected measurements at all of the phase/frequency combinations) for the current event along with all of the archived events. This can be useful in deciding which ratio will yield the best separation. If there are questions about the amplitude measurements themselves, a third display can be brought up, and the user can easily examine group velocity windows for the phases and change them if necessary. If they are changed, the measurements will automatically be re-made and the ratios updated in the main display.

Version 1.7 has several new features including a plot of  $M_s$  vs  $m_b$  and storage of the processing parameters within a custom database table.

### Dendrogram Tool

Dendro Tool provides a tool to perform waveform correlation-based cluster analysis techniques on seismic data. The purpose of Dendro Tool is quite simple: to allow a user to quickly and efficiently determine whether a waveform of interest matches any in the available archives. By arranging the correlations in a hierarchical dendrogram, rather than just determining the most similar waveform, the user gets a much more complete picture of how the current event fits with the archived events. For example, in regions with repeated mining explosions, the mines are often easily identified as distinct clusters, and new mining events can be readily identified as such by association with those clusters.

Dendro Tool consists of many interfaces to help the user assess the effectiveness of the clustering and to use the clusters to identify the events. The main display shows the dendrogram (Figure 4), along with a set of metrics that can be used to determine the correlation level to use to identify the families of events. Once a level has been chosen, the families are assigned separate, distinct colors to make them easier to see. Parameters controlling filtering and windowing of the waveforms, the method used to build the dendrogram, etc. can be set using another display, and the dendrogram will then be updated. The color-coded waveforms for any or all of the families in the dendrogram display can be sent to a variety of tools for further analysis: Free Plot for displaying waveforms, Map Tool for event locations, histograms for time analysis.



**Figure 4.** The Dendrogram Tool (right) employs hierarchical cluster analysis to group similar waveforms. The correlation matrix (left) can be displayed to help validate the relationships defined in the dendrogram.

Dendro Tool can form dendrograms based on a single-phase window for a single station, or the user can choose to use multiple windows and/or multiple stations. The method of combining the multiple correlations (minimum, maximum, mean, median) is user controlled.

The significant new features for Version 1.7 are related to verifying the families, and using the families to automate the task of re-timing arrivals. To verify the families, we provide a plot of the correlation matrix from which the dendrogram was derived (Figure 4). The ordering of the events is the same as in the dendrogram, so one can easily evaluate from this plot the strength of the intracorrelations within groups and the intercorrelations between groups. Factor Analysis provides another method to evaluate the families assigned from the dendrogram (Figure 5). The eigen-vectors of the correlation matrix are computed to consolidate the observed variance in the correlations in as few dimensions as possible. The resulting coordinates from the eigen-vector decomposition are then displayed in a scatter plot, with the events having the same color-coding as in the dendrogram.

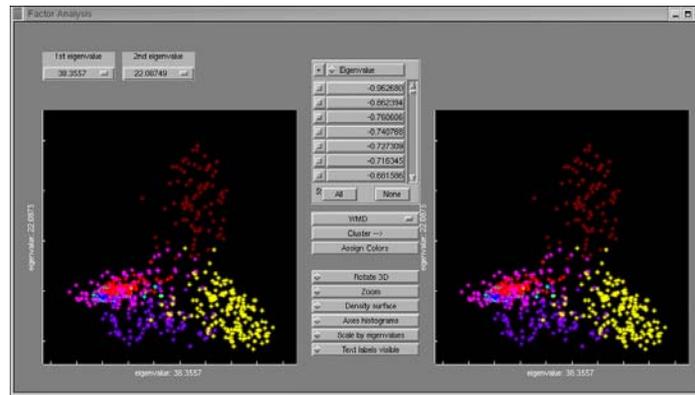


Figure 5. The Factor Analysis figure displays a color-coded scatter plot of the events from the Dendrogram Tool.

For re-timing arrivals, the solution method has been improved to compute the least-squared solution for a group of waveforms (Rowe et al, 2002). Also, the re-timing interface has been integrated with Measure Tool to allow for easy adjustments to the reference arrivals (Figure 6).

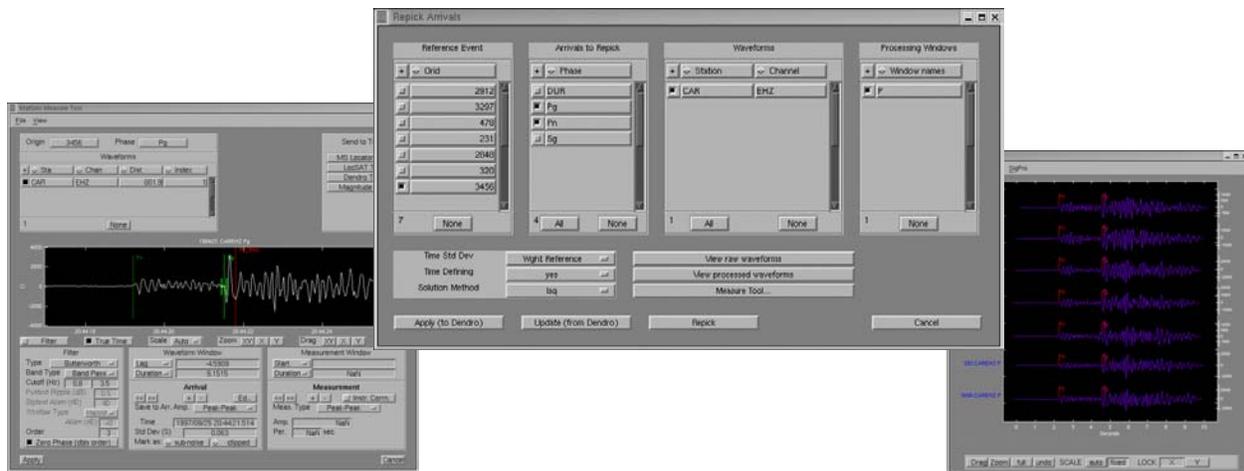
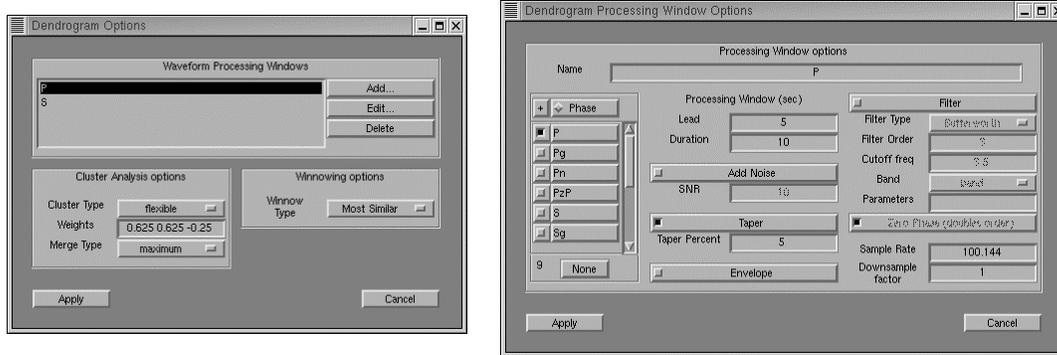


Figure 6. The Dendrogram Repicking interface (center) allows the user to control the operation of the repicking process, provides integration with Measure Tool (left) to manually adjust the arrival timing for the reference waveform, and can display the waveforms and their arrivals in Freeplot (right).

With the new interface, the user can quickly review the waveforms from a given family to choose a reference, decide which phase(s) to re-time, choose which events to include in the re-timing, execute the process, and review the results. The waveform processing parameters have been generalized to allow for greater control over how the processing windows are computed (Figure 7). These generalized parameters will allow analysis techniques such as multiple processing windows with different lengths or filter banks to analyze a variety of frequency bands.



**Figure 7. The Dendrogram Tool can provide any number of processing windows (left). Each processing window can be defined independently of any other processing window (right).**

## **CONCLUSIONS AND RECOMMENDATIONS**

In this paper, we have highlighted some of the more significant changes from the past year to MatSeis and the MatSeis-based regional seismic analysis tools -- Phase Match Tool, Codamag Tool, EventID Tool, and Dendro Tool. These tools will continue to evolve in response to user needs. We also recognize that there are still many other useful research algorithms that could be used by AFTAC, and we will look for good candidates to add into the MatSeis tool suite. We believe that MatSeis continues to offer one of the best, if not the best, platforms to prototype analysis tools.

The official 1.7 version of the basic MatSeis package is available to all from the GNEM R&E web site:  
<https://www.nemre.nnsa.doe.gov/cgi-bin/prod/nemre/matseis.cgi>

Matlab and the Signal Processing Toolbox are required to run MatSeis. Version 6.0 of Matlab or later is required. MatSeis will run on Sun workstations, Windows PC's, and Linux PC's. It should run on other supported Matlab platforms as well, but the C code will need to be re-compiled.

Some of the regional seismic analysis tools may be available to researchers for event monitoring research. Requests should be made though the AFRL/NNSA contracting officer to the NNSA sponsor.

## **ACKNOWLEDGEMENTS**

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