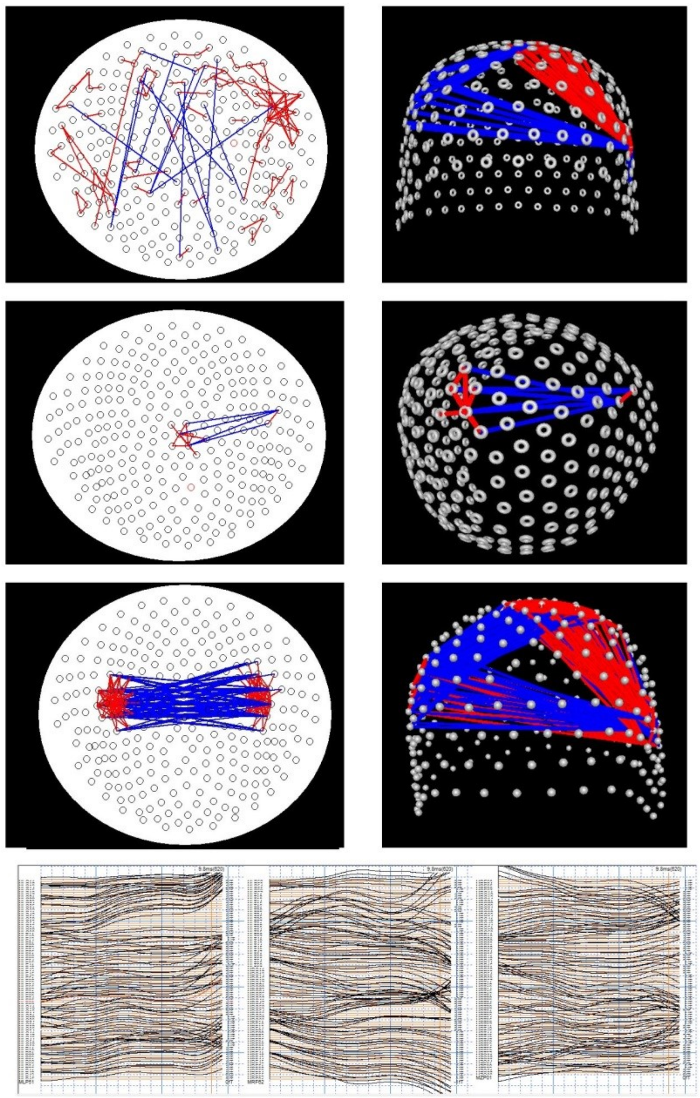
Waveform Channel-Cross-Channel (CxC) Analyses

Software Guide (EEG/MEG Data)



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Features and specifications of this software program are subject to change without notice. This manual contains information and images about EEG (electroencephalography) and MEG (magnetoencephalography) time-frequency software and its user interface, GUI and its other signal processing algorithms, publications that may be protected by copyright.

Sending Your Comments and Critiques: We would like to hear from you. Your comments and suggestions for improving this document are welcome and appreciated. Please e-mail your feedback to BrainX@live.com

Thank you.

Contents

Warnings and Cautions

The correlation between EEG/MEG signals from two channels can be analyzed in several ways. In this manual, we frequently use the term of channel-cross-channel (CxC). “CxC” indicates operations applying to two channels or a channel-pair. An operation of two channels is a “CxC” operation that can produce many possible results. Here are some powerful usages:

1. Virtual channels: similar to many software programs, MEG Processor can produce virtual channel by subtracting or adding two physical channels. Instead of manually defining a virtual channel by subtracting two physical channels or a channel-pair, “CxC” can generate all possible virtual channels by using available physical channels with a set of operations. All the operations can be done by a few clicks. Once you try it, you will the power and usefulness of the “CxC” function. It is amazing, subjective and very efficient.

2. Coherence at sensor levels: coherence, correlation and association of two-sensor can be done by simply selecting “Covariance” or “Correlation” operation. “CxC” can analyze the relationship of all possible physical channel pair according to the setting of operations.

3. Covariance matrices for source localization: many EEG/MEG source localization algorithms require covariance matrices from sensor data. The “CxC” functions enable users to compute, preview and check the covariance matrices for source localization.

The coherence of two channel pair has been frequently used in the study of brain function. The study of the oscillatory synchrony between two channels can be done by computing the coherence. This can be computed in the frequency domain by normalizing the magnitude of the summed cross-spectral density between two signals by their respective power. For each frequency bin the coherence value is a number between 0 and 1. The coherence values reflect the consistency of the phase difference between the two signals at a given frequency. Unfortunately, the computing of each frequency could be time-consuming and requires a lot of memory. Therefore, waveform CxC can be used to compute the correlations of two sensors.

This program is optimized for computing CxC for all possible pair in a group of channels, for example, all MEG sensors. If there are N channel for computing CxC, the result will be a matrix with a size of N by N. Consequently, the results can be systematically analyzed with matrix operations.

Preface

This guide describes the operation applying to the waveforms from two channel pair, which is named CxC. The waveform CxC module is one of the core functions in EEG/MEG data analysis. It is used as the primary tool to determine if the signals from two sensors are correlated. The waveform CxC module provides graphic user interface (GUI) for access the functions.

Intended Audience

This guide is intended for persons responsible for analyzing the correlation of sensor pair, waveform covariance and virtual channel characteristics in EEG and MEG data. This reference is useful to anyone who performs analysis techniques for EEG/MEG data. Operations of correlation and covariance analysis require some expertise to satisfy requirements of accuracy and fitness for use of the results. Technicians may use the application under review by highly trained analytical staff. The guide assumes the reader is familiar with standard EEG/MEG procedures and is familiar with the Windows operating systems.

The covariance and correlation data generated by CxC operation can be used in source localization of MEG/EEG sources.

References

This document assumes familiarity with many terms related to computer operations and physiology. This document also assumes you are familiar with the principles of correlation coefficients, covariance and virtual channels as well as the data collection and recording process. It also assumes some knowledge of EEG/MEG analysis. The document uses terms related to computer operations and physiology as well as many acronyms.

Document Structure

Documents are generally provided in both Microsoft Word® format and Adobe® Acrobat® PDF (Portable Document Format). All editions are distributed on Flash Driver, CD or websites with the related software, and include bookmarks and hyperlinks to assist navigating the document. Please feel free to send your critiques, corrections, suggestions and comments to: BrainX@live.com.

Conventions

Numeric: Numeric values are generally presented in decimal but in special circumstances may also be expressed in hexadecimal or binary. Hexadecimal values are shown with a prefix of 0x, in the form 0x3D. Binary values are shown with a prefix of 0b, in the form 0b00111101. Otherwise, values are presumed decimal.

Units: Units of measure are given in metric. Where measure is provided in imperial units, they are typically shown in parenthesis after the metric units.

A millivolt (mV) is one one-thousandth of a volt (0.001 V or 1 10^{-3}. These units commonly are used in EKG, EMG, and sometimes in EEG. A microvolt (uV) is one one-millionth of a volt (0.000000 V or 1 x 10^{-6}). This is the commonest voltage measure in EEG. A nanovolt (nV) is one-thousandth of one-millionth of a v (0.000000001 V or 1 x 10^{-9}). This measure is used in the specific area of EEG dealing with evoked potentials.

The unit of current is the ampere (A). In EEG, typical smaller amounts are encountered. A milliampere (mA) is one one-thousandth of an ampere (0.001 A or 1 x 10^{-3}). A microamplere (uA) is one one-millionth of an ampere (0.000000 A, or 1 x 10^{-6}).

Magnetic signal strength is given in Teslas (T), the SI unit of flux density (or field intensity) for magnetic fields, also known as the magnetic induction. Typical signal strengths in MEG measurements are in the order of pT (picoteslas = 10^{-12}) or fT (femtoteslas = 10^{-15}).

Changes from Previous Releases

If you used the software before, please read the ReadMeFirst.doc file for late changes that did not make it into this manual and for a list of new functions or options, changes, additions, bug fixes, and known bugs for the application. In comparison with previous version of the software, this version of the software only provides three CxC results: Active, Control and the Results of Active and Control (Act-Ctl). The main reason for this change is to provide better user experience and minimize the use of computer memory. However, the CxC dataset can be increased for specific purposes but those modules are used only for internal tests.

Introduction

This manual describes the various graphical elements that make up wave form CxC analysis module and defines the CxC data throughout the software applications. There are several ways to analyze the correlations of MEG data from two sensors. In this guide, the waveform CxC operations will be discussed according to the computing of CxC data and the visualization of CxC data. The mathematic algorithms will be explained briefly. There three major use of the CxC data.

1. Virtual channels: similar to many software programs, MEG Processor can produce virtual channel by subtracting or adding two physical channels. Instead of manually defining a virtual channel by subtracting two physical channels or a channel-pair, “CxC” can generate all possible virtual channels by using available physical channels with a set of operations. All the operations can be done by a few clicks. Once you try it, you will the power and usefulness of the “CxC” function. It is amazing, subjective and very efficient.

2. Coherence at sensor levels: coherence, correlation and association of two-sensor can be done by simply selecting “Covariance” or “Correlation” operation. “CxC” can analyze the relationship of all possible physical channel pair according to the setting of operations.

3. Covariance matrices for source localization: many EEG/MEG source localization algorithms require covariance matrices from sensor data. The "CxC" functions enable users to compute, preview and check the covariance matrices for source localization.

CxC and Coherence

The analysis of channel-cross-channel (CxC) correlation can be done in time-domain waveform data or time-frequency representation of spectral data. The design of CxC was to include the analyses of coherence. The coherence is a statistic that can be used to examine the relation between two signals or data sets. It can be used to estimate the causality between the input and output or the connectivity of two datasets. Although the computation of channel-cross-channel relationship is easy by a few clicks, the interpretation of the outcomes of those measures in terms of brain networks and activity remains challenging and should be exercised with caution.

Many measures of connectivity exist, and they can be broadly divided into measures of functional connectivity (denoting statistical dependencies between measured signals, without information about causality/directionality), and measures of effective connectivity, which describe directional interactions. The characterization of the correlation between channels can be done with Wave Coherence Manager as well as 2D/3D topography map, it is possible to analyze and describe certain network features in more detail.

Major Innovations in CxC

The use of two physical EEG electrodes or MEG sensors to generate a new set of "virtual channels" is not new. Since an EEG voltage signal represents a difference between the voltages at two electrodes, the display of the EEG for the reading encephalographer may be set up in one of several ways. The representation of the EEG channels is referred to as a montage. The typical montages include (1) Bipolar montage: Each channel (i.e., waveform) represents the difference between two adjacent electrodes. (2) Referential montage: Each channel represents the difference between a certain electrode and a designated reference electrode. There is no standard position for this reference; it is, however, at a different position than the "recording" electrodes. (3)Average reference montage: The outputs of all of the amplifiers are summed and averaged, and this averaged signal is used as the common reference for each channel. (4) Laplacian montage: Each channel represents the difference between an electrode and a weighted average of the surrounding electrodes. Of note, each the montage represents a type of operation (typically subtraction) applied to channel pairs. The main purpose of "montages" is to highlight or better characterize certain features of the EEG/MEG data.

The major innovation in the CxC is to apply operations to all possible channel pairs to generate a CxC matrix. The CxC matrix has all the possible "montages" that is going beyond the conventional "montages". Consequently, the EEG/MEG can be viewed in a systematic manner and reveal some features and characteristics that may not be able to be captured with the conventional montage that is typically selected by reviewers according their desires.

In addition, the CxC can represent the coherence at sensor levels if the operation is “correlation”. The association of two-sensor can be visualized as “links” to reveal the networks of EEG/MEG data at sensor levels. “CxC” can analyze the relationship of all possible physical channel pair according to the setting of operations.

Further move, the CxC data may include the covariance matrices for source localization. In comparison to many previous tool boxes for source localization with covariance, this software provides GUI to compute, visualize, processing and editing the covariance matrix. Consequently, many EEG/MEG source localization algorithms require covariance matrices from sensor data can be refined and optimized.

Menu for Launching Waveform CxC Windows

The menu for launching Waveform CxC windows is in the Main Frame of the EEG Studio program, which is under the WaveCxC menu (Figure 1). EEG/MEG data for CxC analysis can be raw waveform data and/or pre-processed data. Typically, it will be pre-processed. This manual describes the various graphical elements that make up waveform CxC computing, analyzing and visualizing modules throughout the software application.

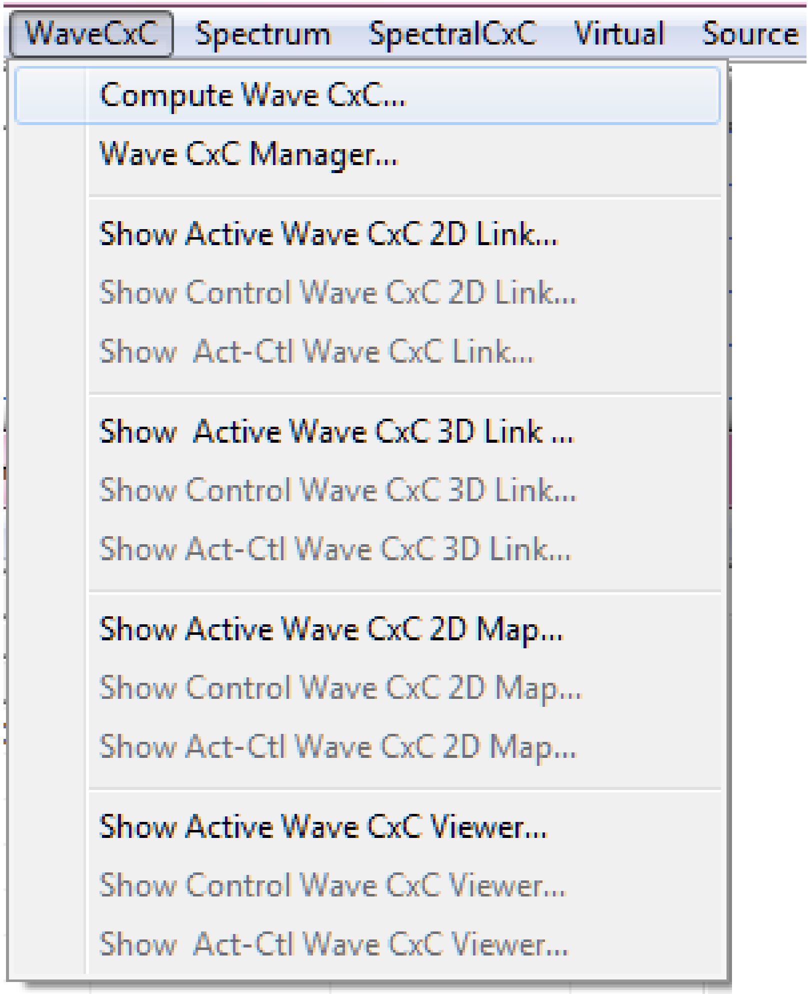

Figure 1. Menu for launching Waveform CxC Windows.

Compute Wave CxC

Selection of “Compute Wave CxC” menu launches the main window for computing CxC data, which are matrices with multiple time slices. The Window GUI application allows you to configure parameters and processing options for CxC computing as well as other kinds of analysis.

Wave CxC is performed after a dataset has been acquired and reviewed. Here is the recommended procedure for a standard analysis using Wave CxC programs:

a) Check and verify that you have the correct dataset and trials in the Waveform Viewer (see the MEG Processor Main Frame Guide).
b) If data averaging is necessary or required, do the averaging first. Once multiple trials have been averaged successfully, there is at least one averaged trial (“virtual trial”) will be added to the MEG dataset, which is available in the main Frame for waveform viewer.

c) Filtering and/or removing DC-offset is typically required or necessary. If you do think so, apply the filtering/DC-offset to the targeted trial;
d) Check and analyze the EEG/MEG data to determine the interest of time-window. Though there is no standardized way, it is a good idea to use “Overlay” viewer to determine the interest of time-window with all “sensors”.
e) If the Waveform CxC main window has not been launched. Select “Compute Wave CxC” in the Menu (see “Menu for Launching Waveform CxC Windows”)
f) During the launching of the window for Settings for Computing CxC data, the program gets the selected time-window as the Active Window. The program also checks the integrity and sanity of the data and may report warning/error messages if necessary.
g) Use the window for “for Settings for Computing CxC data” to inspect the dataset as well as suitable parameters. If required or necessary, change the data selections.

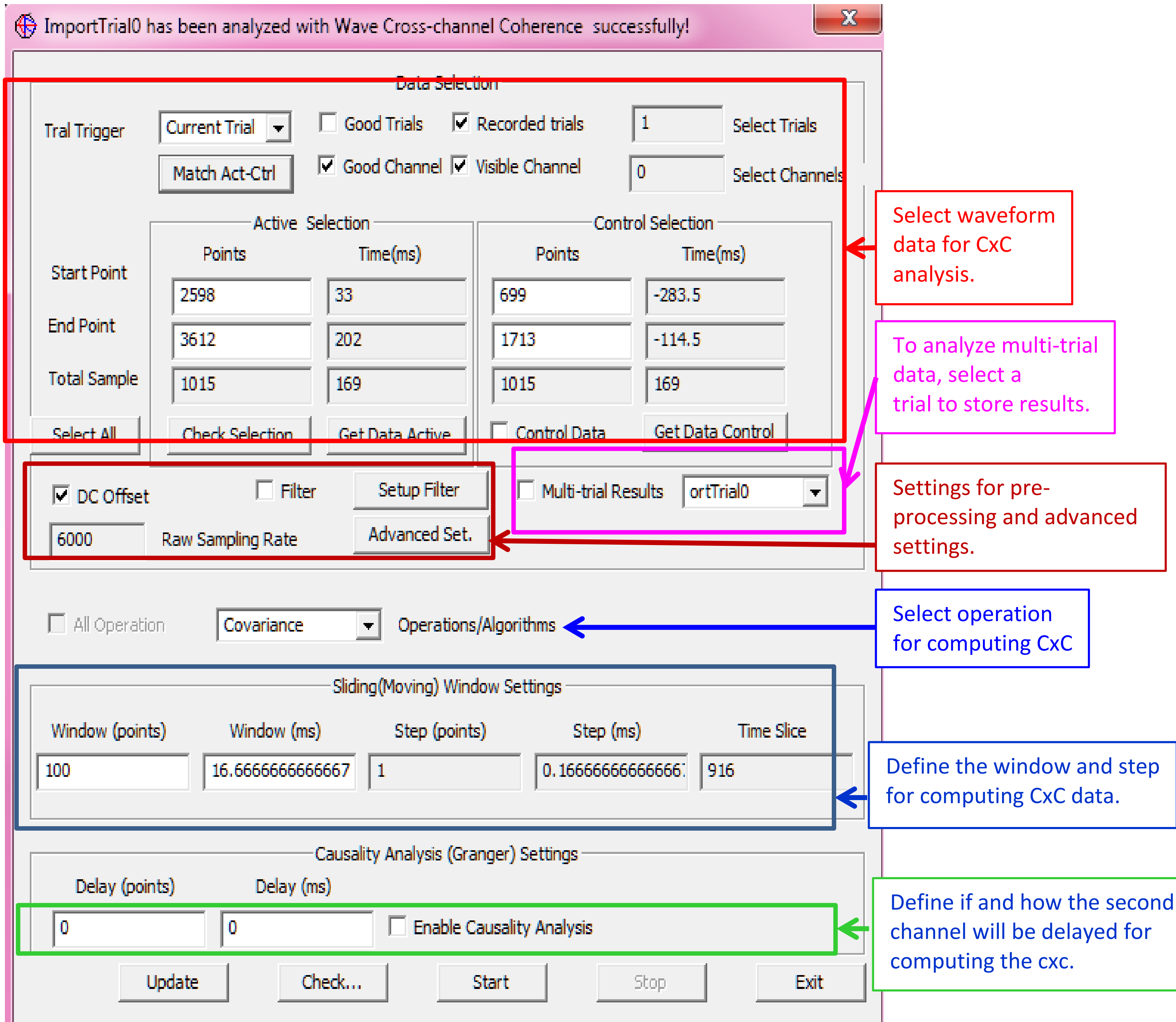

Figure 2. Wave CxC settings for analyzing the correlations of every two channel pairs.

Main Modules in CxC Computing

The full suite of waveform CxC computing comprises the following components.

- Wave Data Selection
- Pre-processing for CxC computing
- Window and step
- Causality Analysis (Granger)

- Start CxC computing

Target data (Time windows)

The data selection specifies the trial, channels to be used for wave CxC computing. The time window parameters specify active- and control-state time windows relative to named triggers or markers or the trial synchronization time point (typically zero). You may use the "Get…" button to get the selection for either active or control time window. You may also change or add the parameters by typing in the edit controls (fields) manually.

Time windows are defined relative to some event in the data — either the beginning of the trial (time zero) or a marker. Triggers (one group of Markers) are added automatically by the Data Acquisition application when the data is acquired. Typical markers are added by the adding Marker programs. They can also be added manually to mark an event of interest using the Selection Mark application.

If you are generating a single-state image, only active-state windows can be defined. If you are generating a dual-state image, both active- and dual-state windows can be defined.

To define a window:

1) Click the "Get Active" or "Get Control" button (Active States or Control States) to get the selection in the waveform viewer window.
2) You may click the "Select All…" to select all data points.
3) To use the control data, you must select "Compute Control" checkbox.
4) The Check Select will check the selection of the data.
5) The Match Act-Ctl (Active-Control) will match the size of the active and control selection so that they have the same length.

Pre-processing for Wave CxC

Wave form data can be preprocessed by using DC-offset, Filter and more advanced settings. Raw sampling rate is shown to help define the parameters such as low and high pass filter as well as the time-window and steps.

Storage of CxC data

For CxC data based on one trial, the results are typically stored with that trial. For CxC data based on multiple trials, the results, which are typically referred as "sum-CxC", are stored in a selected trial. It is necessary to define the targeted trial for storing the results before CxC computing.

CxC Operators

There are increasing operators for the CxC computing for a variety of purposes. For example, the conventional waveform covariance matrix can be computed with "Covariance". However, instead computing one single matrix, this program can compute a set of covariance matrices with many time slices as the computer memory can help.

The “Correlation” operator can be used to compute the correlation of very channel pair. By using time-delay, the Granger Causality can be computed by a few mouse clicks.

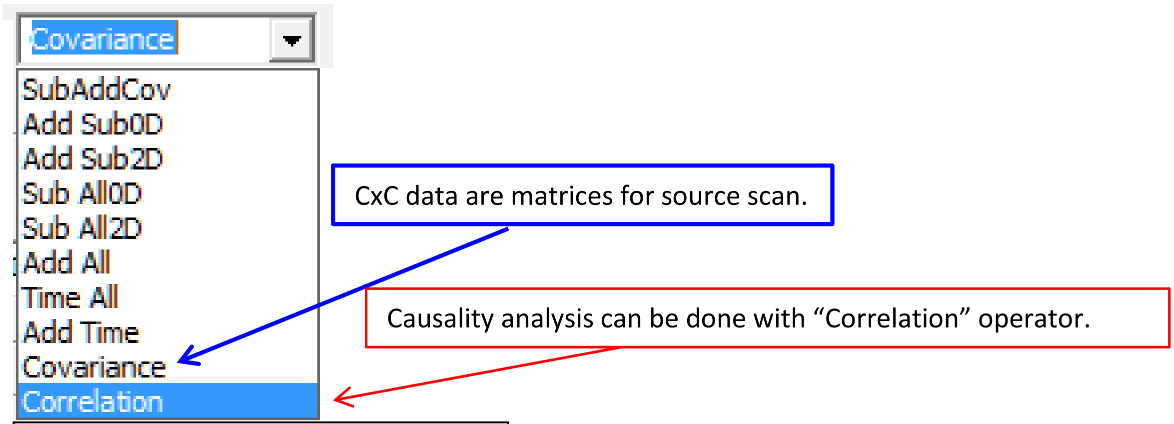

Figure 3. The available CxC Operation/algorithms for computing waveform CxC data.

Sliding Time Window

To generate a CxC matrix for each sensor pair, the parameters in the Wave CxC Settings will be used to compute CxC matrices for all sensors. In other words, the time window and step will be apply to all CxC data sets. Since the size of the CxC in the sensor array is the same, many operations/statistical analysis can be applied to the CxC data.

To define an appropriate time window, it is necessary to check the sampling rate so as to define data points (samples) and time (latency).

1) “Window (points)” indicates how many data points for a window. The minimum is 1; the maximum is the selection of the data size.
2) “Window (ms)” indicates how many milliseconds (ms) for a window. For example, in auditory evoked neuromagnetic activation, a window of 16-26 ms may reliably reveal the correlation between the left and right temporal activation.
3) “Step (points)” indicates the interval between two consecutive windows. The minimum is 1; the maximum is the half of the window size.
4) “Step (ms)” indicates the interval between two consecutive windows in milliseconds.
5) “Time Slice” indicates the number of time-slices in the final CxC datasets or the results of CxC data.

Single-state or Dual-state CxC Matrix

The single-state option generates CxC based on the active state only (i.e., measurements taken when the brain is being stimulated). The dual-state option generates CxC that results from the subtraction of control-state data (measurements taken when no stimulation is applied) from active state data. To generate a dual-state CxC, you must select both active and control data for CxC computing.

Causality Analysis

The causality analysis (Granger) is a statistical hypothesis test for determining whether one time series is useful in forecasting another or cause events in another. Specifically, a time series channel A is said to Granger-cause channel B if it can be shown, usually through a series of t-tests and F-tests on lagged values of A (and with lagged values of B also included), that those A values provide statistically significant information about future values of B.

A long held belief about neural function maintained that different areas of the brain were task specific; that the structural connectivity local to a certain area somehow dictated the function of that piece. Collecting work that has been performed over many years, there has been a move to a different, network-centric approach to describing information flow in the brain. Explanation of function is beginning to include the concept of networks existing at different levels and throughout different locations in the brain. The behavior of these networks can be described by non-deterministic processes that are evolving through time. That is to say that given the same input stimulus, you will not get the same output from the network. The dynamics of these networks are governed by probabilities so we treat them as stochastic (random) processes so that we can capture these kinds of dynamics between different areas of the brain.

Waveform CxC can reflect and reveal information flow from the firing activities of a neuron. When the causality is not turn on, the CxC results are limited in the kinds of conclusions you can draw and tell you little about the directional flow of information, to what degree, and how it can change with time. By using time-delay, a kind of Granger causality analysis, the results may show the direction of information flow in the brain.

Running Wave CxC

Click the “Start” button will start to run the Wave CxC computing. Once it is started, the window title bar will show the progress of the computing.

The Wave CxC calls several internal dynamically linked libraries to perform a variety of operations. Here are some steps:

1) Check and select the waveform data for CxC Computing.
2) Perform filtering and removing DC-offset, if necessary.
3) Compute coefficients and estimate the necessary memory, if necessary
4) Compute CxC data for each channel and each trial
5) Compute the summary of all sensor pairs, if necessary
6) As usual, the resulting CxC are available to be viewed using CxC Viewer.

Wave CxC Manager

Wave CxC data can be viewed, edited and analyzed quantitatively with Wave CxC Manager. In the new version of this program, operation can be applied to Active CxC data and Control CxC data to generate Act-Ctl data, which is the result from the Active and control CxC data. The operations include:

1) Subtraction (A-C)
2) Summation (A+C)
3) Covariance (Time, A*C)
4) Divide (Ratio, A/C)

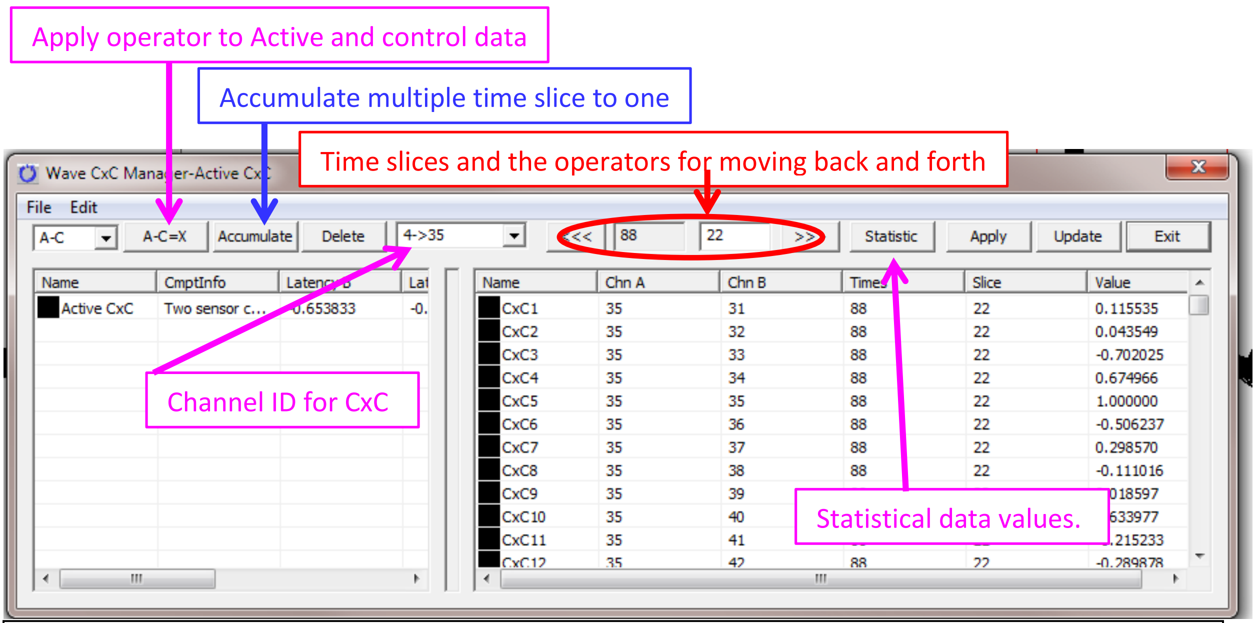

Figure. 3. Wave CxC Manager.

Accumulating Multi-Time Slices to One Slice

Wave CxC data can have many time-slices. Multi-time slice data may reveal dynamic changes of every channel pair. To quantify the characteristics of all channel paired during the entire period of time, a function (“Accum Time”) has been designed to accumulate multiple time slices to one slice. The one slice may reveal the stationary correlations of all channel pairs.

CxC Diagonal

The diagonal values in Wave CxC data have some special meanings. For example, in covariance matrix of EEG/MEG data, the diagonal values may reflect the sensor noise. In correlation matrix, the diagonal values may be 1. This program has designed function to zero diagonal value. To zero diagonal values, launch the Wave CxC Manager, then select the Edit Menu-> Zero Diagonal.

Visualization of CxC Data

CxC data can be visualized in both 2D and 3D. In either 2D or 3D visualization, CxC data of EEG/MEG data can be plotted as link view and topographic (contour map) view.
The link view is designed for viewing the correlation or interaction to two channels. The topographic view is designed for viewing a group of sensors with one central channel for a specified time interval. Of note, there are several ways of graphically representing the data. The visualization of the CxC data varies slightly among the versions of the software.

Launching CxC Link Viewers

Since this program computes the correlation or interaction of channel pairs in several ways, the data visualization windows may be different from the conventional coherence viewers.

Importantly, this program provides three classes of 2D viewers and three classes of 3D Viewers. For example, the viewers include:

1) Active Wave CxC 2D Link Viewer;
2) Control Wave CxC 2D Link Viewer;
3) Act-Ctl Wave CxC 2D Link Viewer;
4) Active Wave CxC 3D Link Viewer;
5) Control Wave CxC 3D Link Viewer;
6) Act-Ctl Wave CxC 3D Link Viewer;

In some cases, the time courses of the correlation and interaction in channel pairs are important. The program has also designed three viewers to the CxC waveforms.

- Active Wave CxC Viewer
- Control Wave CxC Viewer
- Act-Ctl (Active-Controls) Wave CxC Viewer

Please see the “Classification of CxC Data” for explanation about Active, Control and Act-Ctl CxC data.

CxC 2D Link Viewer

2D Link Viewers are commonly used to analyze the spatial correlation of EEG/MEG data in all sensors in a specified time range. In this program, one link shows a link of one channel pair. If color is used, red color is typically used to represent positive correlation or interaction (plus), while blue color is typically used to represent negative correlation or interaction (minus). One circle is typically used to represent the sensor location. This is kind of “coherence” plots of all channels, in a quasi-topographical layout in a specified time interval.

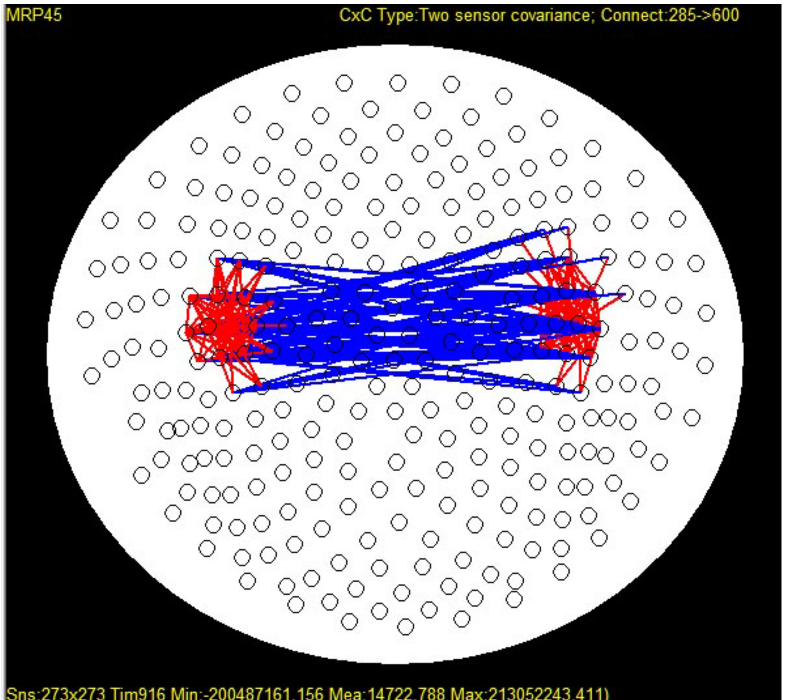

Figure 4. Wave CxC Link Viewers.

Display Controls for Wave CxC 2D Link

The Wave CxC 2D Link Viewer provides a set of options and controls for appropriately displaying the CxC data in all sensors or a group of selected sensors. All the options and the controls are on the top of the window (or Dialog). The Dialog provides a lot of flexibility and power for you to control the display. The Wave CxC 2D Map shows the details about the display items and their controls.

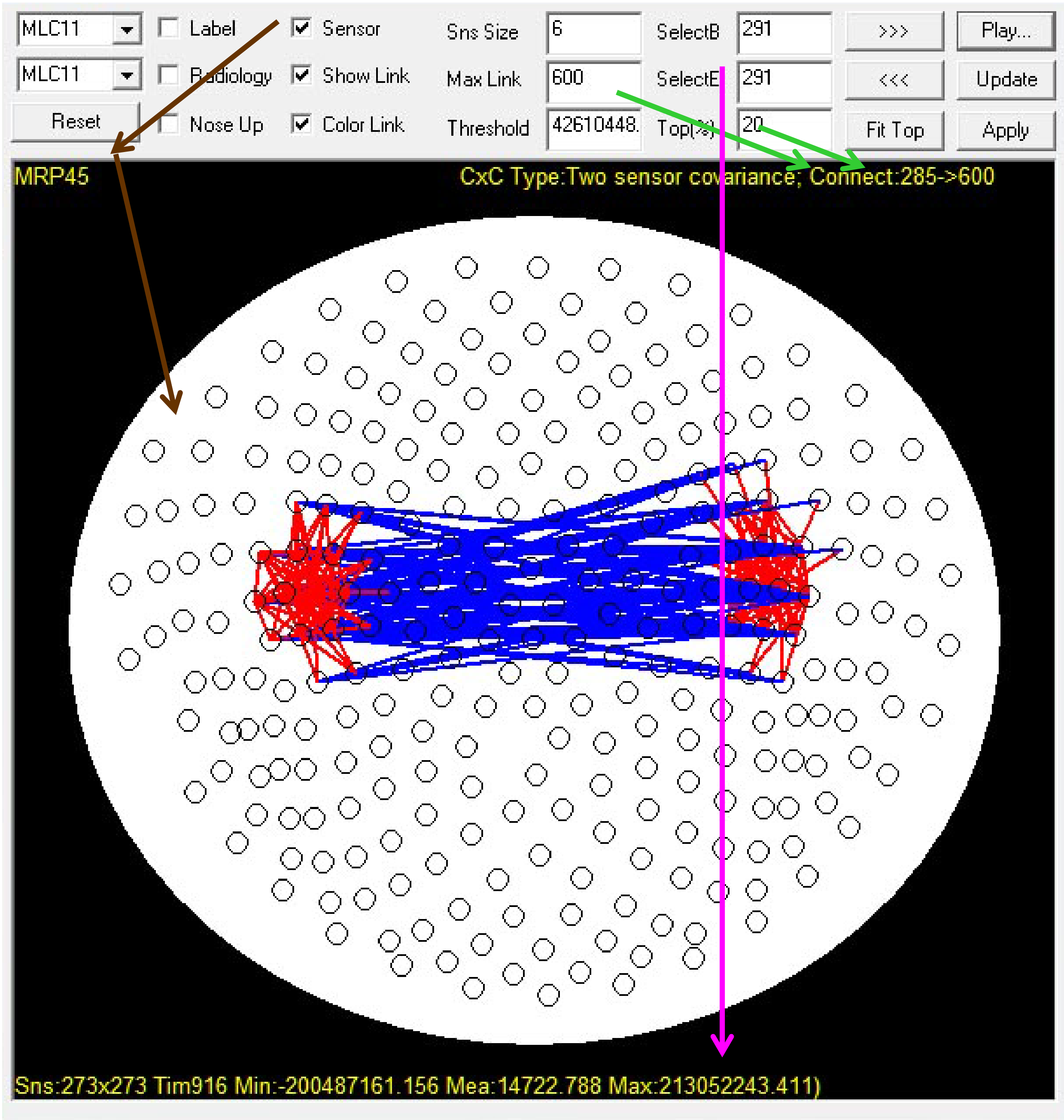

Figure 7. Controls for wave CxC 2D link viewer.

Operations in Wave CxC 2D Link Viewer

The 2D Link Viewer provides a set of options and controls for appropriately displaying the CxC data. All the options and the controls are on the top of the window (or Dialog). The Dialog provides a lot of flexibility and power for you to control the display. The following figure shows the details about the display items and their controls.

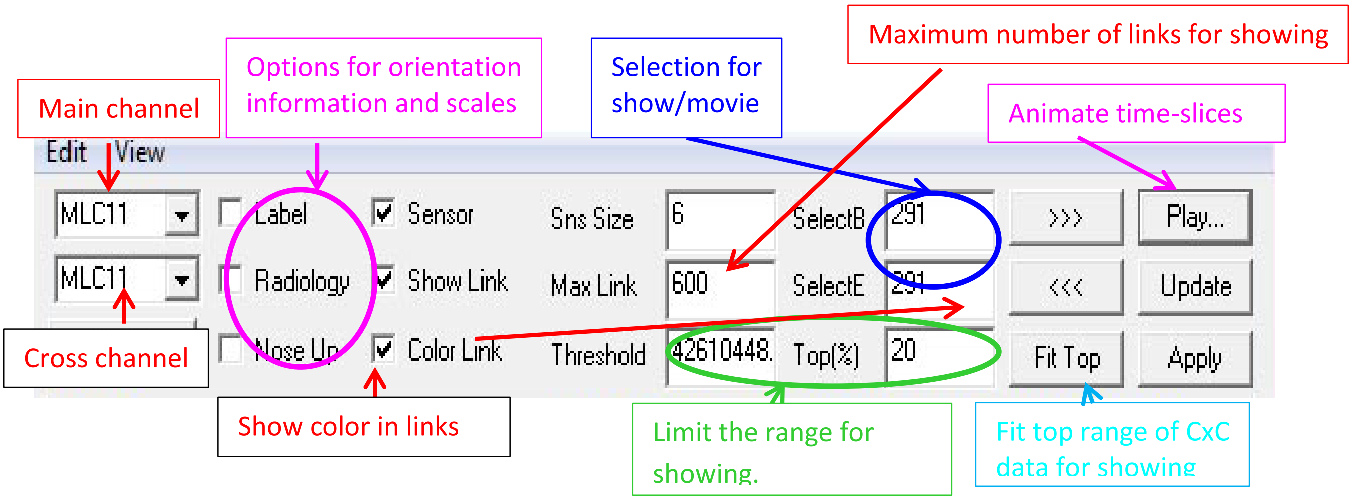

Figure 8. Controls and options in CxC 2D Link Viewer for a group of sensors.

CxC 3D Link Viewer

3D Link Viewers are commonly used to analyze the spatial correlation of EEG/MEG data in all sensors in a specified time range. In this program, one link shows a link of one channel pair. If color is used, red color is typically used to represent positive correlation or interaction (plus), while blue color is typically used to represent negative correlation or interaction (minus). One torus (cube or ball) is typically used to represent the sensor location. This is kind of “coherence” plots of all channels in 3D coordinate in a specified time interval.

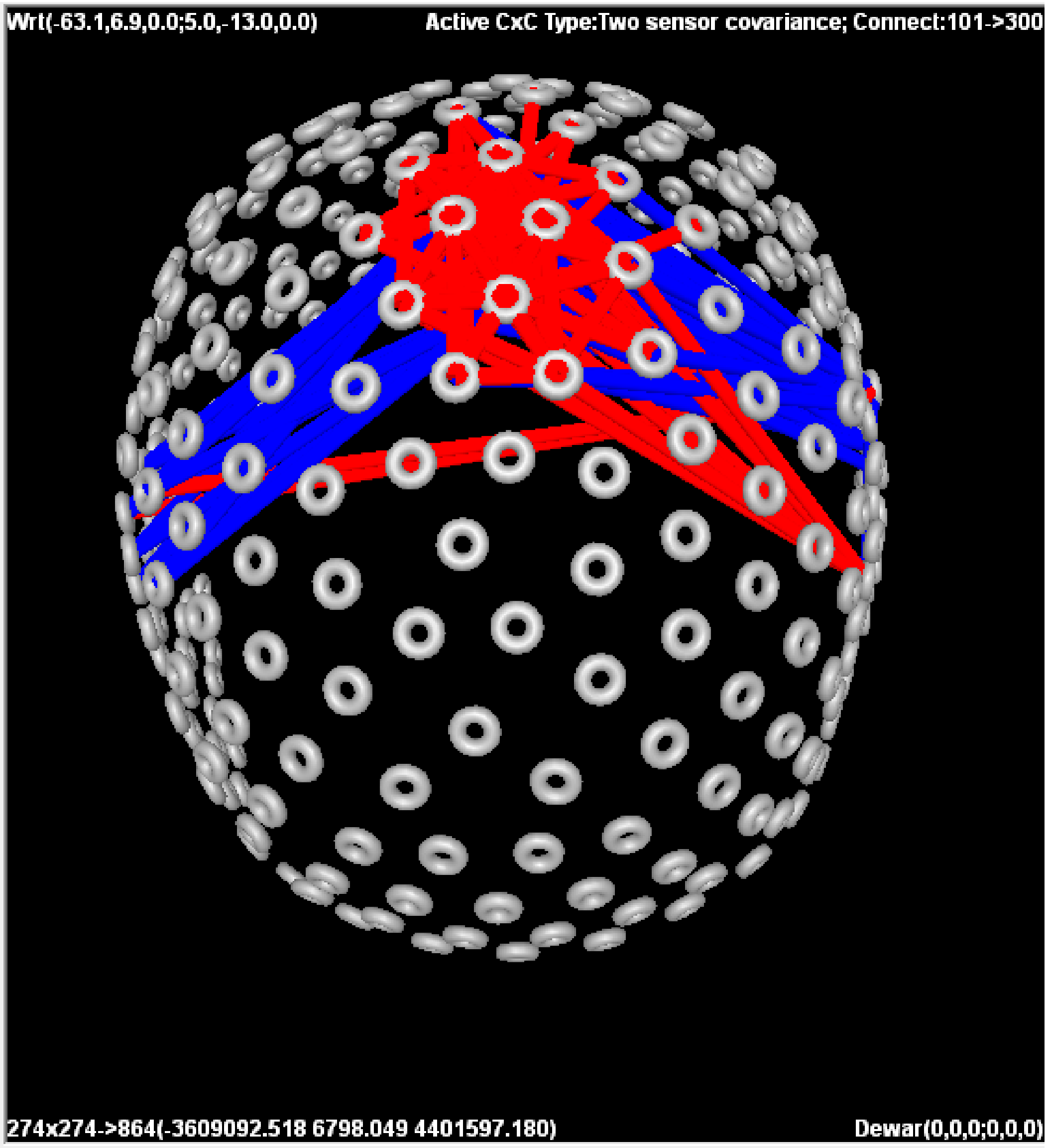

Figure 9. Visualization of wave CxC data in 3D.

Display Controls for CxC 3D Viewer

The 3D Viewer provides a set of options and controls for appropriately displaying the CxC data. All the options and the controls are on the left of the window (or Dialog). The Dialog provides a lot of flexibility and power for you to control the display. The following figure shows the details about the display items and their controls.

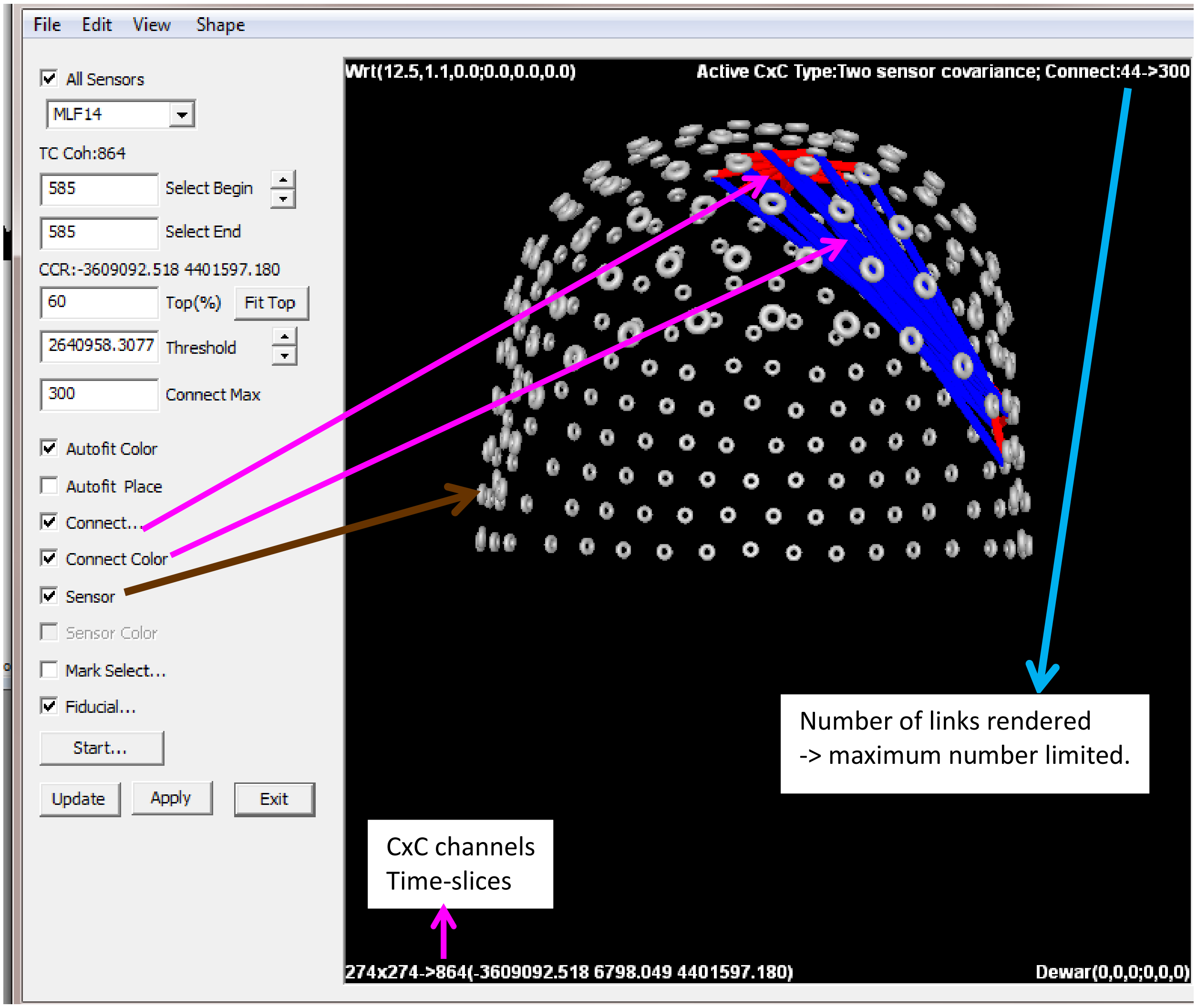

Figure 10. The options and controls of wave CxC 3D Link Viewer for all channel pairs.

Operations in Wave CxC 3D Viewer

The wave CxC 3D link viewer provides a set of tools to operate and analyze waveform CxC data. If the 3D links is computed with multiple time slices, you may select to show the correlation or interaction of sensor pairs in certain latency range or interval.

The number of links can be defined by use both top percentile and absolute threshold. To avoid time-delay, you may limit the maximum number of links or connections. If the number of links meeting the threshold is larger than that of the maximum number of links, the number of links rendered in the 3D viewer will change to red.

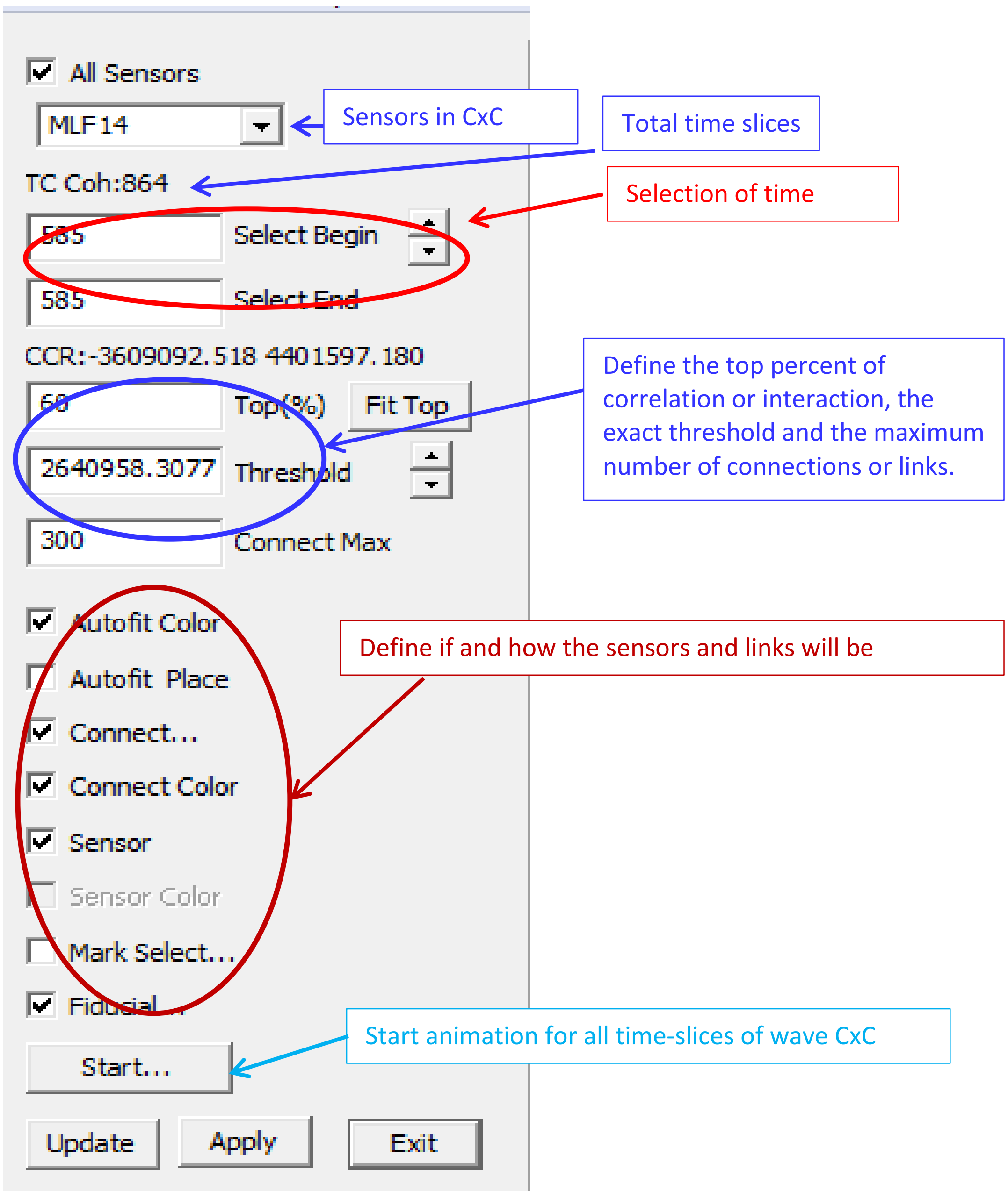

Figure 11. Controls and options in wave CxC 3D link viewer.

Menu in Wave CxC 3D Link

The wave CxC 3D link viewer can be used to visualize and analyze the correlation and interaction of all sensor pairs or a group of sensor pairs.

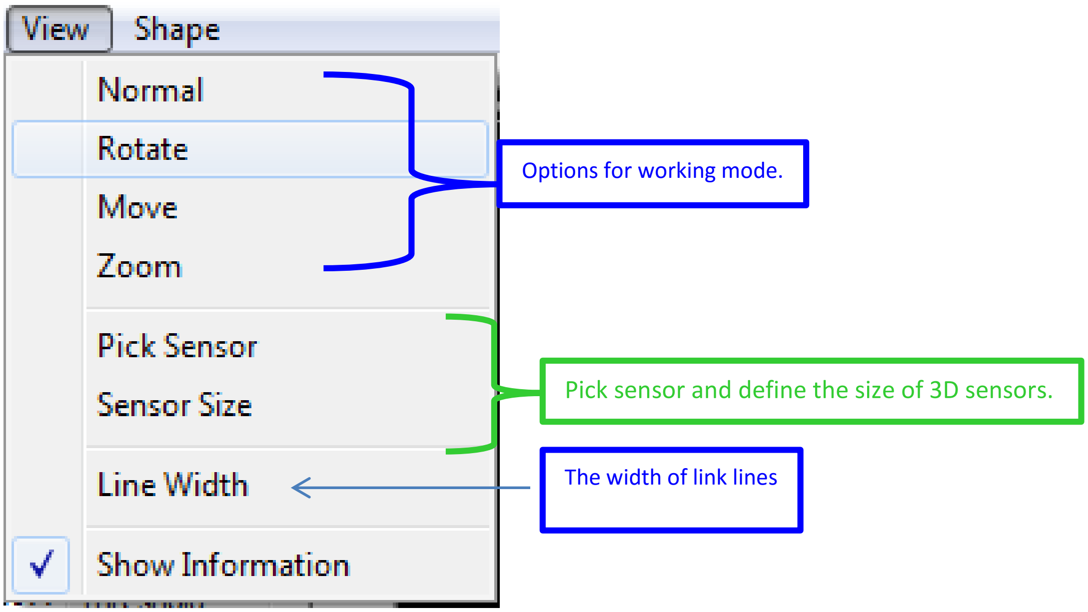

Figure 12. Menu in wave CxC 3D Link Viewer.

Wave CxC 2D Map

Wave CxC 2D maps (topographic CxC virtual channel waveforms) are commonly used to analyze the spatial distribution of CxC data in a specified time ranges or interval. In this program, the amplitude of virtual channel waveform from a sensor can be color coded and displayed on the sensor. This is kind of time-course plots of all channel pairs, in a quasi-topographical and varies among the version due to the variation of the usage of CxC data.

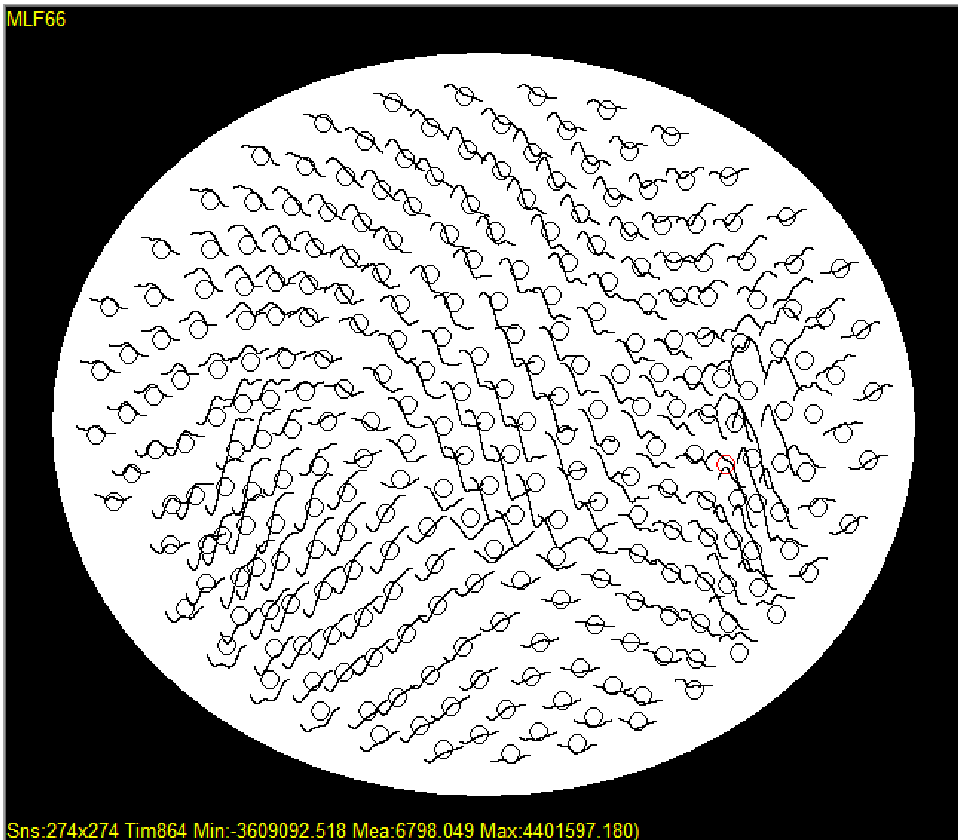

Figure 14. Visualization of CxC data with 2D virtual channel waveforms (2D topographic waveforms). In this type of 2D map, each small torus represents a sensor. The amplitude of the CxC at a selected time ranges can be adjusted.

Display controls for 2D CxC Map

The 3D Contour Map Viewer or Topographic Viewer provides a set of options and controls for appropriately displaying the spectral data in all sensors or a group of selected sensors. All the options and the controls are on the top of the window (or Dialog). The Dialog provides a lot of flexibility and power for you to control the display. The “Controls for Contour Map” shows the details about the display items and their controls.

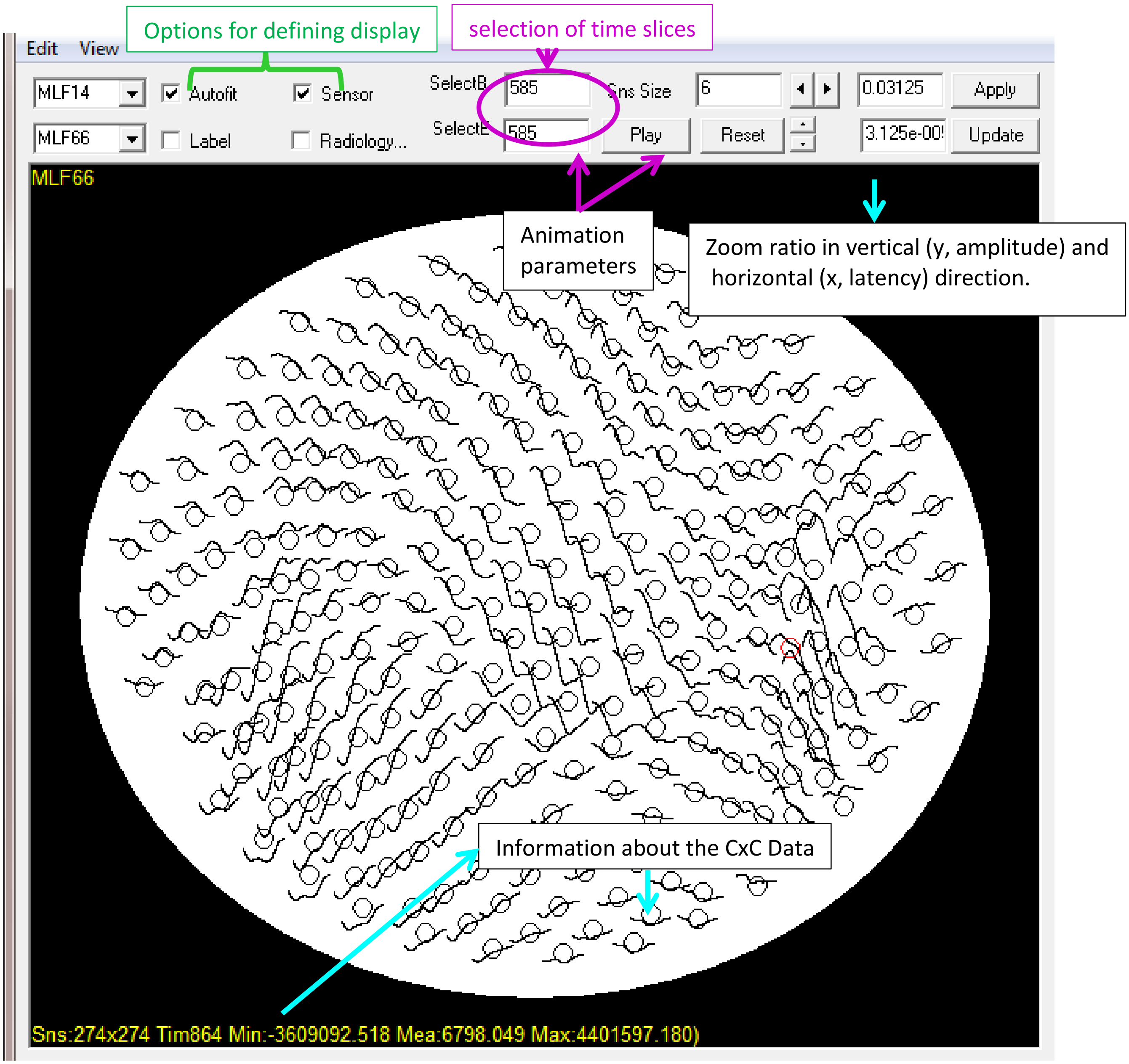

Figure 14. Visualization of CxC data with 2D virtual channel waveforms (2D topographic waveforms). In this type of 2D map, each small torus represents a sensor. The amplitude of the CxC at a selected time ranges can be adjusted.

Menu in 2D CxC waveform Map

The Menu in 2D CxC waveform map provides a set of options and controls for appropriately displaying the CxC data. The following figure shows the details about the display items and their controls.

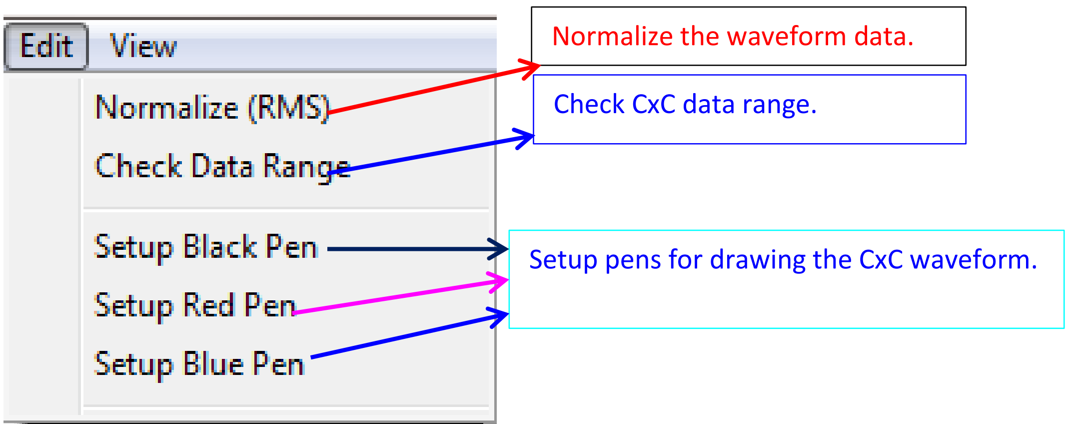

Figure 16. Menu for CxC 2D topographic waveform (virtual channel map).

Wave CxC Virtual Channel Viewer

Wave CxC virtual channel viewer is commonly used to analyze the time course of CxC data. High-amplitude reflection increased correlation or interaction of two channels. The waveforms are all based on a “central channel”. If the operation is minus or plus (subtraction or summation), the “central channel” is similar to the conventional reference and the CxC waveforms are kind of virtual channel waveforms.

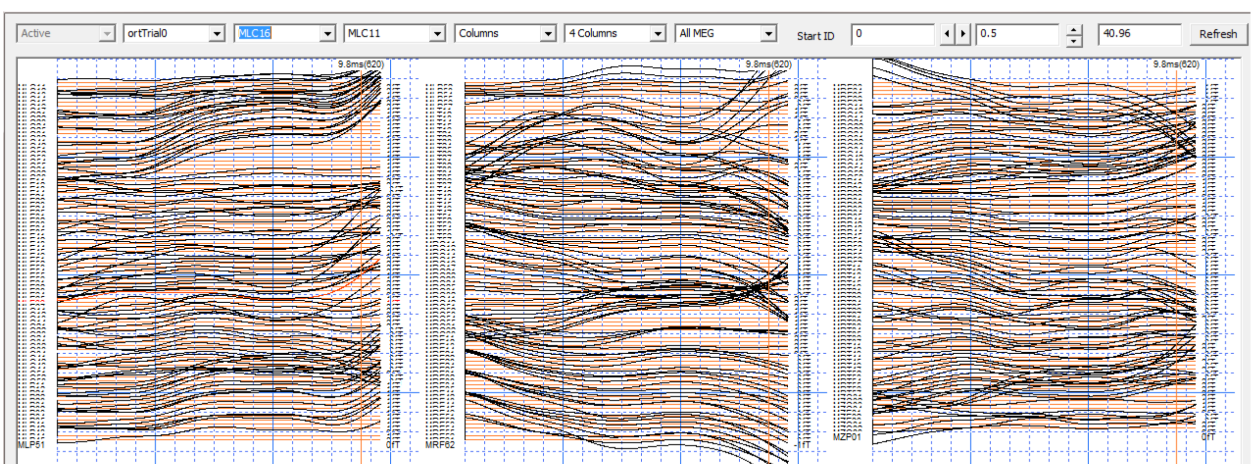

Figure 17. Visualization of amplitude change during a time course in a CxC dataset.

Operations in CxC 2DD Virtual Channel Viewer

The 3D Single Channel Viewer also provides a set of tools to operate and analyze the time-frequency representations of oscillatory data. To analyze the latency, frequency and spectral values, please make sure that the parameters are appropriate used.

If the range of the spectral data is very large, please try to use the "Rotate" and "Zoom" to adjust the position and depth for viewing.

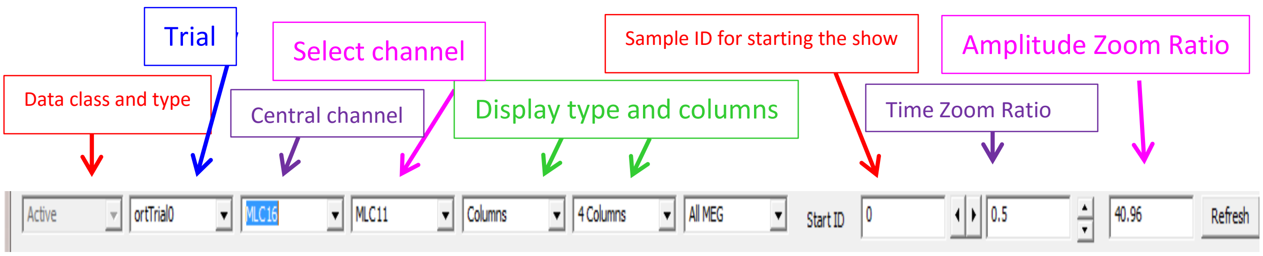

Figure 19. Controls and options in CxC amplitude-time viewer.

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