# *Measurement and Control Engineering Center (MCEC) Nonlinear Time series Analysis Software (NTSAS) in MATLAB®*

*12th Annual AIChE Meeting, Reno, NV*

*[215] National Student Poster Session*

*Poster Number 10e*

*1:00-4:00 PM, Nov. 5, 2001*

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# Abstract

Many chemical processes exhibit strong non-linear and even chaotic behavior. Obviously, for strongly nonlinear systems, the usual approaches to control may not work. In case of some complex processes, it is not even possible to have a process model –thus posing strong difficulties in control and monitoring. It is therefore imperative to know if a process being controlled or monitored is nonlinear. If it is, the diagnostic and monitoring tools should be selected accordingly.

Over the years, MATLAB has become the standard computational engine for scientists and engineers. Through the funding provided by the Measurement and Control Engineering Center (MCEC) we, in the Chaos Research Group (CRG) at the University of Tennessee, Knoxville, have developed a nonlinear and chaotic time series analysis software in MATLAB® with a sophisticated graphic user interface, for the research needs of member companies and CRG. The software is proprietary to MCEC.

Software routines include standard nonlinear and chaotic time series analysis tools, as well as the state-of-the-art routines developed in our research. It has nonlinear time series analysis tools like symbolization analysis, generalized entropies, mutual information, time asymmetry statistic, to name a few, in addition to standard tools as autocorrelation, probability distributions, and spectral analysis. The focus of the software is on system state recognition –with logical extensions to fault diagnosis, event detection, process monitoring and control.

The poster demonstrates the power of the software in nonlinear and chaotic time series analysis, performed on experimental and theoretical data sets. Other than serving an educational purpose, the software provides, for the first time, a GUI based software in MATLAB for nonlinear time series analysis. It lets the user conveniently apply nonlinear and linear time series analysis tools, load and save the data, perform computations and save the results on any platform, other than viewing the results of computations. Demonstration of the software will be available for the interested persons.

# Objectives of NTSAS Development

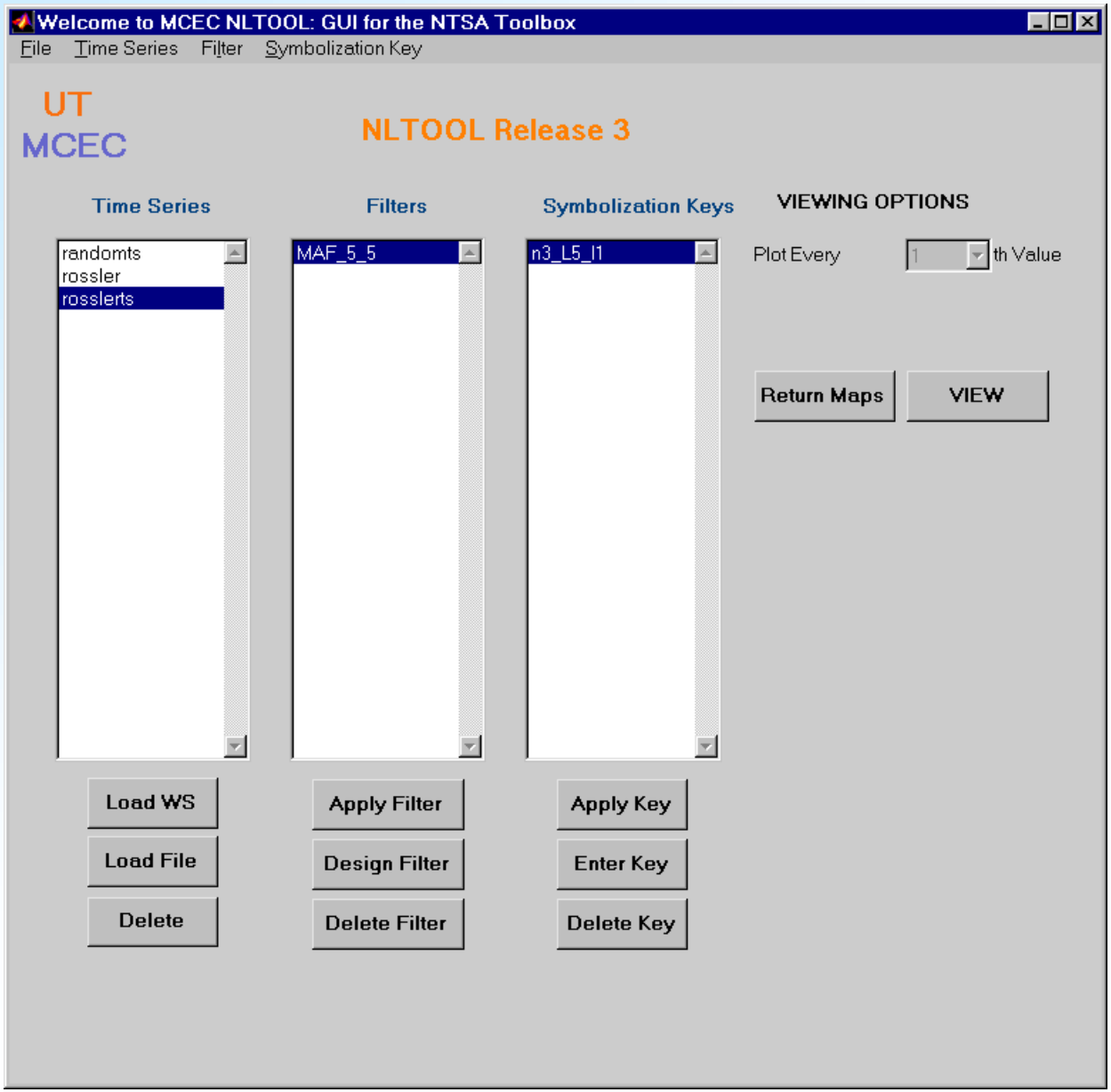
- Fulfill the research and industrial needs of
  - Chaos Research Group
  - Measurement and Control Engineering Center member companies
- Incorporates tools for
  - Fault Diagnosis
  - Process Monitoring and Event Detection
  - Nonlinear filtering
  - Nonlinear and symbol analysis
  - Analyzing non-linear and chaotic dynamics
  - Information theory-based analysis
  - Multivariable time series analysis
- Incorporate own research tools in the software
- A sophisticated, layered, stand-alone product
- Market it

# NTSAS – Nonlinear Time Series Analysis Software

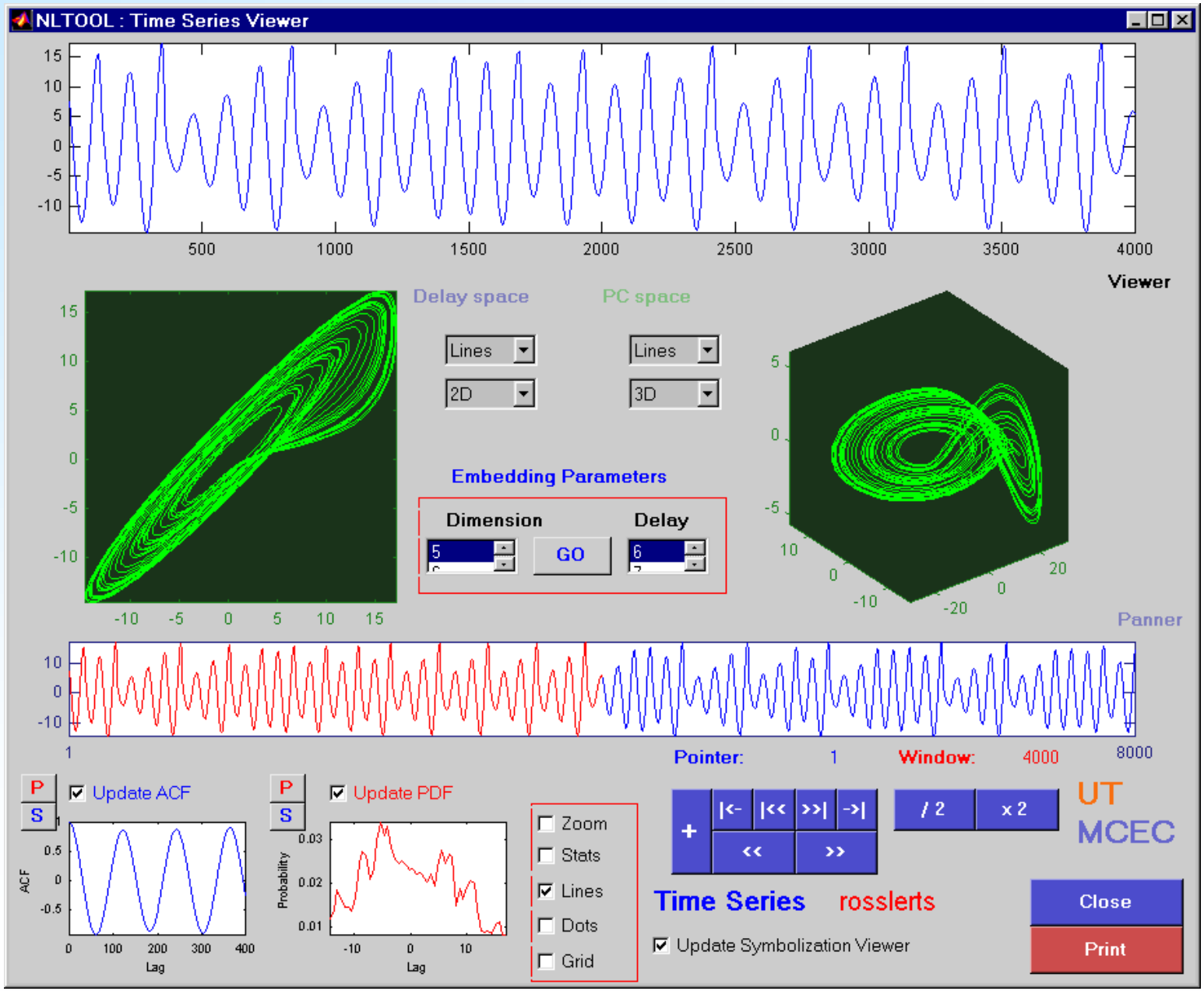
## SALIENT FEATURES

- Load Time Series or matrices from
  - MAT/DAT/TXT files
  - Workspace
- Save & Load Entire or Parts of 'NTSAS Sessions' as Figures or Data
- Device Independent Printing
- GUI for Non-linear & Symbolization Analysis
- Return Map GUI
- Top Level File Menus and Hot Keys for Often-used Commands
- Interactively Design and Apply Filters and Symbolization Keys

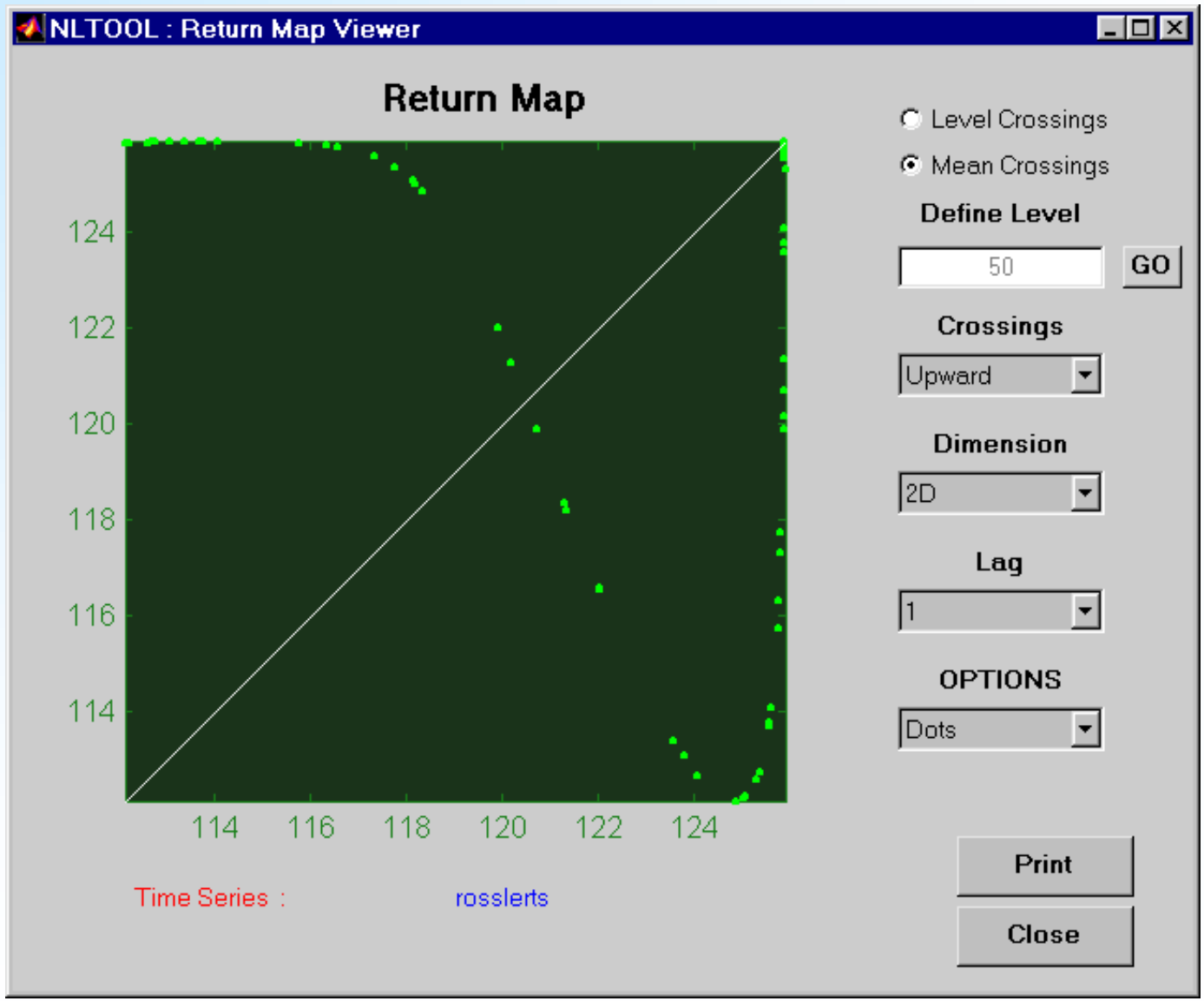
# NLTOOL: ROOT WINDOW



# NLTOOL- Time Series Viewer



# NLTOOL- Return Map Viewer



# Symbolization

- Look for patterns of high and low values

## Symbolization Analysis

- Symbolization tries to assign a symbol value to every measurement
- Every measurement can be called a 0, 1, 2, …
- Helps reduce the noise
- Preserves the necessary information in less storage space
- Data compression techniques can be used from information theory
- Symbol sequences can be made by juxtaposing symbols

# Symbolization

## Symbolization Parameters

- Set Size — Number of distinct symbols
- Sequence Length — Number of symbols in the sequence
- Symbolization Interval — Time difference between symbols in the sequence

***The optimum values of parameters have to be found by trial and error***

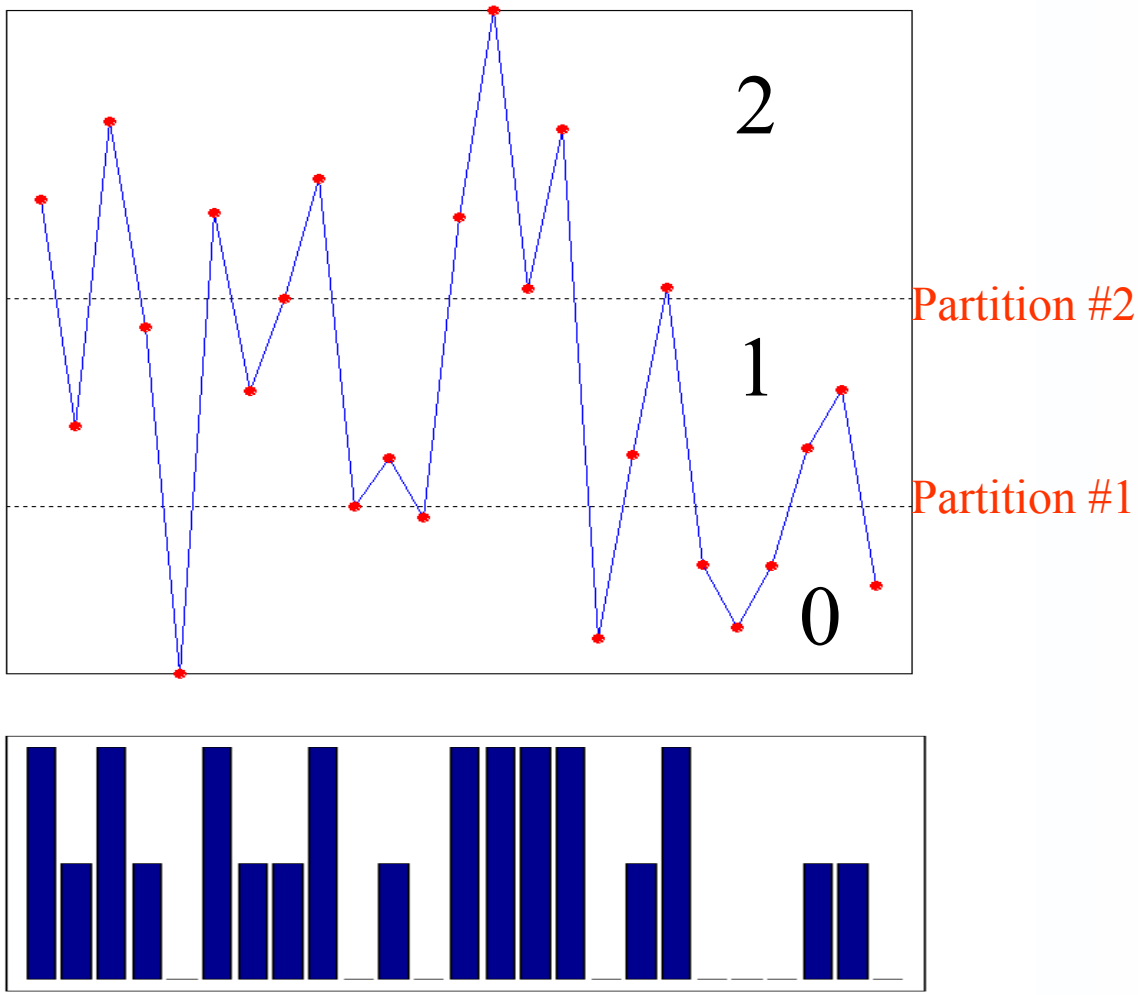
***Symbolization parameters used in this study***

- Set Size = 3
- Sequence Length = 5
- Symbolization Interval = 1

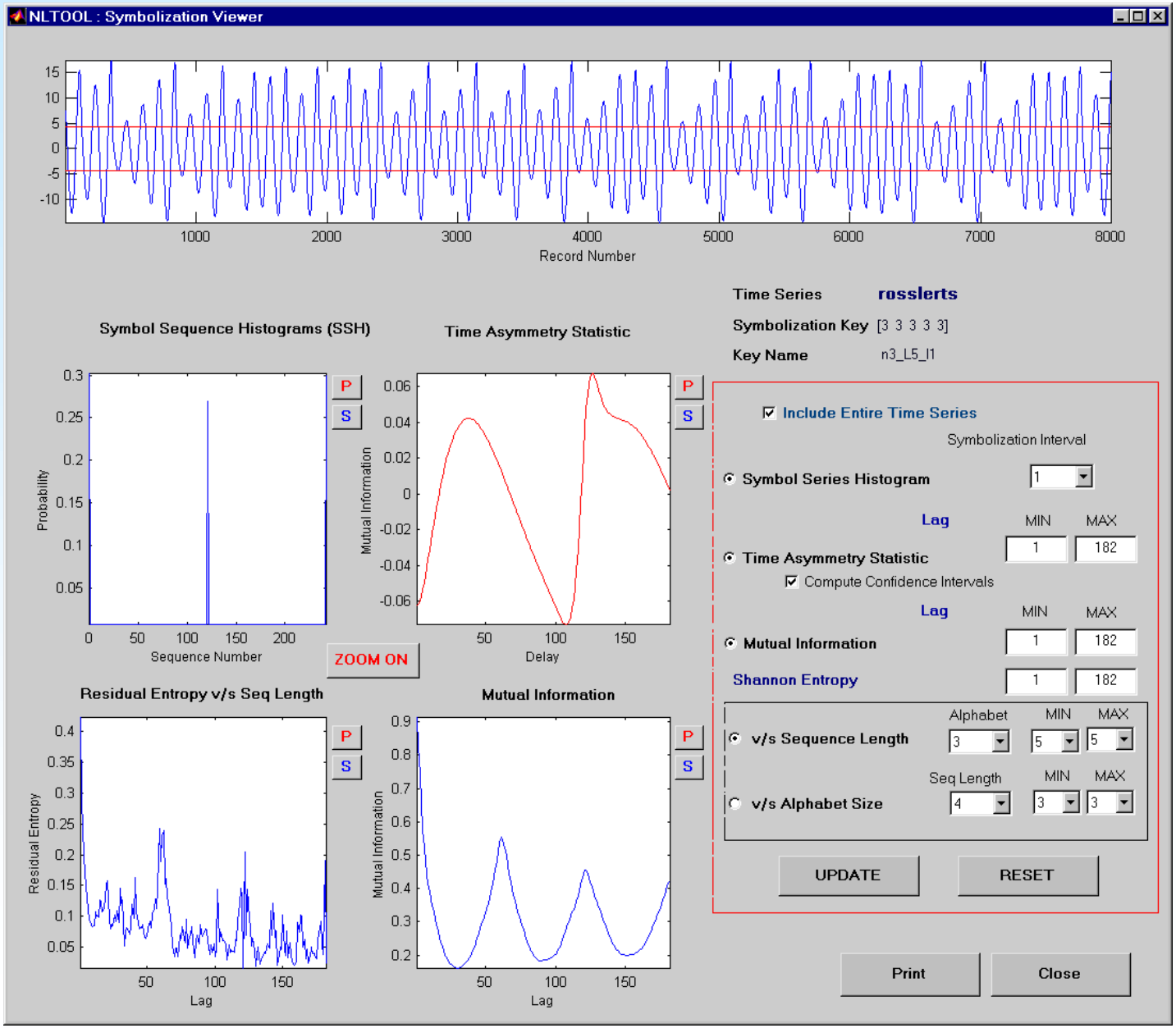
# Illustrating Symbolization

Set Size=3
Seq. Length =4
Sym. Interval=1

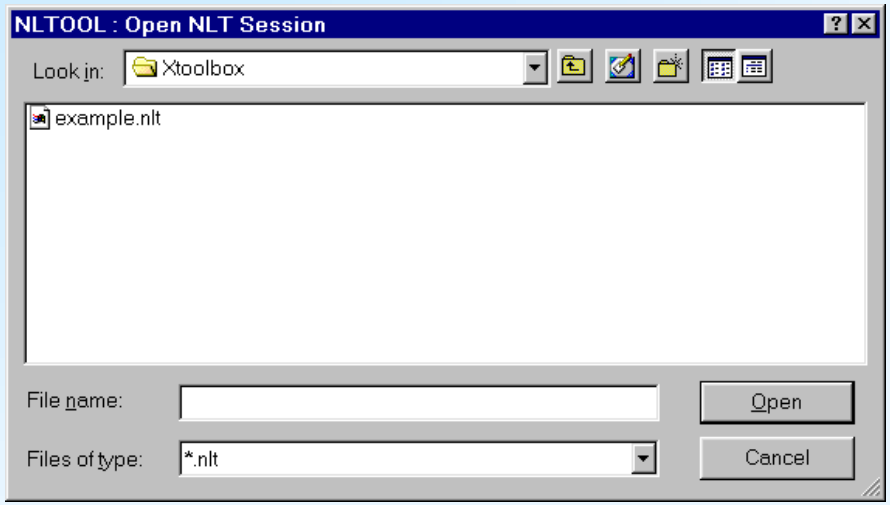
| Multiplier | 27 | 9 | 3 | 1 | Code |
|---|---|---|---|---|---|
| | **2** | **1** | **2** | **1** | **70** |
| | **1** | **2** | **1** | **0** | **48** |
| Symbol Sequences | 2 | 1 | 0 | 2 | 65 |
| | 1 | 0 | 2 | 1 | 35 |
| | 0 | 2 | 1 | 1 | 22 |
| | 2 | 1 | 1 | 2 | 68 |
| | 1 | 1 | 2 | 0 | 42 |

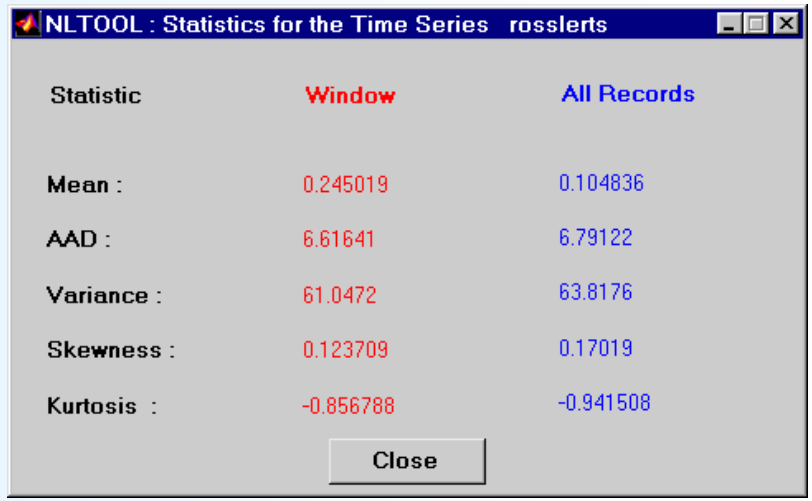


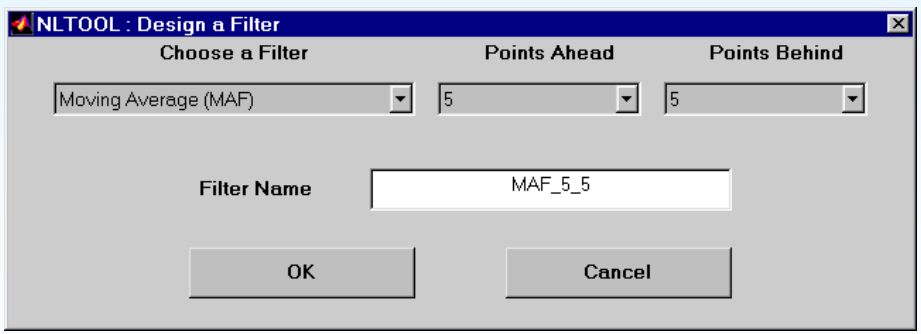
# NLTOOL- Symbolization Viewer



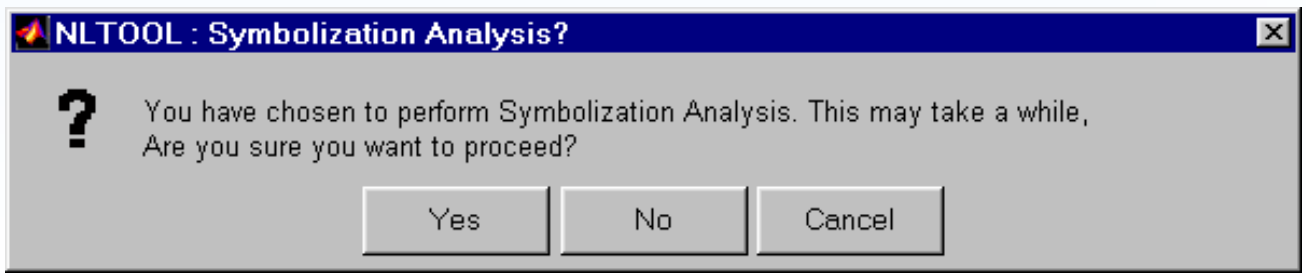
# NTSAS- Other Screens



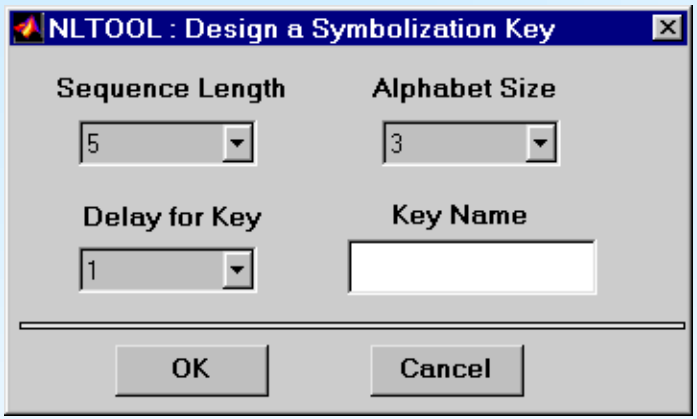



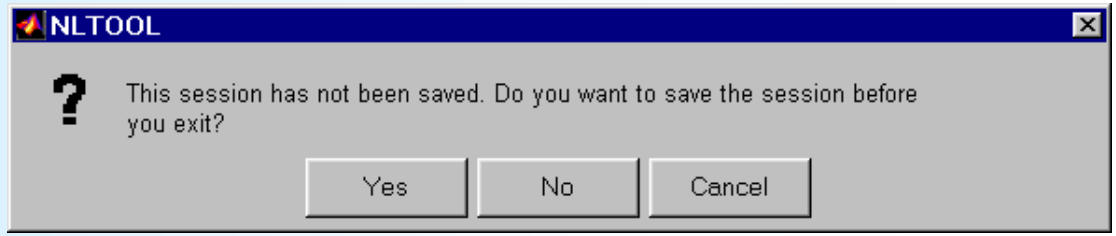



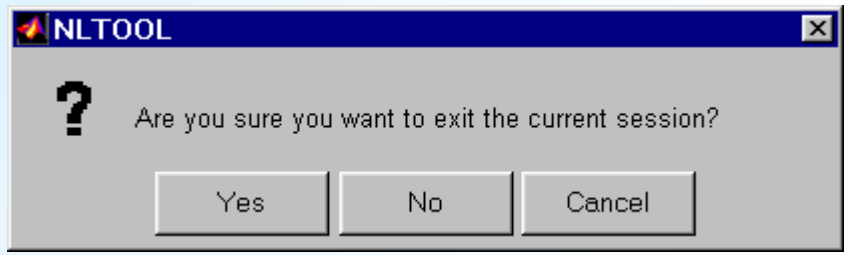


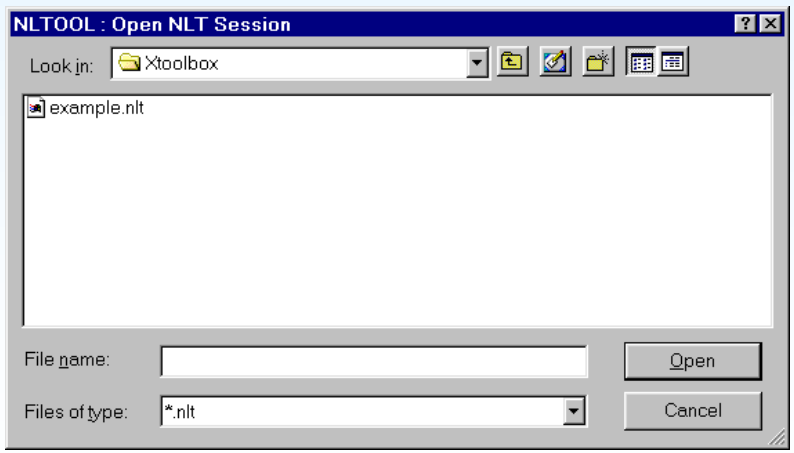


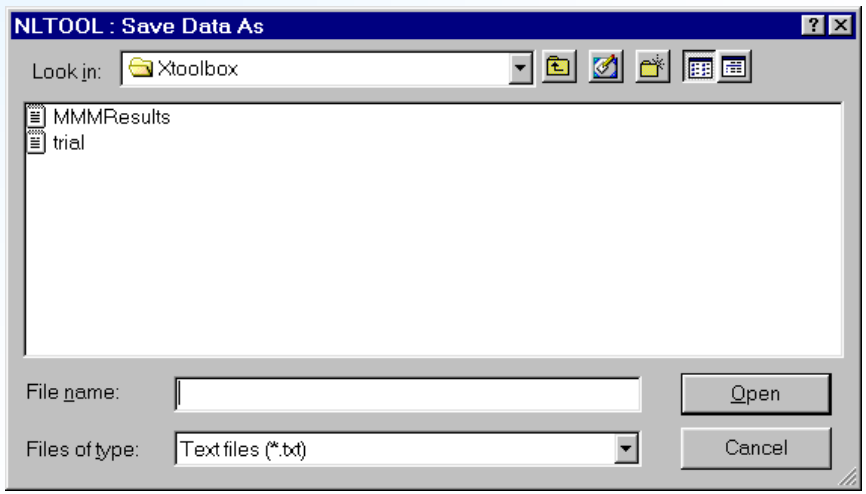
# NTSAS: Other Screens (2)



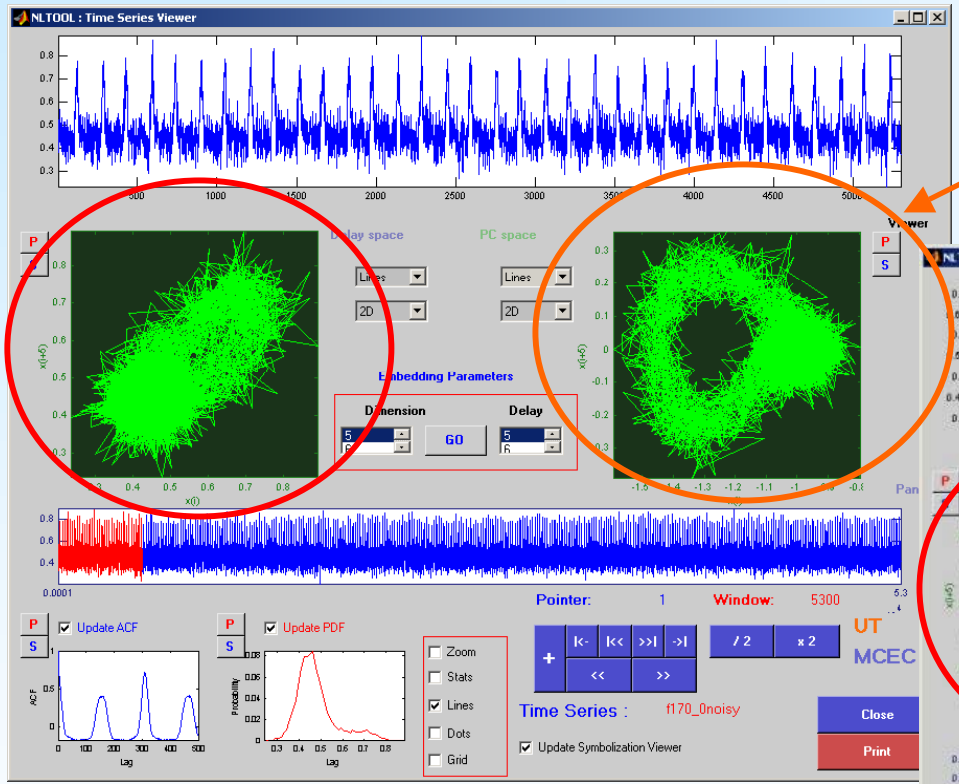



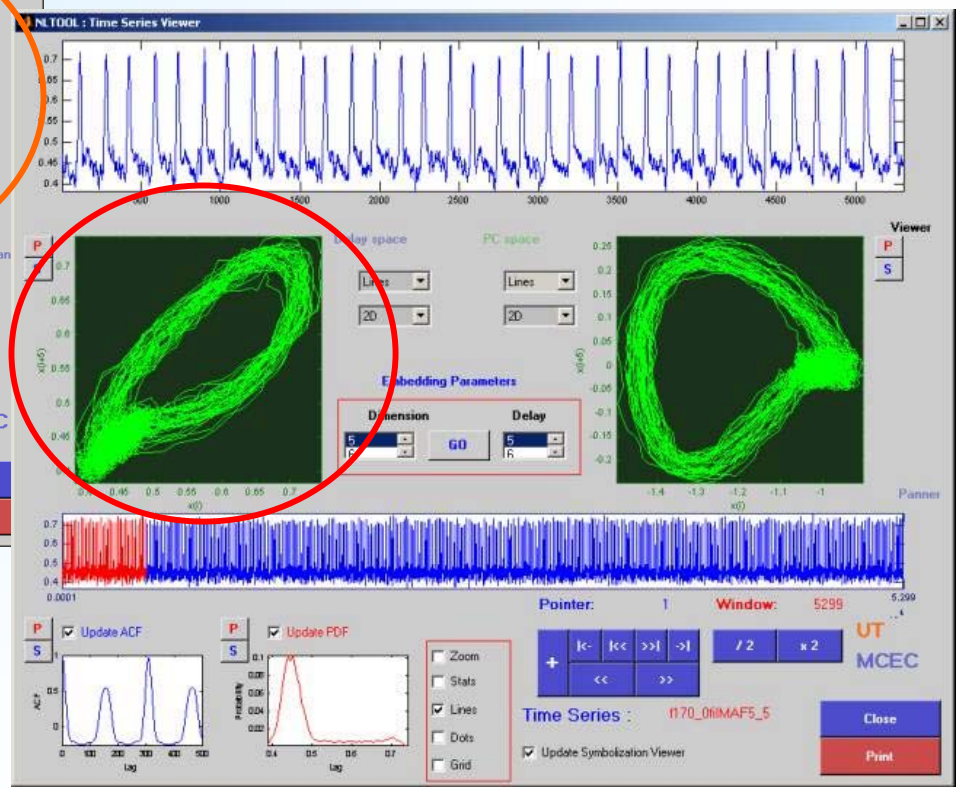



# Filtering Time Series

PCA reduces the noise and brings out clearer structure; local PCA is better for chaotic signals as compared to global PCA

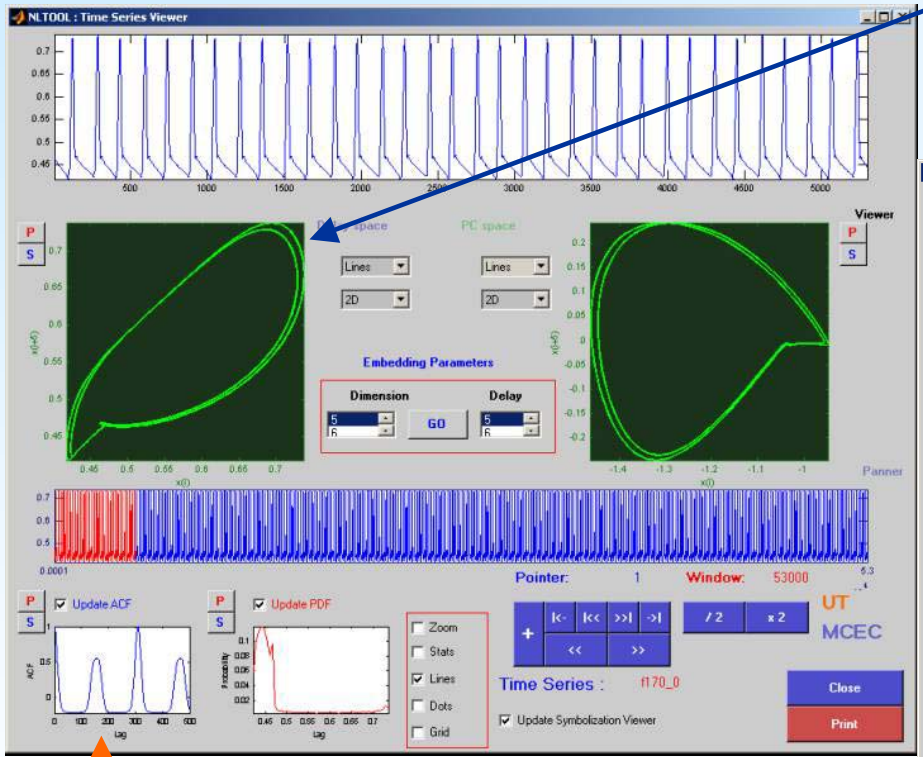


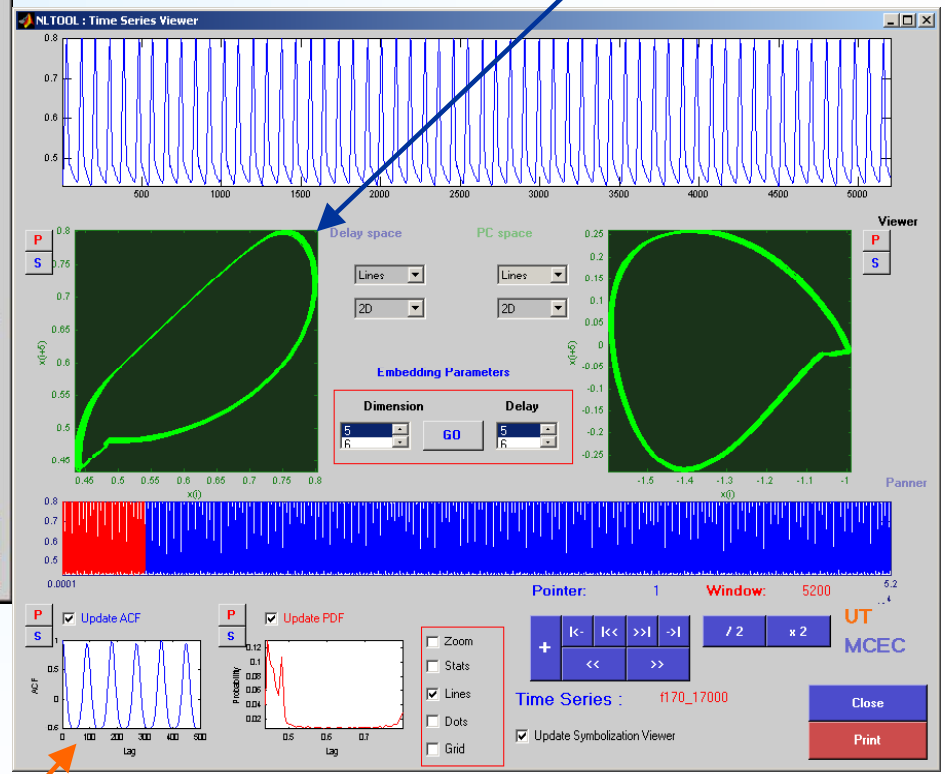




The almost random phase and delay space plots begin showing order and clearer structure after filtering

# Period-2 to Chaos

Notice how the two distinct loops for period-2 behavior blend to a thicker loop :Indication of Chaos

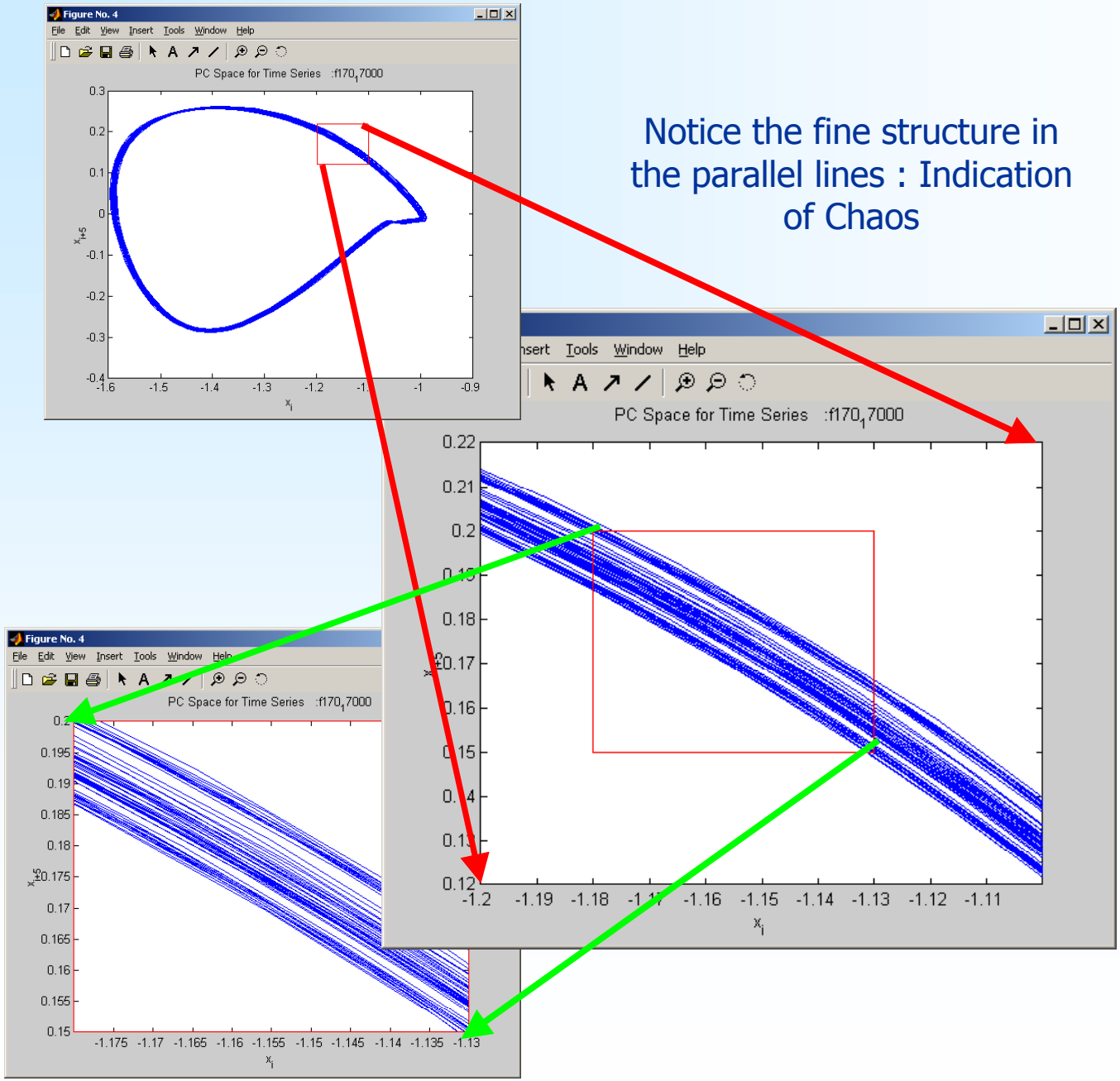



The two distinct peaks in autocorrelation disappear and produce an almost sinusoidal pattern (ignoring fine details)

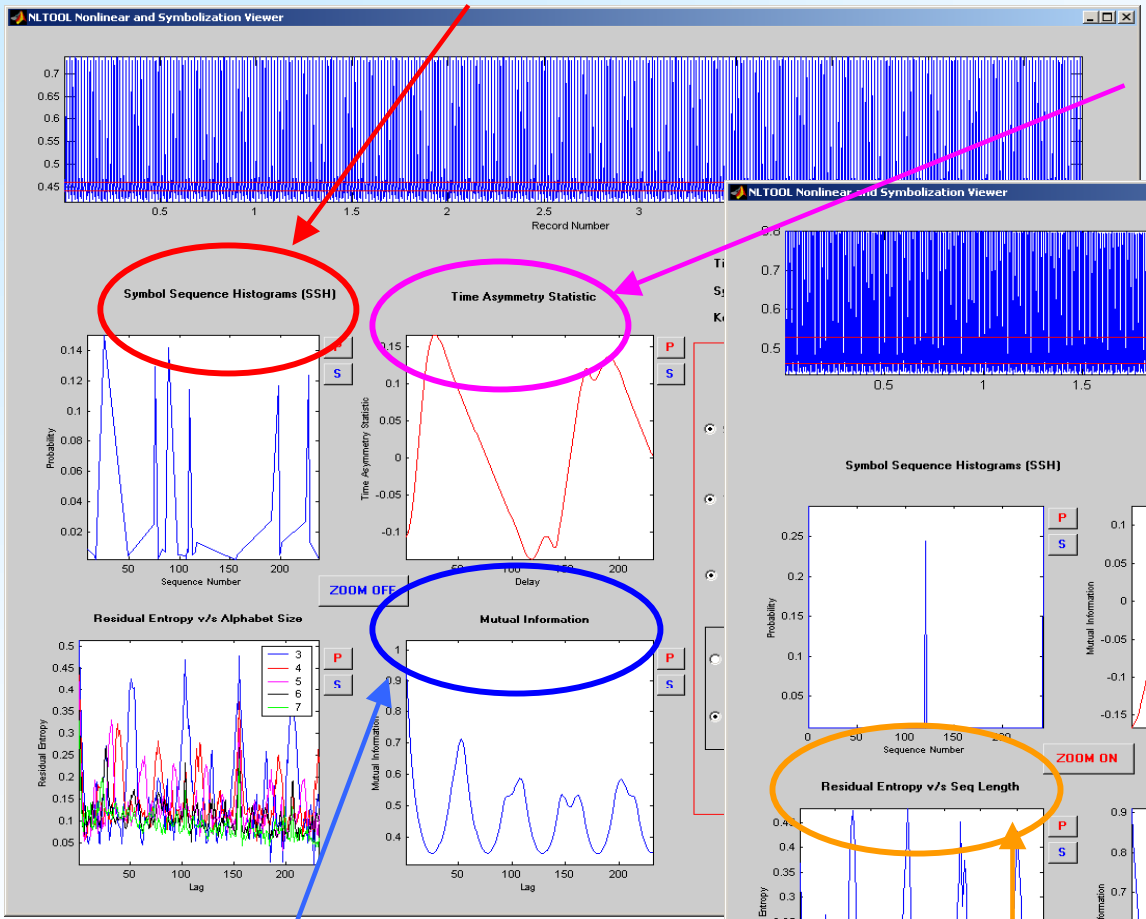
# Chaos

Notice the fine structure in the parallel lines : Indication of Chaos

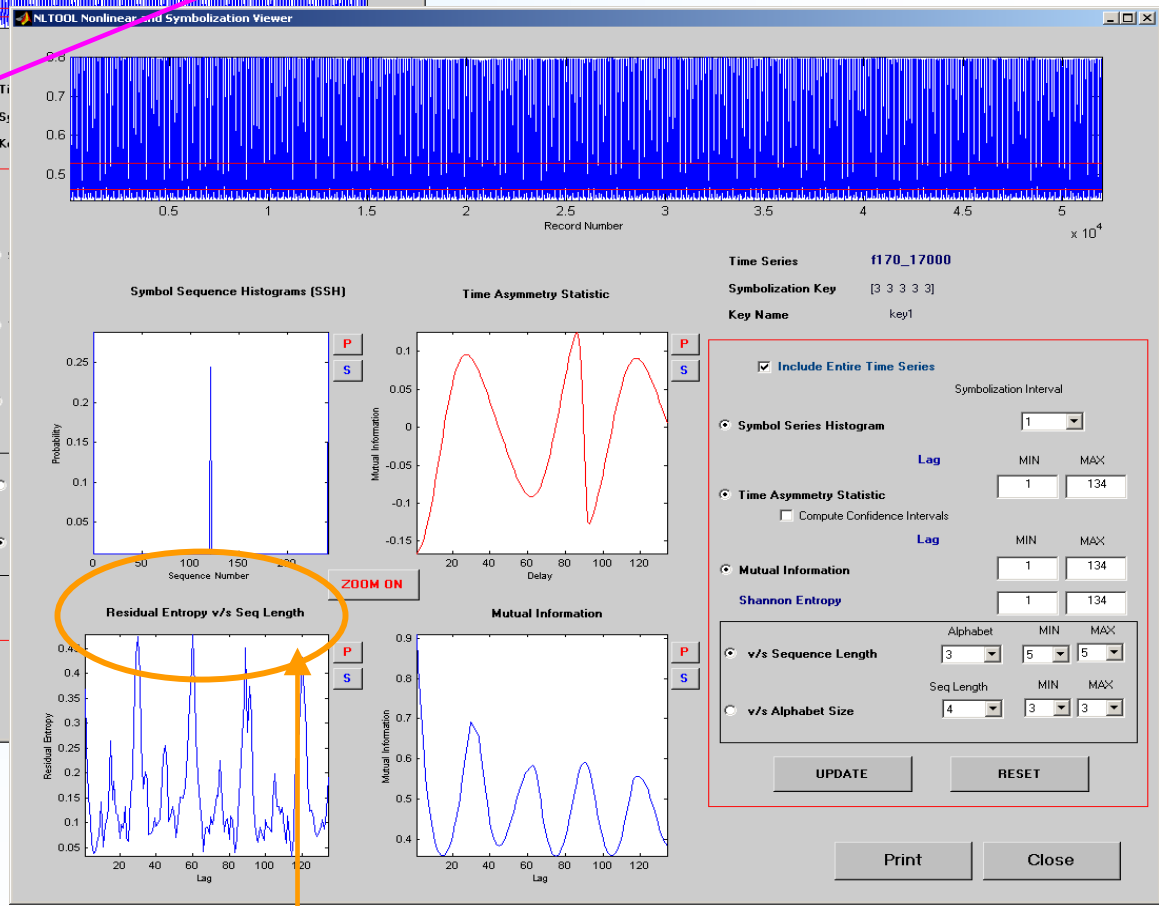


# Nonlinear and Symbolization Analysis

Symbol Sequence Histogram captures patterns with high likelihood



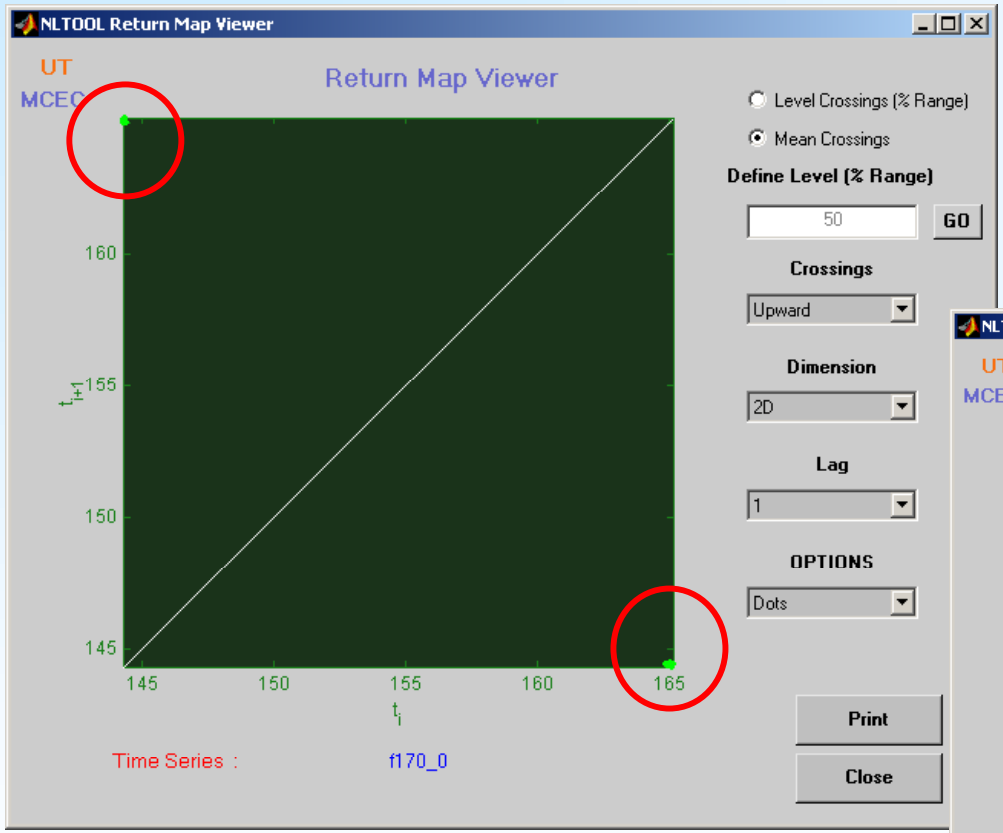

Time Asymmetry statistic finds patterns of rise and fall



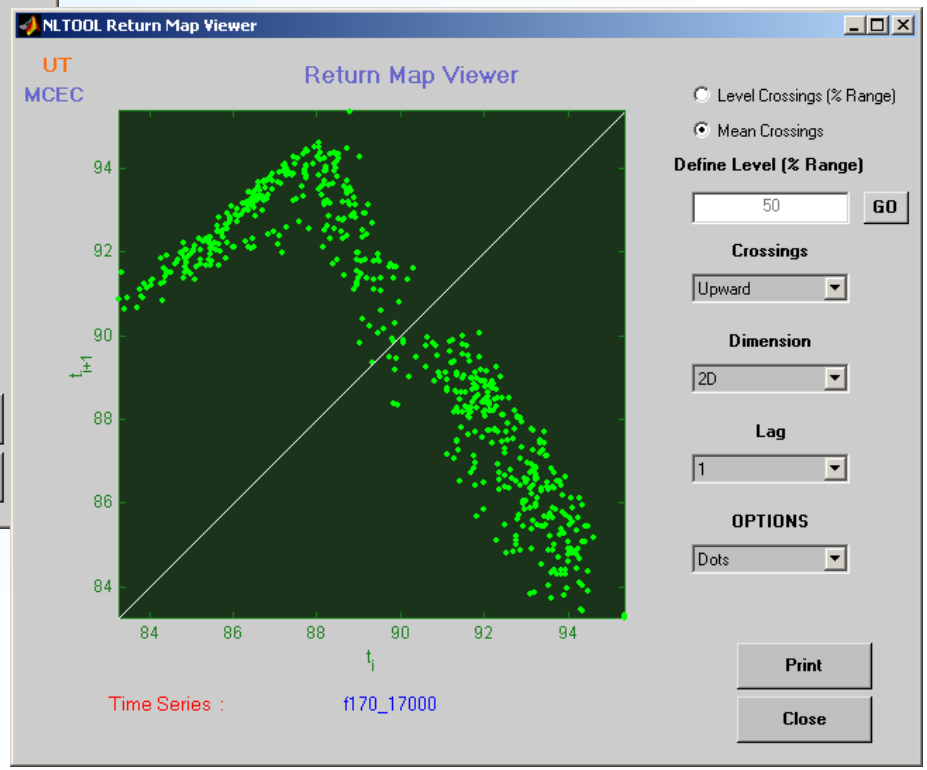

Mutual information or nonlinear autocorrelation finds linear and nonlinear time scales

Entropy finds characteristic non-linear time scales

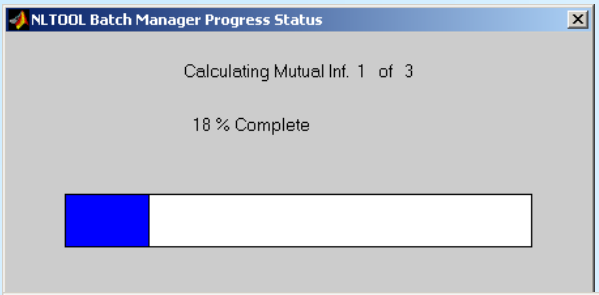
# Return Maps

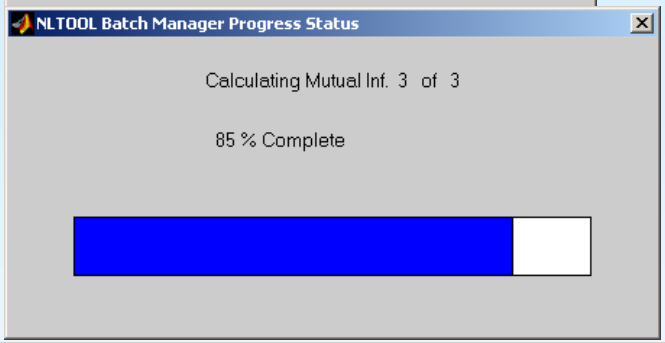


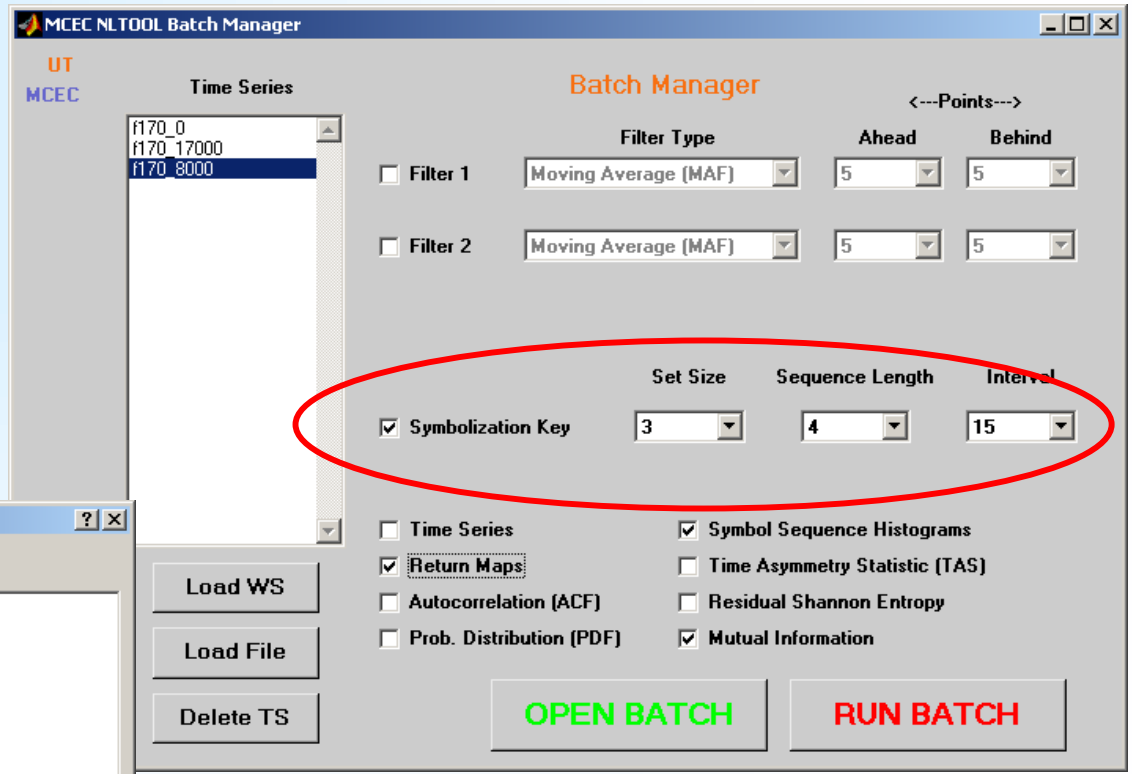

Notice how the clusters in the period-2 behavior give rise to a tent shaped structure : Indication of Chaos

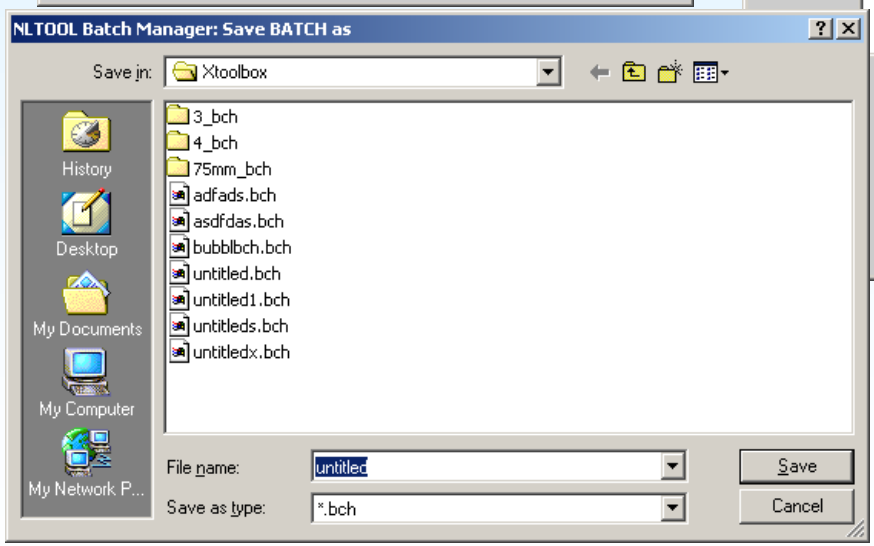


# NLTOOL: Batch Manager



# Batch Viewer