Wavelet Analysis of LIGO Data

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- Outline
  - ➢What are wavelets?
  - ➢How to use wavelets in LIGO data analysis?
  - ➢Wavelet Analysis Tool
  - ➢Current status
  - ➢Plans & Conclusion

LIGO Data Analysis at UF

- LSC White Paper - plan of work on
  - detector characterization
  - development of detection algorithms
  - provision of reduced data sets
- One of the UF group commitments is:
  - Development of Wavelet Analysis Tool for
    - data compression/reduction
    - transient signal characterization
    - un-modeled GW sources identification
  - WAT will be part of LIGO/LSC Algorithm Library
- "Wavelet" people at UF:

  S.Klimenko, G.Mitselmakher, A.Sazonov, B.Whiting

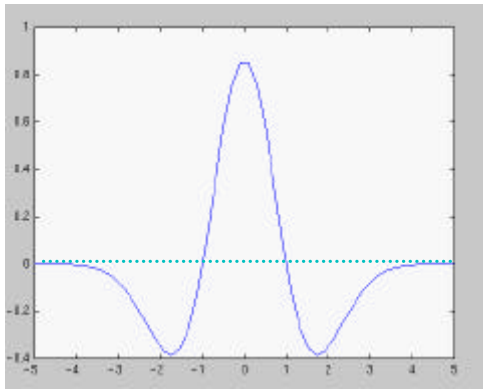
Wavelets

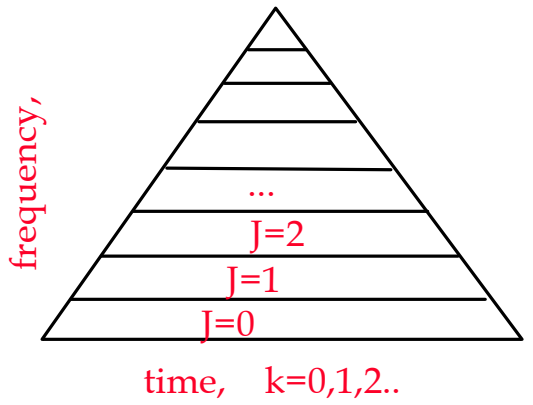
- What are wavelets?
  - set of basis functions $\Psi_{jk} = a^{j/2}\,\Psi_0(a^j x-k)$; Ψ_0 -mother wavelet
  - used in a way similar to Fourier Transform:
    $w_{jk} = \Sigma_i\, f(x_i)\,\Psi_{jk}(x_i)$ - digital wavelet transformation of $f(x_i)$
  - local in time & frequency domains (in contrast to Fourier Transform)
    real signals are finite in time!
- Why wavelets?
  - wavelets are convenient for pattern recognition
    - widely used in image and signal processing.
    - can be used for GW signal and non-gaussian noise identification.
  - allow simple description of signal with minimal number of waveforms
  - mathematics of wavelets is well developed, algorithms are flexible and fast.
- Very promising technique for LIGO data analysis

Wavelet Domain

- Coefficients of wavelet transform W_{jk} represent signal in wavelet domain
- W_{jk} data structure is a pyramid
  - W_{jk} at low layers (j=0,1,..) describe high frequency signal components
  - W_{jk} in a layer (k=0,1,..) represent signal's components separated in time.
- Wavelet methods
  - statistical analysis and selection of W_{jk}
  - pattern recognition in W_{jk} space
  - signal decomposition

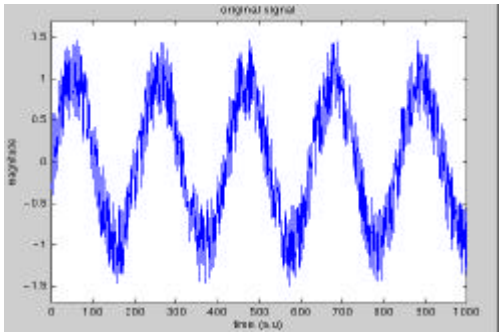
Mexican hat

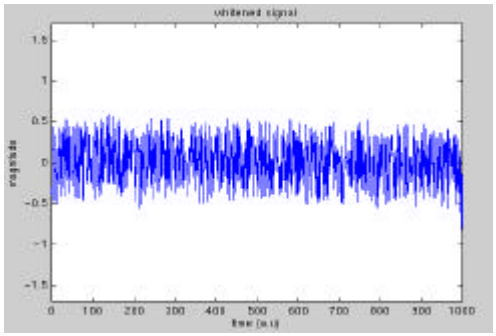


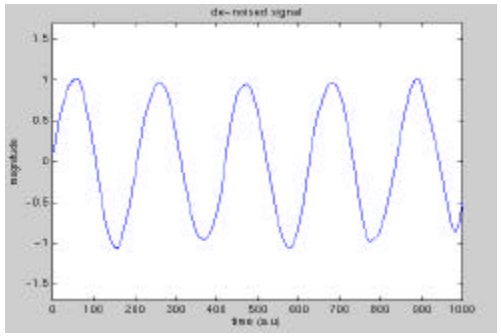


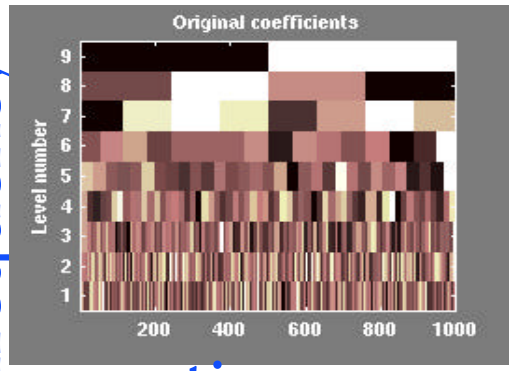
Elementary example of wavelet use (Doubechie 4 wavelet)

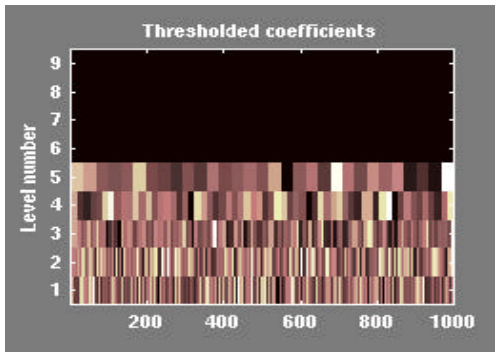
Sin(t)+white noise = noise + sin(t)

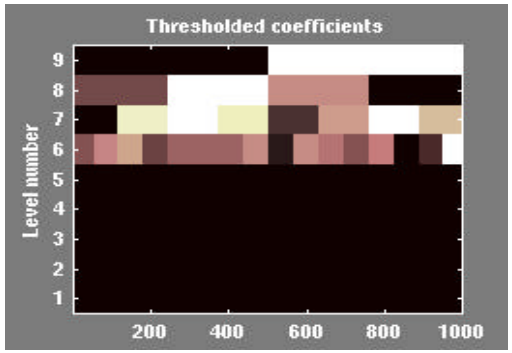












frequency

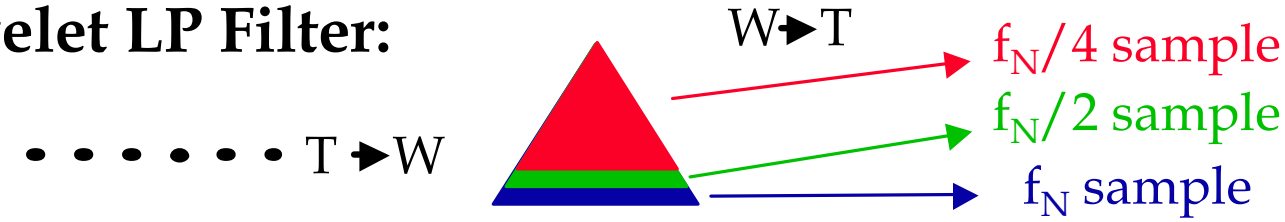
time

- Wavelets filter data
- Wavelets reduce data

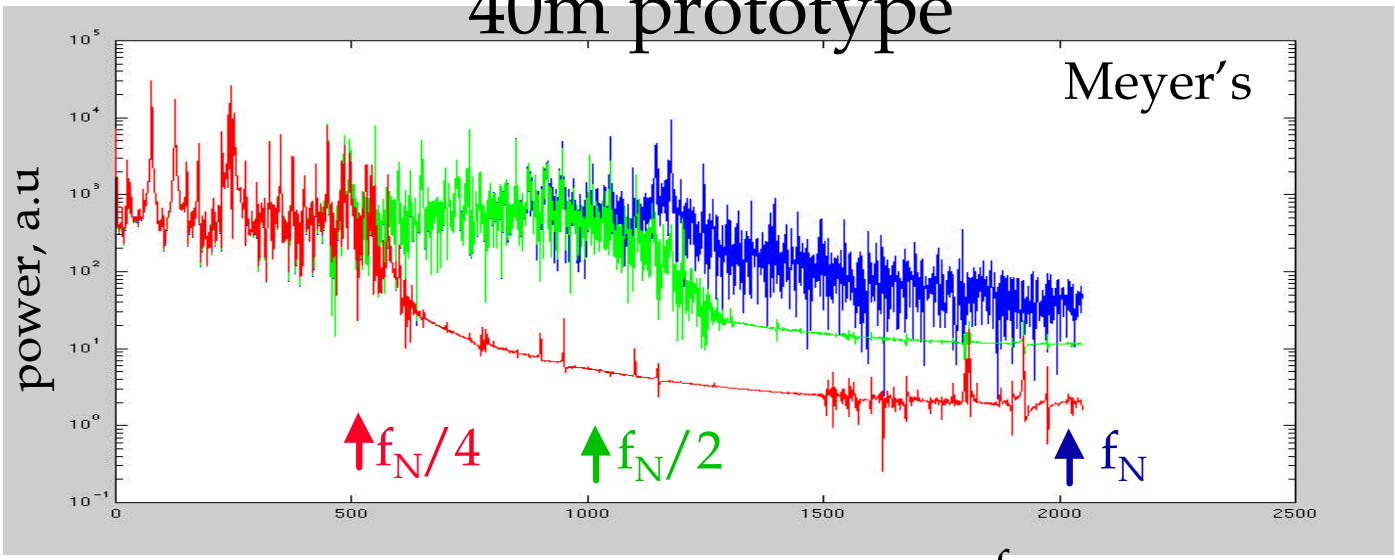
Wavelet low pass filter

- **Low Pass Filter:**

- **Wavelet LP Filter:**

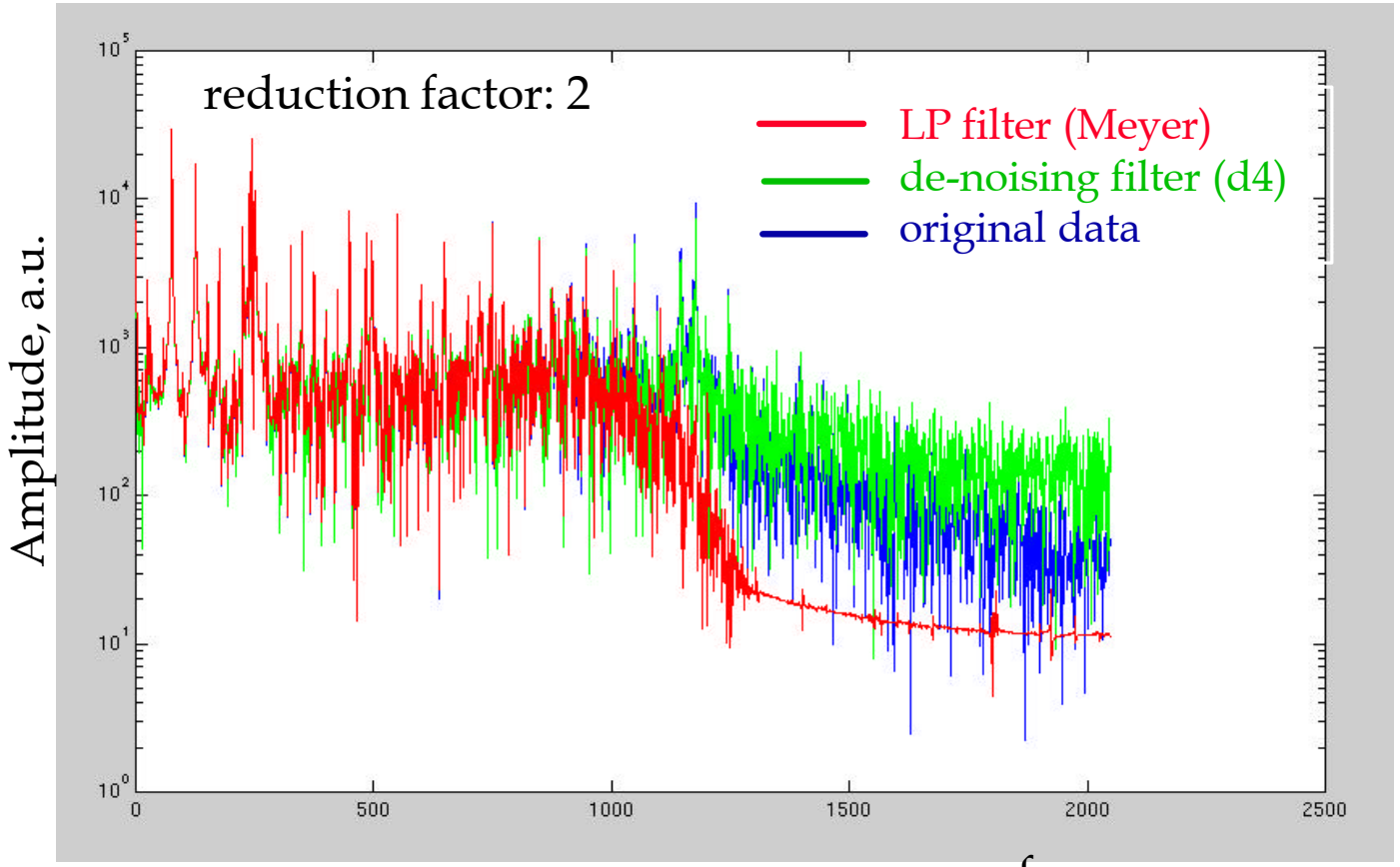


40m prototype



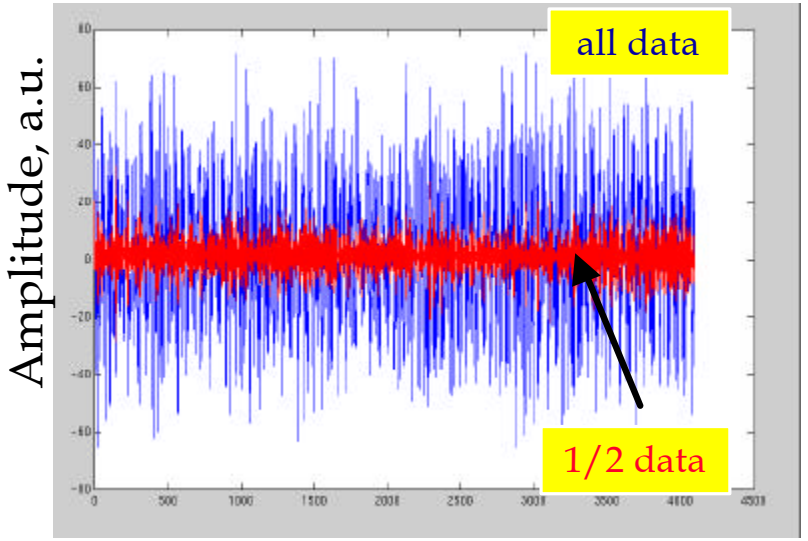
De-noising

- selection of wavelet coefficients with “large amplitude”
- allows compact representation of data in wavelet domain



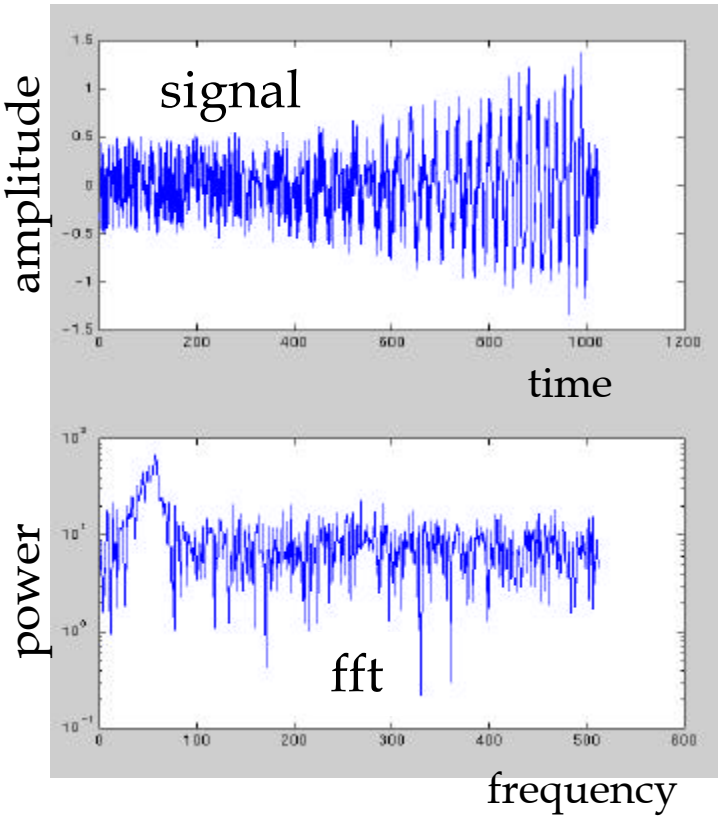
Data Reduction/Compression

- Reduction by
  - ➢filtering out high frequency components (LP filter)
  - ➢de-noising (different de-noising strategies can be used)
  - ➢removing "bad" data
- Reduced data sets for specific analysis tasks
  - ➢ reduction factor of 2-5 depending on the task
- Compression:
  - ➢signal decomposition
  - ➢"zip" data in wavelet domain
- ?compression factor?

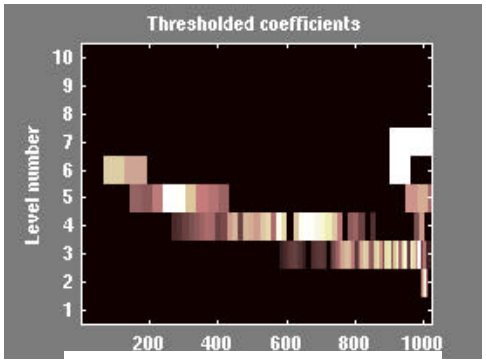


Simple Example of wavelet use (Mayer's wavelet)

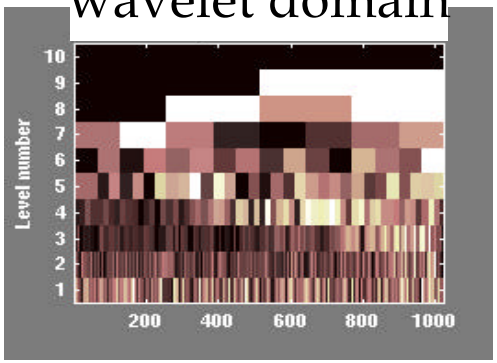
- Chirp + white noise



chirp 'signature'



wavelet domain



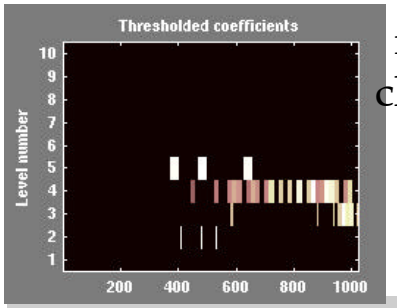
- GW signal or transient can be identified by it's signature

Transients identification

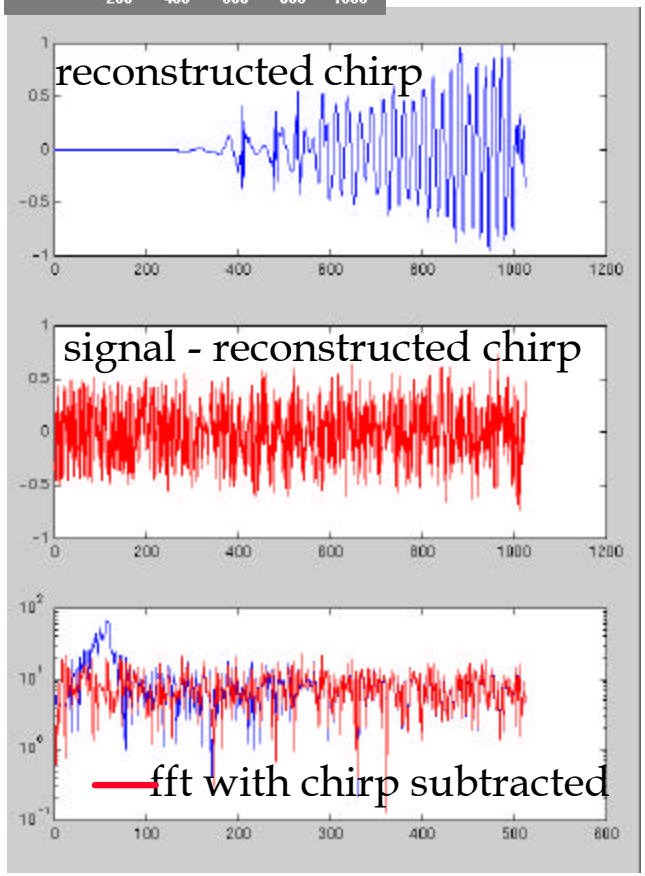
- Transient is characterized by it's signature in wavelet domain
- Wavelet trigger

  identifies transient's signature by statistical analysis of data in wavelet domain. All types of wavelets can be used.
- Wavelet filter -

  trigger implemented with orthogonal (bi-orthogonal) wavelet. Transient can be rebuilt in time domain using it's reconstructed signature and subtracted from the original data.



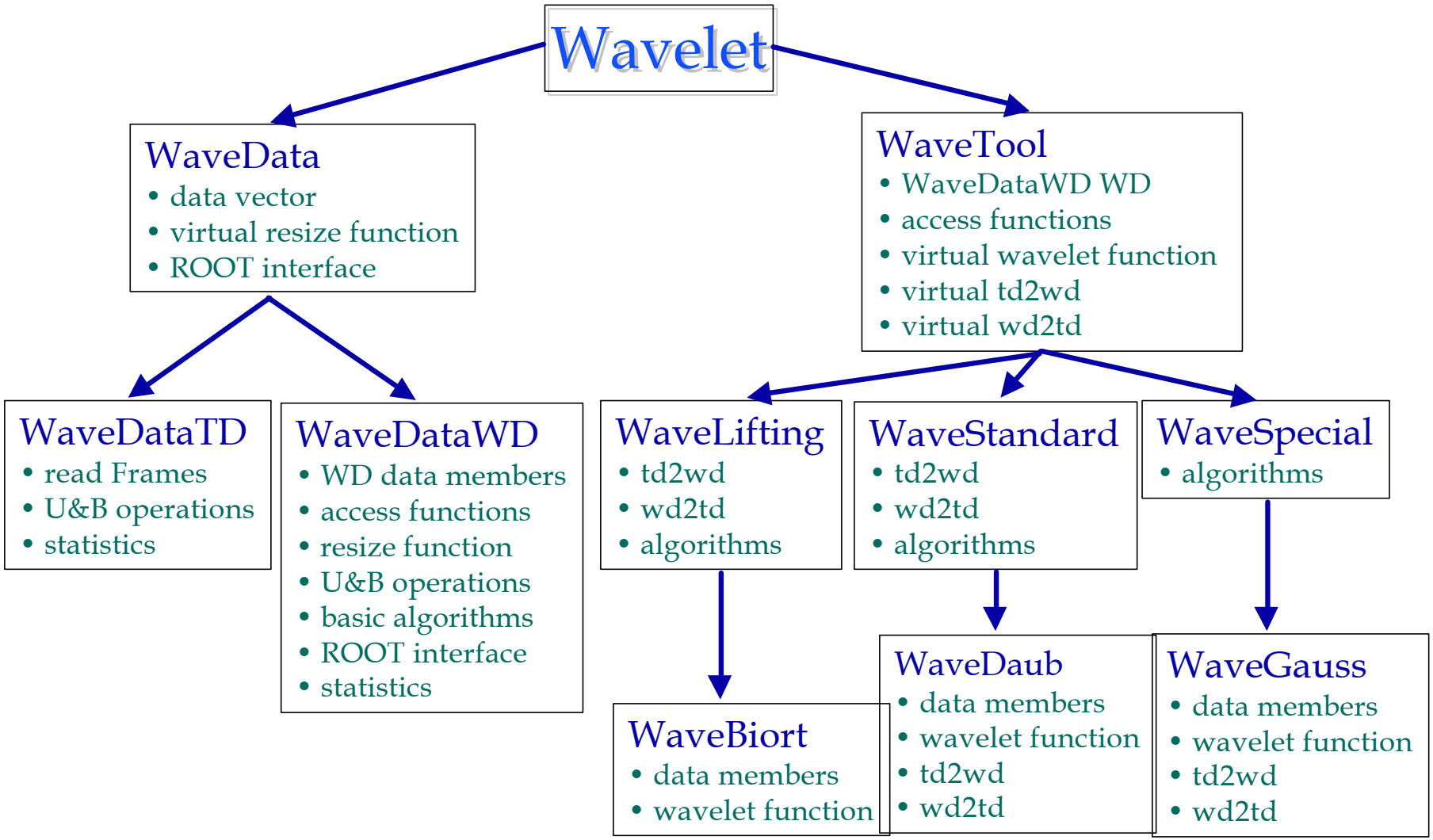
reconstructed chirp signature using simple threshold scheme



Wavelet Analysis Tool

- Toolbox to construct data triggers/filters and process LIGO data.
- WAT components:
  - wavelet class library (C++):
    - wavelet domain data structure and functions
    - wavelet transformations (Doubechie's, Mayer's, Fast Wavelet Transforms)
  - interfaces to LDAS (Frame format) and GUI (ROOT)
  - build in set of wavelet algorithms for data analysis
- Why we need WAT? (?Matlab?)
  - can be used to process large amount of data
  - provides class library for development of new wavelet algorithms
  - will agree with LLAL requirements

Wavelet Class Library



Current Status

- Wavelet Analysis Tool development
  - ➢WAT structure is determined
  - ➢can read Frame data (need switch from Fcl to FrameCpp)
  - ➢lifting wavelets are implemented
  - ➢Gaussian wavelets (in progress)
  - ➢data reduction algorithms (in progress)
  - ➢transients identification (investigating)
  - ➢interface to ROOT (investigating)

Plans

- Short term plan (Aug 2000):
  - develop first version of WAT
    - wavelet class library
    - interfaces to LIGO data and ROOT
    - set of Fast Wavelet Transforms and Gaussian wavelets
  - first algorithms for transient analysis and data reduction
- **Long term plans (2000-2002)**
  - 2000 - initial WAT
    - develop simple and fast wavelets & wavelet algorithms to process large amount of data at earlier stage of analysis.
  - 2001 & 2002 - final WAT
    - develop more sophisticated and hence less time efficient wavelets and wavelet packets for final stage of data analysis.
    - use wavelets to analyze LIGO data

Conclusion

- Wavelets can be used to construct data triggers and filters to sort out GW and noise pulses and produce reduced data sets.
- Flexible Wavelet Analysis Tool is needed
  - ➢ Different wavelets and algorithms need to be used for different tasks
  - ➢ Different wavelets and algorithms will be used at initial and final stages of analysis.
- UF group is working on wavelet algorithms and wavelet software development