

# **Financial Engineering**

## **Modeling Methodology & Applications**

# 財務工程之模型建構與應用

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2004 ~ 2010



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# Signal Processing

## Data Analysis

Transformation, Filters, Regressors, Classification, Co-integrators



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# Signal Processing

“The name of the game then was distinguishing the signal from the noise, which was often difficult. The key question on my mind was typically: What part of each monthly observation on inflation is durable and what part is fleeting?”

— Former Vice Chairman of Federal Reserve Bank Alan Blinder



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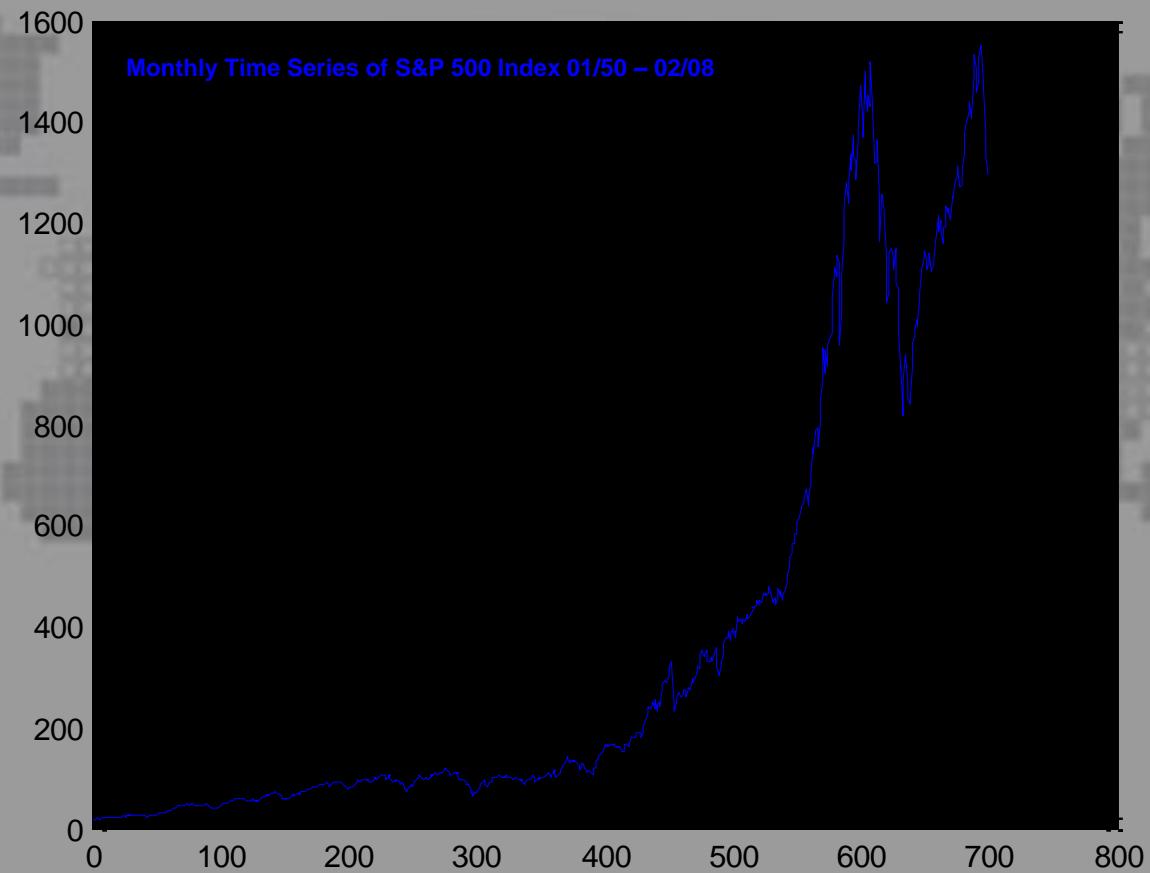
# Signal Processing

Example - I

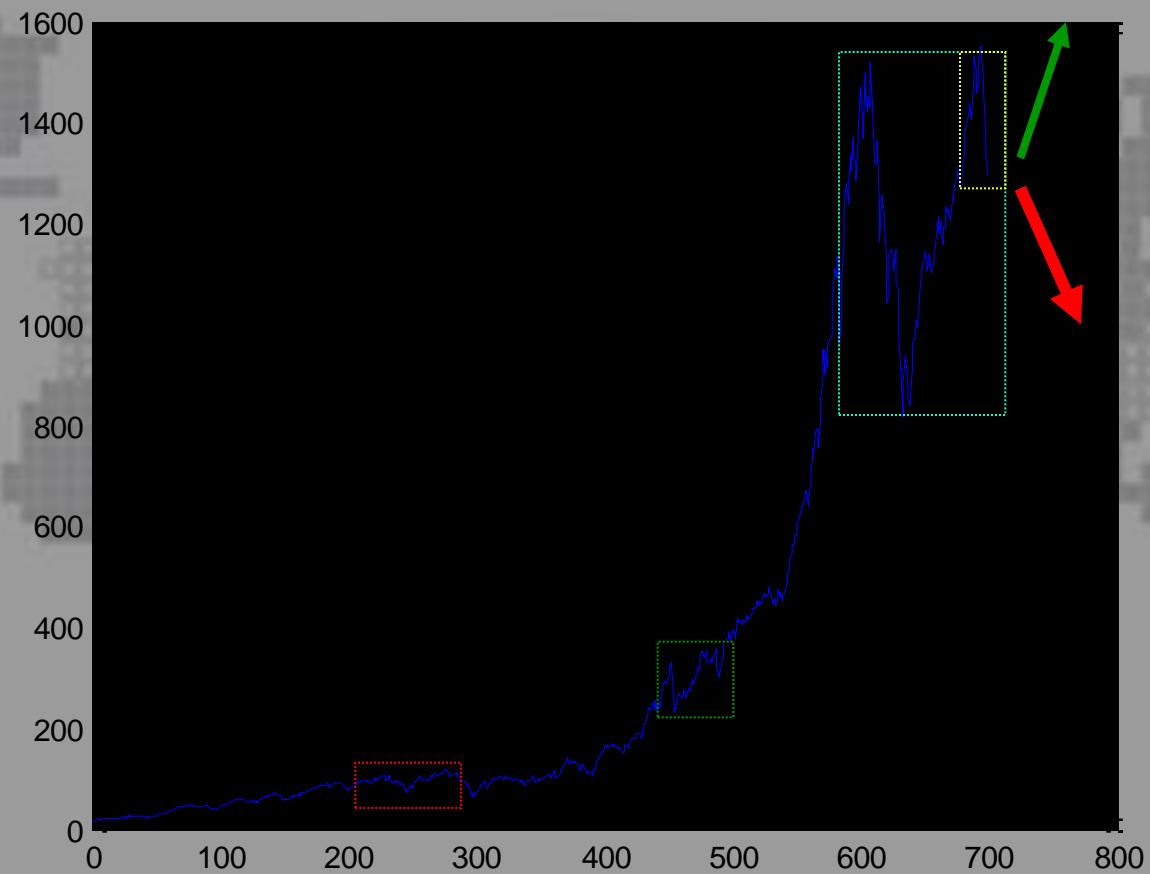
Large Time-Scale S&P 500



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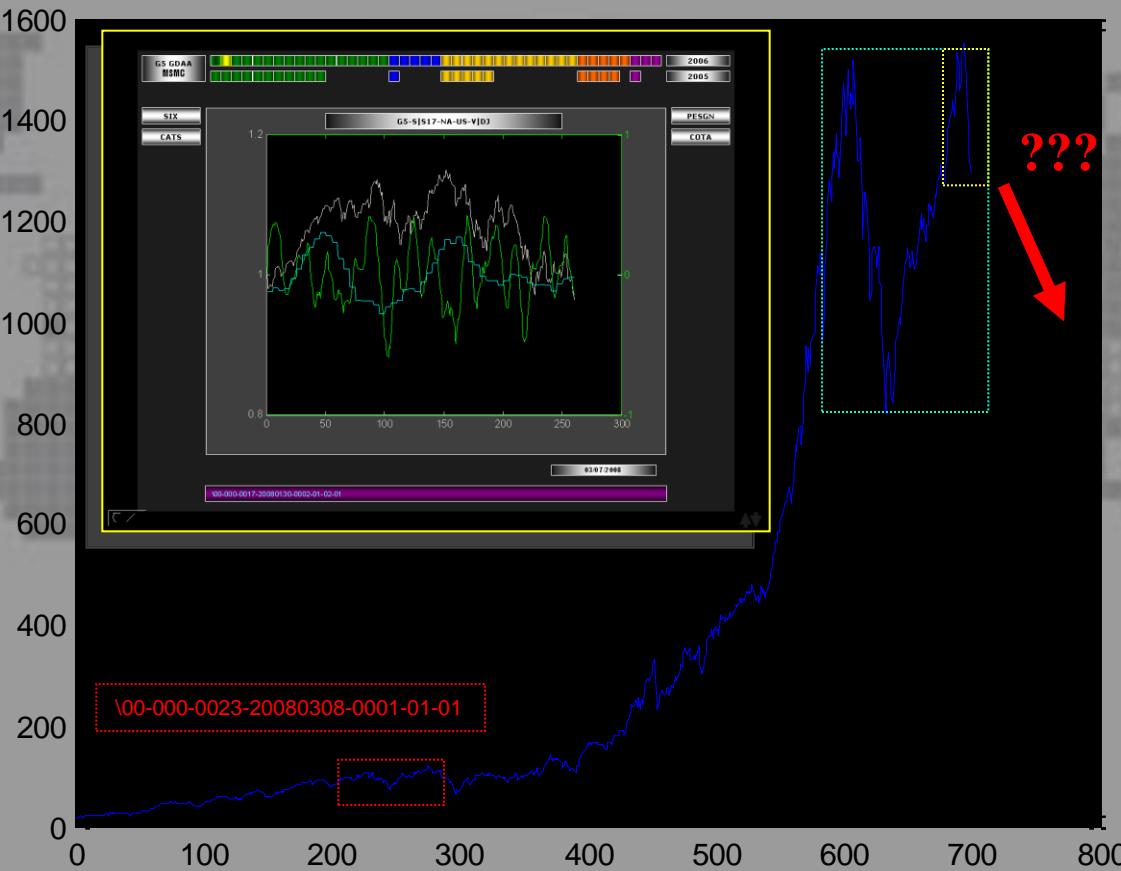


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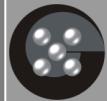
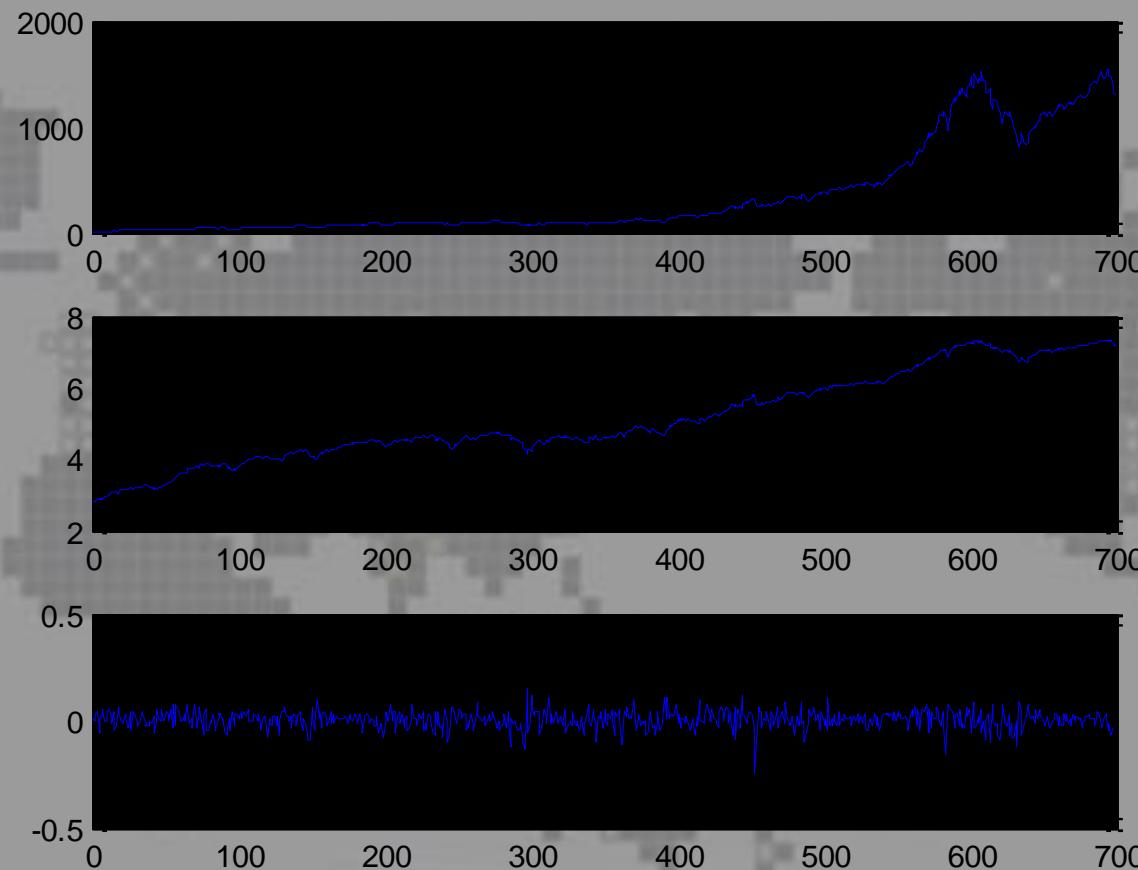
# Financial Signal Processing for justifying Experiences



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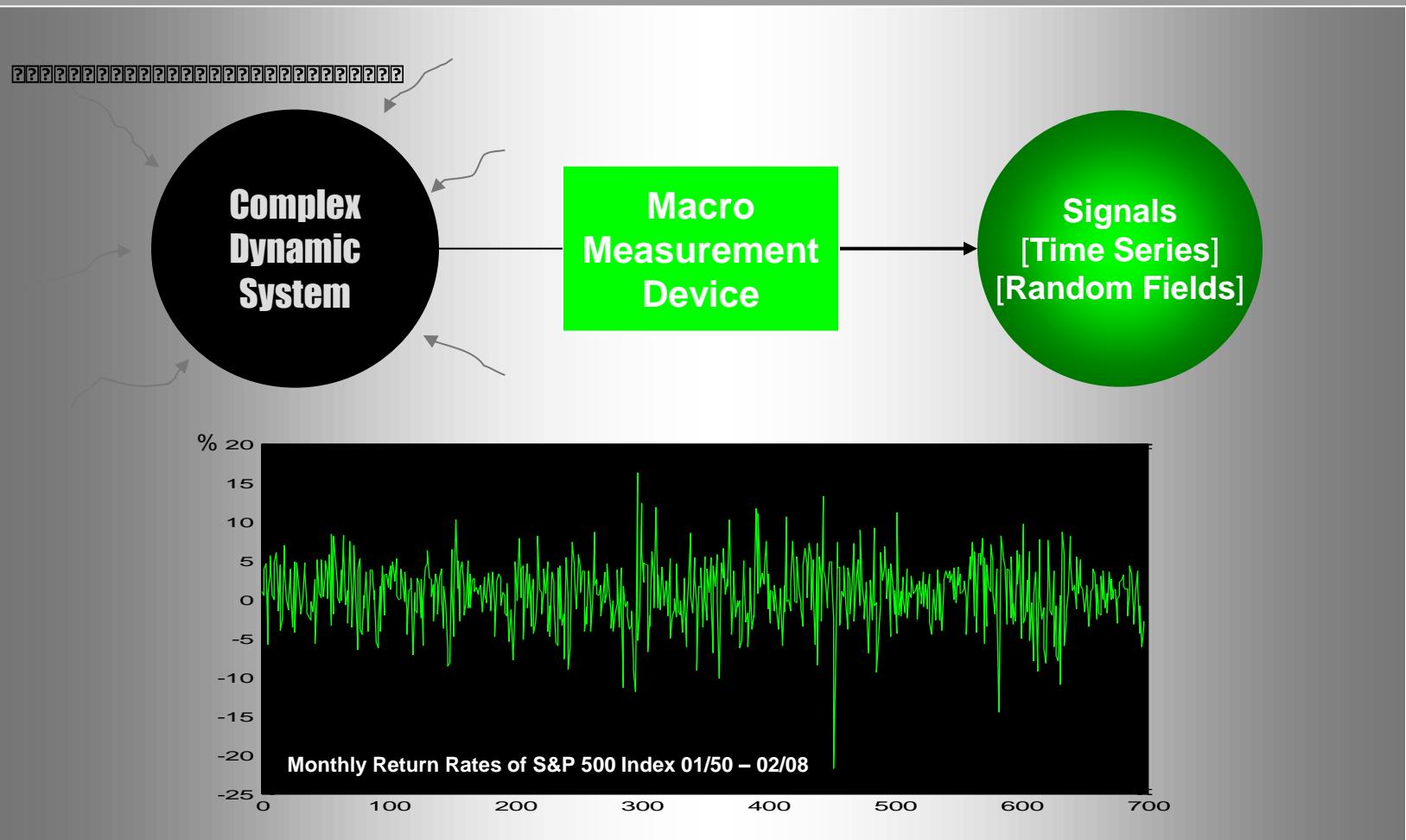
# Difference of Signal Processing from Technical Analysis

just like difference of Astronomy from Astrology



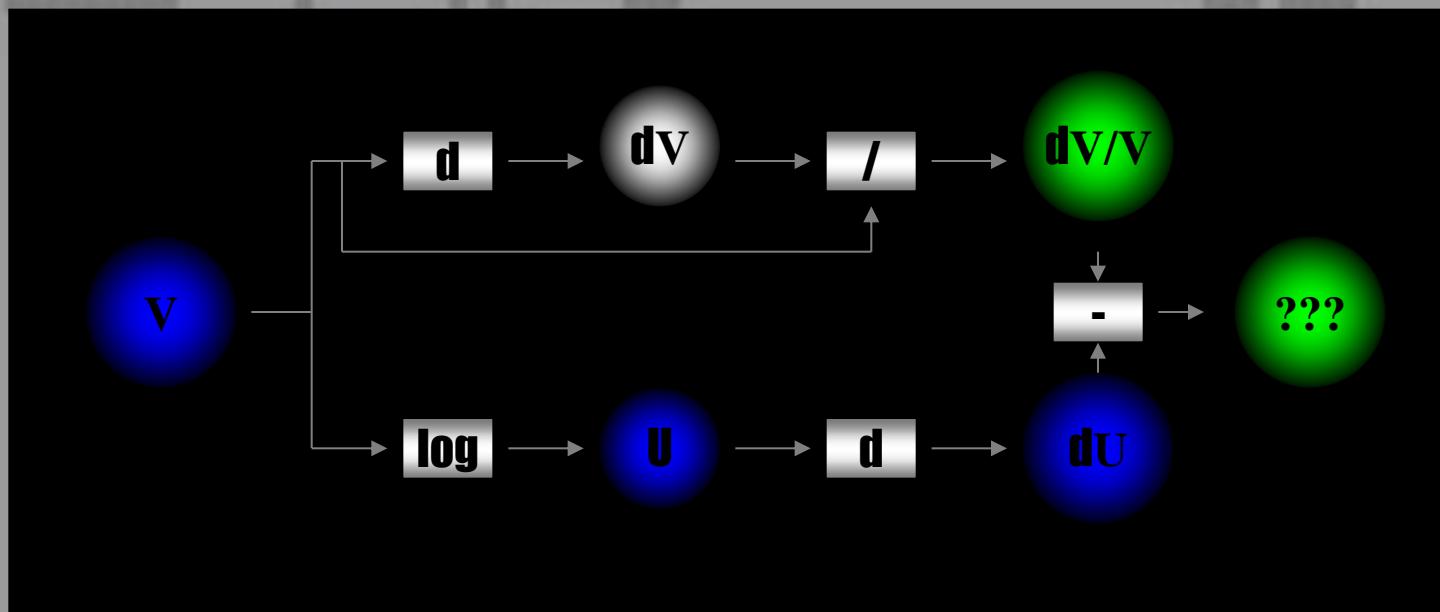
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# Tracking Capital Market as Complex Dynamic System



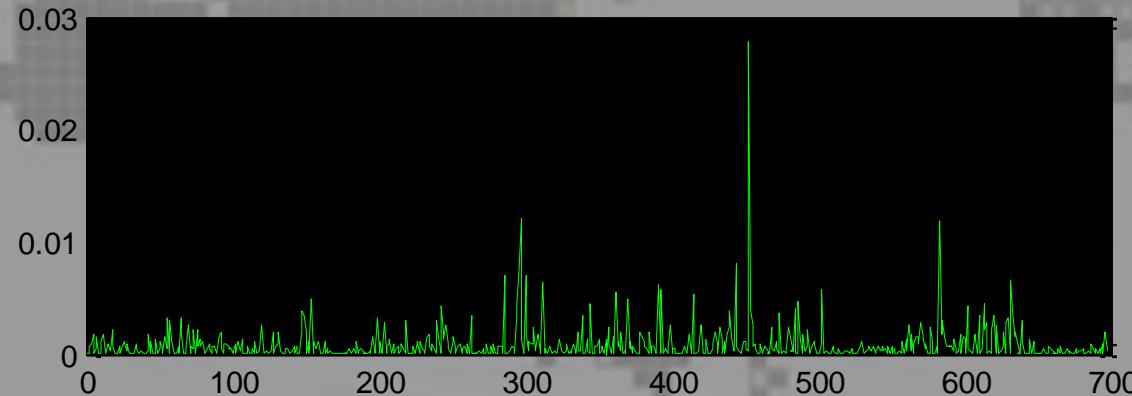
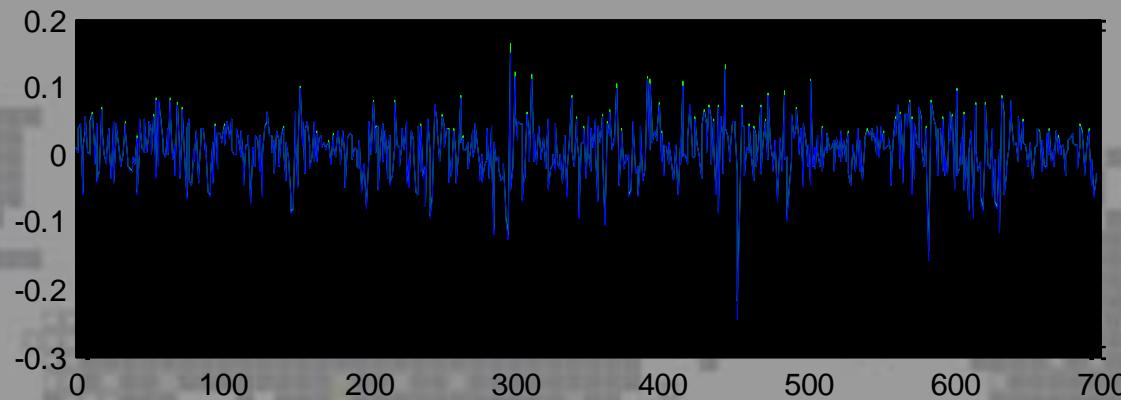
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# Constructive Math (Operator-Format) for Signal Processing

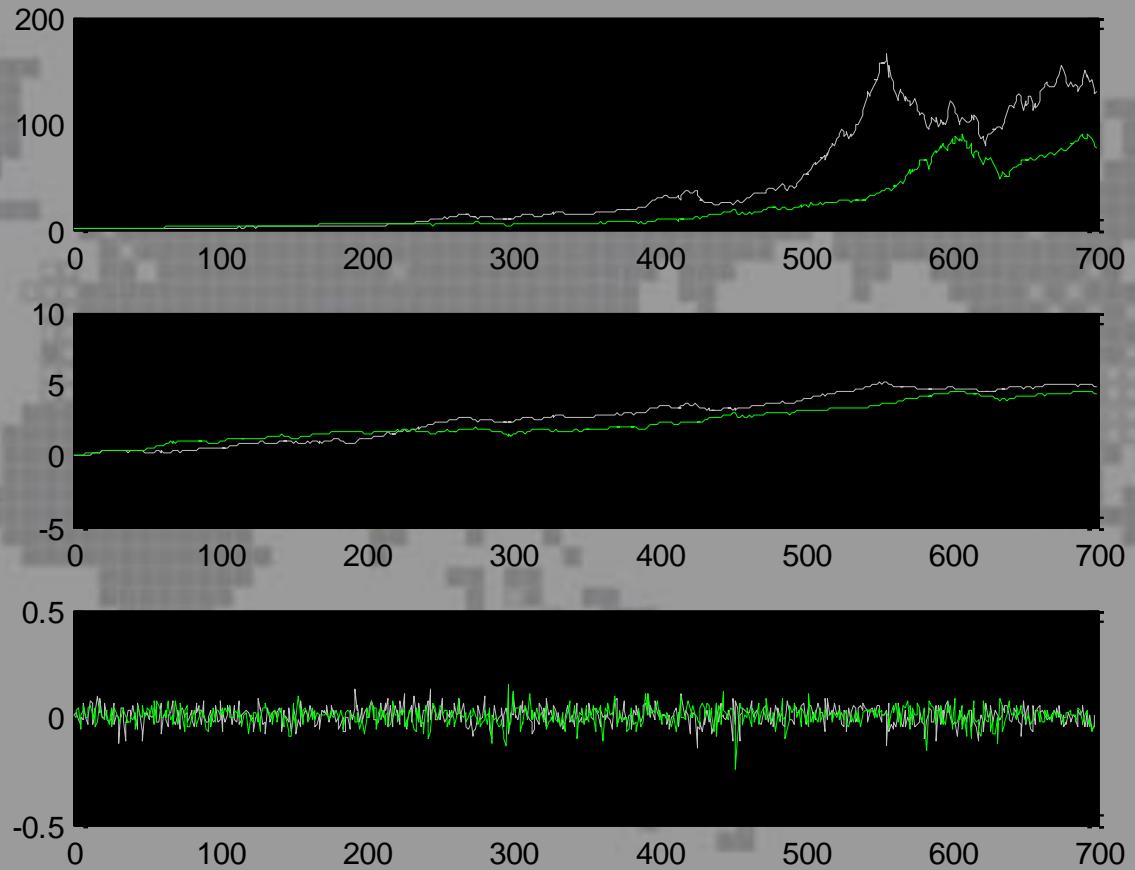


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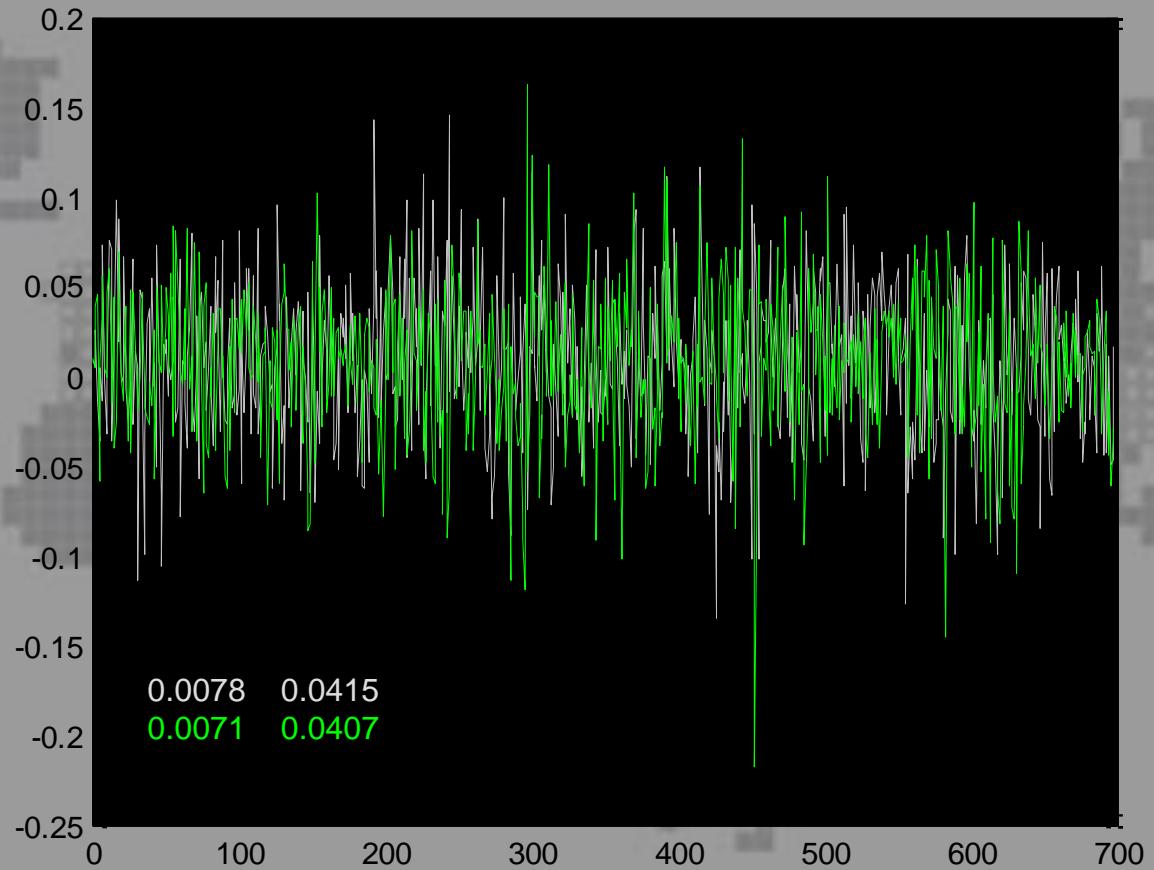
## Math Magic for revealing latent Volatility



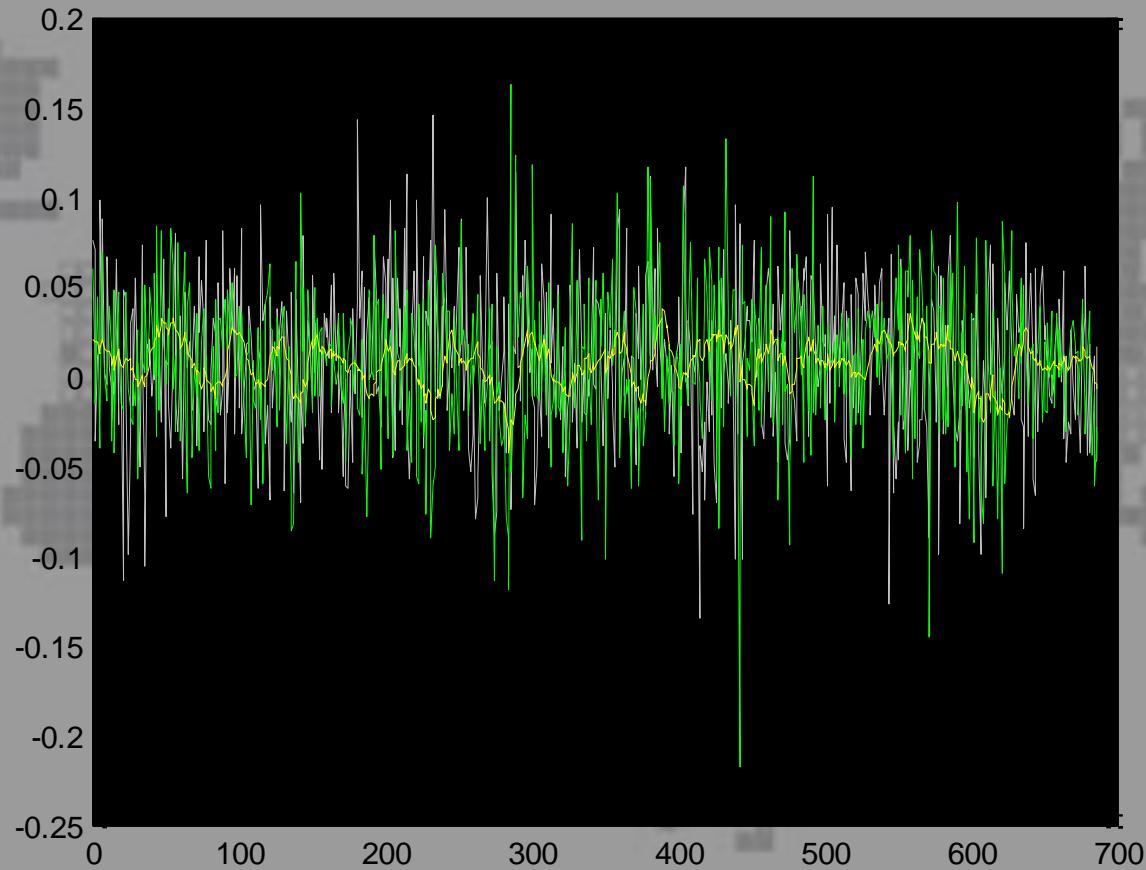
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# Signal Processing Task before modeling Complex Dynamic System

By Reflexivity,

no single simple rule will dominate the stock market index forever.

Signal processing decomposing the constitutional components and exploring the structural nature of the signal.

Short-Time Fourier & Wavelet Analysis



● Trend

● Season

● Cycle

● Change-Point

● Jump

● Shock (Wave)

● Noise

regular components

Fourier Analysis

singularity

餘波盪漾

irregular components



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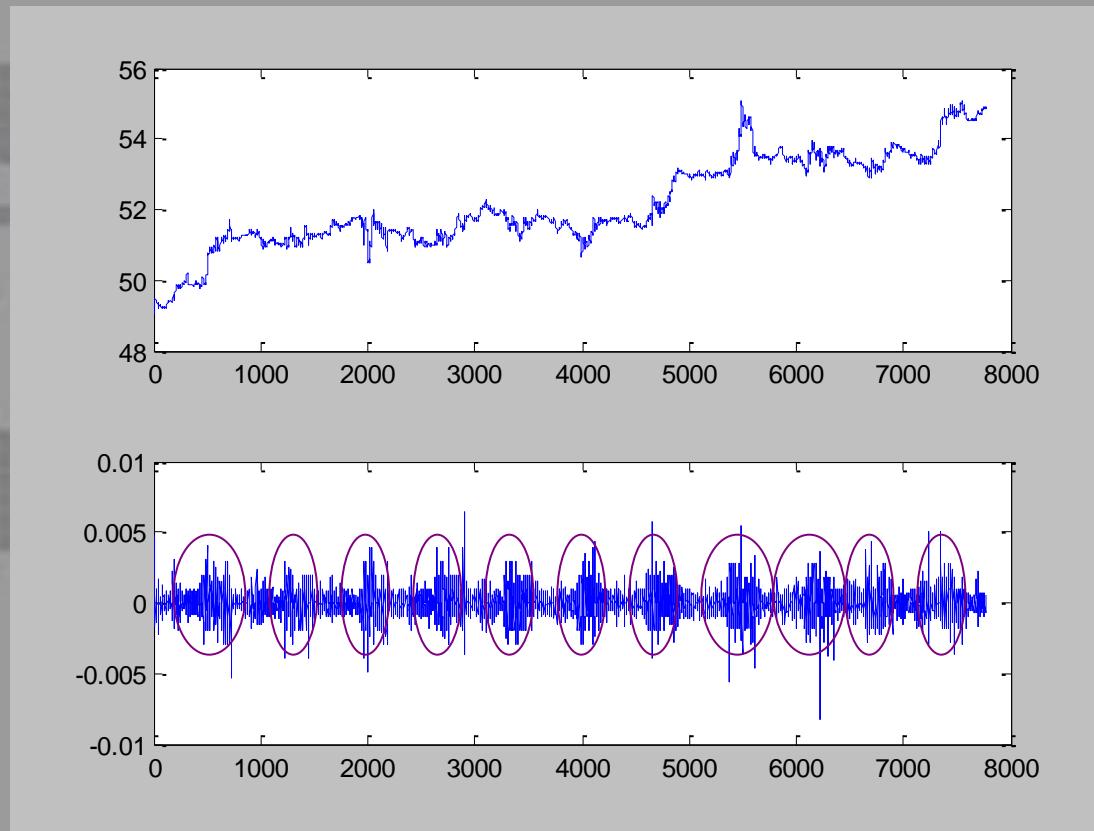
# Signal Processing

**Example - II**

**Crude Oil in Ultra-High Frequency**



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# Signal Processing

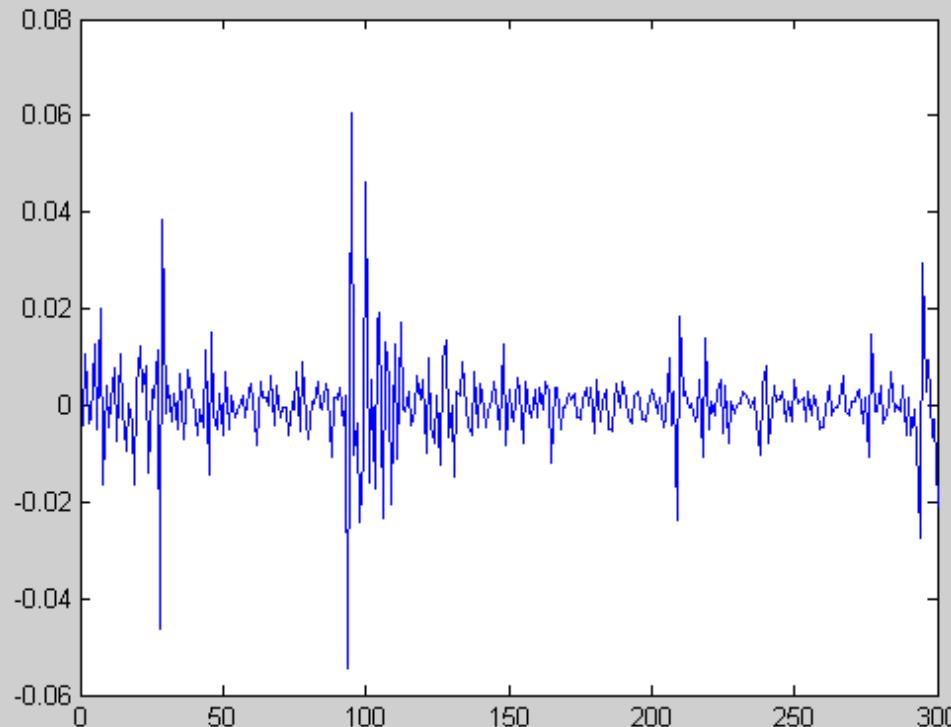
Example - III

TAIEX Future-Spot Return-Rate Spread



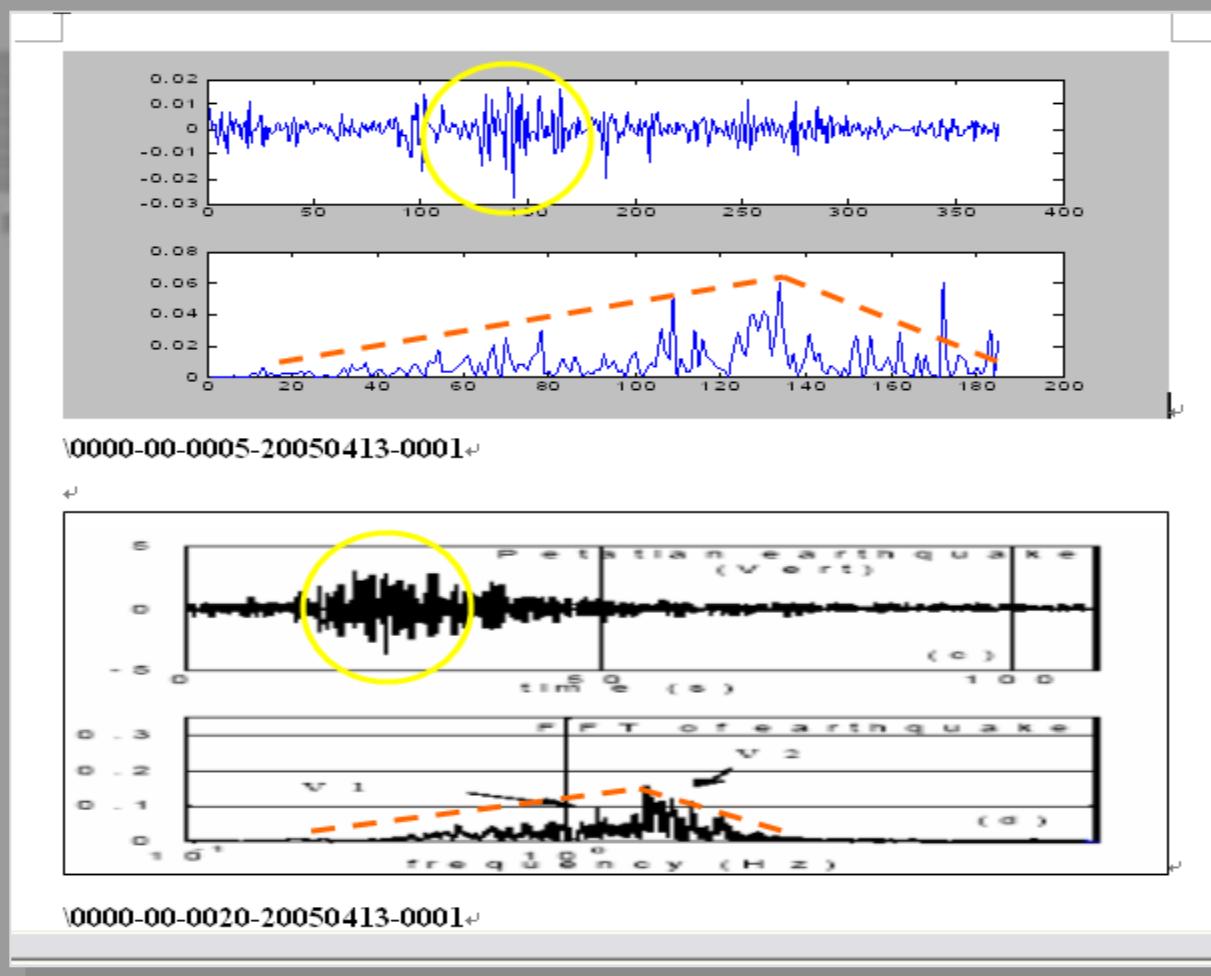
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# Future-Spot Return-Rate Spread



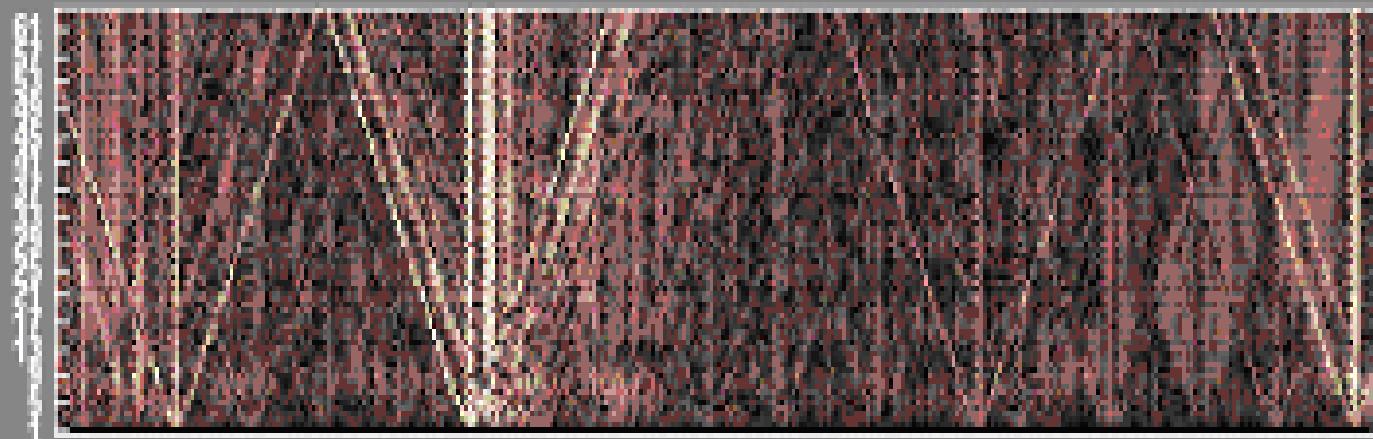
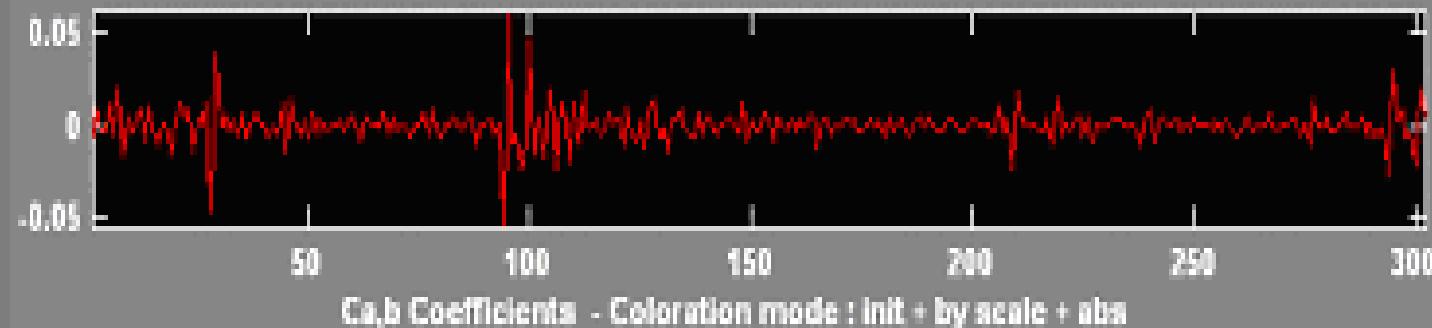
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# Analog in Structural Nature of Signal



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# Continuous Wavelet Transform



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# Signal Processing

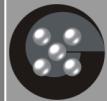
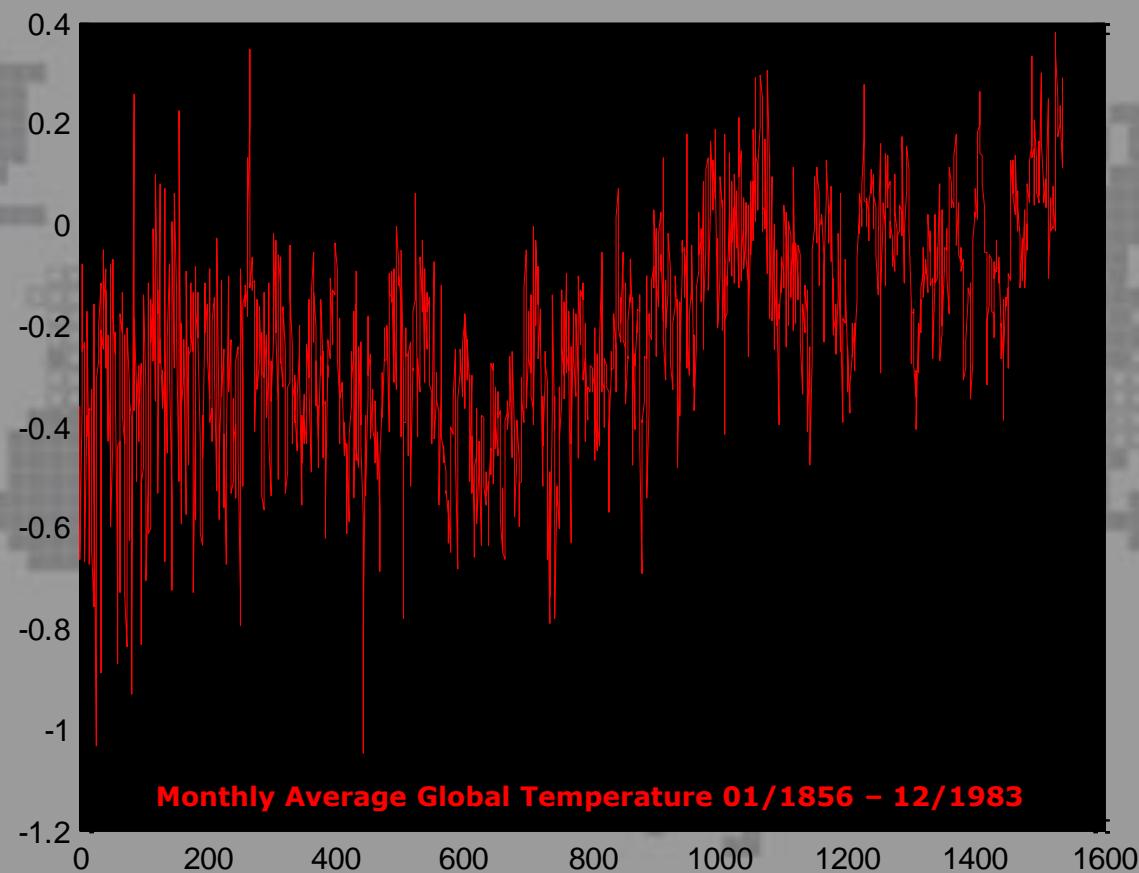
Example - IV

Global Temperature



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# Global Warming

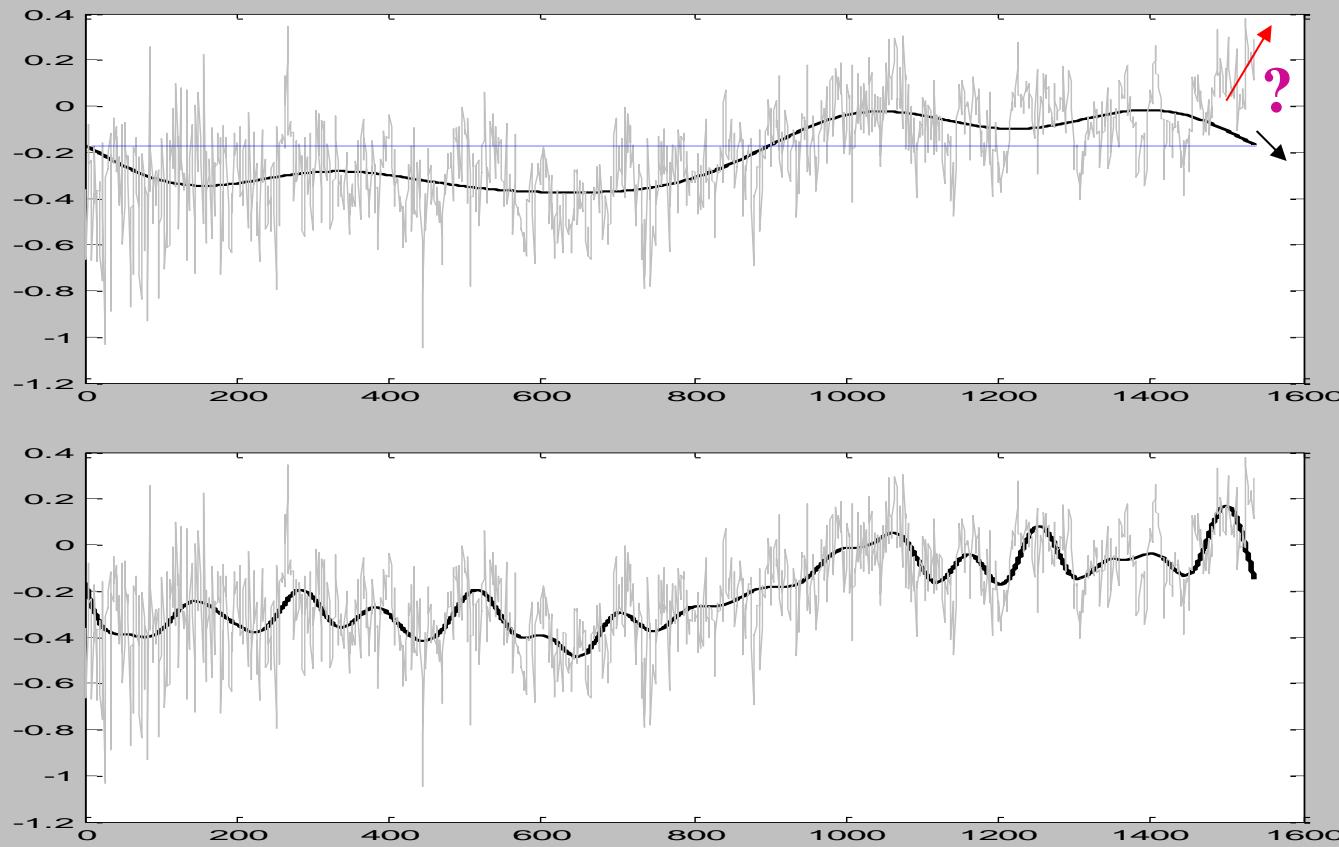


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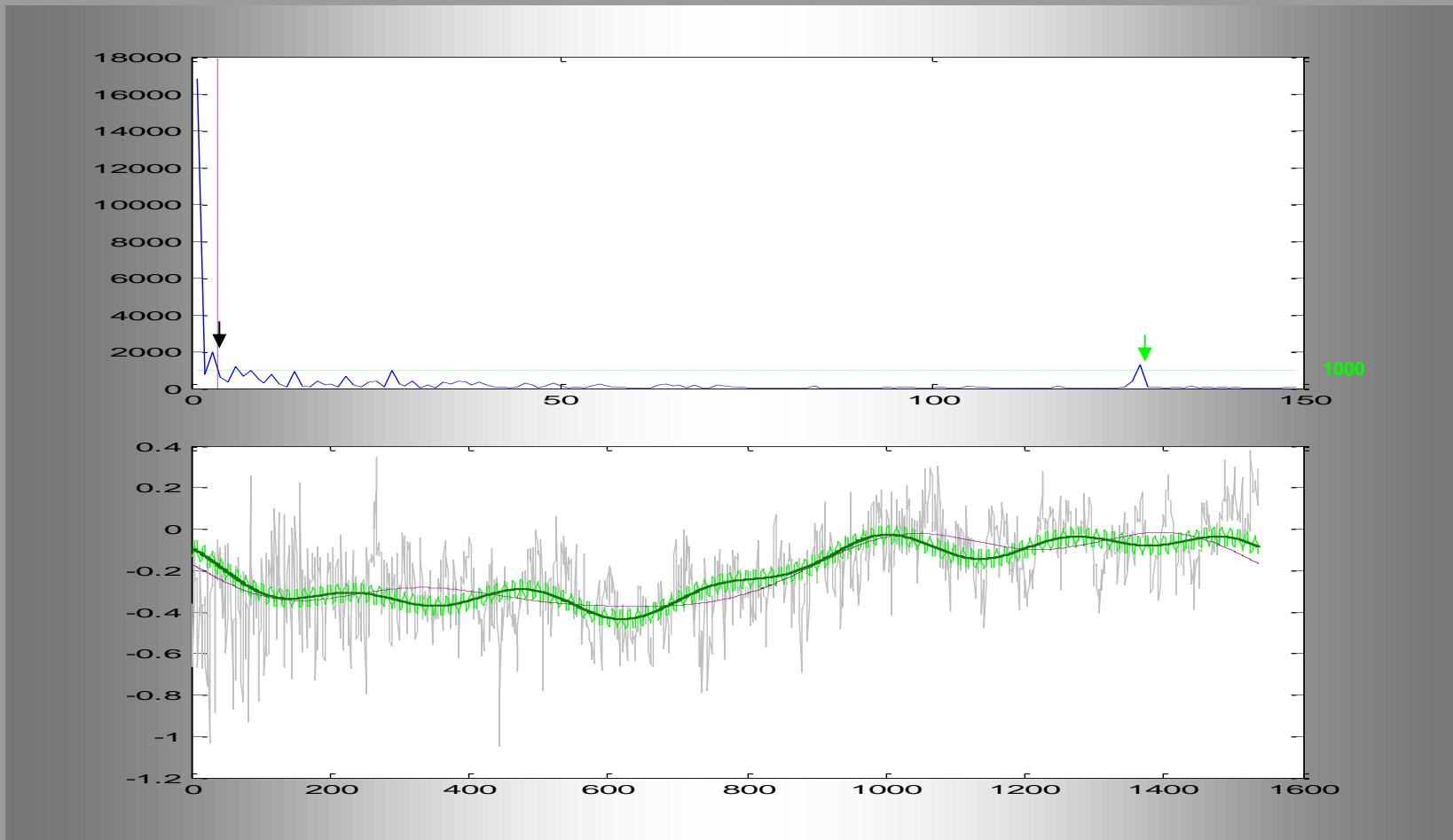
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# Trend of Global Warming



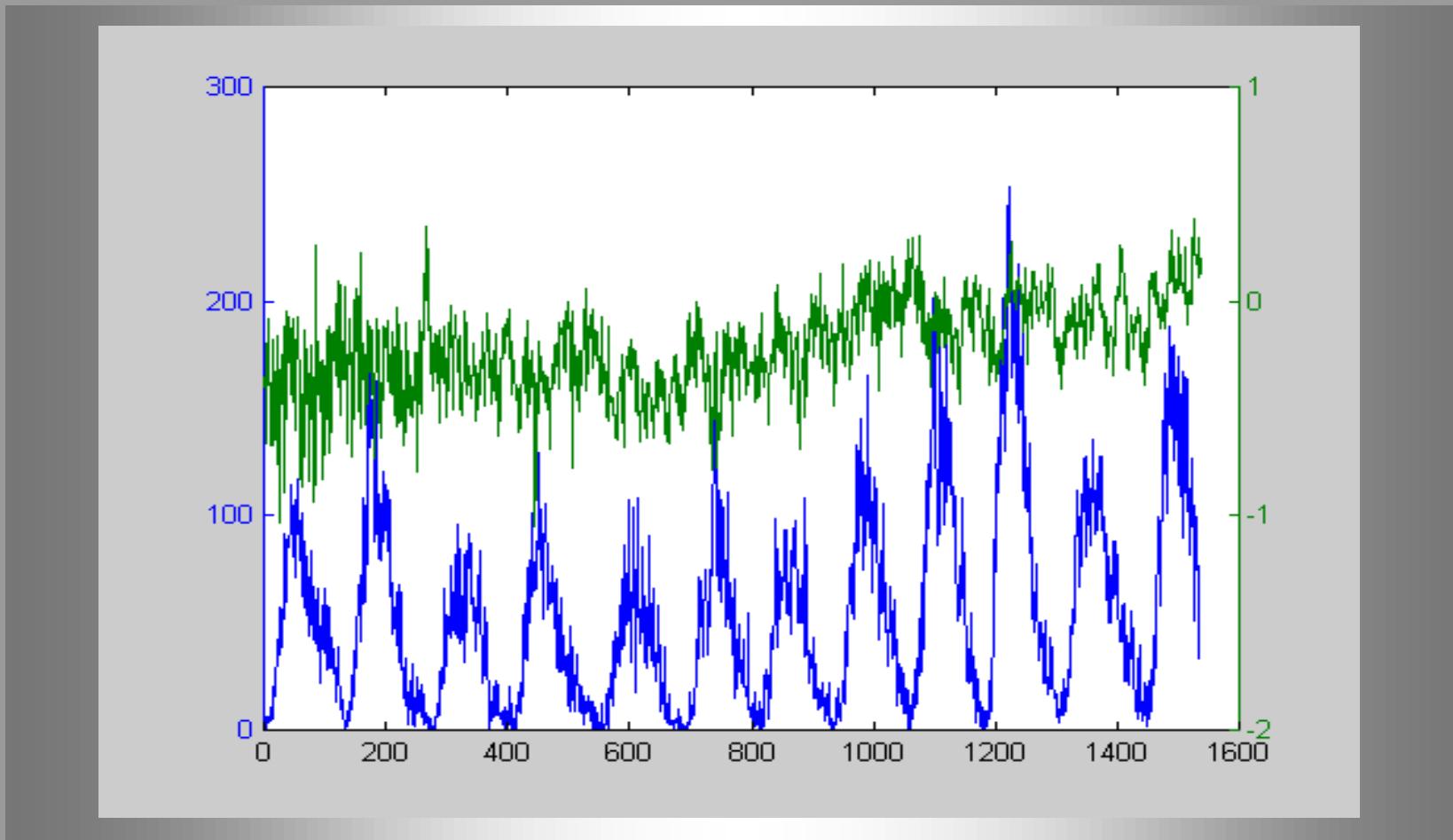
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# Trend of Global Warming



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# Trend of Global Warming



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# De-noising Puzzle of Signal Processing

**Observed Time Series = Signals + Noises**  
in  
**GWN Modeling**

*If we a priori know the structure of the underlying signal,  
we would know how to nicely get the de-noising job done.  
But we usually do not have much information about that  
until we are somehow doing it properly.*



# Foundation of Signal Processing – Fourier Analysis

$$\hat{f}(\omega) = \int_R f(t)e^{-i\omega t} dt, \quad \omega \in R.$$

↔ *Duel Identities of the Signal*

$$f(t) = \frac{1}{2\pi} \int_R \hat{f}(\omega)e^{it\omega} d\omega, \quad t \in R.$$



# Foundation of Signal processing – Fourier Analysis

**Fourier Transform**  $\hat{f}(\omega) = \int_R f(t)e^{-i\omega t} dt, \quad \omega \in R.$

Duel Identities of the Signal



?

$$f(t) = \frac{1}{2\pi} \int_R \hat{f}(\omega) e^{it\omega} d\omega, \quad t \in R.$$

Redundancy Reduction

$$\omega \in N$$

Fourier Series

$f$  **2π-periodic**

$$f(t) = \sum_{n=-\infty}^{\infty} c_n e^{int}$$

$$c_n = \frac{1}{2\pi} \int_{-\pi}^{\pi} f(t) e^{-int} dt.$$

Discrete Fourier Transform

$$\gamma_k = \frac{1}{N} \sum_{j=0}^{N-1} f\left(\frac{2\pi j}{N}\right) e^{-ik\frac{2\pi j}{N}}, \quad k = 0, \dots, N-1.$$



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# Singularity vs/& Irregularity



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# Foundation of analyzing Signal Structure

## Exploring Taylor's Expansion

$$f(t) = \sum_{i=0}^k \frac{f^{(i)}(t_0)}{i!} (t - t_0)^i + R_k(t_0, t), \quad t \in (t_0 - \varepsilon, t_0 + \varepsilon).$$

$R^{(i)}$

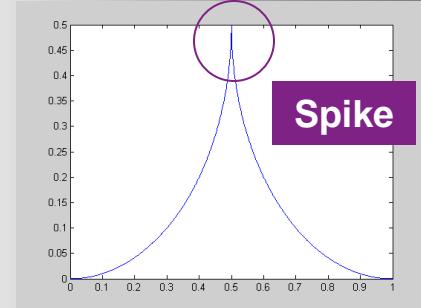
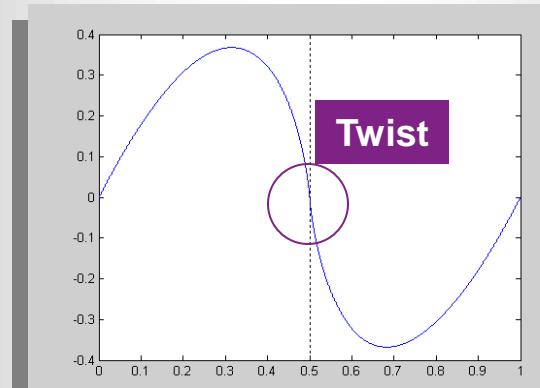
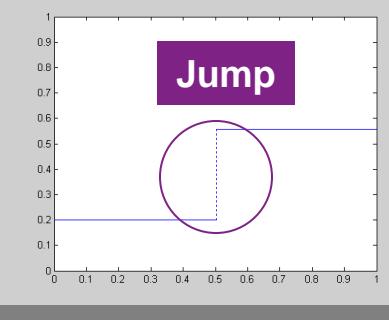
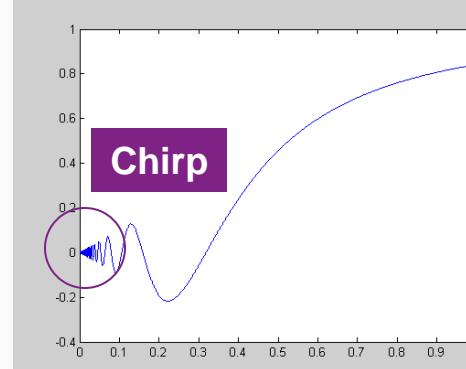
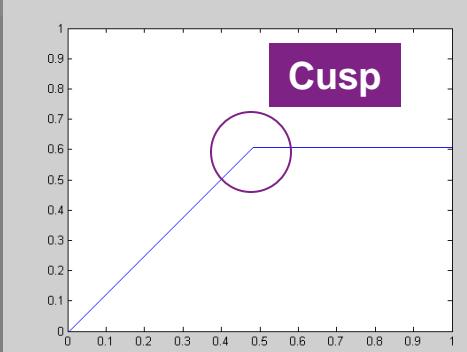
*f is smooth as  $R^{(i)} \downarrow 0$  as  $i \uparrow \infty$ .*

*f is wild as  $R^{(i)} \uparrow \infty$  as  $i \uparrow \infty$ .*

*f is singular as  $R^{(i)} = \infty$  at some  $i$ .*



# Types of Singularity



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# Foundation of analyzing Noisy Behaviors

$$\Delta X_i^n \equiv X_i^n - X_{i-1}^n = [a^n(t_i) \cdot \chi_i^n] \cdot v_i^n(\Delta t)$$

where  $\Delta t = 1/n$ ,  $a^n$  is real-valued,  $v_i^n$  is monotone increasing, and  $\chi_i^n$  is a real-valued random variable.

←

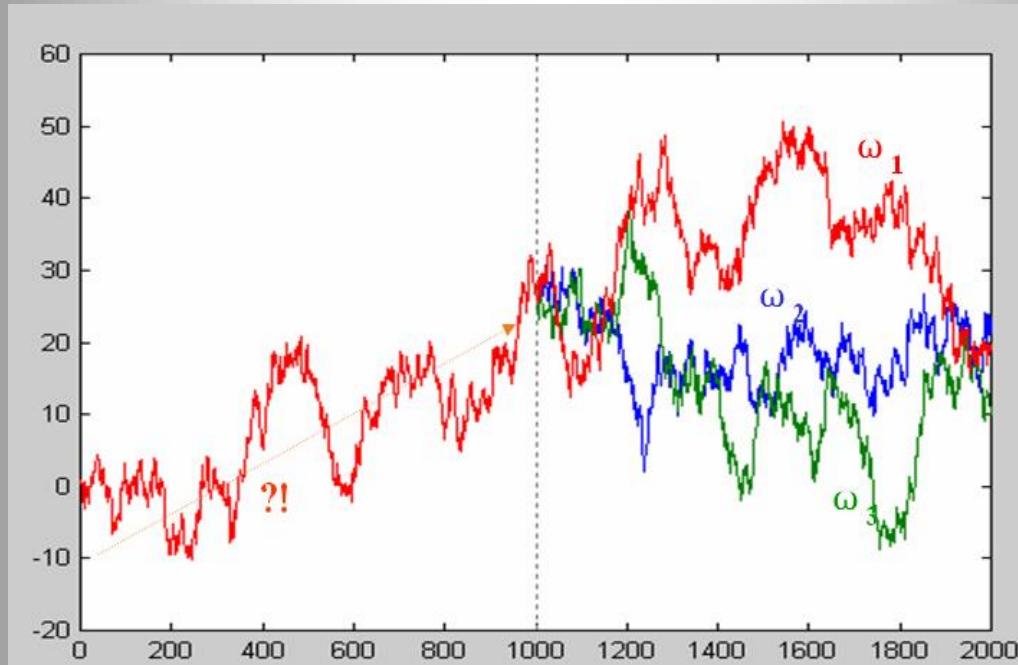
**Remark.** Note that  $[a^n(t_i) \cdot \chi_i^n]$  can be regarded as the stochastic fractal changing rate.

←



# Foundation of analyzing Noisy Behaviors

$$\Delta X_i^n \equiv X_i^n - X_{i-1}^n = [a^n(t_i) \cdot \chi_i^n] \cdot v_i^n(\Delta t)$$



# Examples of Uncertain Fluctuation

## I

$$\Delta X_i^n \equiv X_i^n - X_{i-1}^n = [a^n(t_i) \cdot \chi_i^n] \cdot v_i^n(\Delta t)$$

### *Deterministic Smooth Motion*

Consider the trivial case where  $\chi_i^n = 1$  with probability 1,  $v_i^n(x) = x$  and

$a^n = a$  for all  $i$  and  $n$ . Then  $F_t$  is a smooth path with the derivative  $a(t)$ .



# Examples of Uncertain Fluctuation

## II

$$\Delta X_i^n \equiv X_i^n - X_{i-1}^n = [a^n(t_i) \cdot \chi_i^n] \cdot v_i^n(\Delta t)$$

*Lévy Class – (constant in  $\alpha$ , homogeneous in  $v$ , and  $\chi_i^n$ 's i.i.d.)*

Set  $\alpha = 1$  without loss of generality.

### ● Wiener Process (Brownian Motion)

Consider the simple nontrivial case where  $v_i^n(x) = x^{1/2}$ , and

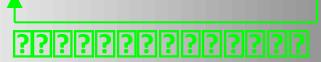
$$\chi_i^n = \begin{cases} = +1 & \text{with probability } \frac{1}{2}; \\ = -1 & \text{with probability } \frac{1}{2} \end{cases}$$

for all  $i$  and  $n$ .



# Examples of Uncertain Fluctuation

## II

$$\Delta X_i^n \equiv X_i^n - X_{i-1}^n = [a^n(t_i) \cdot \chi_i^n] \cdot v_i^n(\Delta t)$$


- *Poisson Process*

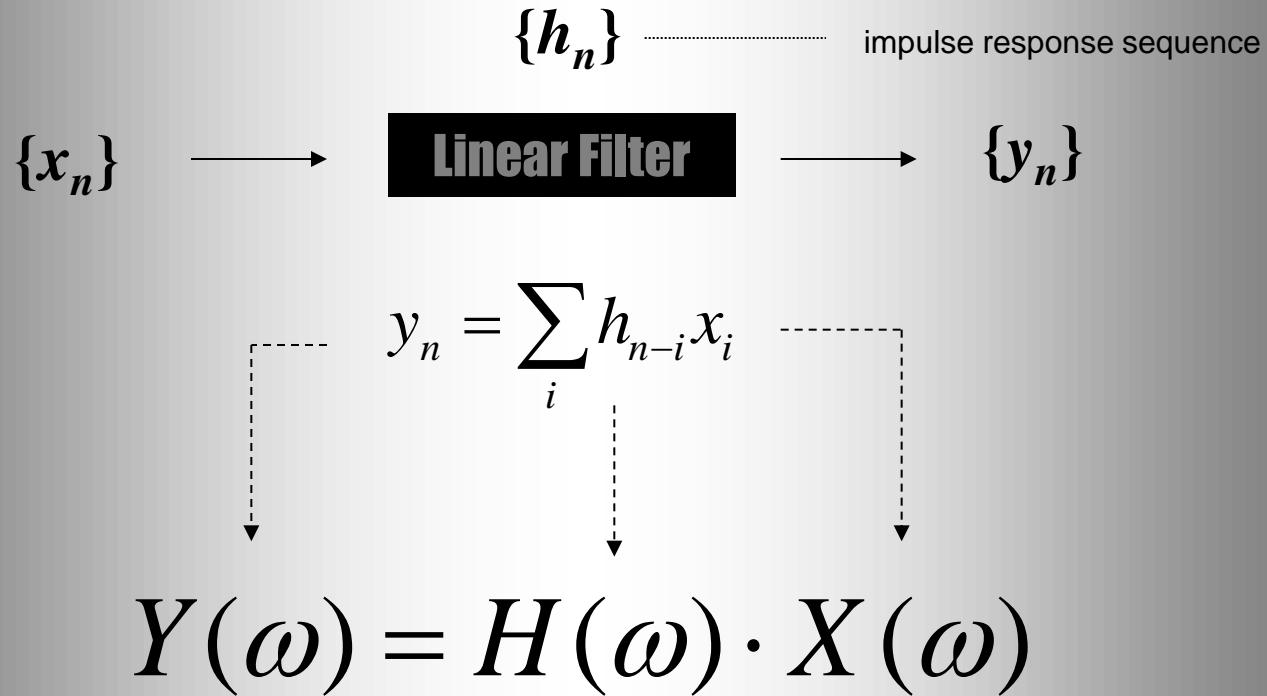
Consider the extreme case where  $v_i^n(x) = x^0 \equiv 1$ , and

$$\chi_i^n = \begin{cases} = 1 & \text{with probability } \lambda \cdot \Delta t, \\ = 0 & \text{with probability } 1 - \lambda \cdot \Delta t \end{cases}$$

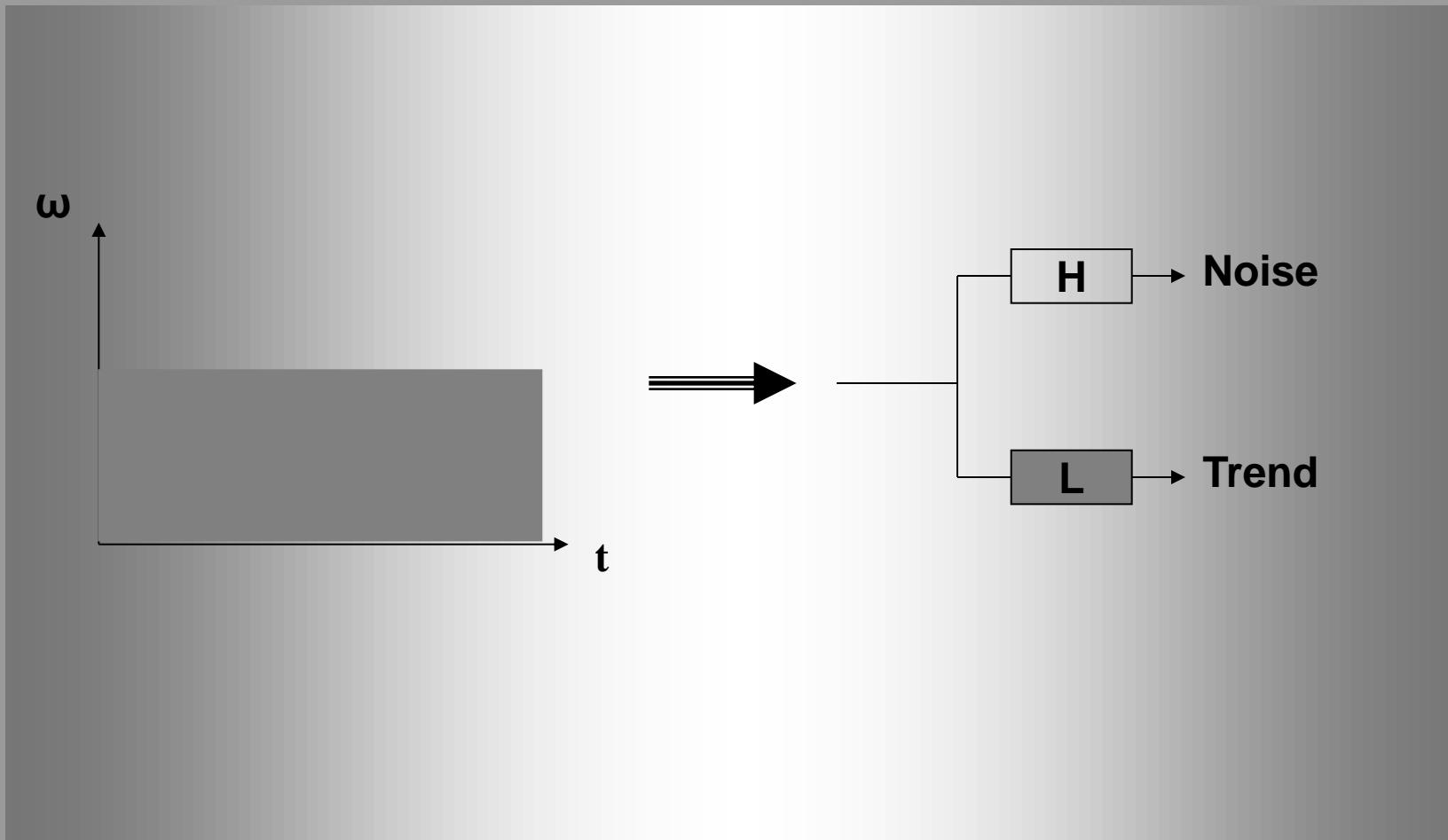
for all i and n.



# Basic Framework of filtering Signal

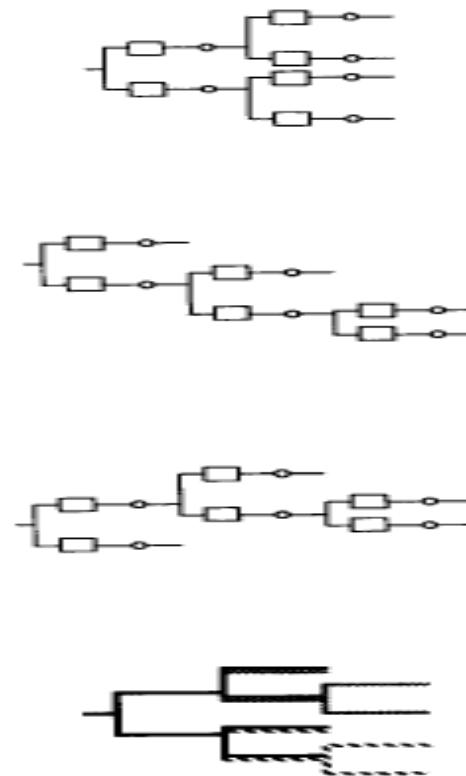
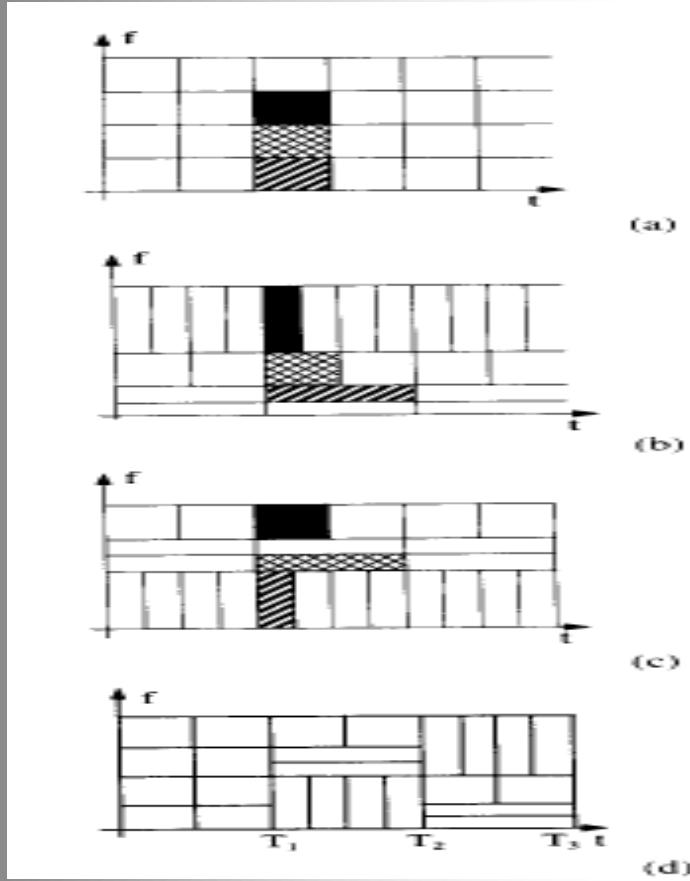


# Basic Framework of filtering Signal



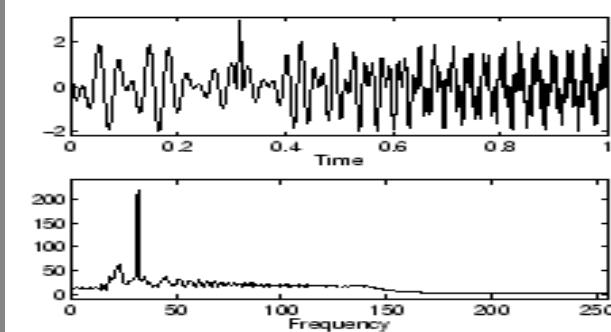
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# Sophisticated Framework of filtering Signal

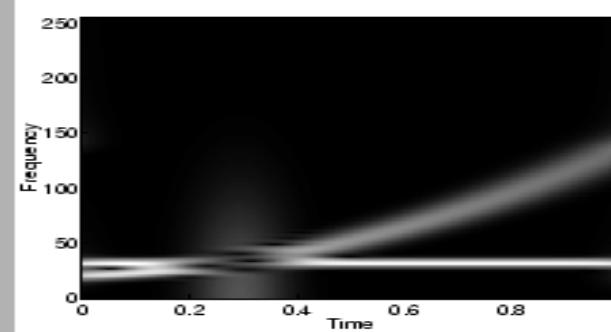


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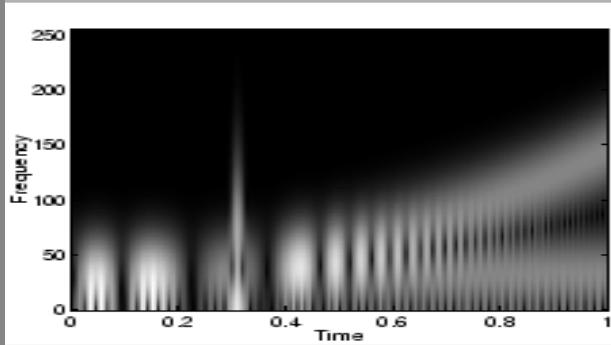
# Short-Time Fourier Transform



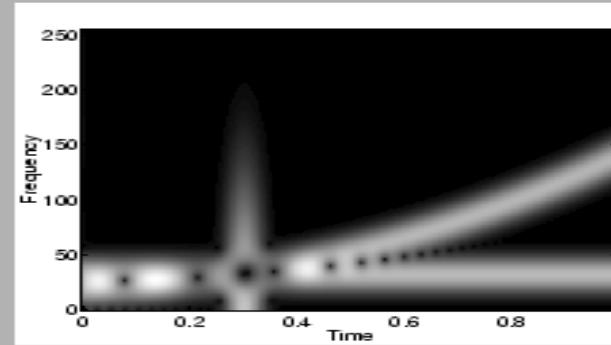
(a) Signal and its Fourier transform



(b) STFT with wide window



(c) STFT with narrow window



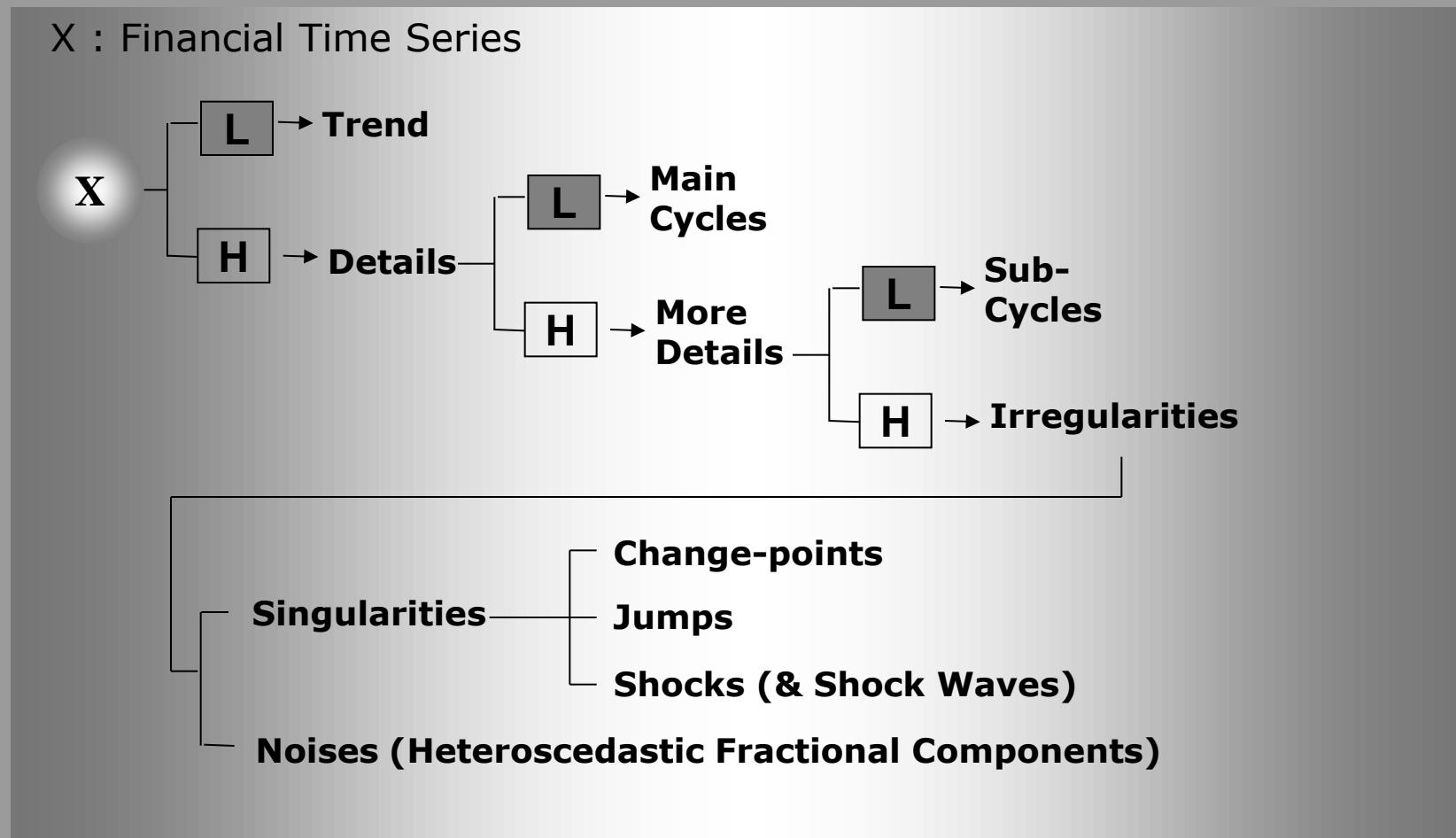
(d) STFT with medium window



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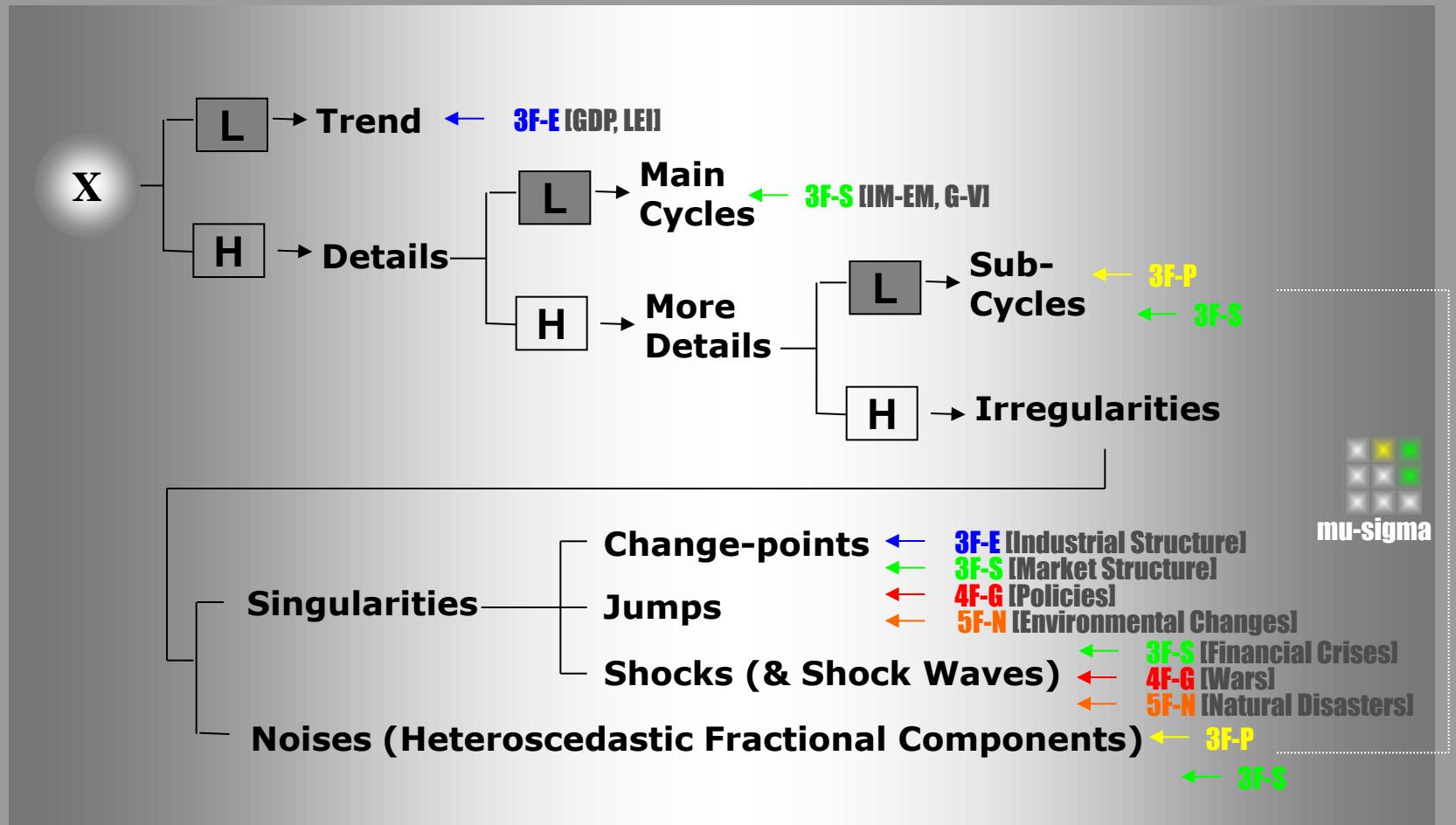
# Multi-resolution Power of analyzing Financial Signal



# Dynamic Relations of Multi-resolutional Components

& Integrated\* Risk Factor Analysis

CMEK



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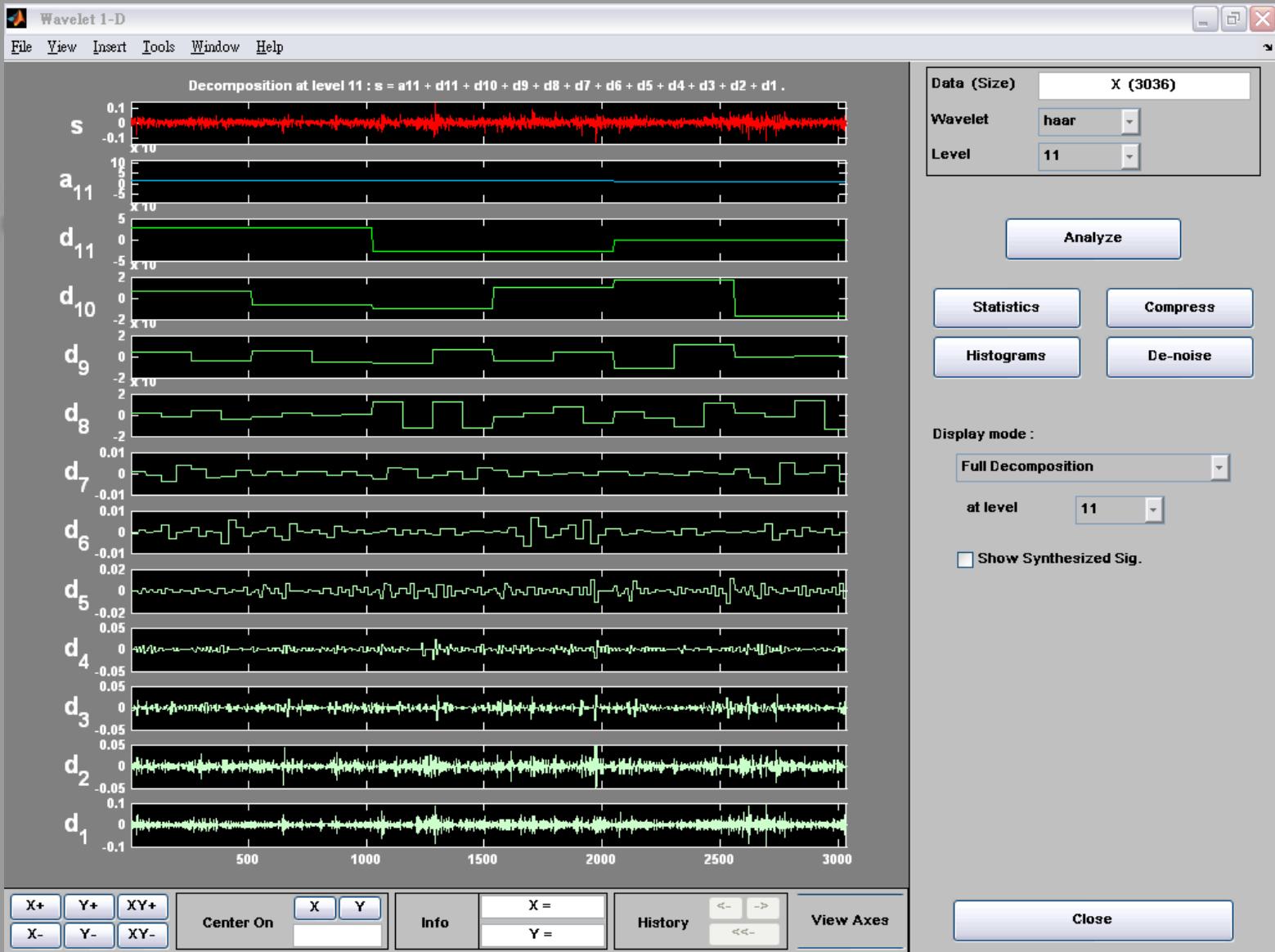
various filter functions for emphasizing on capturing different patterns





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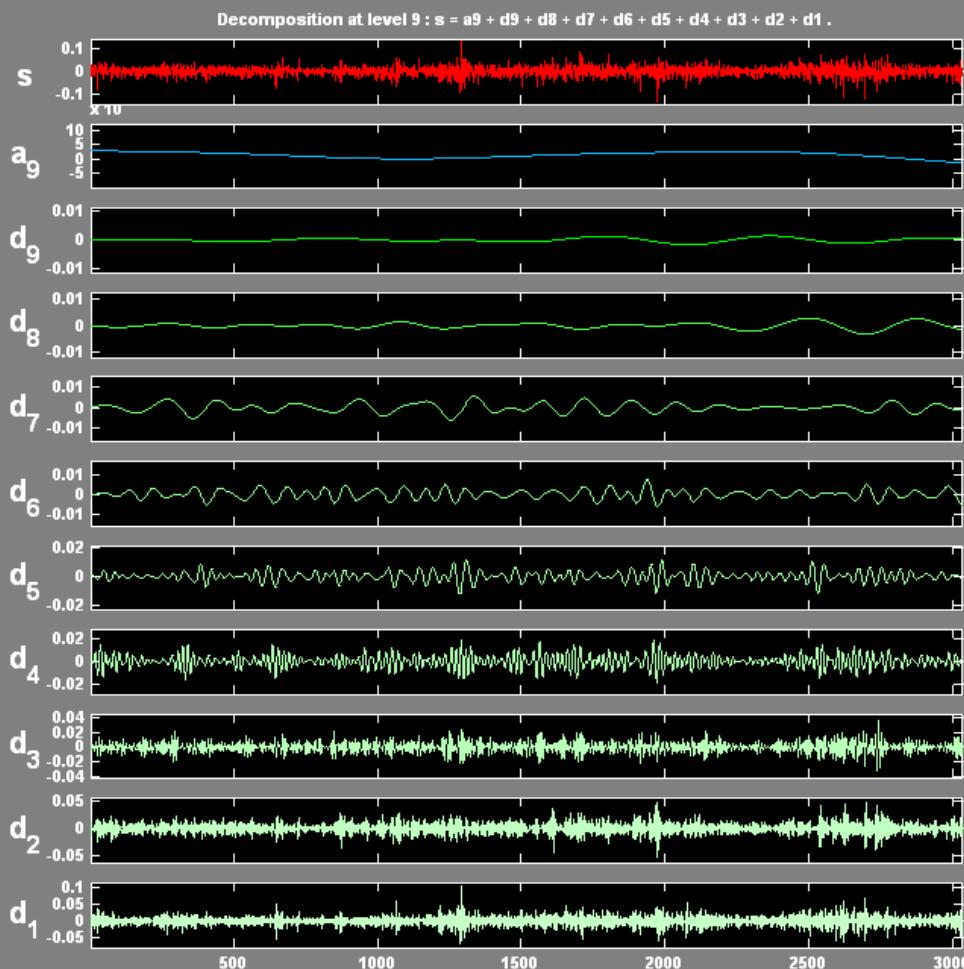


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# Wavelet 1-D

File View Insert Tools Window Help



Data (Size) X (3036)  
Wavelet dmey  
Level 9

Analyze

Statistics

Compress

Histograms

De-noise

Display mode :

Full Decomposition

at level

9

Show Synthesized Sig.

X+ Y+ XY+  
X- Y- XY-

Center On

X Y

Info

X =  
Y =

History

View Axes

Close

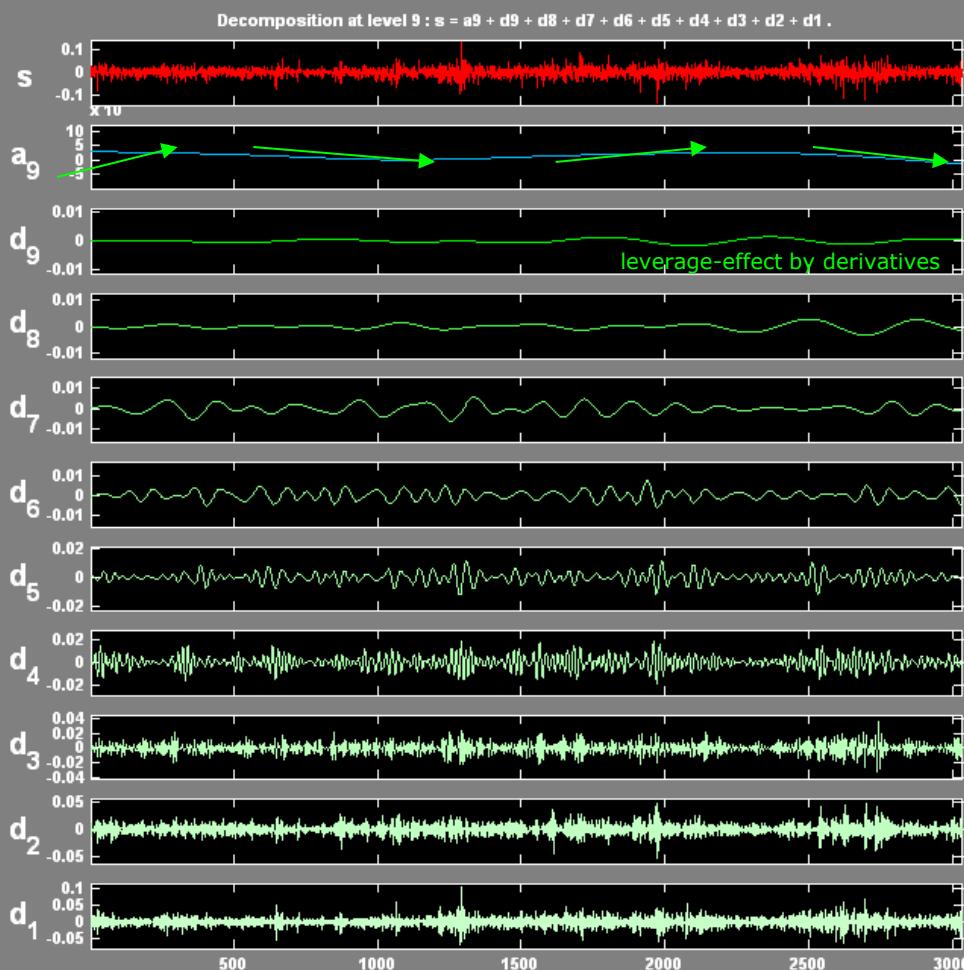


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# Wavelet 1-D

File View Insert Tools Window Help



X+

Y+

XY+

X-

Y-

XY-

Center On

Info

X =

Y =

History

View Axes

Close

Data (Size)

X (3036)

Wavelet

Level

Analyze

Statistics

Compress

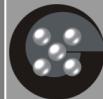
Histograms

De-noise

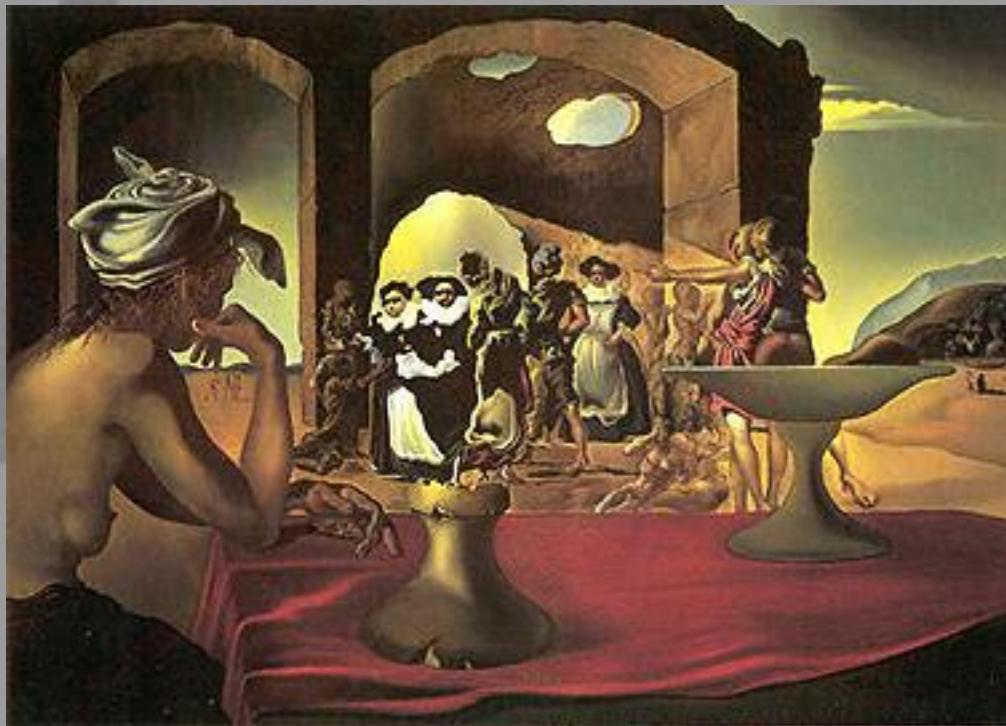
Display mode :

at level

Show Synthesized Sig.



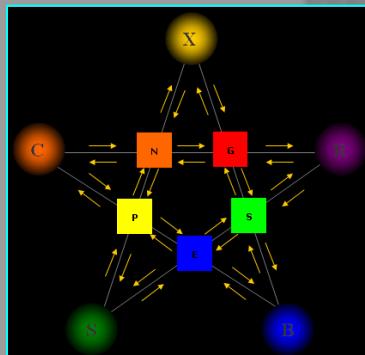
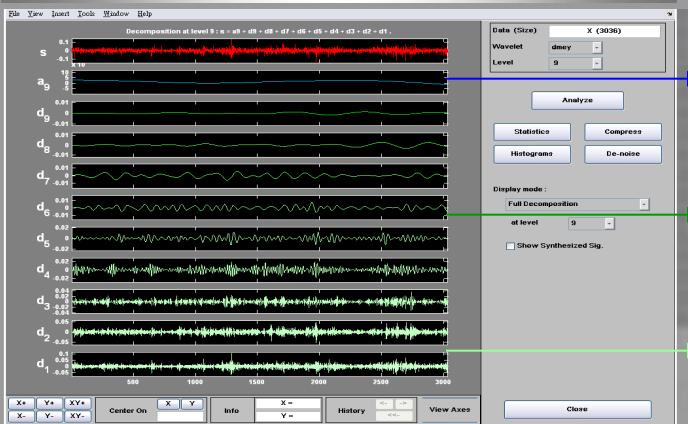
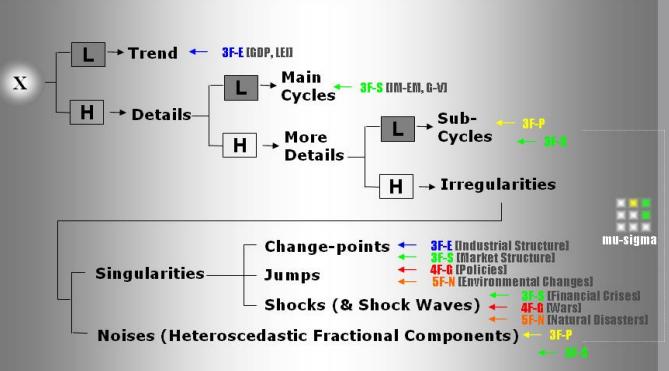
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Slave Market with the Disappearing Bust of Voltaire, *Dali* (1940)



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## Patterns, e.g.

- Yield Inversion & Recession (GDP)
- Yield Expansion & Inflation (CPI, Commodity Price)
- Stock-Bond Correlation Variation
- Neutral Interest-Rate & Fair Leverage-on-VaR

Structural Sense for designing Exotic\* Derivatives

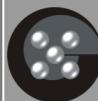
## Dynamics & Stochastics

- External (Exogenous\*) –
  - Direct Regression with Explicit Risk Factors
  - Co-integration with Implicit Risk Factors
- Internal (Endogenous\*) –
  - Transformation fitting Asset Nature & Product Structure
  - Auto-Regression revealing Market Pricing Mechanism

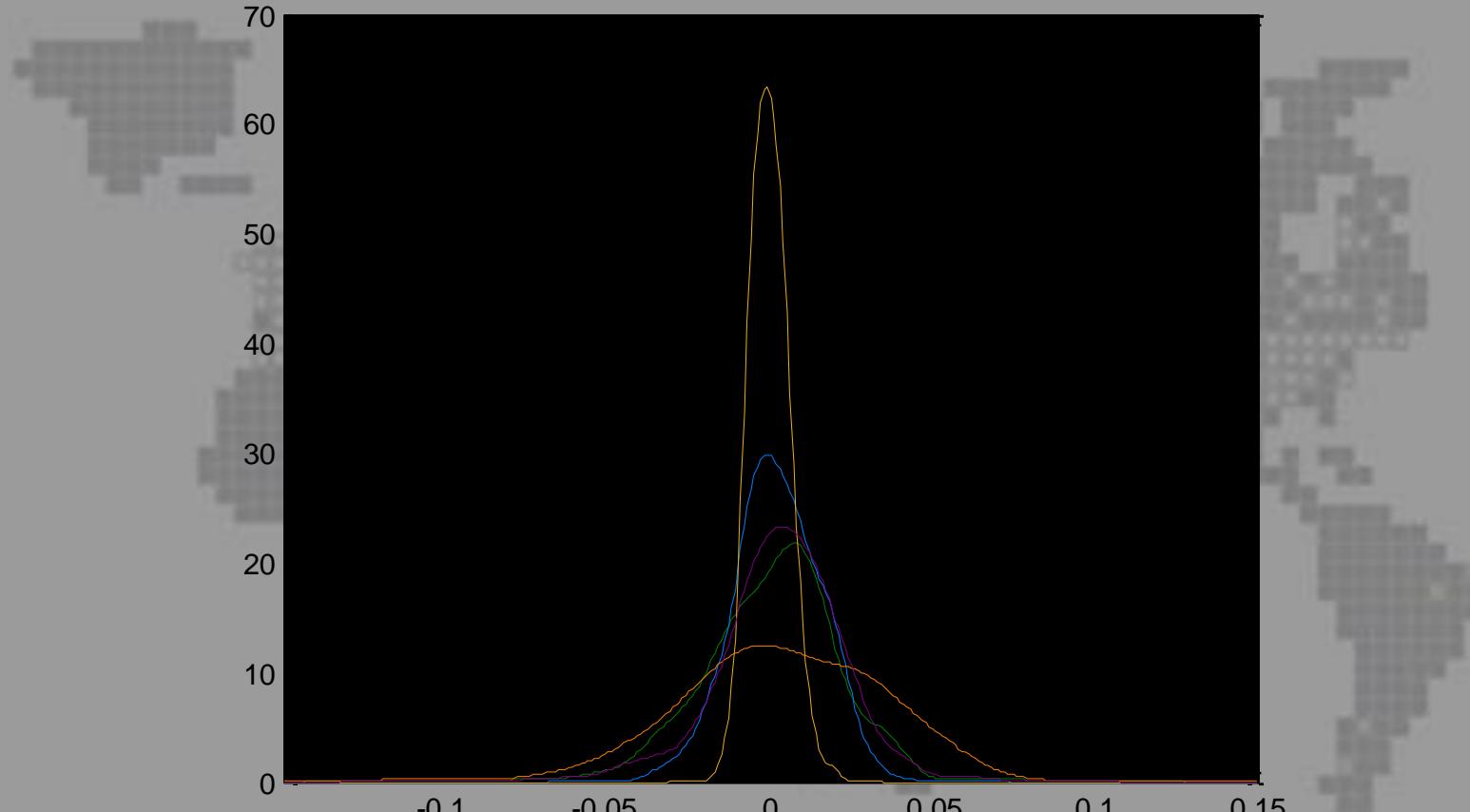
5-Risk & 5-Asset Classification  
→ **GDA-STD**

## Preliminary –

- Probability Distribution Characterization
- Joint Distribution - Copula
- Correlation & Regression
- Auto-Correlation
- Co-integration - PPR



0.0004	0.0022	-0.0004	0.0034	0.0028
0.0212	0.0131	0.0058	0.0309	0.0198
-0.3696	-0.0978	0.3384	-0.4209	-0.6394
4.9570	2.9737	3.2717	3.7971	5.4063



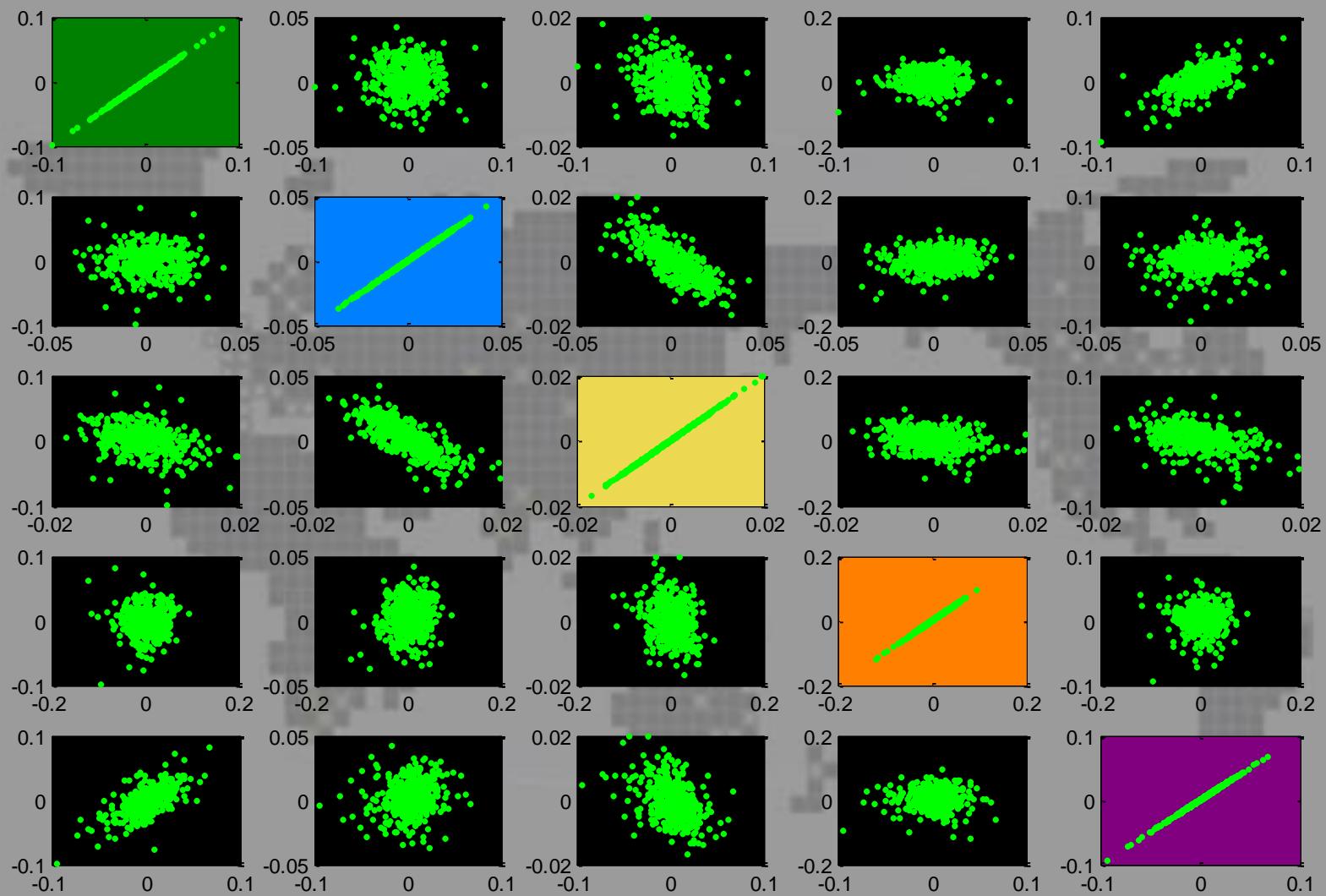
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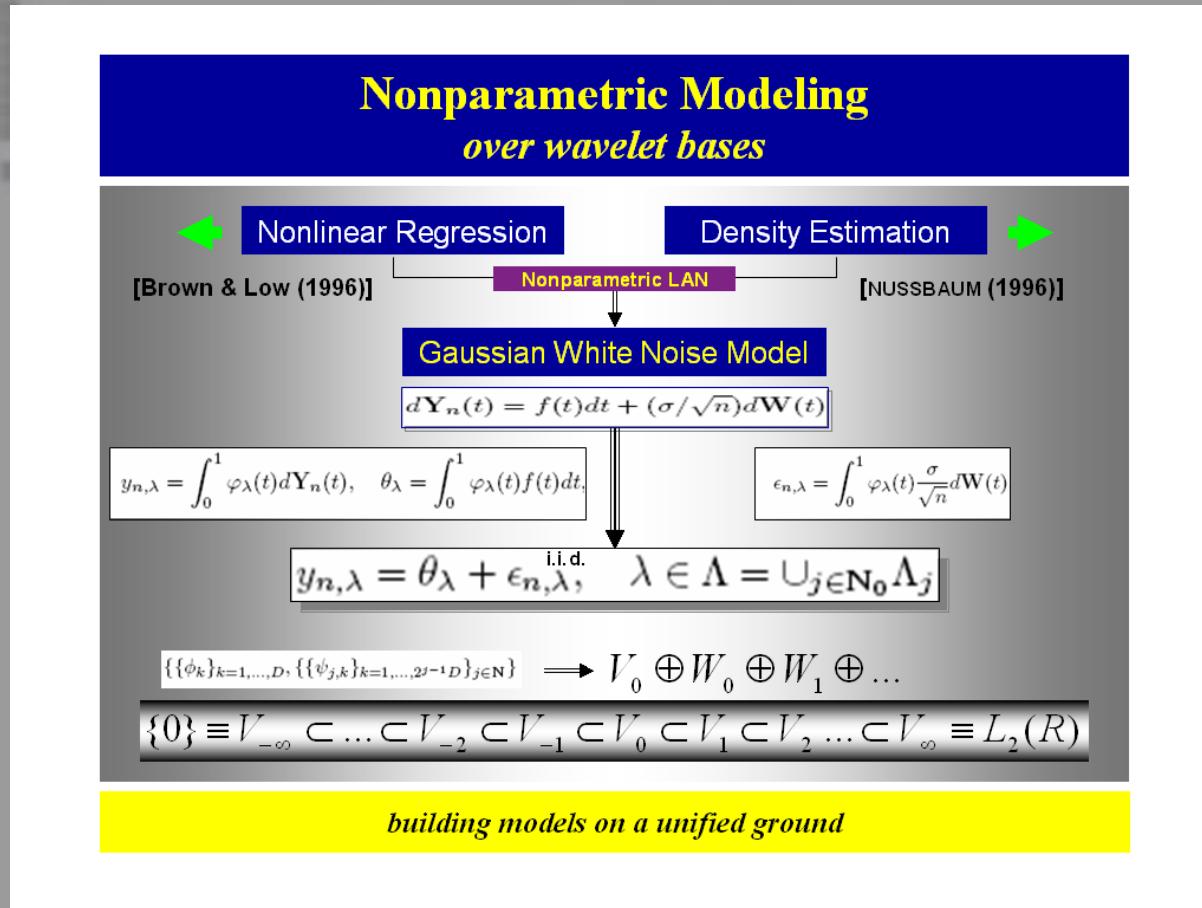


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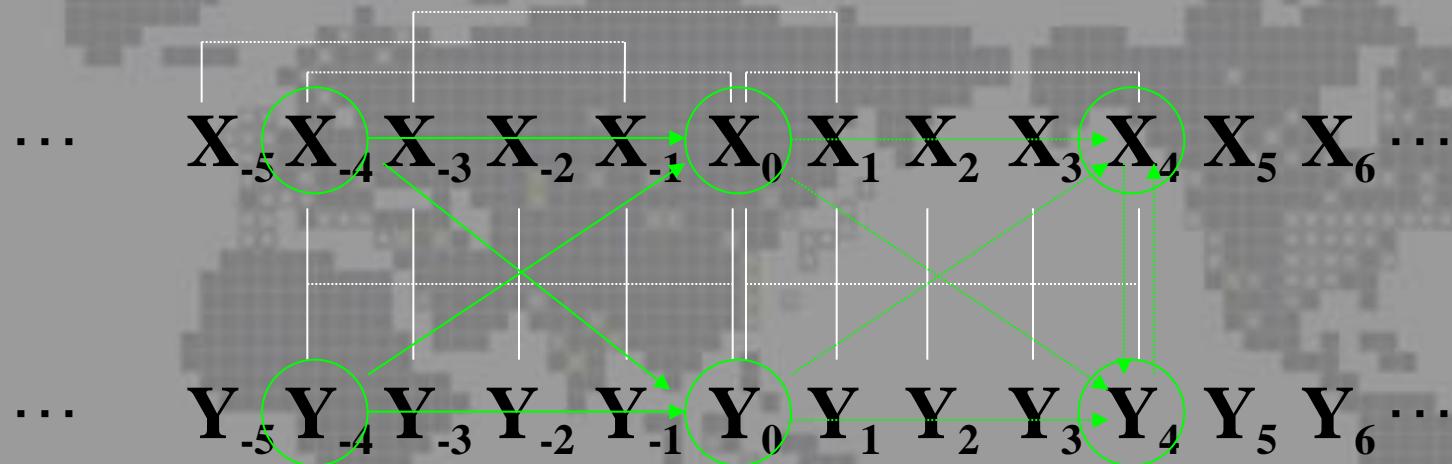


# Regression = Signal Processing ?!?

from Perspectives of Abstract Inference



# Financial Signal Processing based on Information Theory



Mutual Information for Prediction



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# Heuristic Example for understanding Information Theory

inference via moment-generating & entropy-based information calculation



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