Forecasting Solar and Geomagnetic Activity Indices Using Neurofuzzy Modeling and Mutual Information Approaches: a Tutorial

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September 2008

Outline

- Talking about Complex Problems
- A Brief Introduction of Data Driven Approaches
- Designing process of Data Driven Tools
- Applications
- Concluding Remarks

Outline

- Talking about Complex Problems
  - Problem in modeling real phenomena
  - Complex phenomena
  - Linear/nonlinear
  - Exotic phenomena
  - Bottlenecks
  - How such problems are solved in nature?
- A Brief Introduction of Data Driven Approaches
- Designing process of Data Driven Tools
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- Talking about Complex Problems
- A Brief Introduction of Data Driven Approaches
- Applications
  - Space weather
- Concluding Remarks

Talking about Complex Problems

Problem in Modeling

- There are many subjective phenomena that cannot been measured by physical quantities.
- There are several complex phenomena that happen rarely (but have important effects on human life).
- It is not easy to describe many real phenomena by existing models.
- It is not easy to collect satisfactory data to model some exotic phenomena.

Complex phenomena

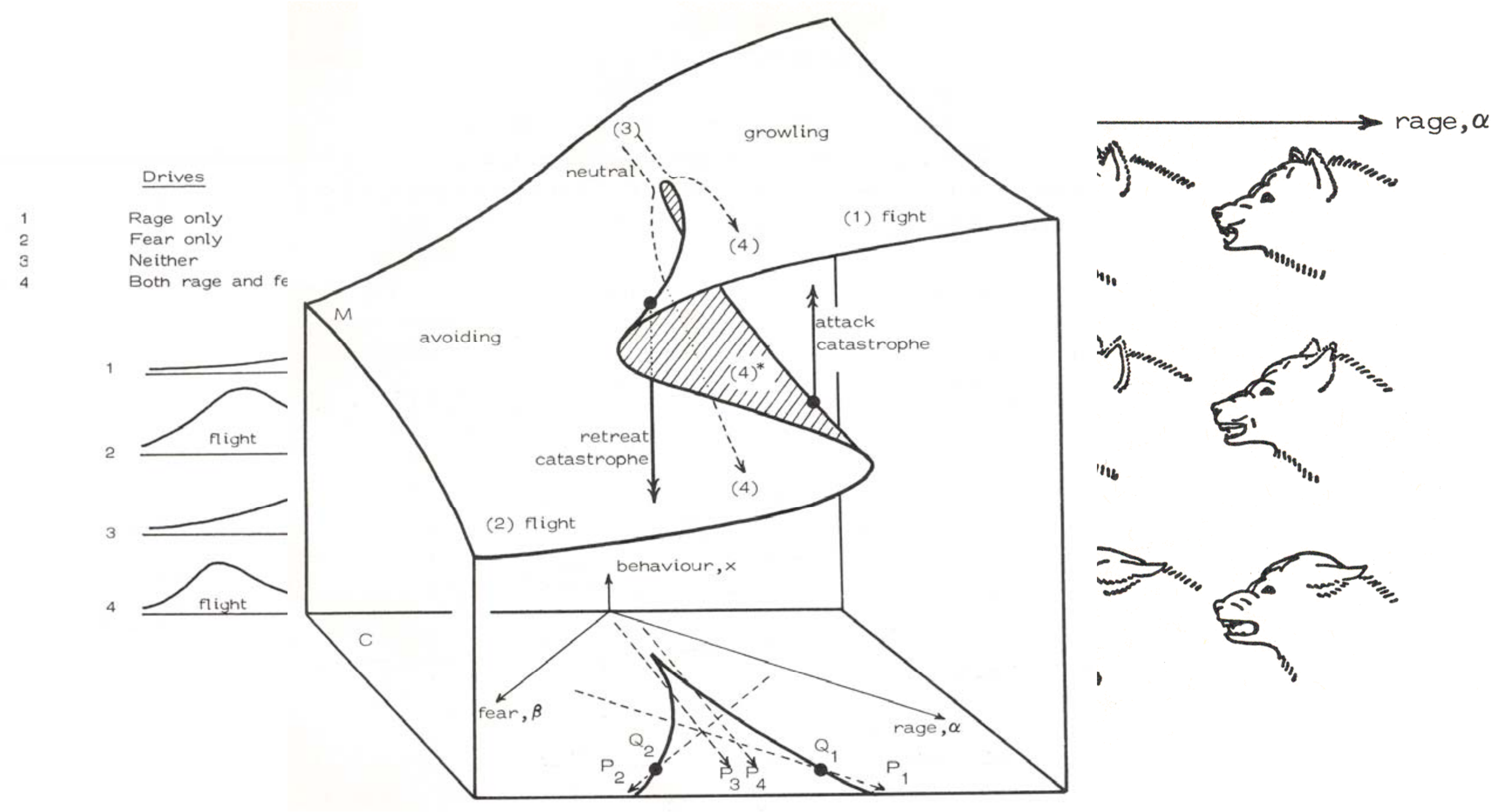
Nature is full of complexity. In many applications simple model suffice, but for some problems it is not possible to model a phenomenon via a simple model such as linear models because such phenomena exist in nonlinear realm!

Is Your World Linear or Nonlinear?

- Linear Process:
  - Simple rules → simple behaviors
  - Things add up
  - Proportionality of input/output
  - High predictability, no surprises

- Nonlinear Process:
  - Simple rules → complex behaviors
  - Small changes may have huge effects
  - Low predictability & anomalous behaviors

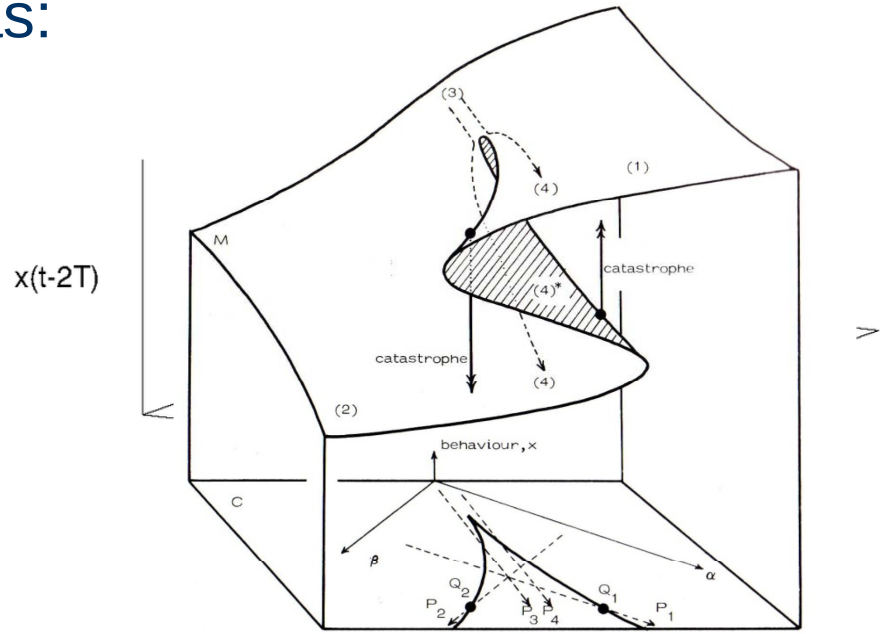
Examples



Drives
1 Rage only
2 Fear only
3 Neither
4 Both rage and fe
1
2
flight
3
4
flight
growling
(3)
neutral
(4)
(1) fight
M
avoiding
attack
catastrophe
(4)*
retreat
catastrophe
(4)
(2) flight
behaviour, x
C
fear, β
rage, α
Q2
Q1
P2
P3
P4
P1
rage, α

Exotic Phenomena (Ctd.)

- Most natural phenomena are nonlinear.
- Nonlinear systems have many interesting characteristics such as:
  - Chaotic behavior
  - Catastrophic Jump
  - Bifurcation
  - Singular Points
  - Phase Transition
  - …



Why such models should be developed?!!!

- There are many natural phenomena with chaotic and catastrophic behavior
- Most of the human artifacts are designed for ordinary conditions and all of them are vulnerable to such phenomena
- Nowadays, it is an urge to have some alarming systems (esp. to protect elderly people) to avoid exotic phenomena in some protected environment

Bottlenecks

- Collecting fair data
- Industrial managers
- Constructing the state space (dimensions, state variables, …) from physical observations

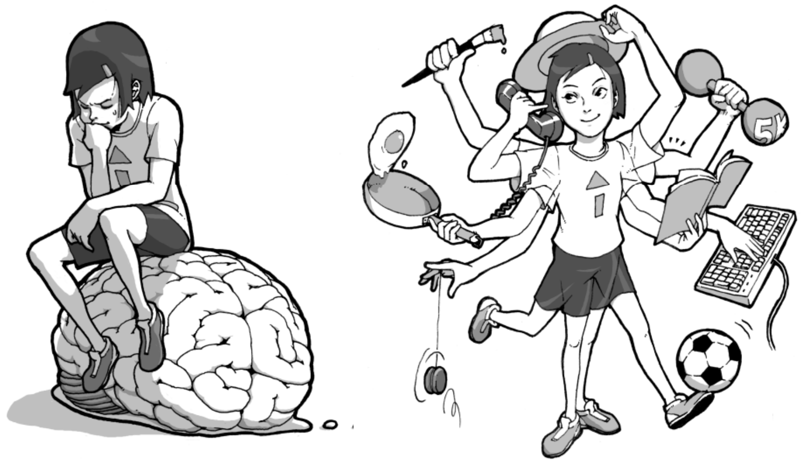
How Such Problems are Solved in Nature

- There are several complex problems around us.
- We solve most of them automatically
- In addition, several creatures in nature do something odd in handling such problems
- Let us have some examples.

Two views of intelligence

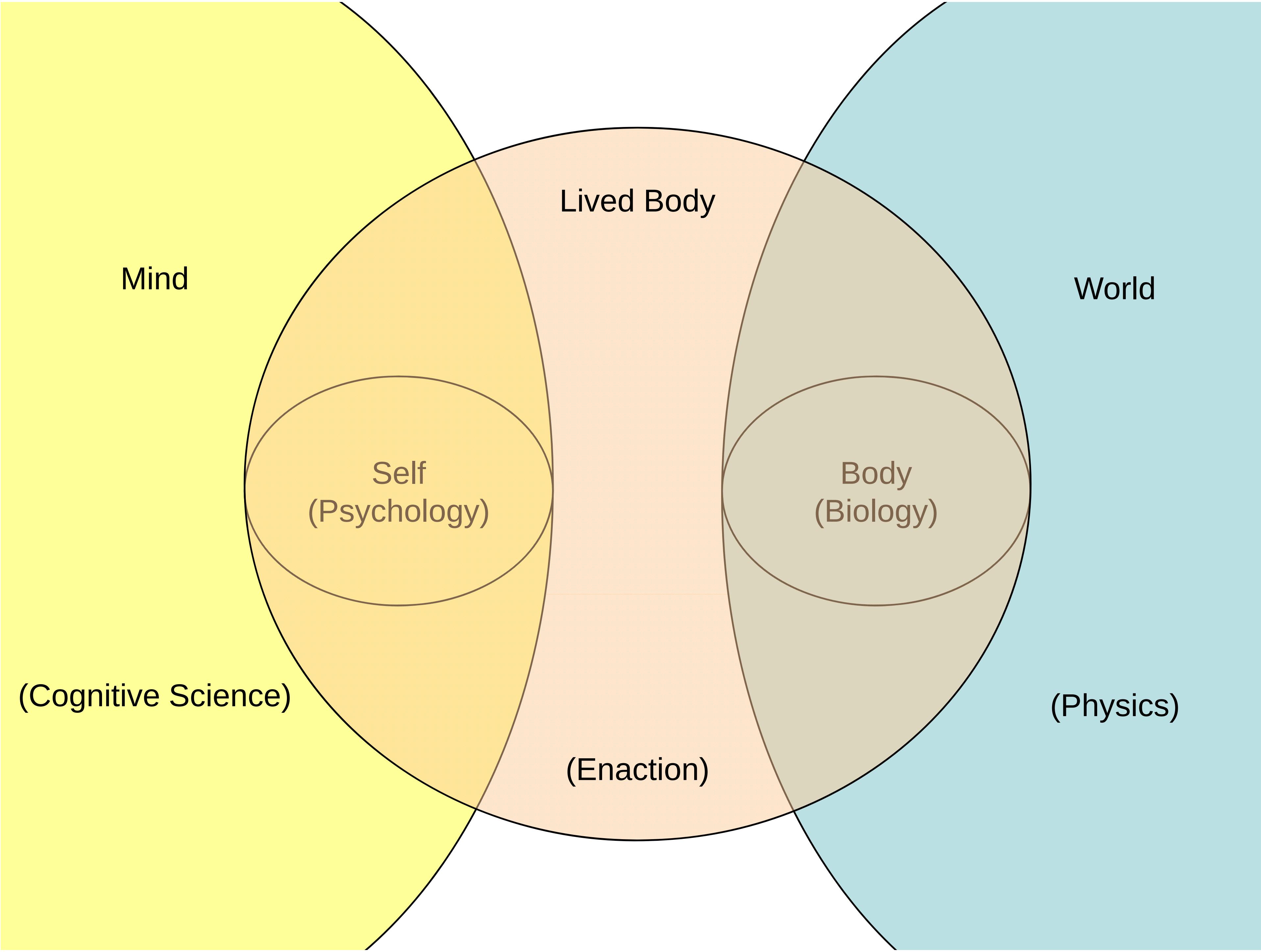
classical:
"cognition as computation"

embodiment:
"cognition emergent from sensory-motor and interaction processes"

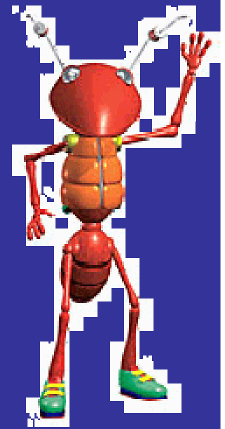


**"How the body shapes the way we think –
A new view of intelligence"**
Rolf Pfeifer and Josh Bongard
Illustrations by Shun Iwasawa
Foreword by Rodney Brooks

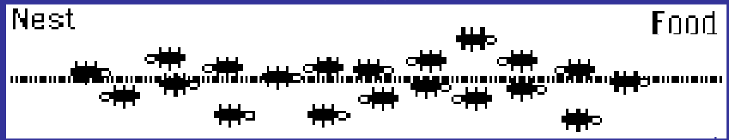
MIT Press, Aug/Sept 2006
(popular science style)


Mind
(Cognitive Science)
Lived Body
(Enaction)
Self
(Psychology)
Body
(Biology)
World
(Physics)

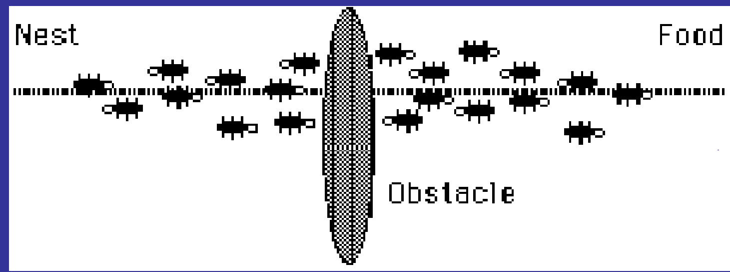
Learning from/by Ants



Look at the ant, thou sluggard,
Consider her ways and be wise:



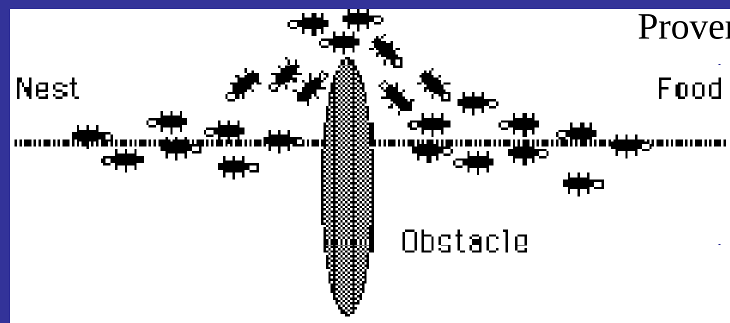
Which **having no chief, overseer or ruler,**



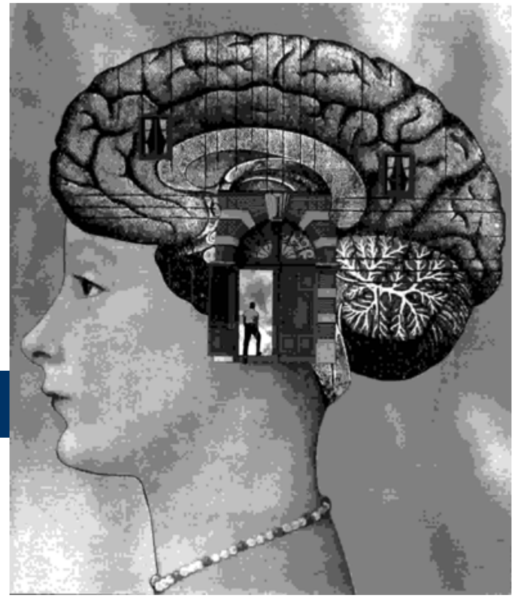
Provides her meat in the summer

And gathers her food in the harvest

Proverbs 6:6-8



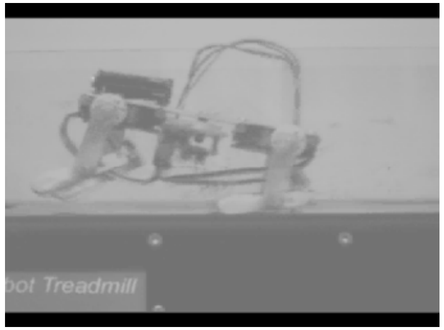
Historical



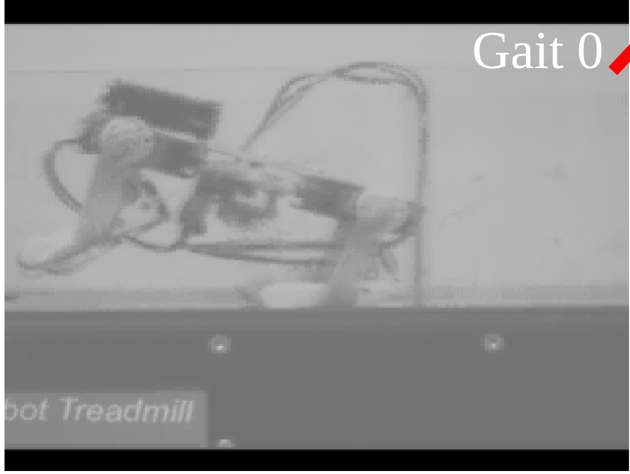
1956	Dartmouth Conference
	GOFAI (Haugeland)
end 70s	expert systems (e.g.)
mid 80s	neural networks
	“Embodiment” (Rodney Brooks, MIT)
end 80s	problems with expert systems
90s/21st cent.	“The new landscape of AI”
	biological inspiration

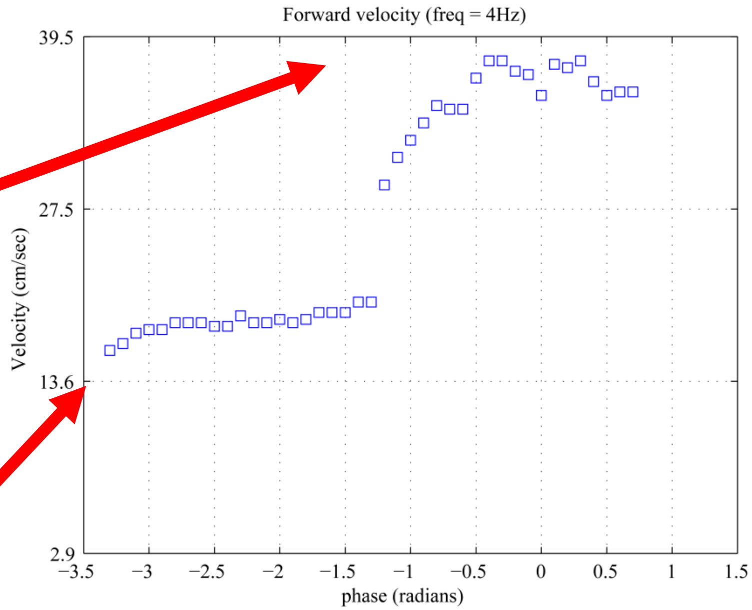
classical (dis-embodied):
“cognition as computation”

“Puppy” on the treadmill



Gait patterns as a proto-symbol





Fore legs: $P_{1i} = A_{1i} \sin(\omega_i t) + B_{1i}$

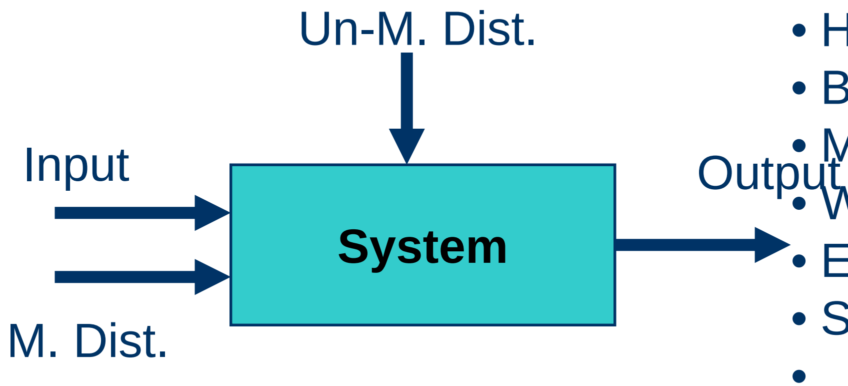
Hind legs: $P_{2i} = A_{2i} \sin(\omega_i t + \theta_i) + B_{2i}$

A Brief Introduction of Data Driven Approaches

Data Driven Approaches

Inferring models from observations and studying their properties is really what sciences are about (Ljung).

A system is an object in which variables of different kinds interact and produce observable signals.



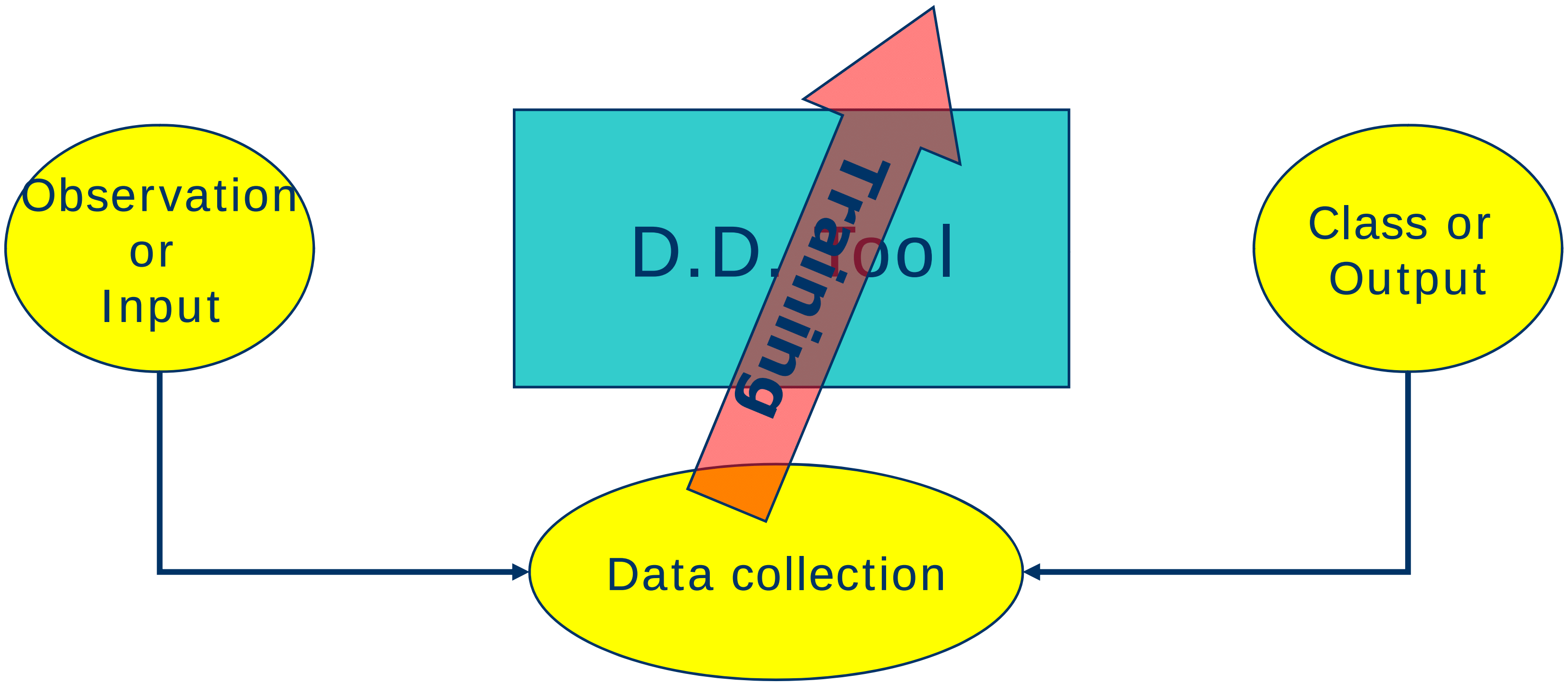
- Motor
- Heat Exchanger
- Brain
- Mass
- Weather
- Earth
- Society
- …

Data Driven Approaches

- White Box Modeling: Only Considering Physical Rules
- Gray Box Modeling: Considering Data and physical rules simultaneously
- Black Box Modeling: Considering Only Data

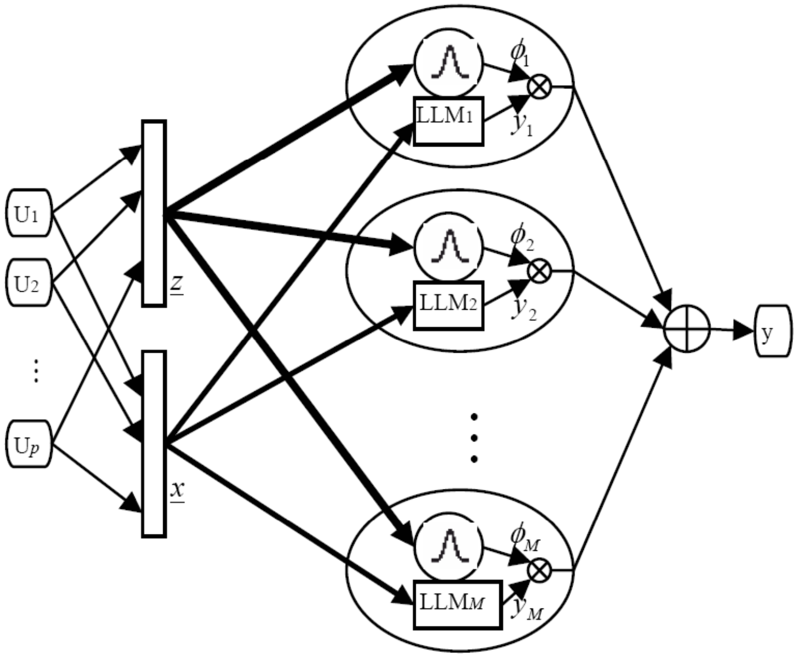
Training in Data Driven Approaches

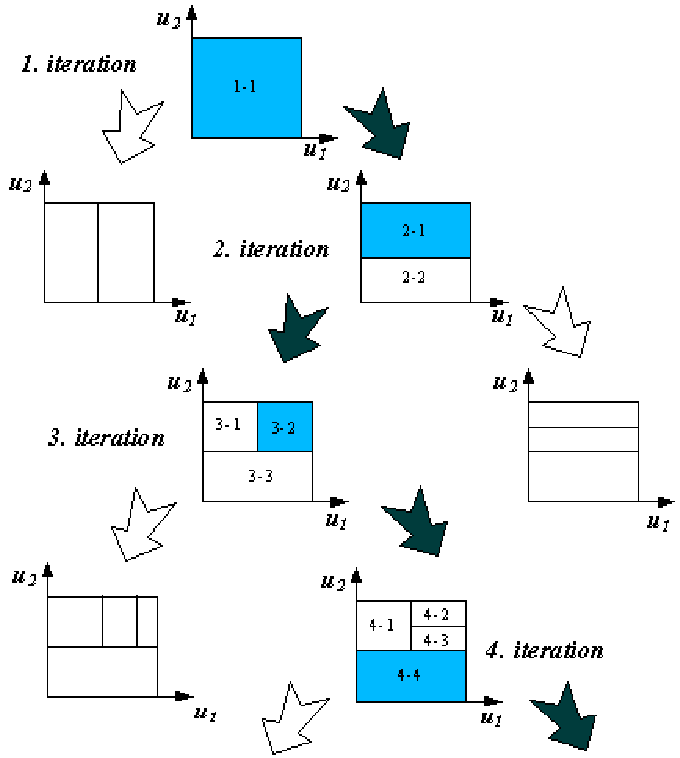
- Training or learning



LLNF Models as Nonlinear System Identification Tools

Locally Linear Neuro Fuzzy (LLNF) Models with LoLiMoT Learning Alg.





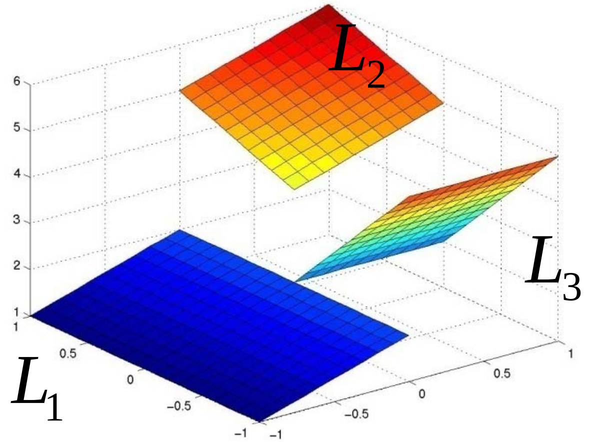
LOLIMOT: Principle

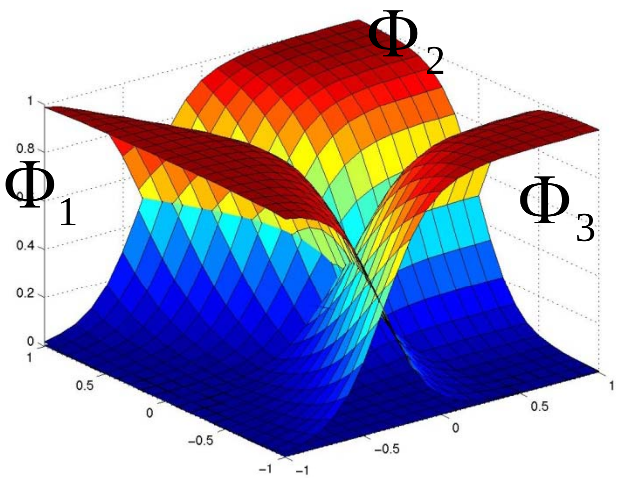
$$LOLIMOT(x) = \sum_{i=1}^{N} \Phi_i(x).L_i(x)$$

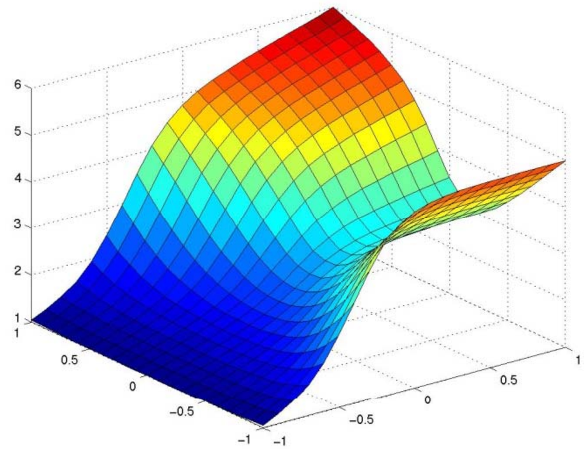
L_i : *linear functions*

Φ_i : *membership functions*

$$\left(\sum_{i=1}^{N} \Phi_i = 1 \right)$$

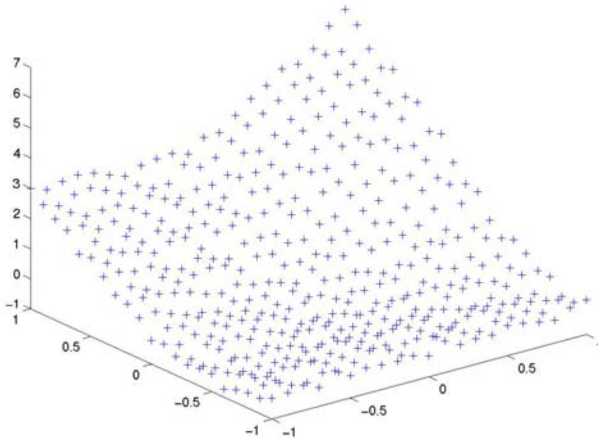


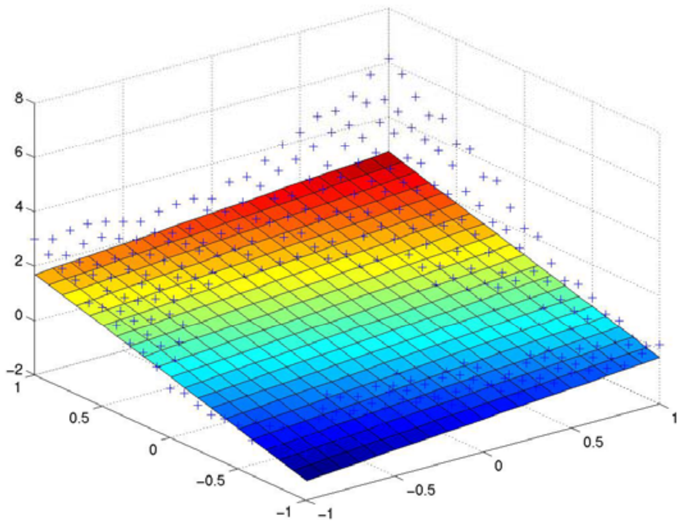


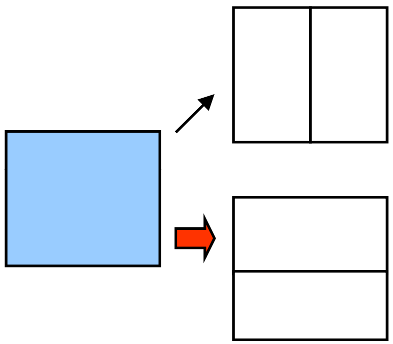


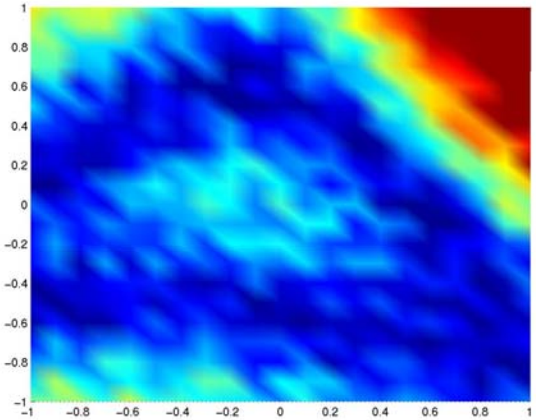
LOLIMOT: Principle

Example





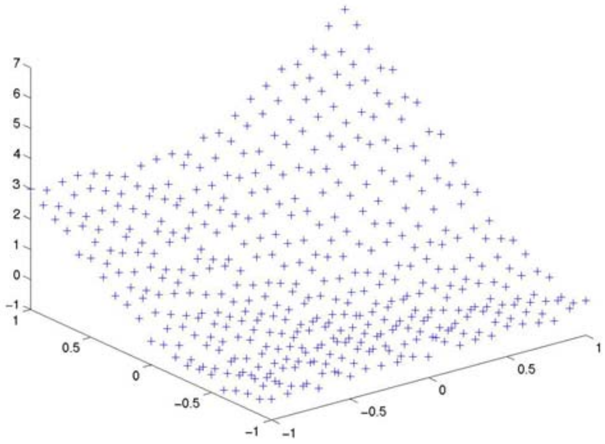


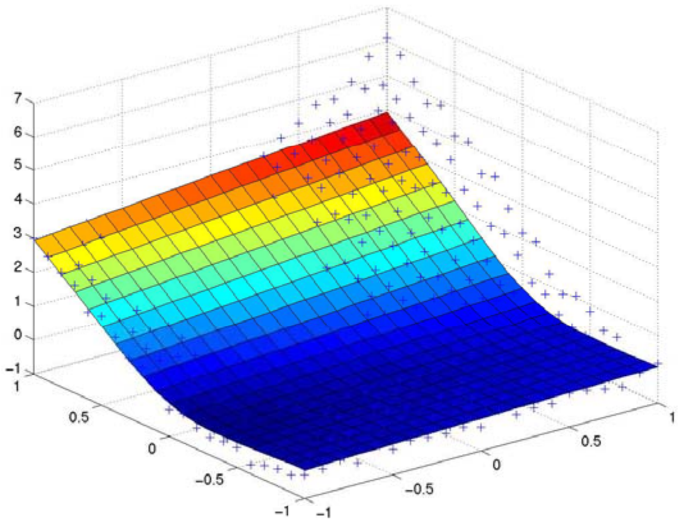


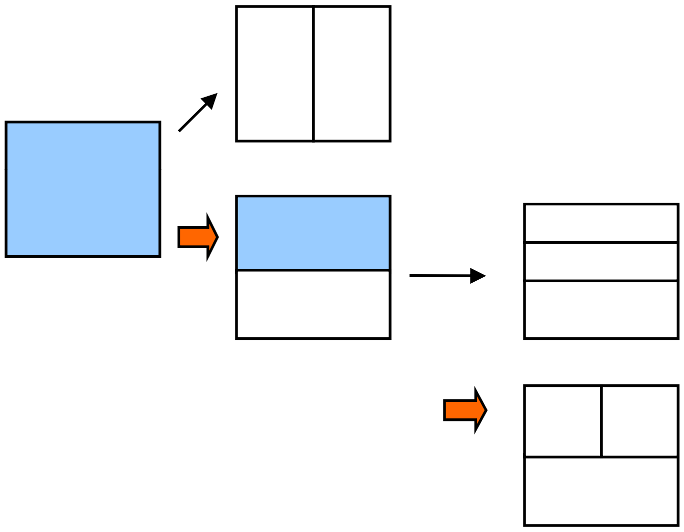
Residual

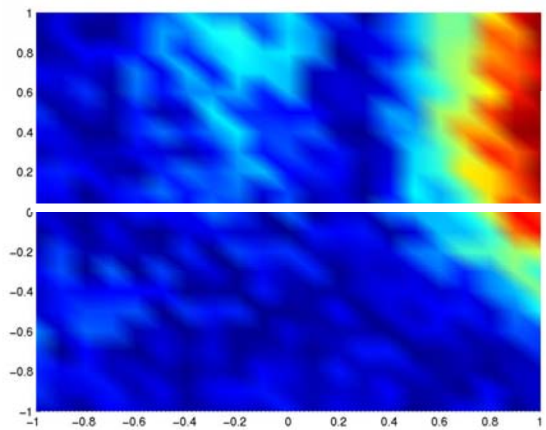
LOLIMOT: Principle

Example





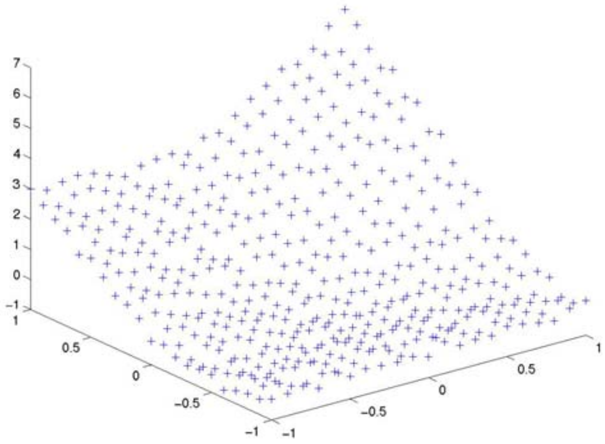


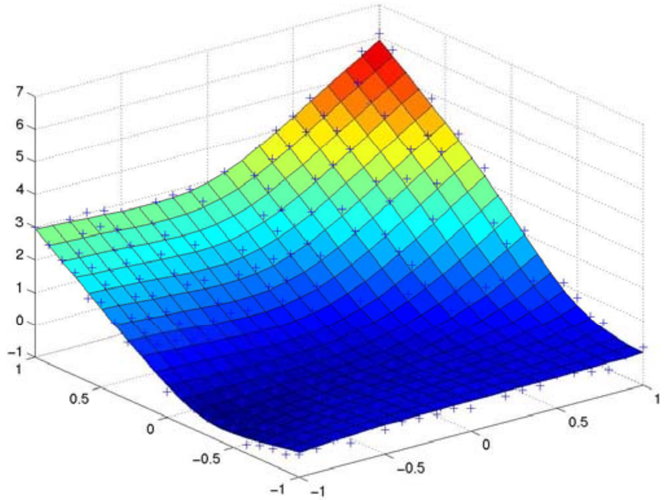


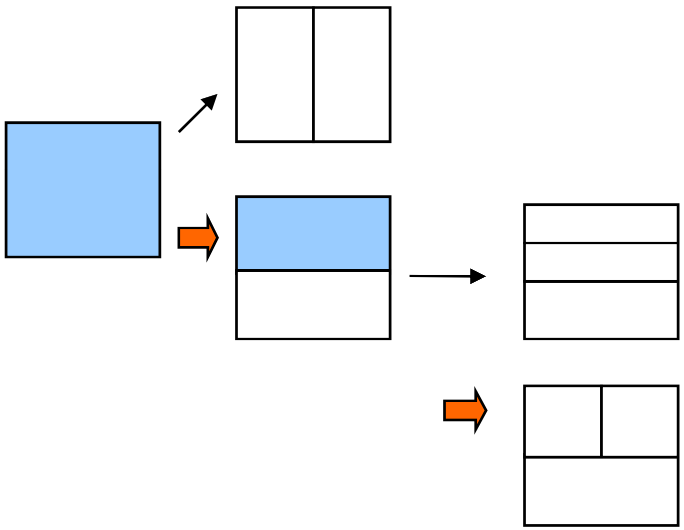
Residual

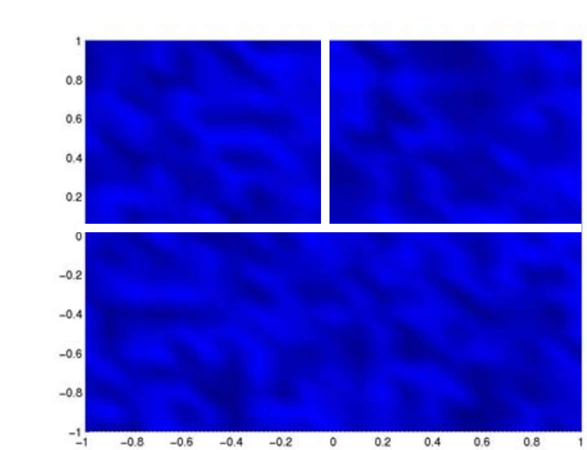
LOLIMOT: Principle

Example









Residual

Singular Spectrum Analysis

Singular Spectrum Analysis

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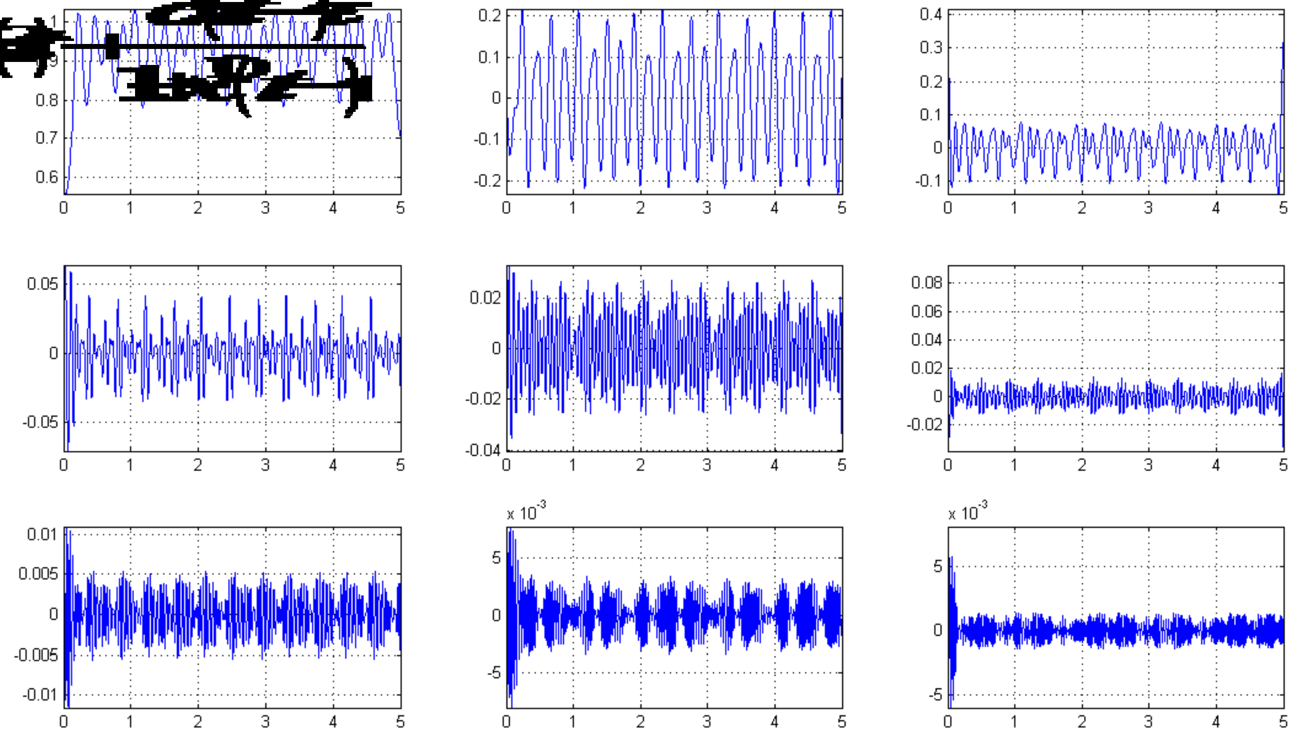
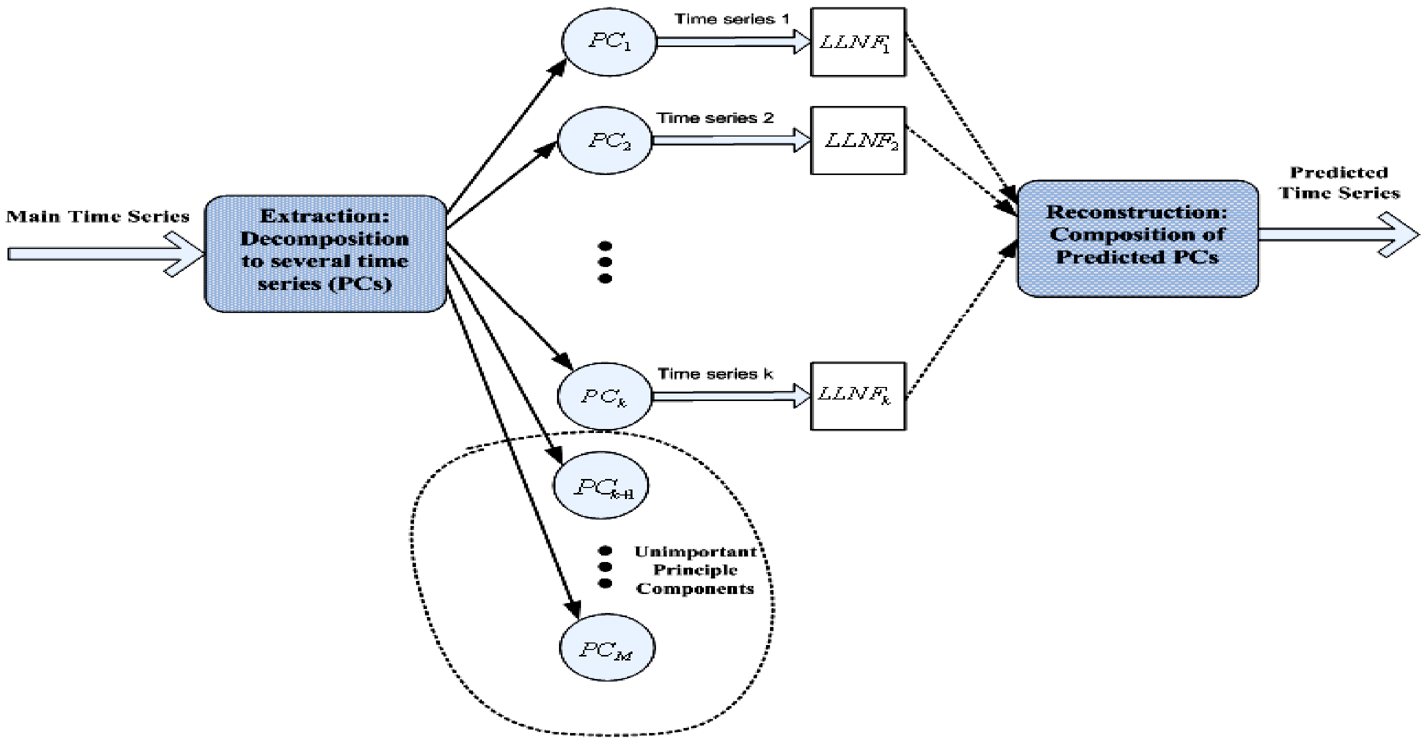


LLNF+SSA

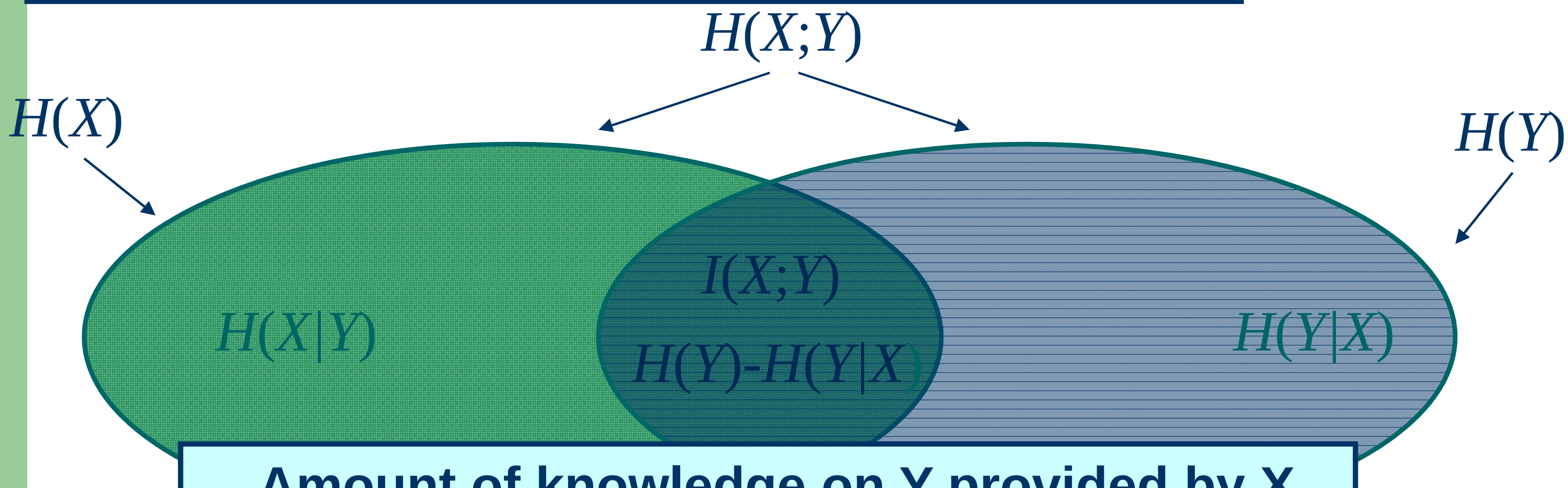

Main Time Series
Extraction: Decomposition to several time series (PCs)
PC_1
PC_2
PC_k
PC_{k+1}
PC_M
Time series 1
Time series 2
Time series k
$LLNF_1$
$LLNF_2$
$LLNF_k$
Unimportant Principle Components
Reconstruction: Composition of Predicted PCs
Predicted Time Series

Mutual Information for Feature/Input Selection

Mutual Information (1)

In Probability Theory, especially in Information Theory

To evaluate the dependencies between random variables (linear or non-linear relations).



Amount of knowledge on Y provided by X
(or amount of knowledge on X provided by Y)

Mutual Information (2)

From Shannon's Entropy

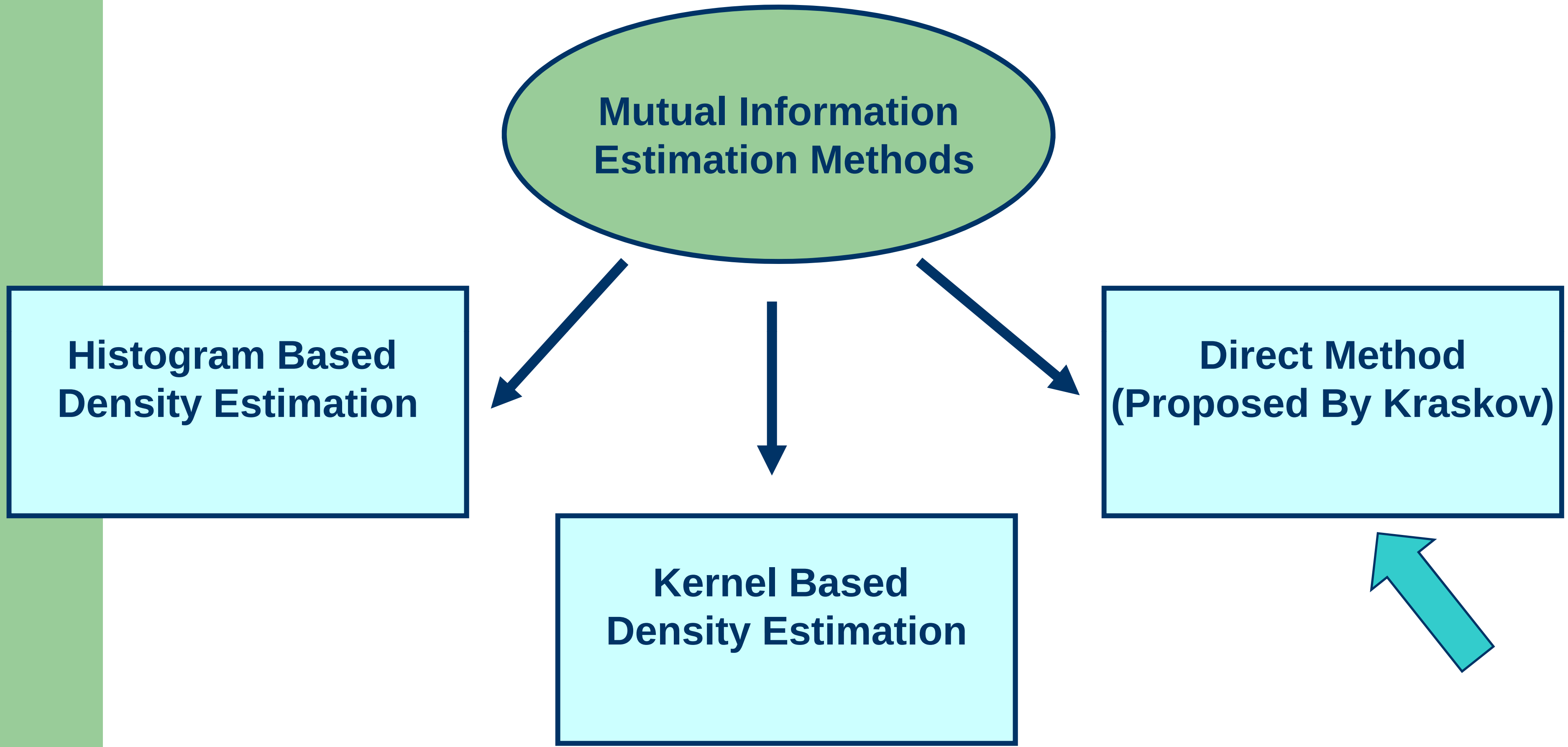
$$H(X) = -\int_x p_X(x) \log p_X(x) dx$$

$$I(X;Y) = H(X) - H(X|Y) = H(Y) - H(Y|X)$$
$$= H(X) + H(Y) - H(X;Y)$$

$$I(X;Y) = \int_x \int_y p_{X,Y}(x,y) \log \frac{p_{X,Y}(x,y)}{p_X(x) p_Y(y)} dxdy$$

If X and Y are independent, then *I*(*X*;*Y*) = 0

Mutual Information (3)



What to Expect

- Data driven approaches (specially intelligent approaches) are general tools.
- The performance of these methods does not need to be optimal in all applications!
- If there is an optimal solution, the performance of such methods should be close enough to the optimal solution.

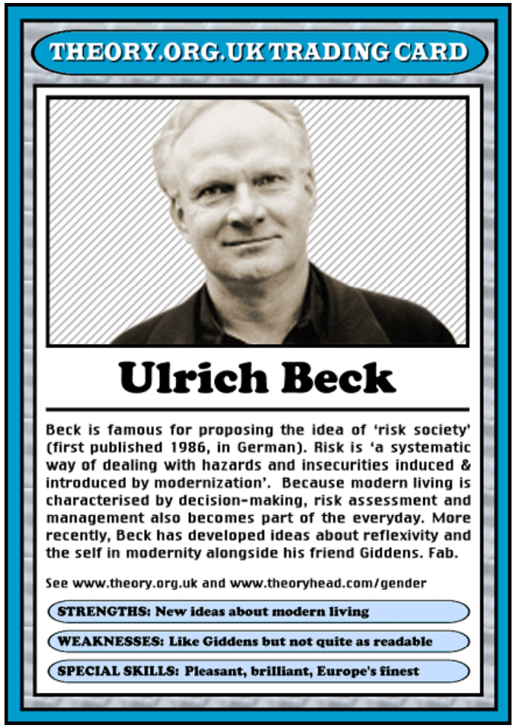
Applications

RISC SOCIETY

Are We Living in a Risk Society?

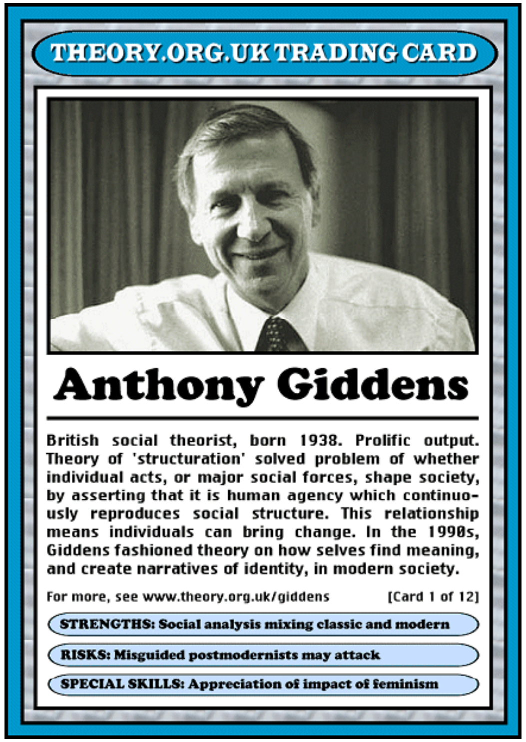
Hazards that may occur in a 'Risk Society' are distinctive because they are…

- **generated by humans as well as nature** (unlike traditional hazards)
- **global in scope** (unlike traditional & modern hazards)
- **irreparable and unlimited** (unlike traditional & modern hazards)



Key Work: "Risk Society: Towards a New Modernity" (1986/1992)

'…the ecological and high-tech risks that have upset the public for some years now…have a new quality. In the afflictions they produce they are no longer tied to their place or origin…By their nature they endanger *all* forms of life on this planet.' (Beck, 1992: 22)



Key Work: "Modernity and Self-Identity" (1991)

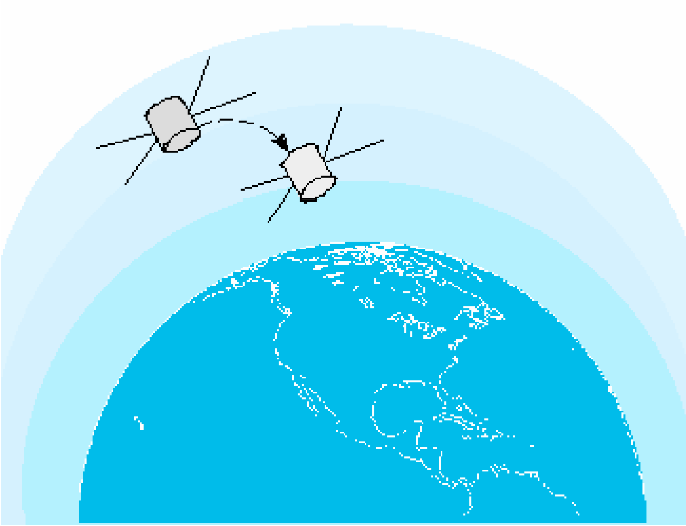
Is it only recently that individuals have taken a 'reflexive' rather than a 'traditional' attitude to risk? (Alexander, 1996)

Space Weather

Space weather

Space Weather refers to changes in the space environment and effects that those changes have on Earth and mankind's activities.
These affect **Earth climate on various temporal and spatial scale** as well as **communications, navigation and many other space and ground based systems.**
Space Weather refers for short-term , very dynamic and highly variable conditions in the geo-space environment.

Disrupted Systems



Communications

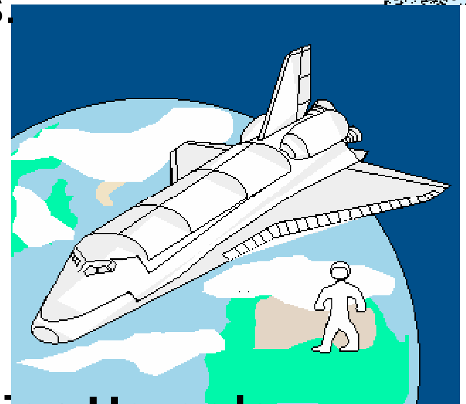
Many communication systems utilize the ionosphere to reflect radio signals over long distances. Ionospheric storms can affect radio communication at all latitudes.

Electric Power

On March 13, 1989 in Montreal, Quebec, 6 million people were without commercial electric power for 9 hours as a result of a huge geomagnetic storm.

Satellites

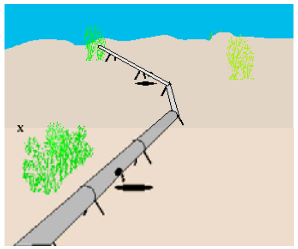
Increased drag on satellites in space, causing them to slow and change orbit energetic solar particles. Energetic solar particles can cause physical damage to microchips and can change software commands. Another problem for satellite operators is differential charging



Radiation Hazards

Intense solar flares release very-high-energy particles that can be injurious to humans

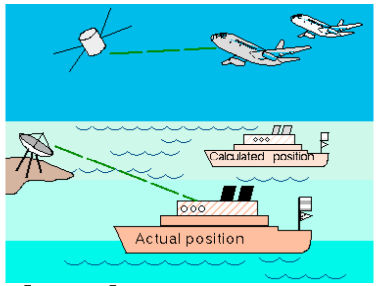
Solar proton events can also produce elevated radiation aboard aircraft flying at high altitudes



Pipelines

Geologic Exploration

Climate **Biology**



Navigation Systems

Railway signalling systems in Sweden were affected by a geomagnetic storm in July 1982. Figure credits: Andrew Pam.

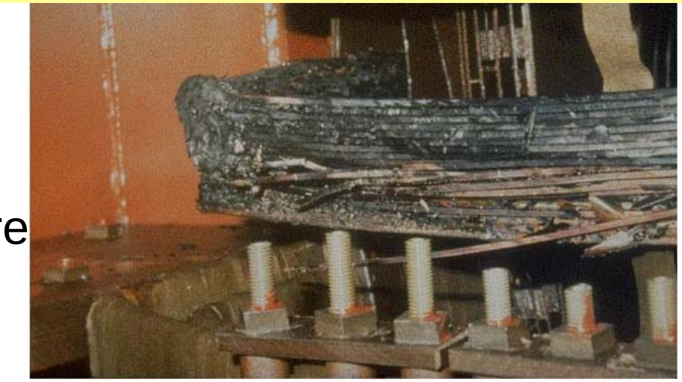
High-voltage power transmission systems are affected by geomagnetic disturbances.

First effects of GIC were experienced on telegraph equipment.

transformers located at corners of a power system suffer from large GIC values. Also, long transmission lines carry larger GIC. The problems caused to power grids are due to a half-cycle saturation of transformers resulting from GIC. This means that a transformer which normally operates with a very small exciting current starts to draw an even hundred times larger current which results in a large asymmetry, and the transformer operates beyond the design limits.

Image about the installation of a sea cable.

Magnetic surveys used in oil and gas exploration are disturbed by geomagnetic variations.



Damaged transformer windings.

Some Achievements

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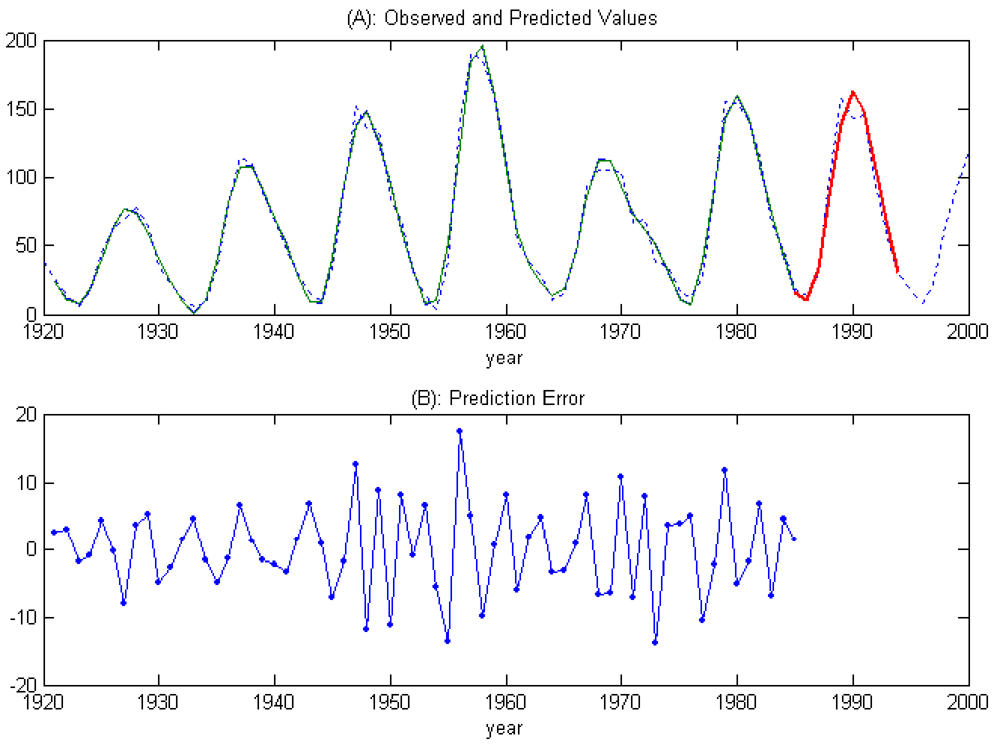
- Th nd the pe rm.



Some Achievements

- For f… an
  incr… d
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- Afte… solar
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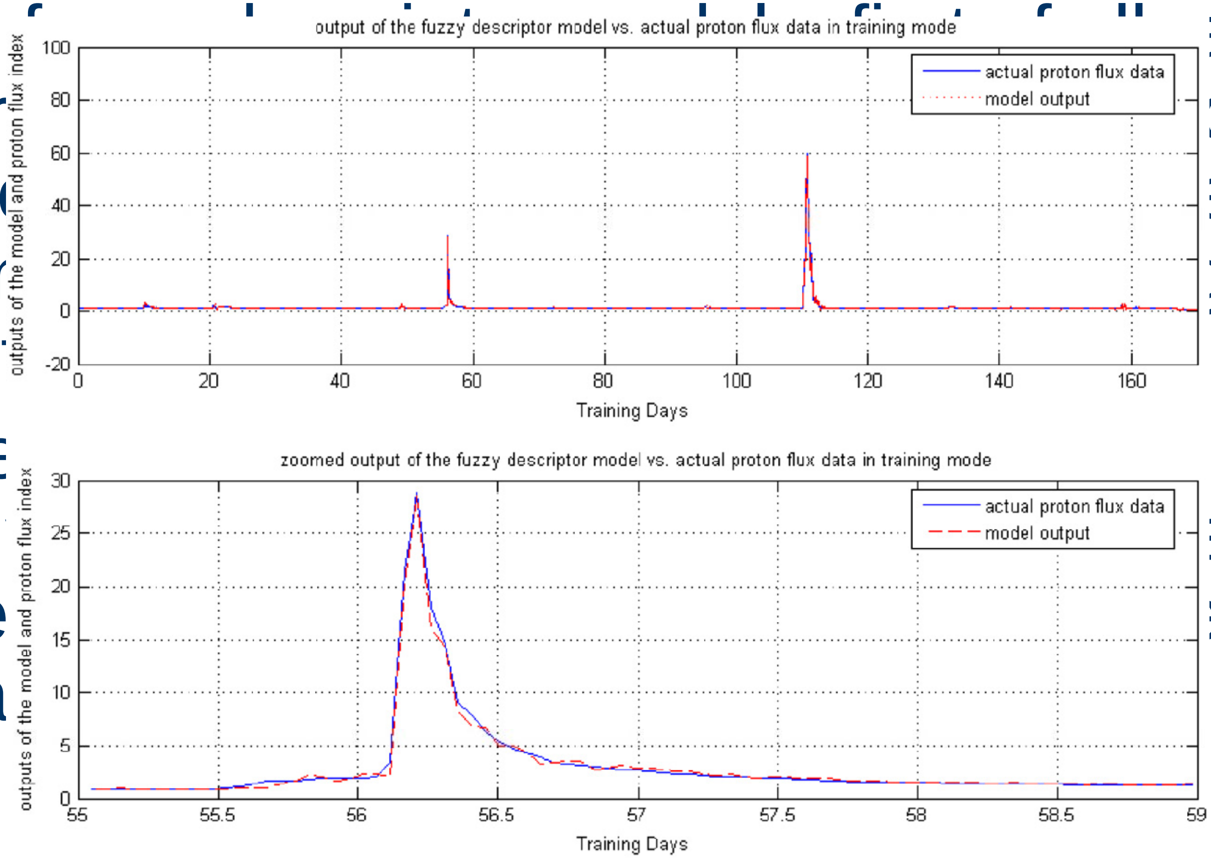
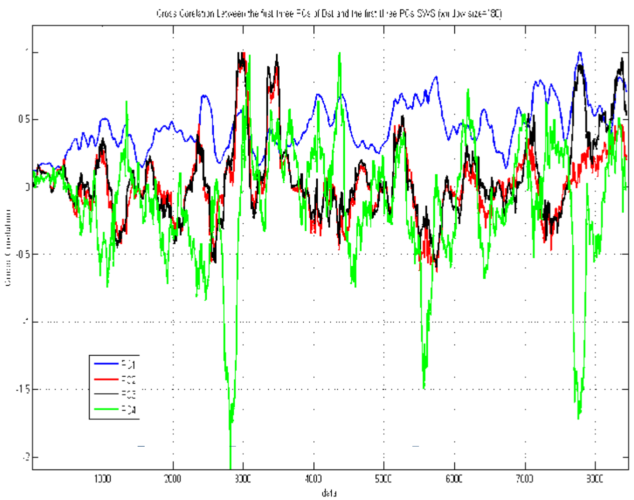


Some Achievements

- In addition, three related solar activities were



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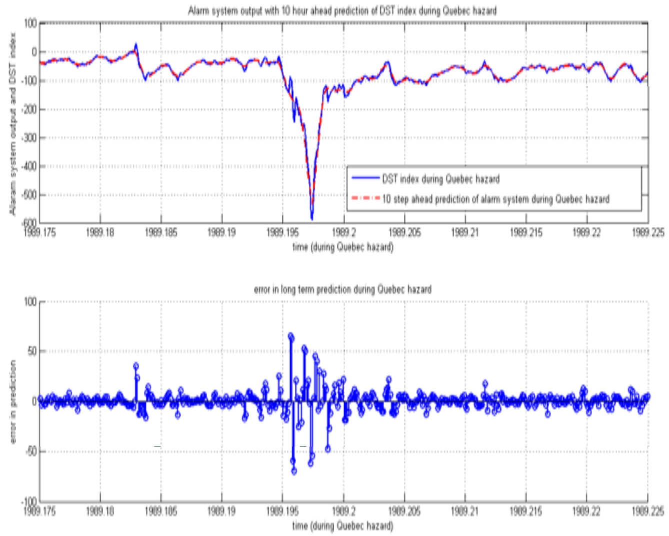

Rezaei).

Some Achievements

TABLE I

Order of input variables selection according to applied algorithm

Input variables	Proposed algorithm	Correlation analysis	Gamma test
$x(t\text{-}1)$	1	1	1
$x(t\text{-}2)$	5	7	2
$x(t\text{-}3)$	14	15	3
$x(t\text{-}4)$	12	10	9
$x(t\text{-}5)$	3	6	5
$x(t\text{-}6)$	6	8	13
$x(t\text{-}7)$	8	12	12
$x(t\text{-}8)$	11	11	15
$x(t\text{-}9)$	7	4	14
$x(t\text{-}10)$	4	2	4
$x(t\text{-}11)$	2	3	7
$x(t\text{-}12)$	9	5	6
$x(t\text{-}13)$	15	13	8
$x(t\text{-}14)$	13	14	10
$x(t\text{-}15)$	10	9	11

TABLE II

Nmse error in ssn prediction via different input variables selection algorithm

Input variables selection algorithm	NMSE error
Arbitrary input selection	0.1182
Correlation analysis	0.2216
Gamma test	0.1029
Proposed algorithm	0.1062

Concluding Remarks

Concluding Remarks

- Collecting fair data is an urge for data driven approaches
- Feature selection and input selection may be is the most important part in such approaches
- If there is a known model for a phenomenon, black box modeling is not suggested.
- It is better to know the problem before choosing the modeling tool!
- The performance of the intelligent approaches does not need to be optimal in all applications
- Look to the nature to get great ideas

Thank you for your attention