

# Advanced Data Analysis for Industrial Applications

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*retired from*



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*<http://www.smartgrids2015.eu/>*

# Typical tasks

**Marketing** – analysis of *big data* available from eShops, social media, internet of things etc. Extremal data may be present, they sometimes disturb analysis, sometimes supply the most valuable information.

**Quality control** – detection of defects, preferably when the quality of the product is still within acceptable limits.

**Process control** – analysis of real time data, early detection of departure from optimum conditions.

**Safety** – real-time analysis of concentration of hazardous waste, early detection of dangerous concentration.

*Demand for robust methods of data analysis!*

## Statistical paradigm of uncertainty

- Distribution of errors known *a priori*, normal distribution often silently assumed in textbooks of statistics for engineers (ANOVA, F-test,  $\chi^2$  test)
- Robust statistical methods require additional assumptions on the distribution function of outliers
- Continuous distribution function derived for an infinite data set
- Properties of data obtained by extrapolation from an infinite to a finite data sample

## Questions

- Do we know the distribution of data? (*quality of products, concentration of poisonous waste, flow rate of leakage, heterogeneities in the raw material, power consumption of home and industrial consumers*)
- Is the data sample large enough to make the extrapolation to the finite data sample valid?
- Are the outliers rare?
- Can the outliers be discarded without loss of important information?
- Is the data analysis algorithm robust so that it can run unattended and produce reliable results?

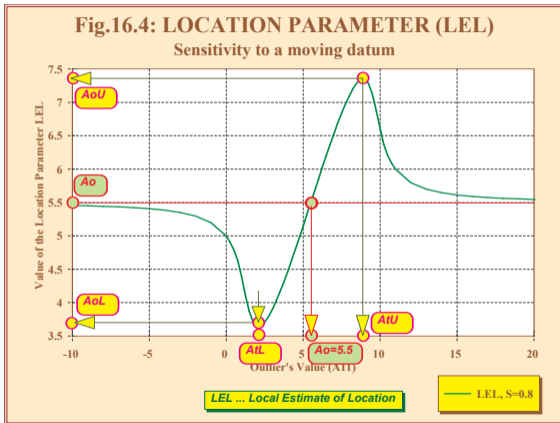
# Principles of mathematical gnostics

- Derived from the fundamental laws of nature
- Based on the properties of each individual measurement
- Properties of a data sample obtained by aggregation of properties of individual data, hence the results are valid also for small data samples
- The distribution function as well as the metrics of the space estimated during data analysis: *Let the data speak for themselves!*
- Robustness is the inherent property

P. Kovanic, M. B. Humber: *The Economics of Information (Mathematical Gnostics for Data Analysis)*. 717 pages. Updated in September 2013.

<http://www.math-gnostics.com/index.php?a=books>

# Properties of the local estimate of location



## Example 1, marginal analysis

Data from NIST Webbook Chemistry, <http://webbook.nist.gov>

Normal boiling temperature of 1,4-dichlorobutane (CAS 110-56-5)

Available data: 12 measured values

Value reported by NIST:  $410 \pm 80$  K

## Results obtained by mathematical gnostics

Parameter	Certifying Bound	Cum. Probability
<i>LB</i>	426.187	0
<i>LSB</i>	426.250	0.071
<i>ZL</i>	426.938	0.411
<i>ZOL</i>	427.057	0.457
<i>ZO</i>	427.097	0.472
<i>ZOU</i>	427.130	0.484
<i>ZU</i>	427.261	0.533
<i>USB</i>	428.150	0.929
<i>UB</i>	428.216	1



## Data classification

Class No.	Condition	Data class
1	$D_x \leq LB$	L-outlier
2	$LB < D_x \leq LSB$	L-dubious
3	$LSB < D_x \leq ZL$	L-subtypical
4	$ZL < D_x \leq ZOL$	L-typical
5	$ZOL < D_x < ZO$	L-tolerated
6	$D_x = ZO$	Max. density
7	$ZO < D_x \leq ZOU$	U-tolerated
8	$ZOU < D_x \leq ZL$	U-typical
9	$ZL < D_x \leq USB$	U-overtypical
10	$USB < D_x < UB$	U-dubious
11	$UB \leq D_x$	U-outlier

## Results of data certification

Standard data			
Data No.	Value	Cum. Prob.	Class No.
8	426.25	0.071	2
12	426.65	0.293	3
10	427.05	0.454	4
3	427.1	0.473	6
6	427.15	0.492	7
11	428	0.830	8
4	428.15	0.929	8

Nonstandard data (outliers)					
Data No.	9	5	2	7	1
Data value	308.15	322	433	434.65	435.2

## Example 2, marginal analysis

Data from NIST Webbook Chemistry, <http://webbook.nist.gov>

Normal boiling temperature of chloroform (CAS 67-66-3)

Available data: 37 measured values

Value reported by NIST:  $334.3 \pm 0.2$  K

## Results obtained by mathematical gnostics

Data split to 7 subsamples, 5 with 5 items each, 2 with 6 items each.

Parameter	Median	MAD	%
<i>LB</i>	334.199	0.104	0.031
<i>LSB</i>	334.240	0.059	0.018
<i>ZL</i>	334.328	0.040	0.012
<i>ZOL</i>	334.331	0.033	0.010
<i>ZO</i>	334.334	0.041	0.012
<i>ZOU</i>	334.340	0.043	0.013
<i>ZU</i>	334.339	0.043	0.013
<i>USB</i>	334.450	0.044	0.013
<i>UB</i>	334.451	0.071	0.021

*MAD = mean absolute deviation from the median*

## Example 3, particle size distribution

- Particle size distribution in atmospheric aerosol measured by an SMPS (scanning mobility particle sizer) and the data transferred via internet once per hour
- Time series filtered in order to remove disturbances caused by instrument malfunction and local pollution events
- Distribution function estimated, number of modes estimated using a condition of equality of entropy of the data and the distribution function
- The results graphically displayed in near real time on the web – <http://hroch486.icpf.cas.cz/Kosetice/>

*The procedure runs reliably since May 1, 2008. The graphical display offers early detection of instrument malfunction and usually even diagnostics on distance.*

## Example 4, energetics

- Real time measurement of transferred power plant output
- Real time measurement of the electrical network frequency
- Measurement of frequency/power sensitivity  
(failure of 1000 MW block in Germany not detected in Prague but the quasiperiodic response to switching the Vltava cascade on/off for 2 minutes repeated four times can be detected)

Kovanic P., Votlučka J., Blecha K.: *Experimental determination of the frequency/power coefficients of an electricity distributing system by means of periodical impulses of power* (in Russian), *Elektrotechnický obzor* (Review of Electrical Engineering) 68 (1979), 3, 133–139.

## Development of an experimental technique

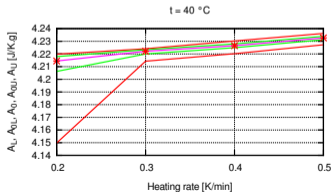
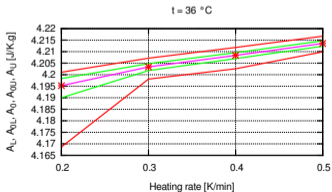
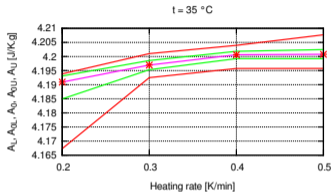
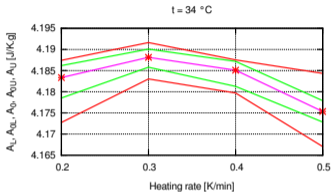
Measurement of heat capacity ( $C_p$ ) by a continuous method by using a Setaram DSC3EVO calorimeter

Task: find the heating rate ensuring the best repeatability  
( $n_{\min}$  = minimum sample size for 10% error in deviation)

Distribution	Kurtosis	$n_{\min}$	time [weeks]
Uniform	1.8	21	4
Normal	3.0	51	10
Exponential	6.0	126	26
Laplace	9.0	201	41
Lognormal	15.0	351	72

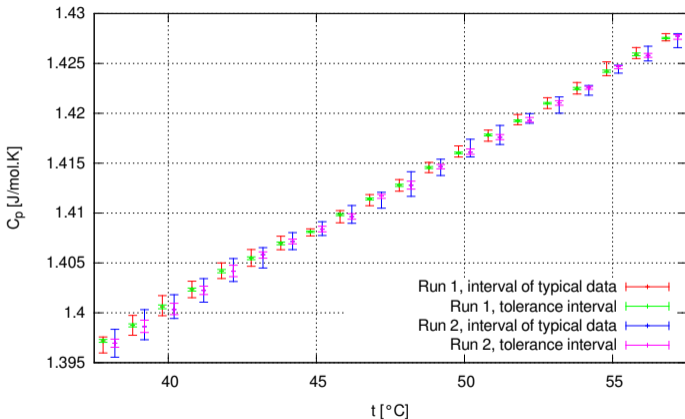
Time needed for reliable determination of tolerance interval and interval of typical data by mathematical gnostics: *less than 1 week*

# Analysis of results of $C_p$ measurement





# Comparison of two series of $C_p$ measurement



8 values in each run, by mistake heating rate 0.2 K/min used

## Conclusion

- Methods of data analysis by mathematical gnostics do not impose any kind of a distribution function *a priori*.
- Robustness is the inherent property of mathematical gnostics.
- The algorithms of mathematical gnostics are robust, can run *unattended* so that large number of data samples can be analyzed automatically.
- In many cases mathematical gnostics can extract additional information that is not obtainable by statistical methods.
- *It is important to understand that mathematics provides us with tools that can only extract information from data, nothing less, nothing more. The information must be interpreted in order to be useful.*

See also – Nassim Taleb: *The Black Swan*.

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KNOWLEDGE IS THE GREATEST WEALTH

<http://ttsm.icpf.cas.cz/team/wagner.shtml>