Appendix Q

On using quasi Newton algorithms of the Broyden class for model-to-test correlation

Jan Klement
(Tesat-Spacecom GmbH & Co. KG, Germany)

Abstract

The correlation of a model with test results is a common task in thermal spacecraft engineering. Often genetic algorithms or adaptive particle swarm algorithms are used for this task. A different approach has been developed at Tesat Spacecom using quasi Newton algorithms of the class defined by C. G. Broyden in 1965. A study is performed with thermal space industry models showing the performance of this approach. By comparing it to the results of other studies it is shown that this approach reduces the number of iterations by several orders of magnitude.

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On using quasi Newton algorithms of the Broyden class for model-to-test correlation

Jan Klement, 15.10.2014

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Using just one scalar

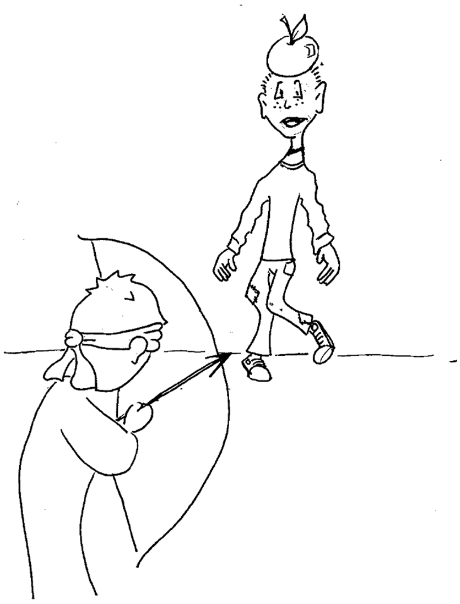

Illustration by Wiebke Klement

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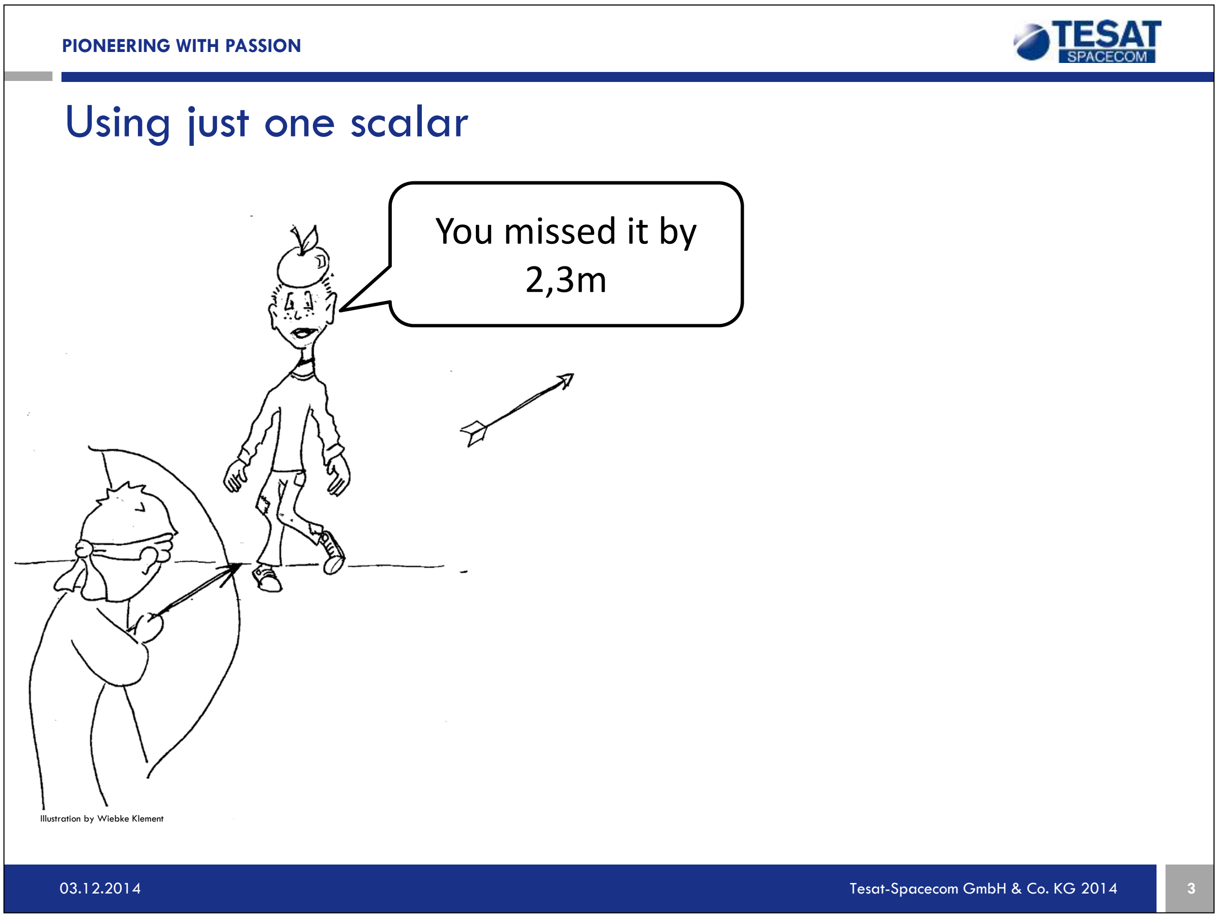
PIONEERING WITH PASSION
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Using just one scalar
You missed it by 2,3m
Illustration by Wiebke Klement
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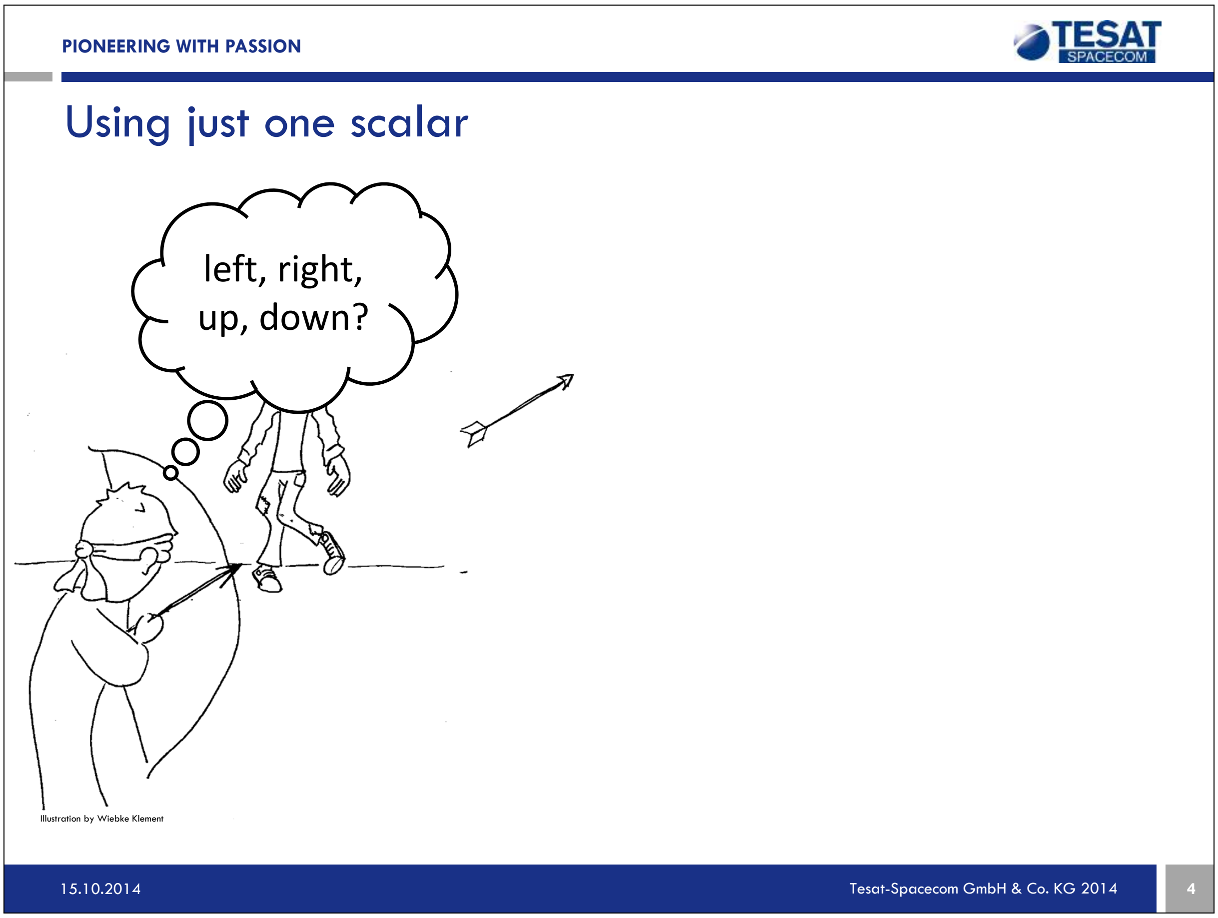
PIONEERING WITH PASSION
TESAT SPACECOM
Using just one scalar
left, right, up, down?
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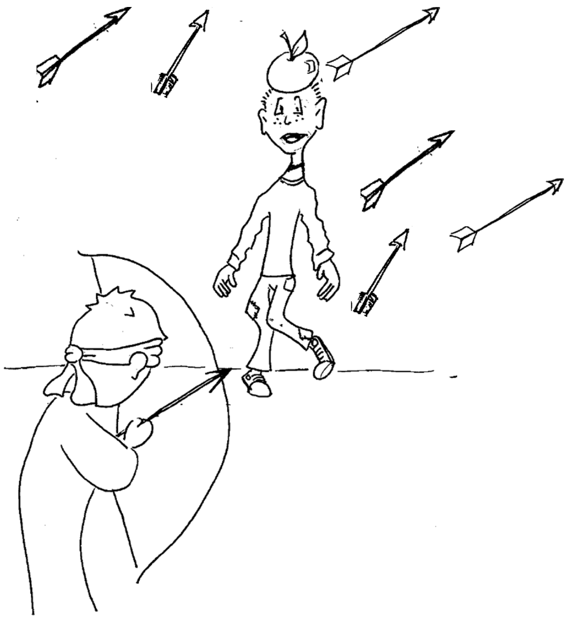
Using just one scalar



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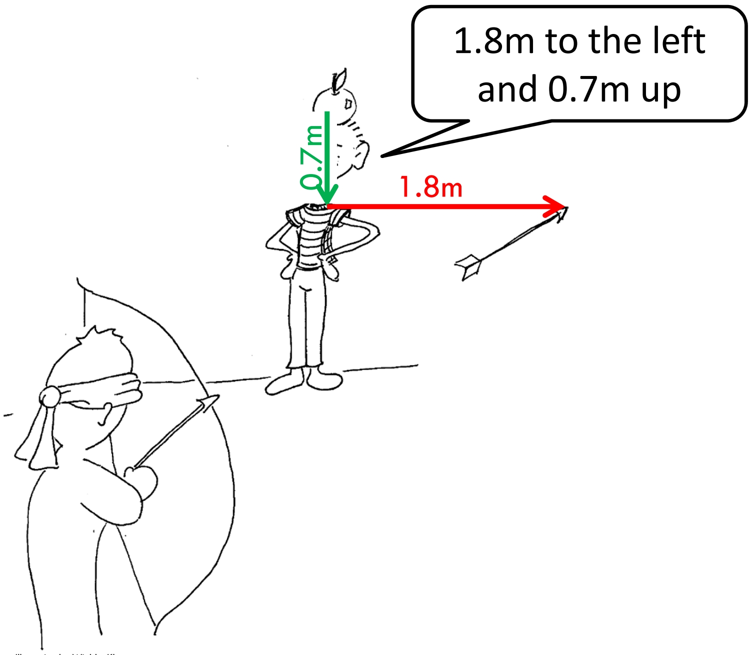
Using an vector



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Definition of the parameters

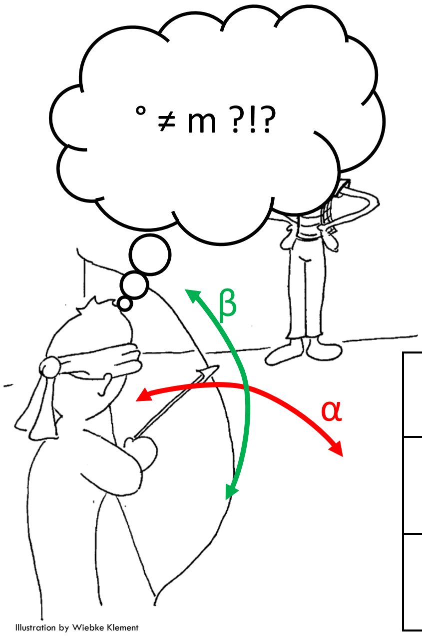
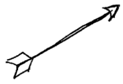


Illustration by Wiebke Klement



Equation system to be solved:

$$x(\alpha,\beta)=0$$
$$y(\alpha,\beta)=0$$

		1st arrow	2nd arrow	3rd arrow	4th arrow	5th arrow
parameter p	α	0°				
	β	0°				
target e	x	1.8m				
	y	-0.7m				

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Calculation of the first partial derivatives

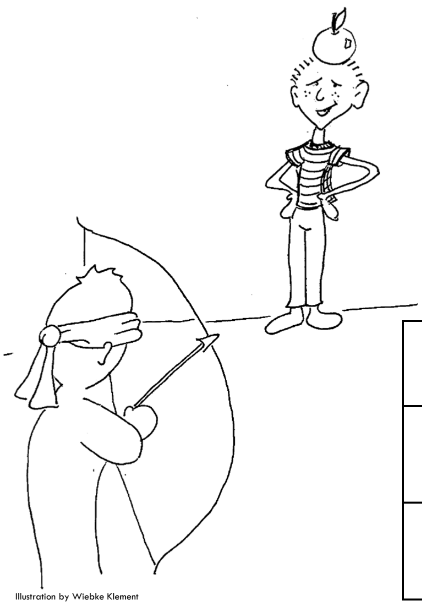
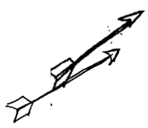


Illustration by Wiebke Klement



$$\frac{\Delta x}{\Delta\beta}=\frac{1.8m-1.8m}{1^\circ}=0m/^\circ\approx\frac{\partial x}{\partial\beta}$$

$$\frac{\Delta y}{\Delta\beta}=\frac{-0.5m-(-0.7)m}{1^\circ}=0.2m/^\circ\approx\frac{\partial y}{\partial\beta}$$

		1st arrow	2nd arrow	3rd arrow	4th arrow	5th arrow
parameter p	α	0°	0°			
	β	0°	1°			
target e	x	1.8m	1.8m			
	y	-0.7m	-0.5m			

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Calculation of the first partial derivatives

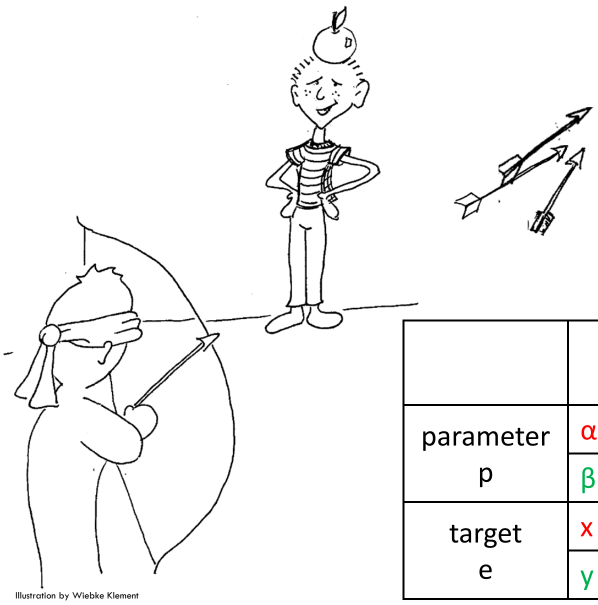

Illustration by Wiebke Klement

$$\frac{\Delta x}{\Delta \alpha} = \frac{1.9m - 1.8m}{1^\circ} = 0.1m/^\circ \approx \frac{\partial x}{\partial \alpha}$$

$$\frac{\Delta y}{\Delta \alpha} = \frac{-0.71m - (-0.7m)}{1^\circ} = 0.01m/^\circ \approx \frac{\partial y}{\partial \alpha}$$

		1st arrow	2nd arrow	3rd arrow	4th arrow	5th arrow
parameter p	α	0°	0°	1°		
	β	0°	1°	0°		
target e	x	1.8m	1.8m	1.9m		
	y	-0.7m	-0.5m	-0.71m		

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Solving the linear equation system

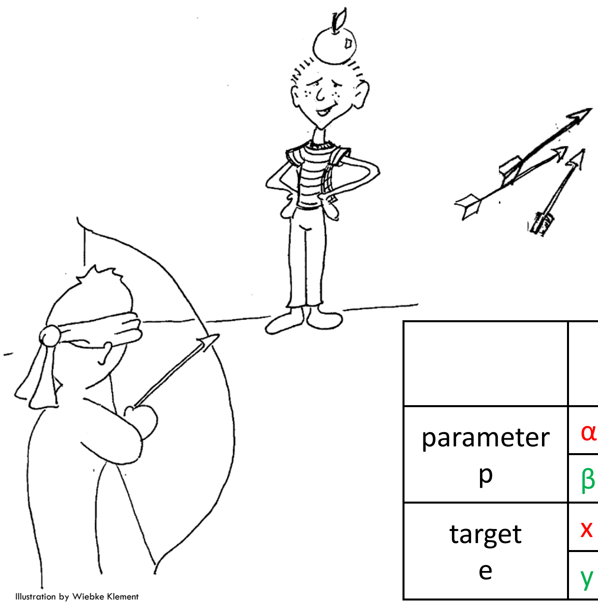

Illustration by Wiebke Klement

Jacobian matrix:

$$J_1 = \begin{bmatrix} \frac{\partial x}{\partial \alpha} & \frac{\partial x}{\partial \beta} \\ \frac{\partial y}{\partial \alpha} & \frac{\partial y}{\partial \beta} \end{bmatrix} \approx \begin{bmatrix} 0.1 & 0 \\ 0.01 & 0.2 \end{bmatrix} m/^\circ$$

$$p_4 = (-J^{-1} e_1) + p_1$$

		1st arrow	2nd arrow	3rd arrow	4th arrow	5th arrow
parameter p	α	0°	1°	0°	-18°	
	β	0°	0°	1°	4.4°	
target e	x	1.8m	1.9m	1.81m		
	y	-0.7m	-0.7m	-0.5m		

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Testing the solution of the linear system

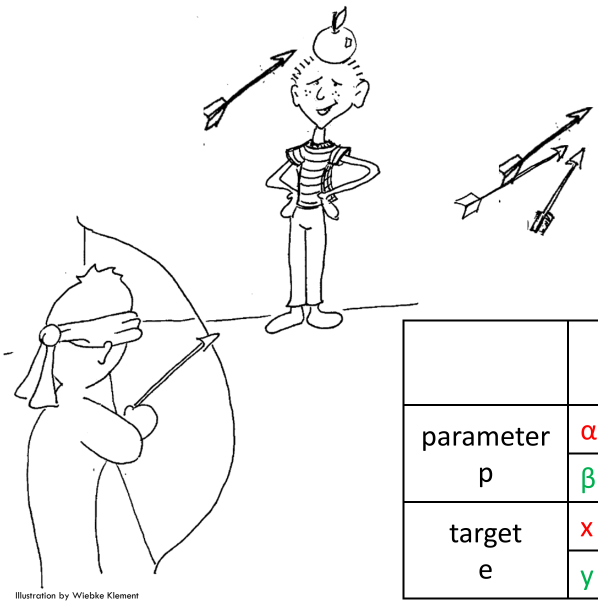

Illustration by Wiebke Klement

Missed because it is NOT Linear!

		1st arrow	2nd arrow	3rd arrow	4th arrow	5th arrow
parameter p	α	0°	1°	0°	-18°	
	β	0°	0°	1°	4.4°	
target e	x	1.8m	1.9m	1.81m	-0.2m	
	y	-0.7m	-0.7m	-0.5m	-0.1m	

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A new Jacobian matrix

Option 1 – Continue using the same Jacobian matrix

Option 2 – Calculate a new Jacobian matrix using 2 additional arrows (multidimensional Newton algorithm)

Option 3 – Guess a new Jacobian matrix using the secant condition (algorithms of the class defined by C. G. Broyden in 1965)

Quelle Wikipedia

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Testing the solution of the linear system

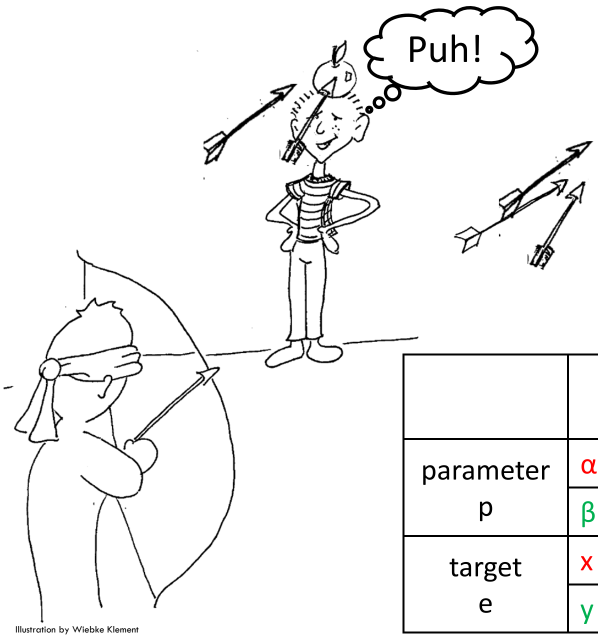

Illustration by Wiebke Klement

		1st arrow	2nd arrow	3rd arrow	4th arrow	5th arrow
parameter p	α	0°	1°	0°	-18°	-16°
	β	0°	0°	1°	4.4°	4.8
target e	x	1.8m	1.9m	1.81m	-0.2m	0.01m
	y	-0.7m	-0.7m	-0.5m	-0.1m	0.02m

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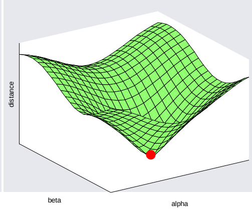
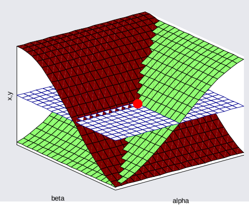
Comparision of the approches

	minimizing the distance	solving an equation system
Data per iteration	1 scalar	vector
Function	1 complex function	2 nearly linear functions





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Applying the method to thermal correlation

	blindfolded archer	thermal model correlation
	Arrows	Iterations
Input Parameters	α, β	λ, ε, α, c
Results	x, y	T_{calc}-T_{mes}
Function to be minimized	Distance to the Apple	RSS of temperature differences

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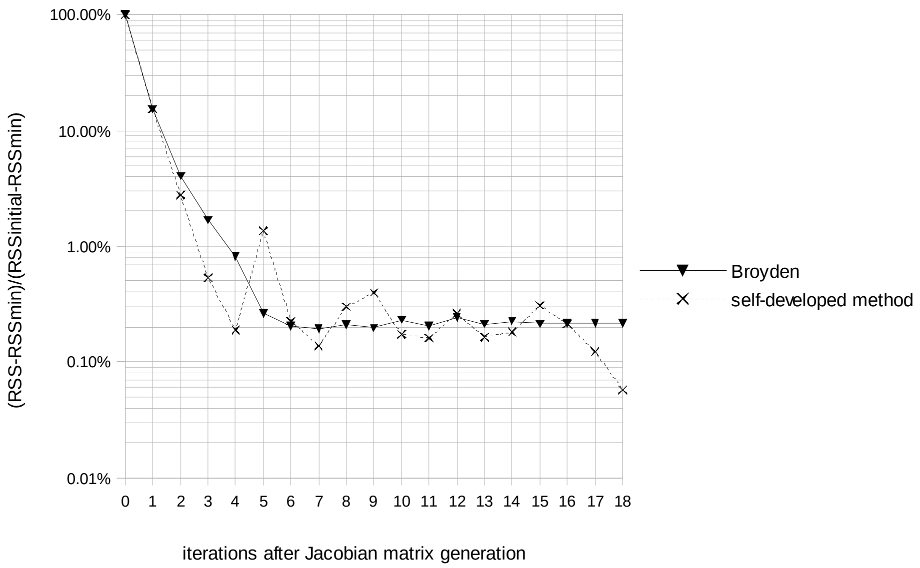
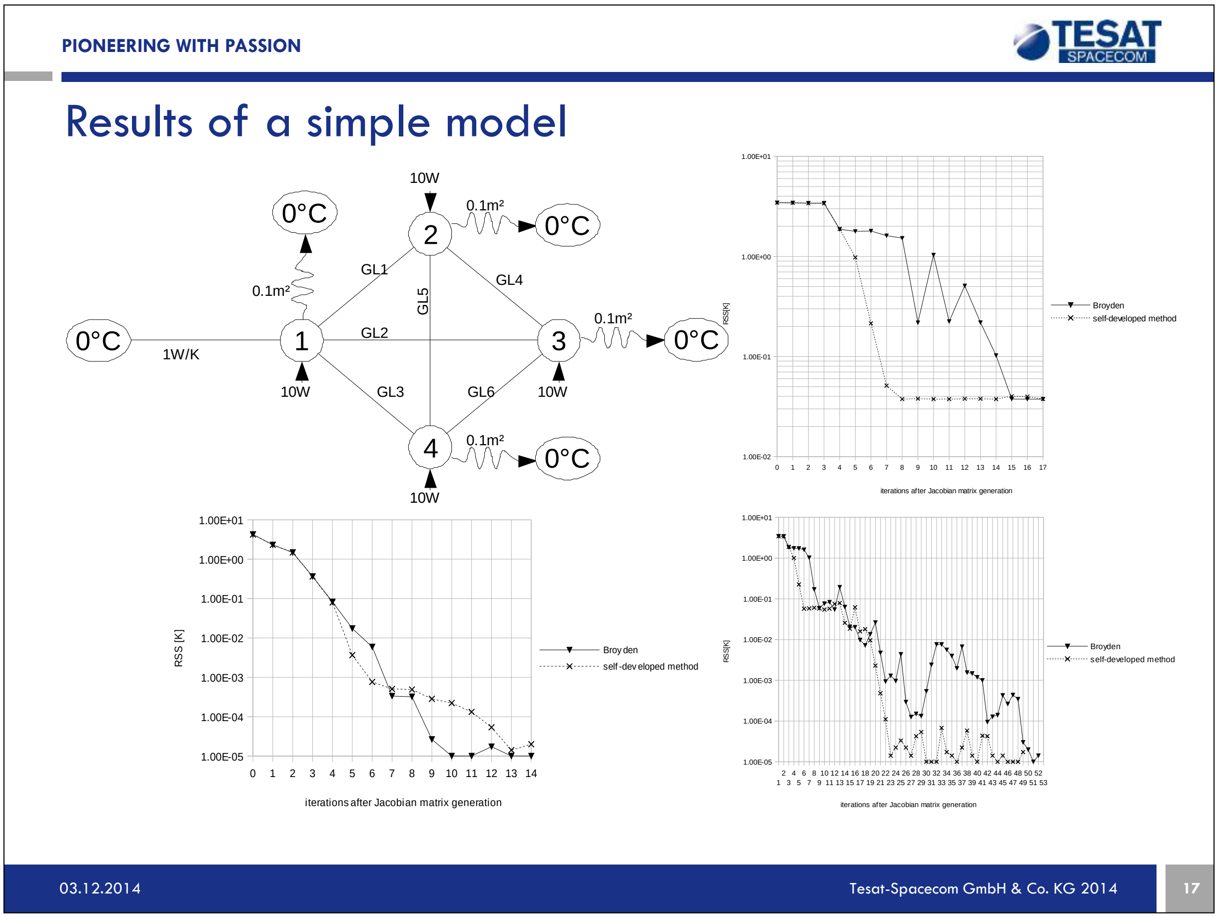
Results of a correlation of a transient complex system model with a TV test



2062 nodes , 156 temperatures (26 sensors 6 points in time)

13 parameters used for correlation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Results of a simple model
0°C
0.1m²
10W
0°C
2
GL1
GL4
GL5
0.1m²
0°C
1W/K
1
GL2
3
0.1m²
0°C
10W
GL3
GL6
10W
4
0.1m²
0°C
10W
RSS [K]
iterations after Jacobian matrix generation
Broyden
self-developed method
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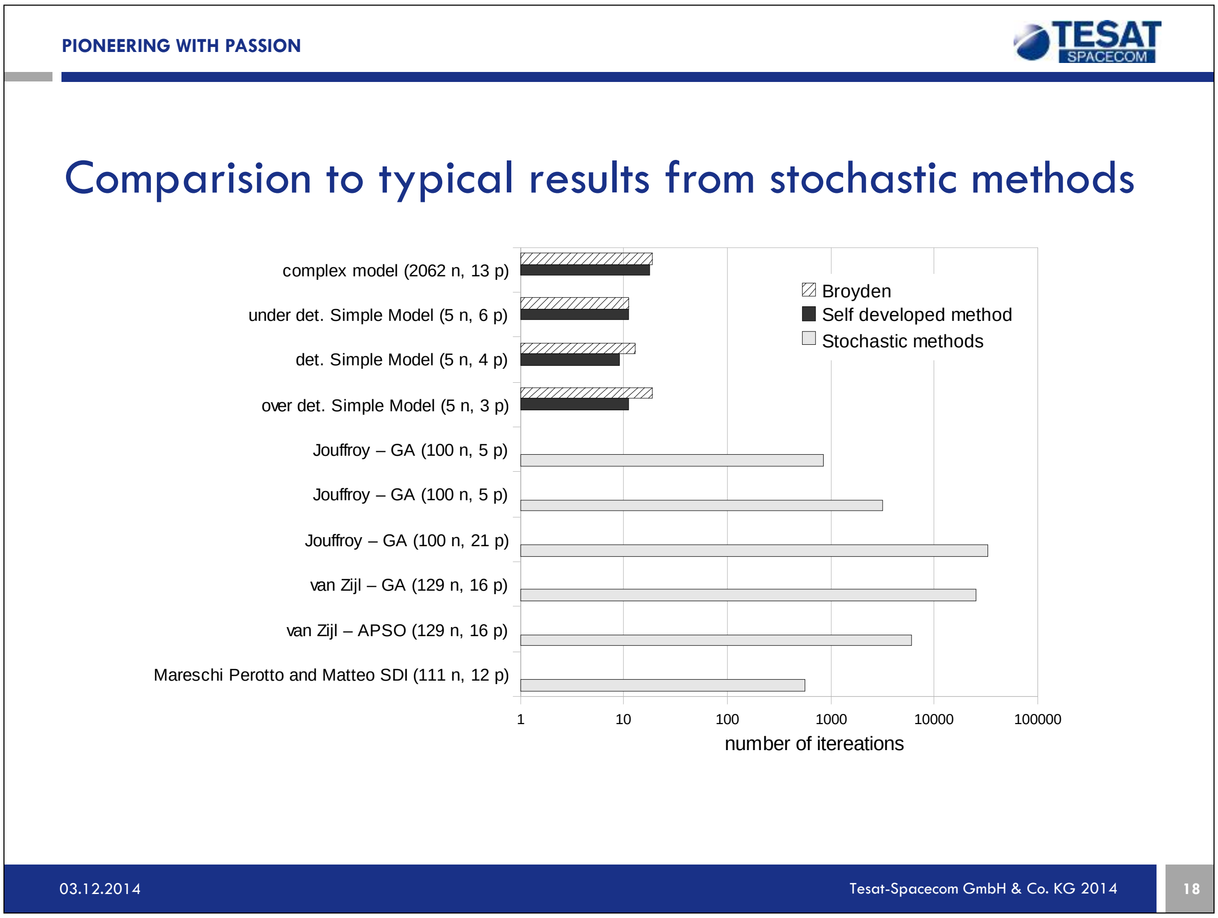
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Comparision to typical results from stochastic methods
complex model (2062 n, 13 p)
under det. Simple Model (5 n, 6 p)
det. Simple Model (5 n, 4 p)
over det. Simple Model (5 n, 3 p)
Jouffroy – GA (100 n, 5 p)
Jouffroy – GA (100 n, 5 p)
Jouffroy – GA (100 n, 21 p)
van Zijl – GA (129 n, 16 p)
van Zijl – APSO (129 n, 16 p)
Mareschi Perotto and Matteo SDI (111 n, 12 p)
Broyden
Self developed method
Stochastic methods
1
10
100
1000
10000
100000
number of itereations
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Limits of the algorithm

The method can be used as long as:

- The functions are monotone and differentiable
- Each parameter has an effect on at least one result
- Each result is influenced by at least one parameter

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Conclusion and Questions

See also:

- Klement, J. , 2014,“On using quasi-Newton algorithms of the Broyden class for model-to-test correlation”, Journal of Aerospace Technology and Management www.jatm.com.br doi: 10.5028/jatm.v6i4.373, available online: http://www.jatm.com.br/ojs/index.php/jatm/article/view/373/pdf_38
- Klement, J, 2014, “Satelliten heiß-kalt Thermische Modelle an die realen Testergebnisse angleichen“, Elektronik Industrie, 2014/11, pp 134-139, also available online: http://www.all-electronics.de/texte/anzeigen/56104/Modelle-von-Satelliten-Komponenten-an-reale-Testergebnisse-angleichen

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- WenLong , C., Na, L., Zhi, L., Qi, Z., AiMing, W., ZhiMin, Z. and ZongBo, H., 2011, "Application study of a correction method for a spacecraft thermal model with a Monte-Carlo hybrid algorithm", Chinese Science Bulletin, Vol. 56, No. 13, pp. 1407-1412. doi: 10.1007/s11434-010-4053-z.

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test2.ske

```
$MODEL CORRELA

# Model by Jan Klement to test correlation algorithms
# 4.11.2014
# further details see:
# Klement, J. ,to be published 2014, "On using quasi−Newton algorithms of the Broyden class for model−to−test correlation",
# Journal of Aerospace Technology and Management, http://www.jatm.com.br
# or
# Klement, J. ,2014,"Modelle von Satelliten−Komponenten an reale Testergebnisse angleichen",
# http://www.all−electronics.de/texte/anzeigen/56104/Modelle−von−Satelliten−Komponenten−an−reale−Testergebnisse−angleichen


$LOCALS
#READ "parameters.nwk"
$NODES
# Boudary:
B10 = 'boundary';
# dissipative  nodes:
D1 = '1',       T=0.0E+00,      C= 1.0, A= 0.00000E+00;
D2 = '2',       T=0.0E+00,      C= 1.0, A= 0.00000E+00;
D3 = '3',       T=0.0E+00,      C= 1.0, A= 0.00000E+00;
D4 = '4',       T=0.0E+00,      C= 1.0, A= 0.00000E+00;
$CONDUCTORS
GL(1,10) = 1.0;
GL(1,2) = cond_1;
GL(1,3) = cond_2;
GL(1,4) = cond_3;
GL(2,3)= cond_4;
GL(2,4)= cond_5;
GL(3,4)= cond_6;
GR(1,10)=0.1;
GR(2,10)=0.1;
GR(3,10)=0.1;
GR(4,10)=0.1;
$CONSTANTS
$REAL
$INTEGER
$CHARACTER
$CONTROL
  STEFAN = 5.6686D−08;
  RELXCA = 1.0000D−5;
  NLOOP  = 10000;
  TIMEO  = 0.D+00;
  TIMEND = 1000;
  DTIMEI = 1.D+00;
  OUTINT = 1.D+00;
$ARRAYS
$REAL
$SUBROUTINES
$INITIAL
  QI1=10.0;
  QI2=10.0;
  QI3=10.0;
  QI4=10.0;
$VARIABLES1
$VARIABLES2
$EXECUTION
          CALL SOLVIT
$OUTPUTS
# LIST OF ALL NODES TEMPERATURES
       CALL PRNDTB(' ',' L,T,C,QI',CURRENT)
       open(11,FILE='results.csv')
       write(11,*) 'Temp;T10;T1;T2;T3;T4'
       write(11,'(A3,";",16((F10.5),";"))') 'Tem',T10,T1−8.85234,T2−17.67466,T3−17.59433,T4−17.51947
$ENDMODEL
```

parameters.nwk

```
$LOCALS
$REALS
#target
 cond_1=0.11;
 cond_2=0.12;
 cond_3=0.13;
 cond_4=0.14;
 cond_5=0.15;
 cond_6=0.16;

#undetermined model initial conditions
 cond_1=0.5;
 cond_2=0.5;
 cond_3=0.5;
 cond_4=0.5;
 cond_5=0.5;
 cond_6=0.5;

#determined  model initial conditions
 cond_1=0.5;
 cond_2=0.5;
 cond_3=0.13; #const
 cond_4=0.5;
 cond_5=0.5;
 cond_6=0.16; #const

#overdetremined model initial conditions
 cond_1=0.5;
 cond_2=0.5;
 cond_3=0.13; #const
 cond_4=0.5;
 cond_5=0.5;  #const
 cond_6=0.16; #const
```