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Application of an evolution algorithm and cluster computing for parameters identification of the Friderick-Armstrong's material model

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Introduction

Internal parameters

Processes observed in cyclicly loaded material could be modelled by internal parameters introduced into constitutive relation. Following parameters could be distinguished:

- kinematic hardening,
- isotropic hardening,
- damage parameter and others.

Therefore constitutive relation becomes differential or integral equation, very often without a solution as an elementary function.

Material model

General assumptions

- elastic-plastic material model with Frederick-Armstrong's kinematic hardening parameter,
- Hubera-Mises yield condition:

$$\sqrt{(s-X)(s-X)} - R = 0, \qquad (1)$$

where s - stress tensor deviator, X - back stress, R - yield point.

Material model

Constitutive equation

Applying appropriate evolution equation one may achieve

$$\dot{X}_{ij} = C^{(k)}\dot{\varepsilon}^{p}_{ij} - \gamma^{(k)}\dot{\lambda}X^{(k)}_{ij}, \quad (2)$$

where $\dot{\lambda} = \sqrt{\frac{2}{3}\dot{\varepsilon}^{p}_{ij}\dot{\varepsilon}^{p}_{ij}}$ - change of plastic strain trajectory, $C^{(k)}$ i $\gamma^{(k)}$ - parameter that may be functions of internal variables, ε^{p}_{ij} - plastic strain tensor.

Material model

Constitutive equation

In 1D case, for one plasticity surface ($k = 1$) and linear Frederick-Armstrong's evolution equation:

$$\dot{X} = C\dot{\varepsilon}_p - \gamma|\dot{\varepsilon}_p|X \qquad (3)$$

and

$$\sigma = X \pm R. \qquad (4)$$

For constant C i γ equation (3) is a linear equation with a solution as an elementary function

$$\sigma = (R - \sigma_a - \frac{C}{\gamma})e^{-\gamma(\varepsilon_p + \varepsilon_{ap})} + \frac{C}{\gamma}. \qquad (5)$$

Material model

Constitutive equation

If the γ is a function of plastic strain trajectory

$$\gamma = \gamma(\lambda), \quad \lambda = \int_0^t |\dot{\varepsilon}_p| dt. \tag{6}$$

$$\dot{X} = C\dot{\varepsilon}_p - \gamma(\lambda)|\dot{\varepsilon}_p|X \tag{7}$$

Experiment

- austenitic steel AISI 304 ($E = 1,93e5[MPa]$),
- material exhibit strong hardening under cyclic loads,
- round specimen,
- material test system by MTS company,
- load – constant amplitude total strain signal.

Experiment

Modelling material cyclic hardening implies taking:

- variable yield point R,
- variable relaxation parameter γ.

Second option was selected because parameter γ defines relaxation that decreases due to increase of martensitic phase.

Identification procedures

Identification criterion

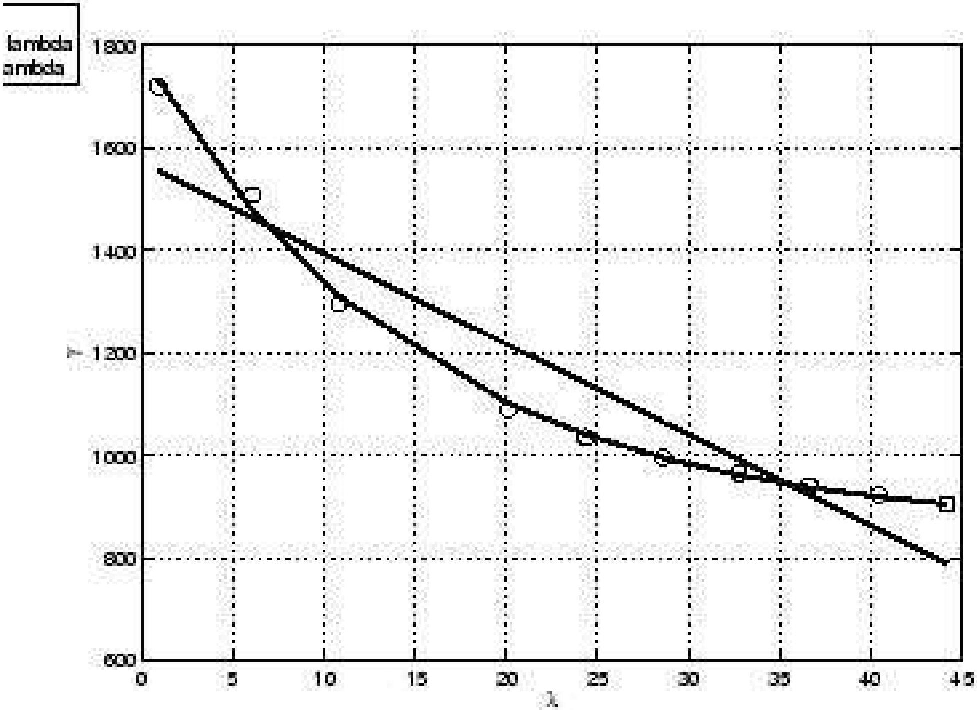
Following identification criterion was assumed

$$Q = \sum_{i=0}^{N} (\sigma(t_i) - \tilde{\sigma}(t_i))^2 \qquad (8)$$

where $\sigma(t_i)$ - measured material response (stress signal),
$\tilde{\sigma} = \tilde{\sigma}(t_i; C, R, X_0, \gamma(\lambda(t_i)))$ - computed material response.

Identification procedures

Function $\gamma(\lambda)$



Identification procedures

Function $\gamma(\lambda)$

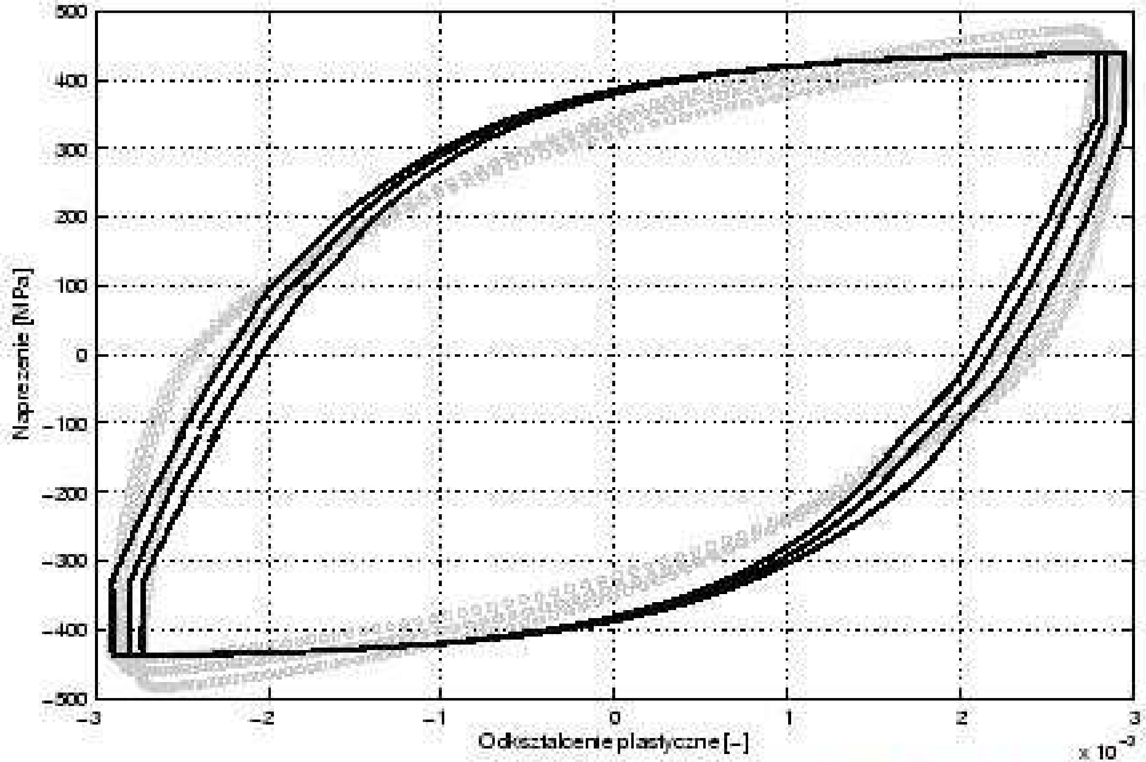
Relaxation function

$$\gamma(\lambda) = e^{a\lambda+b} + c \tag{9}$$

was selected and therefore identification parameters vector takes following form $x_i = [C, R, X_0, a, b, c]$.

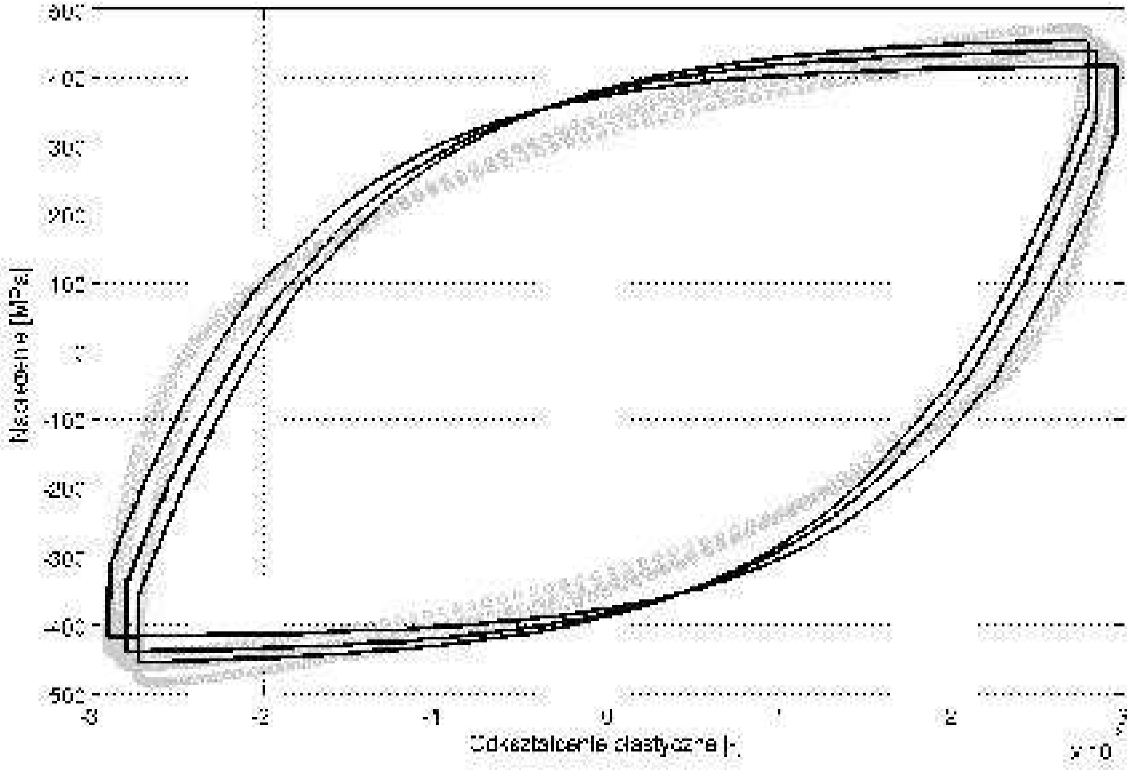
Identification procedures

Typical plots for constant γ



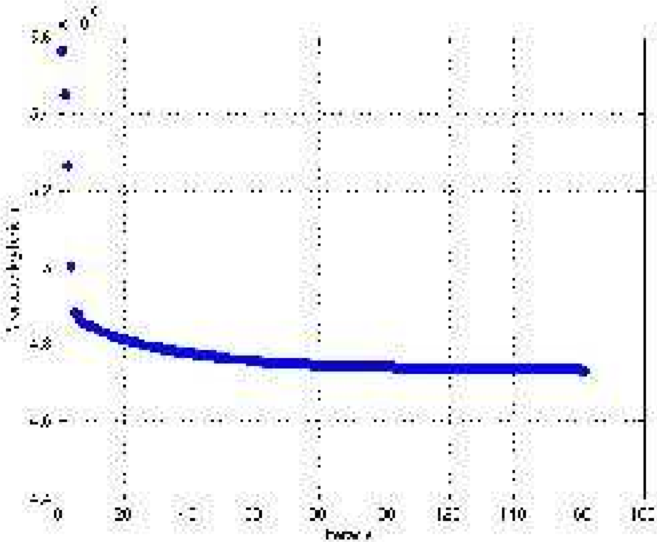
Identification procedures

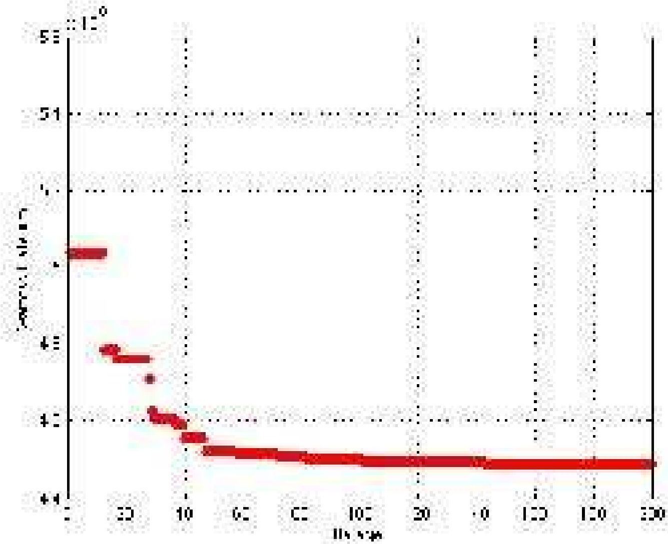
Typical plots for variable γ



Identification procedures

Typical plots of criterion value changes

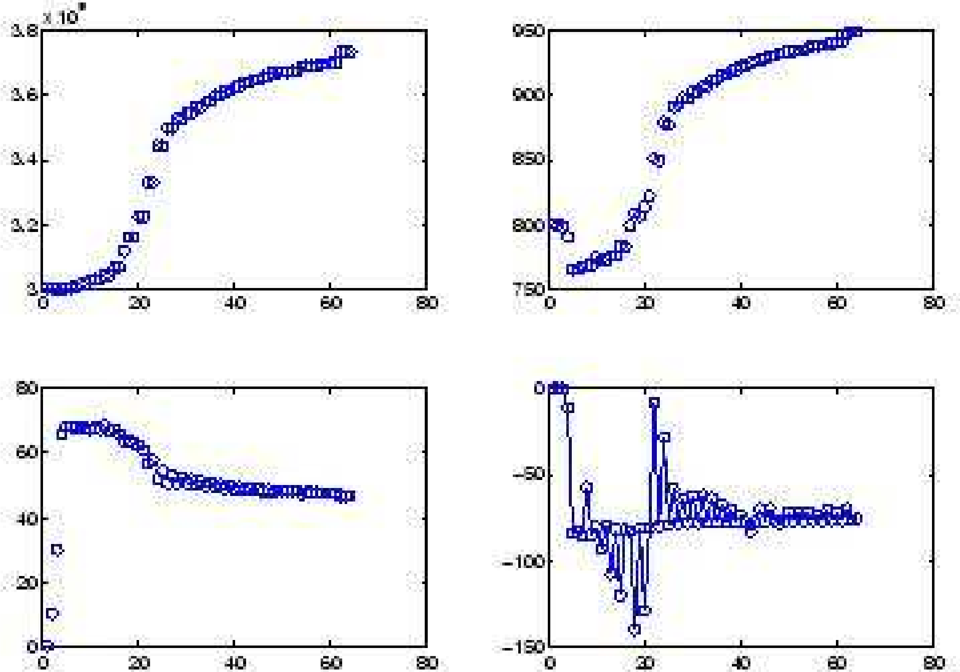




$$x_{CG} = [377079; 49; -324; -0,067; 6,92; 874]$$
$$x_{DE} = [431892; 38; -193; -0.062; 7.02; 971]$$

Identification procedures

Typical plots of identified parameters' values changes



Behind the scenes

Differential evolution algorithm

- One of the world fastest optimisation algorithm.
- Developed by Price & Storn for Chebyschev Polynominal fitting problem in 1995.
- Since that applied in many fields like:
  - digital filter design,
  - neural networks learning,
  - electricity market simulation,
  - wide range of optimisation problems.

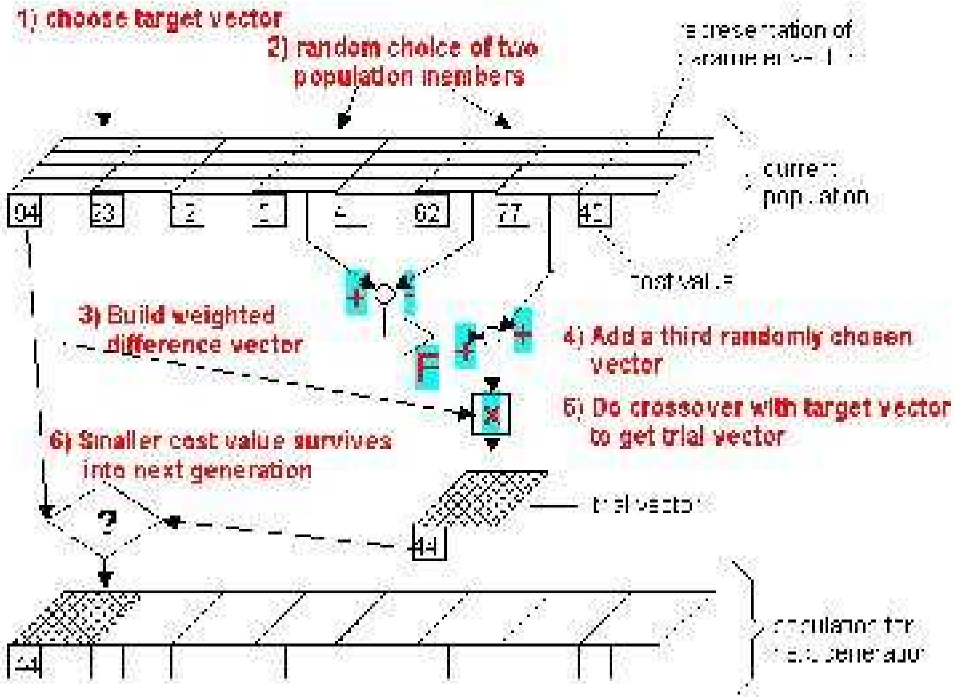
Behind the scenes

Differential evolution algorithm outline

- random choice of initial population of parameter vectors from defined range,
- computation criterion value for each vector,
- cross, according to selected strategy, two vectors and generate third one,
- build second generation of parameter vectors.

Behind the scenes

Differential evolution algorithm outline



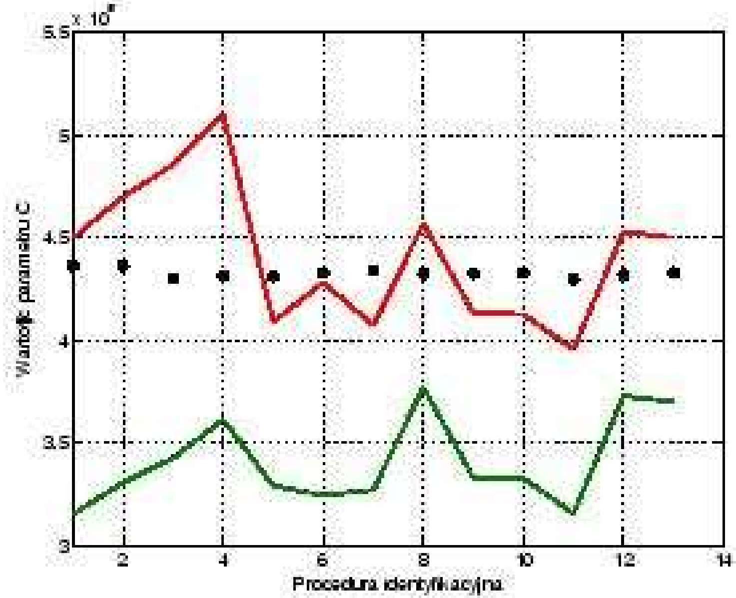
Behind the scenes

Example of cluster application

- 13 nodes were used,
- 13 ranges for initial vector parameters population were randomly chosen,
- 13 values for every parameter were computed in time needed for computation of 1 value on a single computer.

Behind the scenes

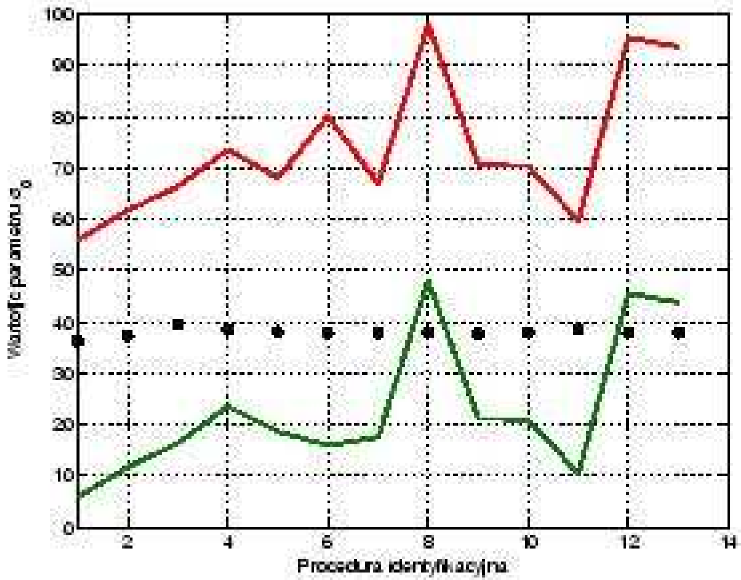
Example of cluster application



Parameter C obtained on cluster nodes and initial vector parameter range

Behind the scenes

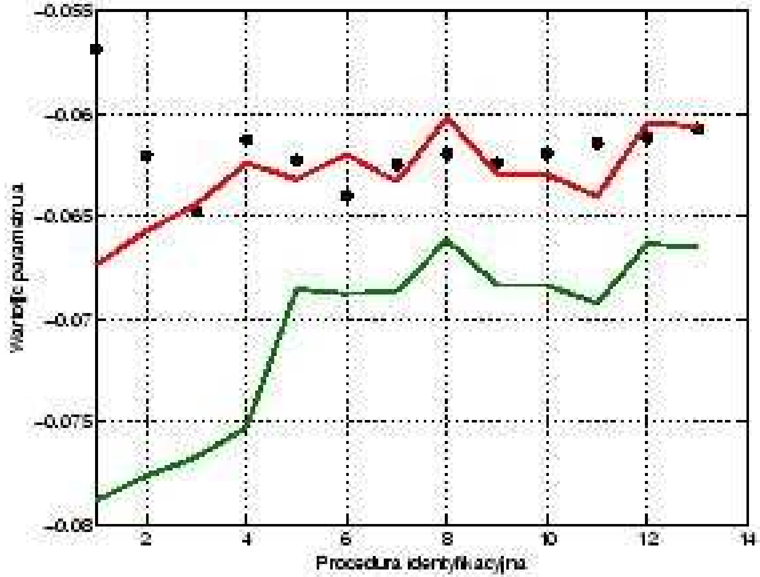
Example of cluster application



Yield point *R* value obtained on the cluster nodes and initial vector parameter range

Behind the scenes

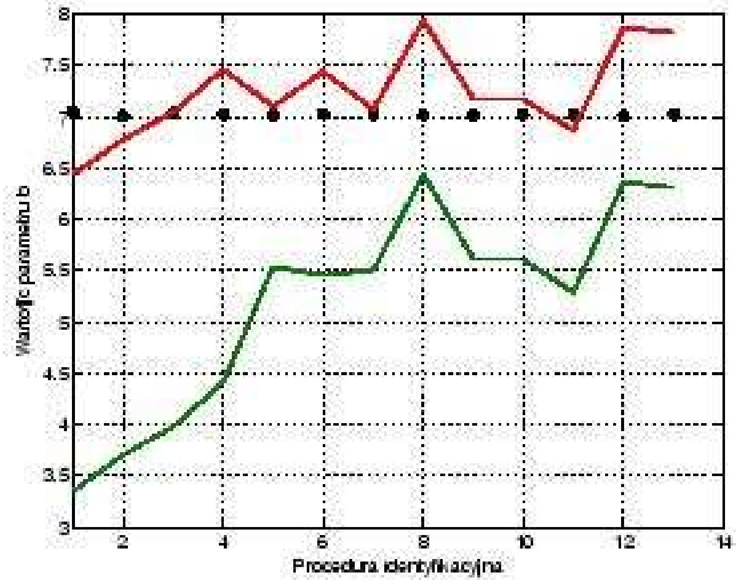
Example of cluster application



Parameter *a* obtained on the cluster nodes and initial vector parameter range

Behind the scenes

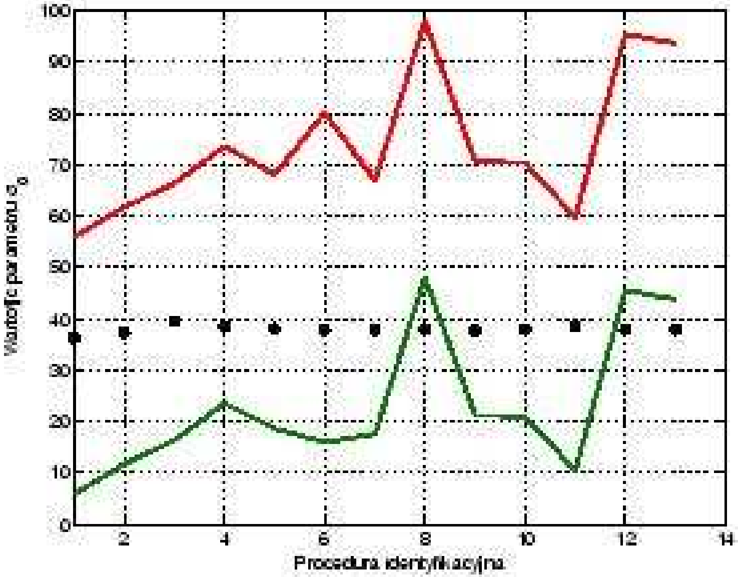
Example of cluster application



Parameter *b* obtained on the cluster nodes and initial vector parameter range

Behind the scenes

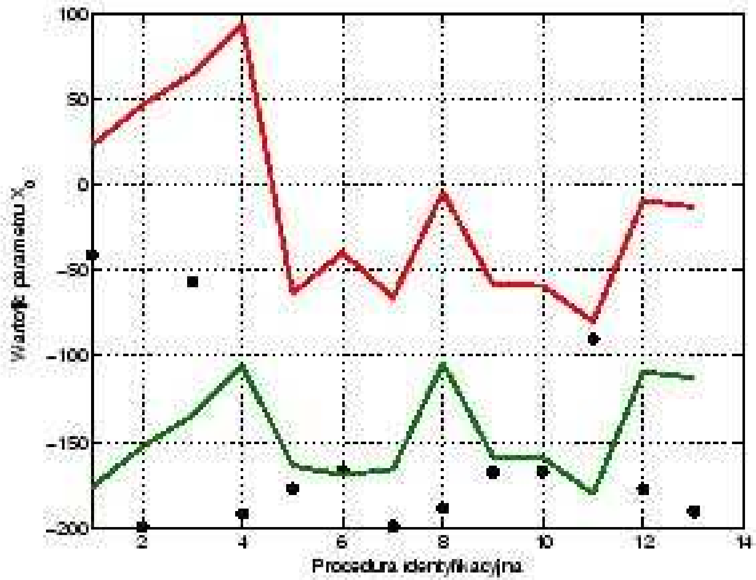
Example of cluster application



Parameter *c* obtained on the cluster nodes and initial vector parameter range

Behind the scenes

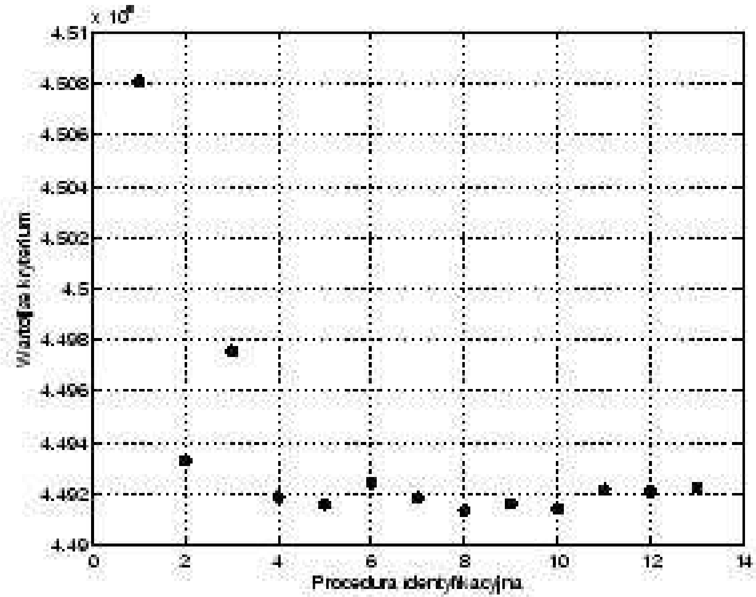
Example of cluster application



Parameter X_0 obtained on the cluster nodes and initial vector parameter range

Behind the scenes

Example of cluster application



Criterion value computed on the cluster nodes

Behind the scenes

Cluster facts

- Built upon computers regularly utilised in the Institute's computer laboratory.
- Consists of virtually the same 17 64-bit AMD Athlon machines (nodes) with 0,5GB RAM installed and over 100GB HDD.
- The nodes run Debian GNU/Linux operating system, Torque cluster software and Maui queuing application.
- Approximate total computing power is c.a. 18GFLOPS.

Summary

- differential evolution algorithm applied to the presented optimisation problem is faster and gives better fits than standard gradient algorithm,
- cluster computing significantly decreases computation time,
- the drawback of the presented approach is large amount of data to deal with,
- the drawback may be partially overcome by keeping clear structure and use of object-oriented programming techniques in optimisation and data manipulation procedures.

Literature

[1] Maciejewski, Ł., Myszka, W. and Ziętek G.: Estymacja parametrów nieliniowego równania konstututywnego przy obciążeniach cyklicznych. W: XXI Sympozjum Zmęczenie i Mechanika Pękania, Bydgoszcz 2006

[2] Storn, R. and Price, K.: Differential Evolution - a Simple and Efficient Adaptive Scheme for Global Optimization over Continuous Spaces. Technical Report TR-95-012, ICSI, March 1995.

Summary

Thank you for your attention!