SPP1712

Automatic development of material models at large strains using a genetic algorithm

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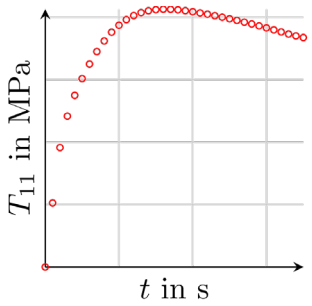
17th Technology Day

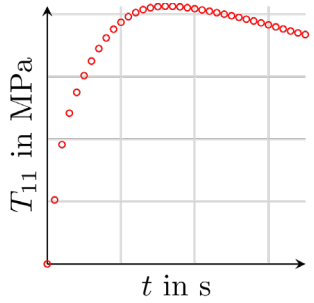
Werfenweng, 3rd March 2020

Process chain for the development of material models



basis for the development

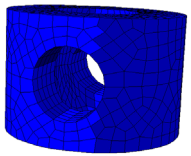
Process chain for the development of material models

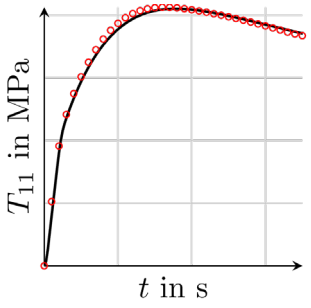


basis for the development

1. Analysis of experimental data to identify the phenomenology
2. Literature review
3. Formulation of the material model:
   - Rheological model
   - Formulation of free energy
   - Evaluation of Clausius-Duhem inequality
4. Development and implementation of solution procedure
5. Identification of material parameters

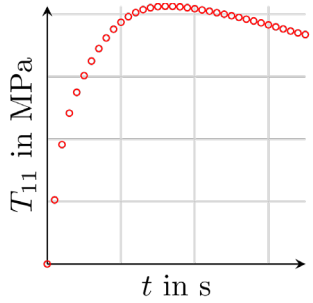
development of material models





aim of the development

Process chain for the development of material models



basis for the development

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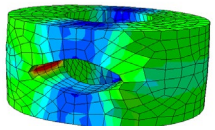
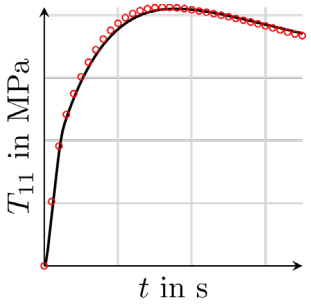
development of material models





aim of the development

Outline

1 Material modeling at large strains based on directly connected rheological elements

2 Encoding of rheological models

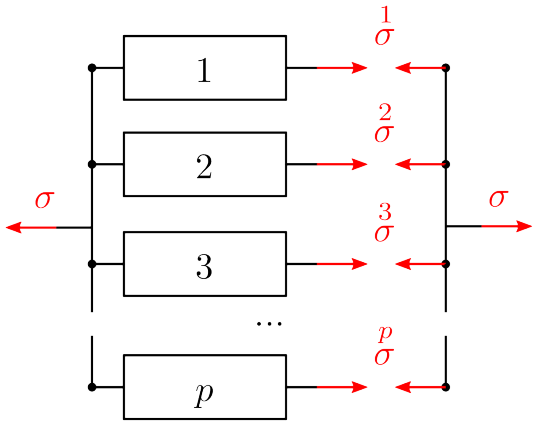
3 Genetic algorithm for the identification of material models

4 Results of first identifications

5 Concluding remarks

Connection relations of a parallel connection

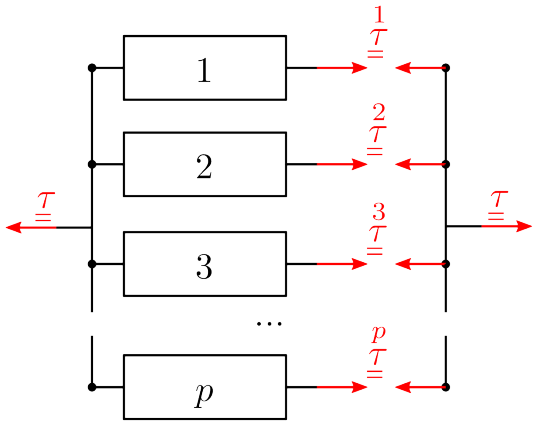
small strain



$$\varepsilon = \overset{1}{\varepsilon} = \ldots = \overset{p}{\varepsilon}$$

$$\sigma = \sum_{i=1}^{p} \overset{i}{\sigma}$$

large strain



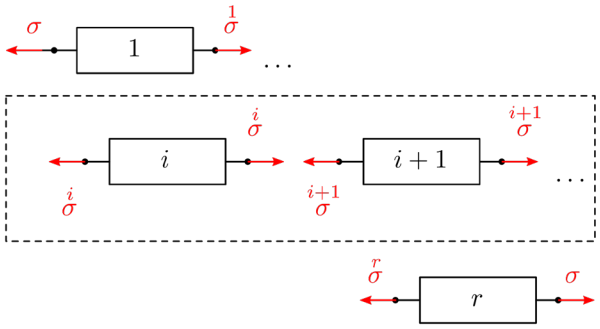
$$\underline{\underline{F}} = \overset{1}{\underline{\underline{F}}} = \ldots = \overset{p}{\underline{\underline{F}}}$$

$$\underline{\underline{T}} = \sum_{i=1}^{p} \overset{i}{\underline{\underline{T}}}$$

kinematic relation | kinetic relation

Connection relations of a series connection

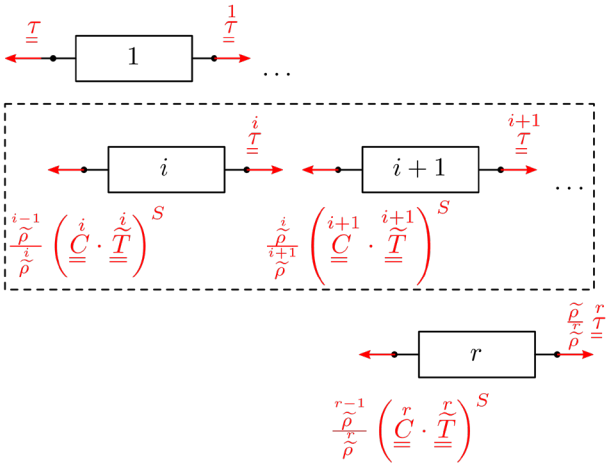
small strain



$$\varepsilon = \sum_{i=1}^{r} \overset{i}{\varepsilon}$$

$$\sigma = \overset{1}{\sigma} = \ldots = \overset{r}{\sigma}$$

large strain



$$\underline{\underline{F}} = \overset{r}{\underline{\underline{F}}} \cdot \overset{r-1}{\underline{\underline{F}}} \cdot \ldots \cdot \overset{1}{\underline{\underline{F}}}$$

$$\overset{i}{\underline{\underline{\tau}}} = \frac{\overset{i}{\widetilde{\rho}}}{\underset{i+1}{\widetilde{\rho}}} \left[\overset{i+1}{\underline{\underline{C}}} \cdot \overset{i+1}{\underline{\underline{T}}} \right]^S$$

$$\underline{\underline{\tau}} = \frac{\widetilde{\rho}}{\underset{r}{\widetilde{\rho}}} \overset{r}{\underline{\underline{\tau}}}$$

$$\underline{\underline{X}}^S := \frac{1}{2}\left(\underline{\underline{X}} + \underline{\underline{X}}^T\right), \quad \overset{i}{\underline{\underline{C}}} := \overset{i}{\underline{\underline{F}}}^T \cdot \overset{i}{\underline{\underline{F}}}$$

kinematic relation

kinetic relation

Rheological elements

elasticity | hyperelasticity

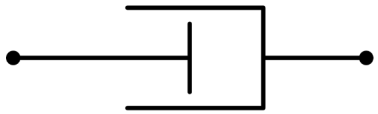
$$\sigma = E\,\varepsilon$$

$$\underline{\underline{\widetilde{T}}} \cdot \underline{\underline{C}} = 2\left\{\frac{\partial\,\widetilde{\rho}\psi}{\partial\,J_1}\left(\overset{G}{\underline{\underline{C}}}\right)' - \frac{\partial\,\widetilde{\rho}\psi}{\partial\,J_2}\left[\left(\underline{\underline{C}}^{-1}\right)^{G}\right]' + \frac{1}{2}\frac{\partial\,\widetilde{\rho}\psi}{\partial\,J_3}\underline{\underline{I}}\right\}$$

$$J_1 = \mathrm{tr}\left(\overset{G}{\underline{\underline{C}}}\right), \quad J_2 = \frac{1}{2}\left[\mathrm{tr}\left(\overset{G}{\underline{\underline{C}}}\right)^2 - \mathrm{tr}\left(\overset{G}{\underline{\underline{C}}}^2\right)\right], \quad J_3 = \sqrt{\det\left(\underline{\underline{C}}\right)}, \quad \overset{G}{\underline{\underline{X}}} = \det\left(\underline{\underline{X}}\right)^{-\frac{1}{3}}\underline{\underline{X}}$$

model kit

viscous flow



$$\sigma = \eta\,\dot{\varepsilon}$$

$$\underline{\underline{X}}^h = \frac{1}{3}\mathrm{tr}\left(\underline{\underline{X}}\right)\underline{\underline{I}}, \quad \underline{\underline{X}}' = \underline{\underline{X}} - \underline{\underline{X}}^h$$

$$\underline{\underline{\widetilde{T}}} \cdot \underline{\underline{C}} = f\left(\left(\underline{\underline{C}}^{-1} \cdot \dot{\underline{\underline{C}}}\right)\right)$$

$$\overset{\text{z.B.}}{=}\ \eta\left(\underline{\underline{C}}^{-1} \cdot \dot{\underline{\underline{C}}}\right)' + K\left(\underline{\underline{C}}^{-1} \cdot \dot{\underline{\underline{C}}}\right)^h$$

plastic flow

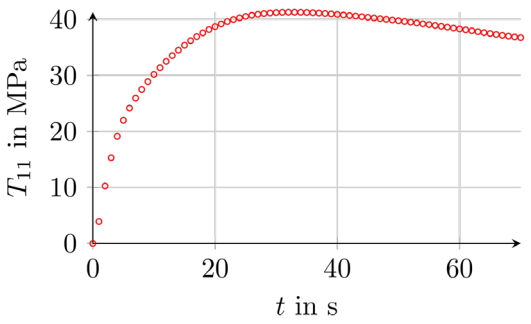
$$\dot{\varepsilon} = \chi\,\mathrm{sign}\left(\sigma\right)$$
$$\Phi = |\sigma| - \left[\sigma_F + R\left(\varphi\right)\right]$$
$$\chi \geq 0\,, \quad \Phi \leq 0\,, \quad \chi\Phi = 0$$

$$\left(\underline{\underline{C}}^{-1} \cdot \dot{\underline{\underline{C}}}\right)' = \chi\left(\underline{\underline{\widetilde{T}}} \cdot \underline{\underline{C}}\right)$$
$$\Phi = \sigma_v\left(\underline{\underline{\widetilde{T}}} \cdot \underline{\underline{C}}\right) - \left[\sigma_F + R\left(\varphi\right)\right]$$
$$\chi\Phi = 0\,, \quad \chi \geq 0\,, \quad \Phi \leq 0$$

Black Box for material model evaluation and parameter identification

Input

- set of experimental data



- rheological model
- initial parameters

Black Box

evaluation of material models:

- read the rheological model
- recursive evaluation of the connection relations

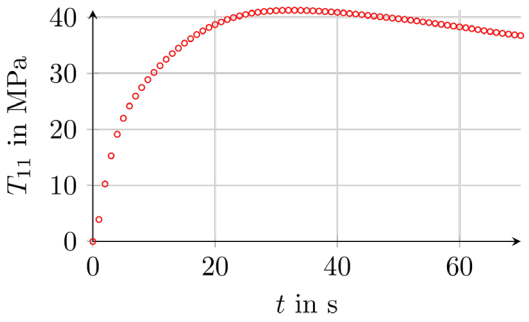
parameter identification:

- Levenberg-Marquardt algorithm
- parallel execution

Black Box for material model evaluation and parameter identification

Input

- set of experimental data

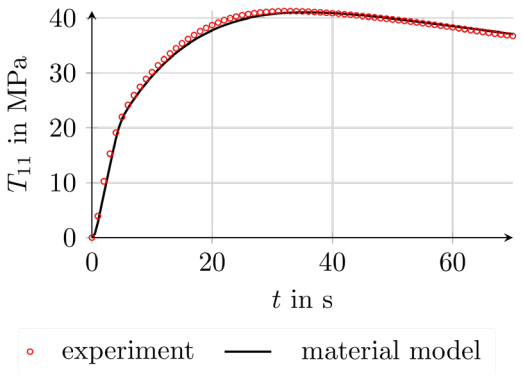


- rheological model
- initial parameters

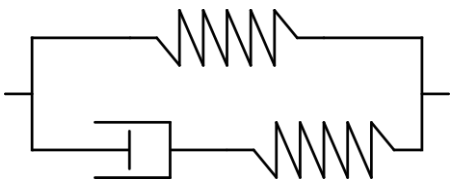
Black Box

Output

- identified material parameters
- error sum of squares
- error messages
- evaluated material model



Encoding of rheological models

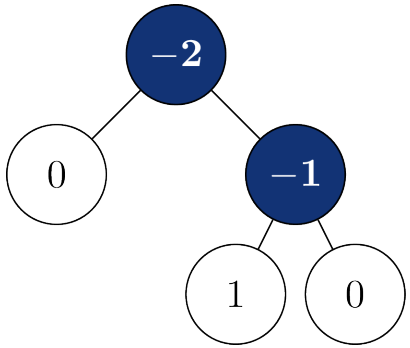


rheological connection

- tree encoding for rheological connections

function nodes

connection type	code
parallel connection	-2
series connection	-1



leaf nodes

code	element
0	hyperelasticity
1	viscous flow
2	plastic flow
3	Maxwell model
4	endochronic element

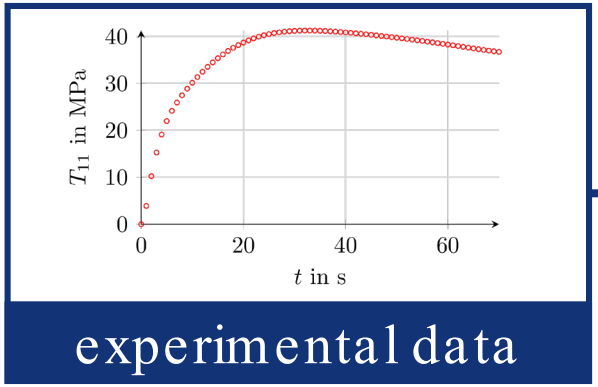
-2 2 0 -1 2 1 0

list of integers

Genetic algorithm for the identification of material models

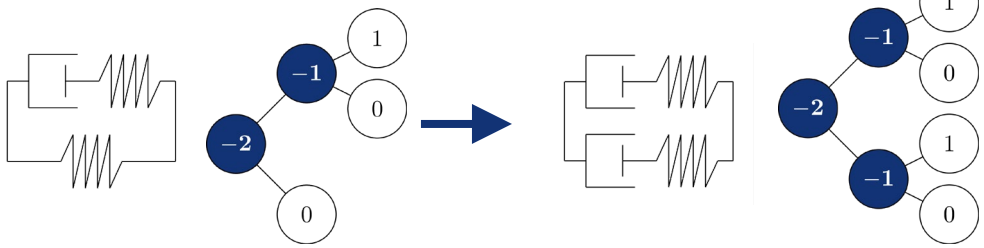
Motivation for genetic algorithm

genetic algorithm



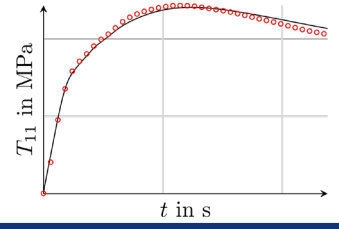
experimental data

- modification of known connections
- encoding of the rheological connection



creation of rheological models

- evaluation of connection
- parameter identification

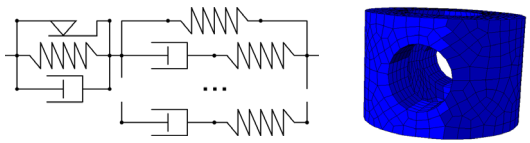


parameter identification

no

yes

$r \leq \mathrm{TOL}$

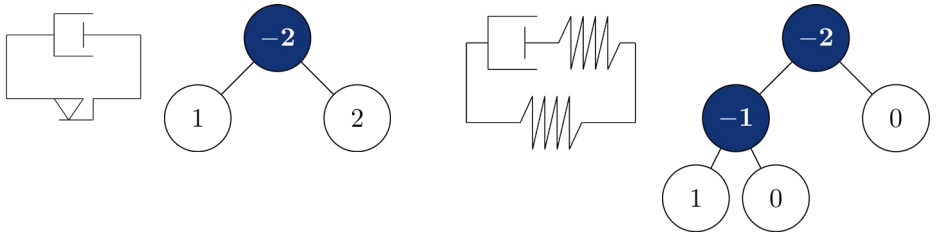


material model in FEM

Genetic algorithm - procedure

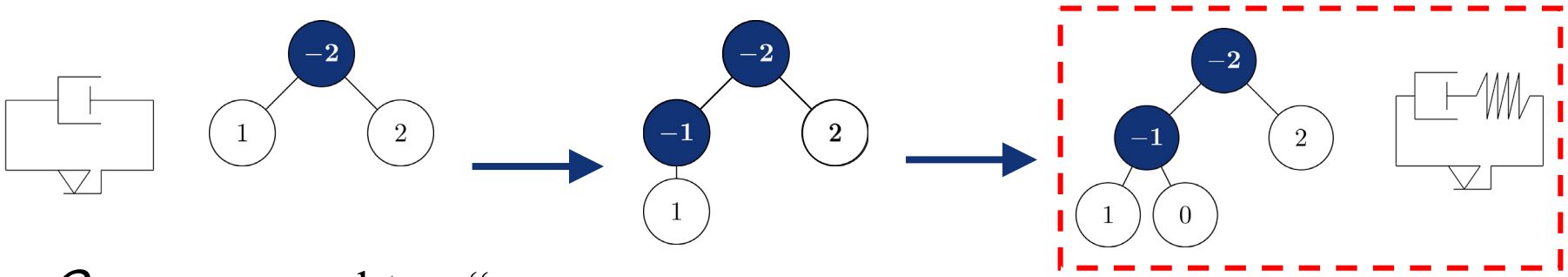
initial population

generation of new individuals

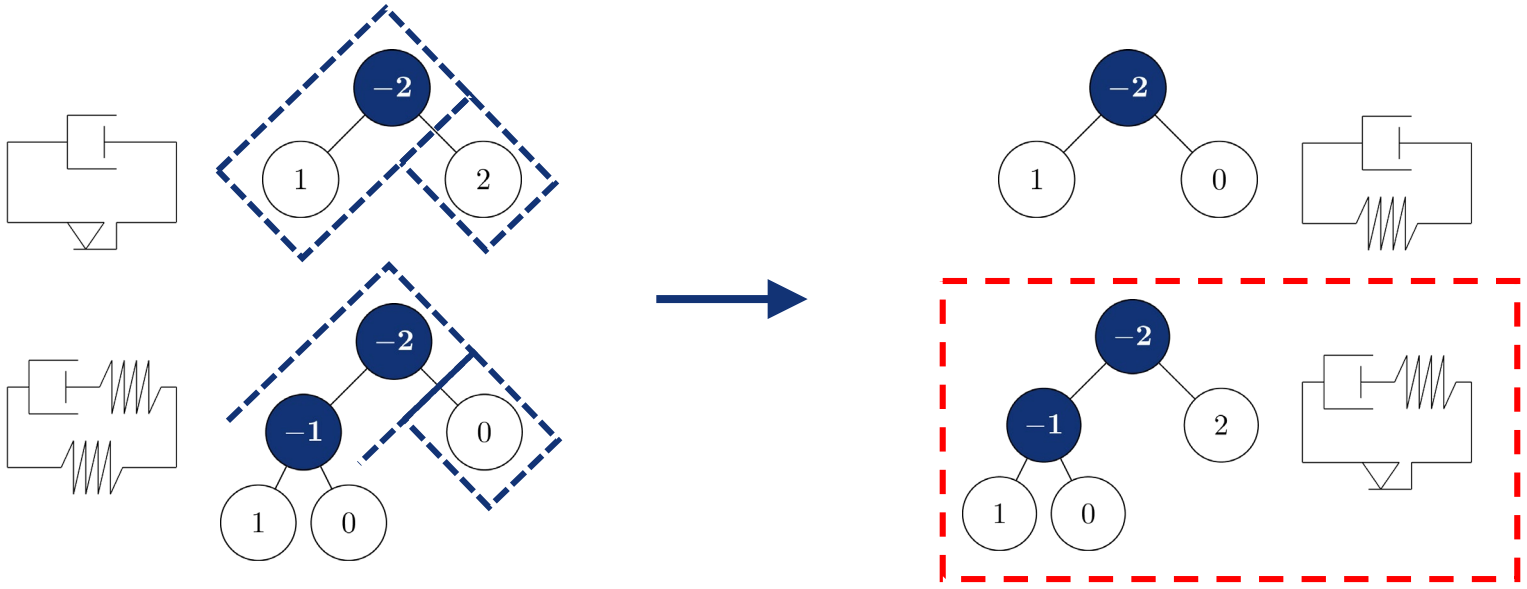


Genetic algorithm – operators (examples)

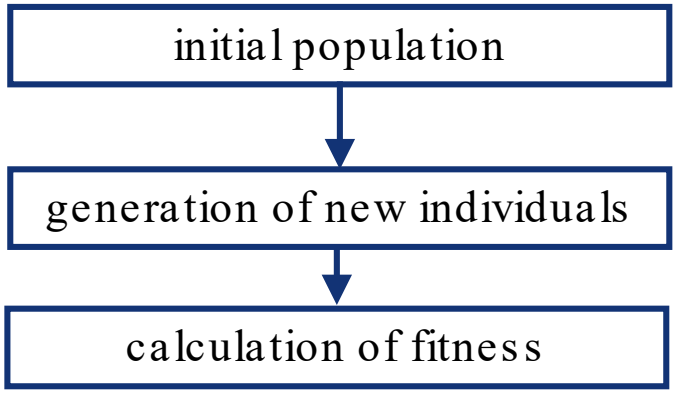
- *Mutation:* „add to leaf“

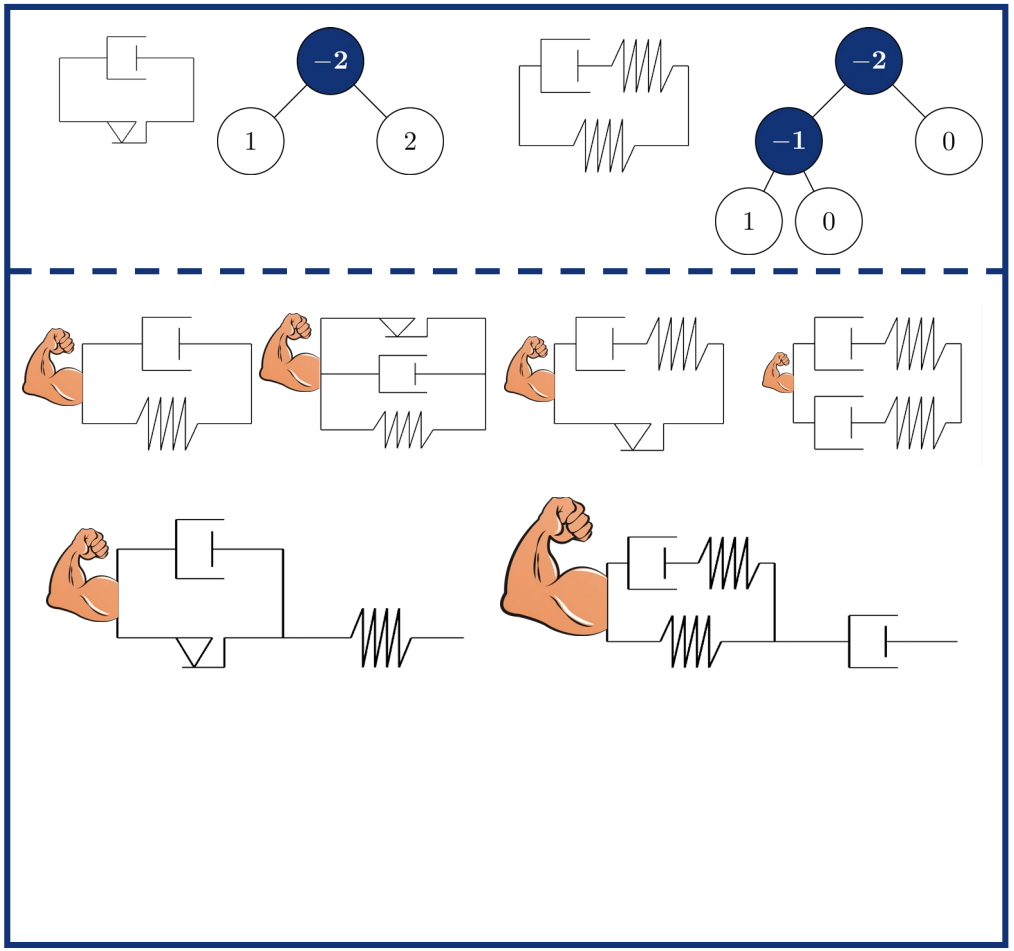


- *Crossover:* „subtree“

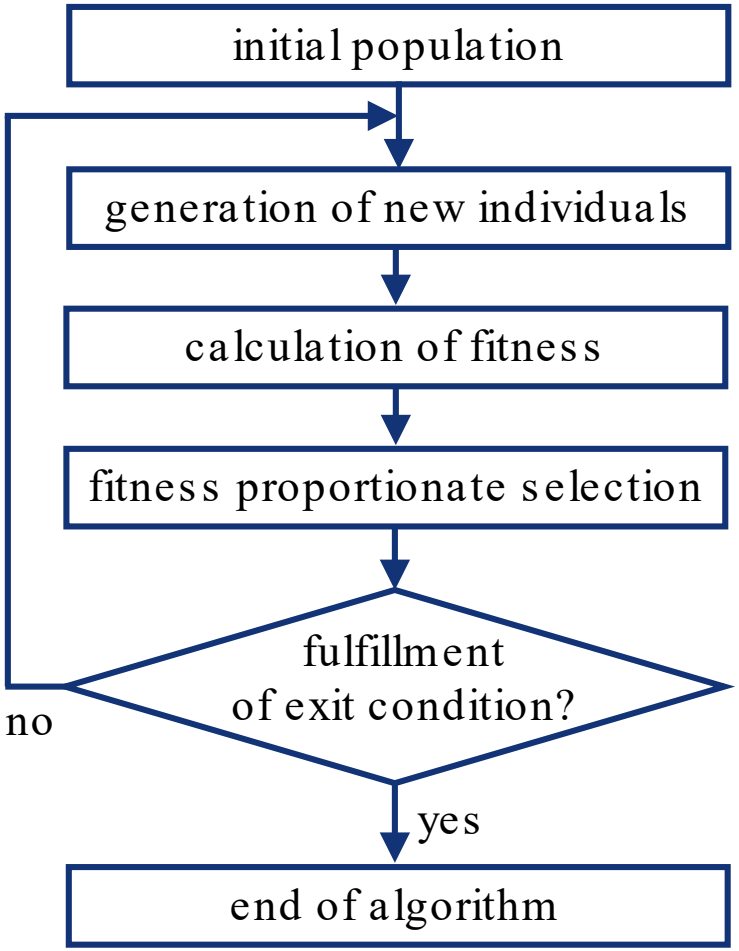


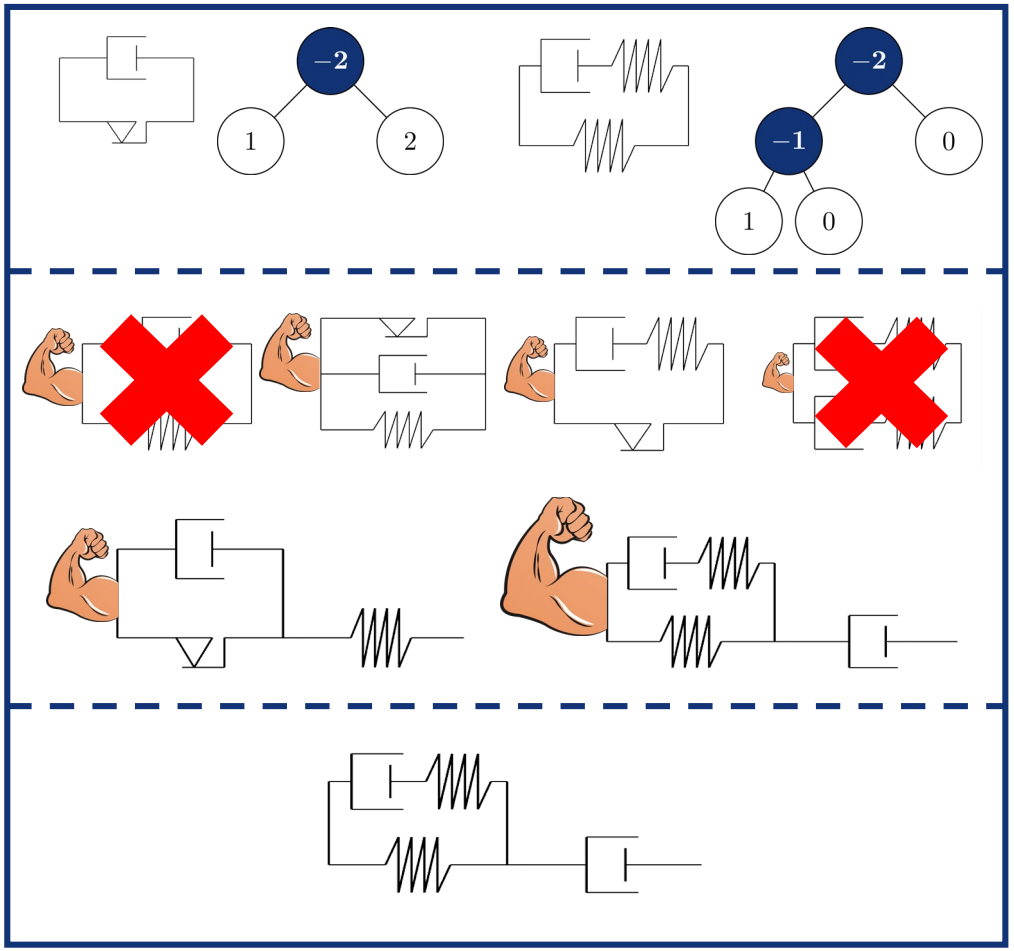
Genetic algorithm - procedure





Genetic algorithm - procedure

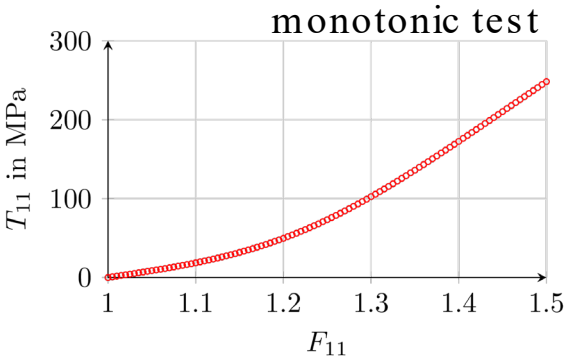


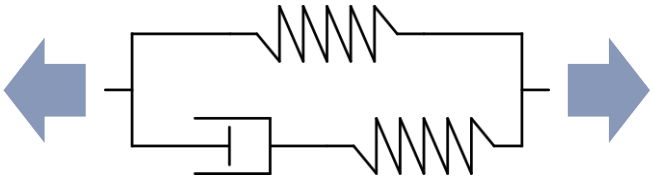


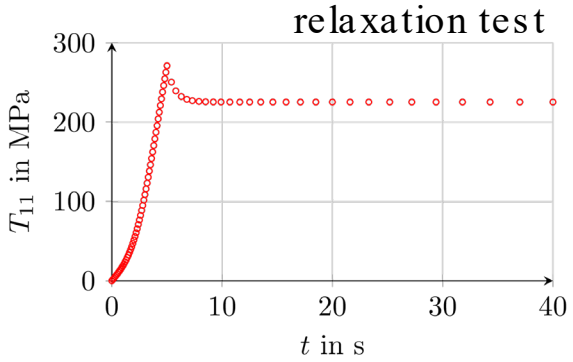
Results of first identifications

Validation using synthetic data (viscoelasticity)

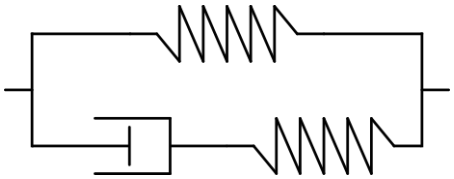
- synthetic data:



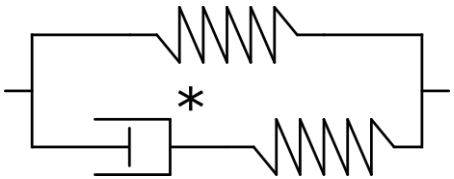




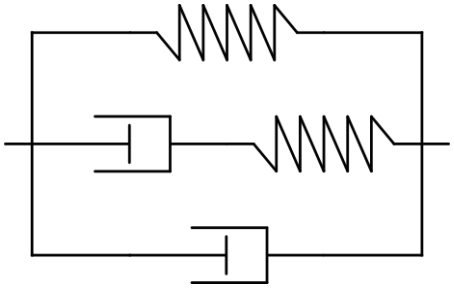
- identified material models:



7th generation,
34th individual



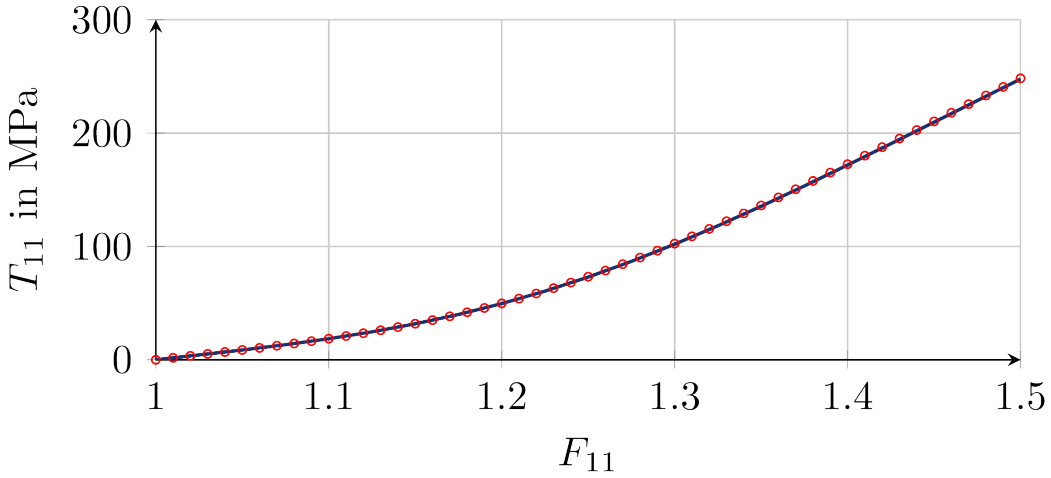
9th generation,
44th individual

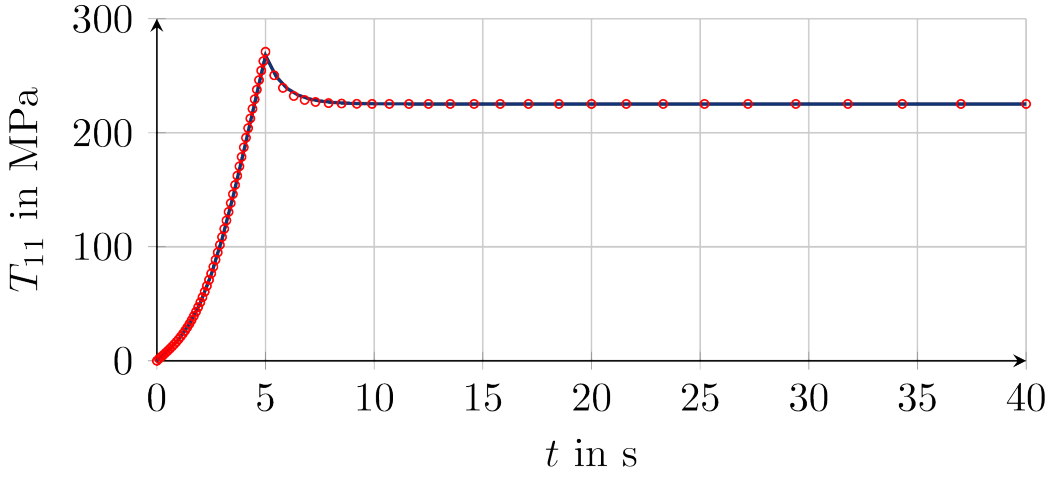


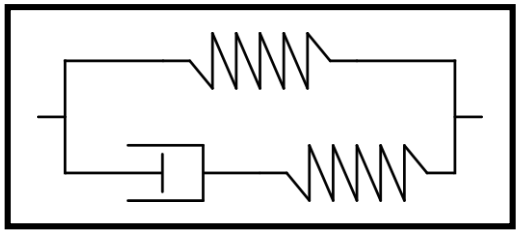
19th generation,
96th individual

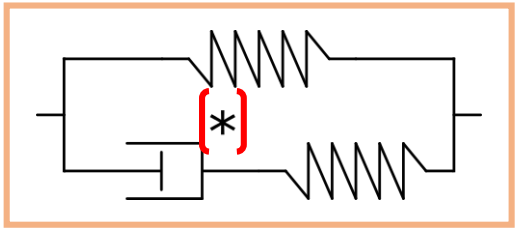
Results of first identifications

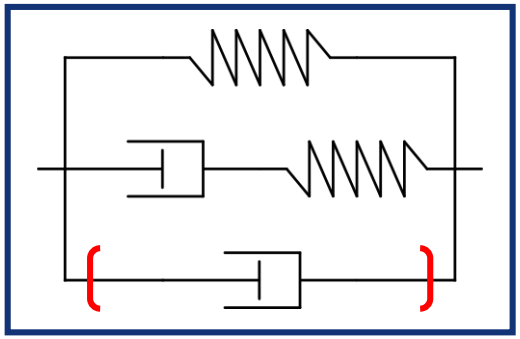
Validation using synthetic data (viscoelasticity)







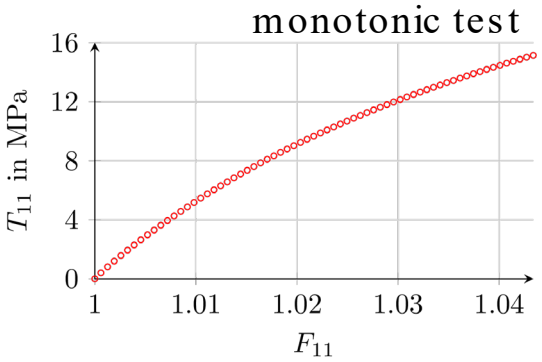


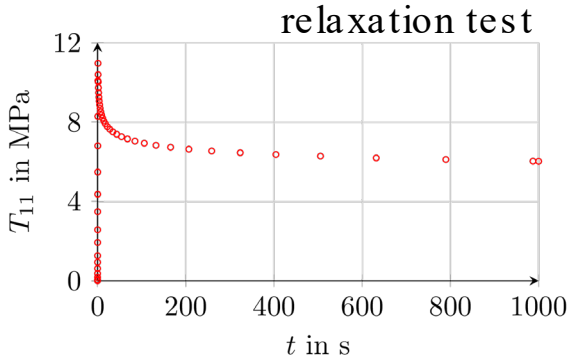


Results of first identifications

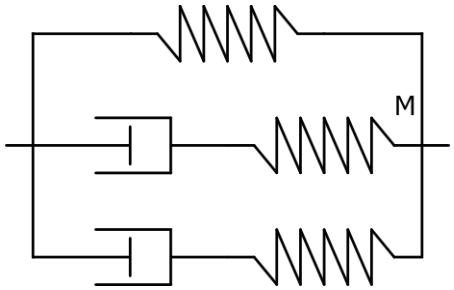
Testing with experimental data

- experimental data:

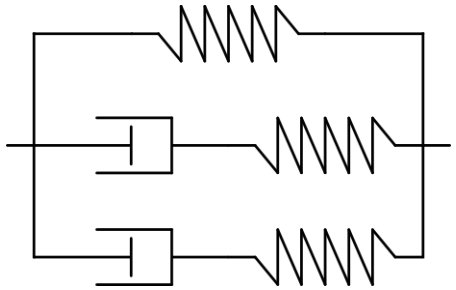




- identified material models:

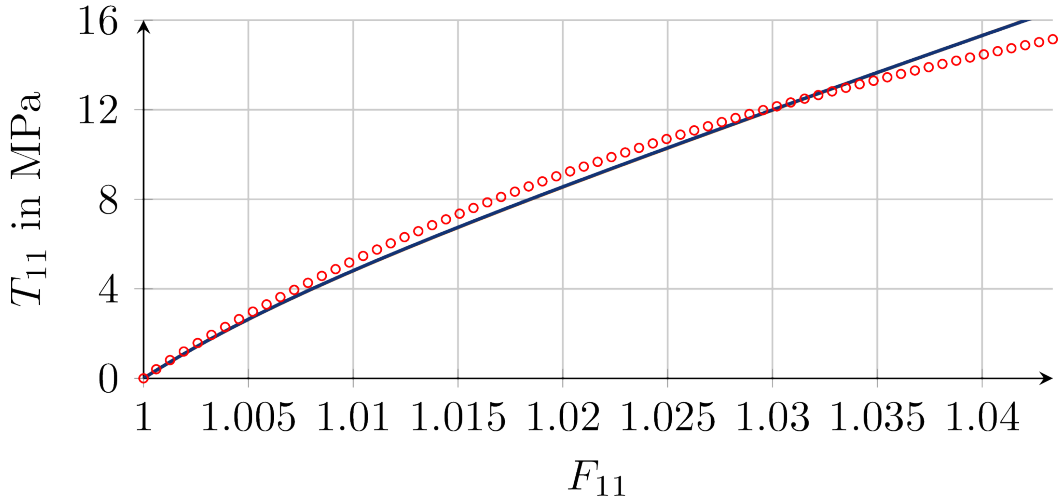


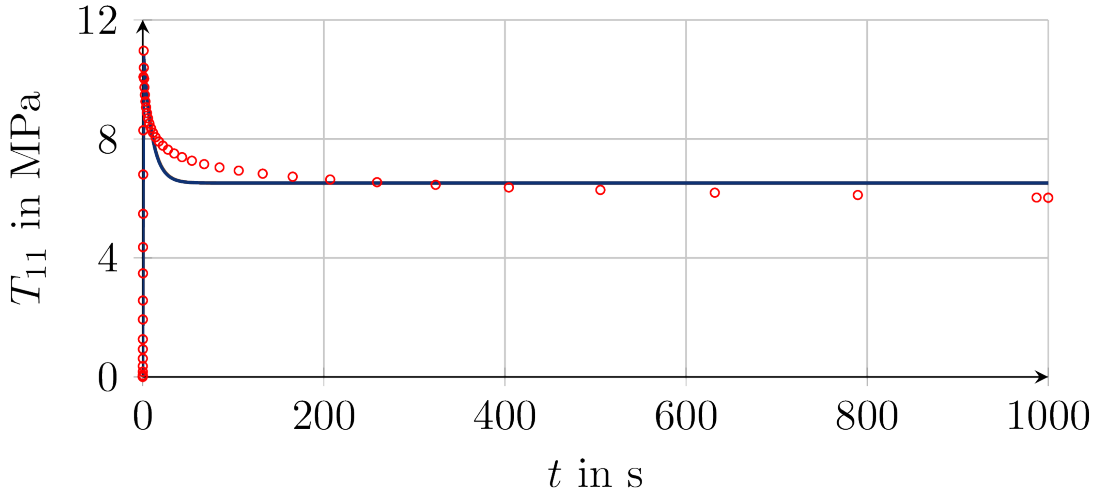
29th generation,
144th individual

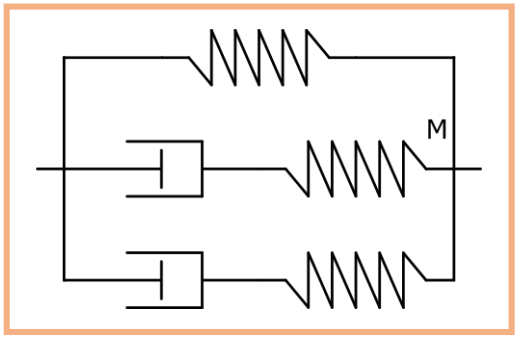


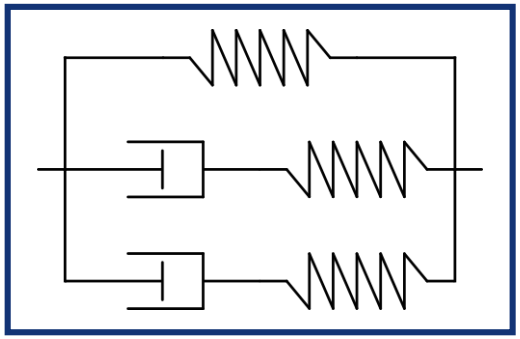
41st generation,
205th individual

Testing with experimental data

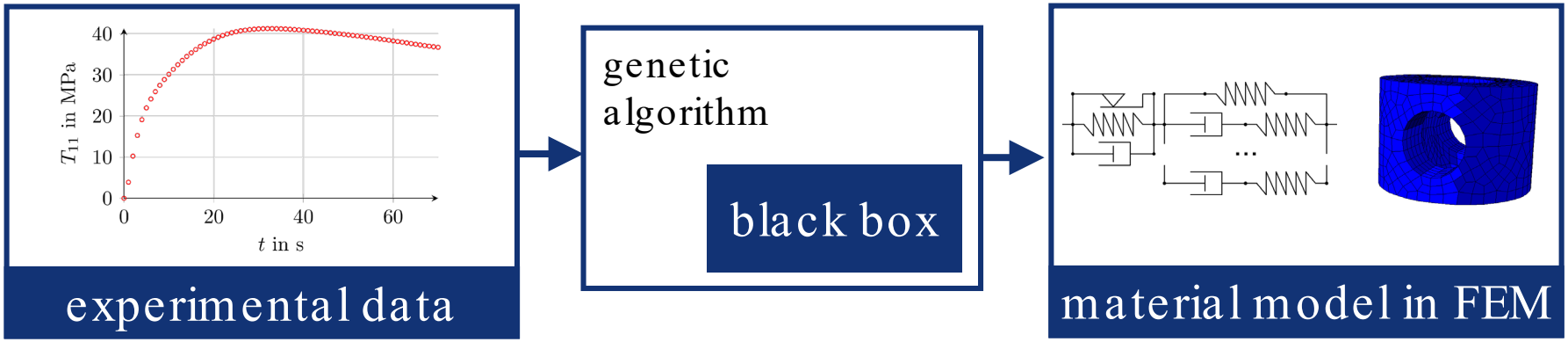








Concluding remarks



Summary

- realization of a method for the automated identification of material models at large strains
- first validation using synthetic data
- first testing with experimental data

Outlook

- improving the genetic algorithm and the black box
- definition of an experimental investigation procedure
- development of an analyzer of the experimental data

Concluding remarks

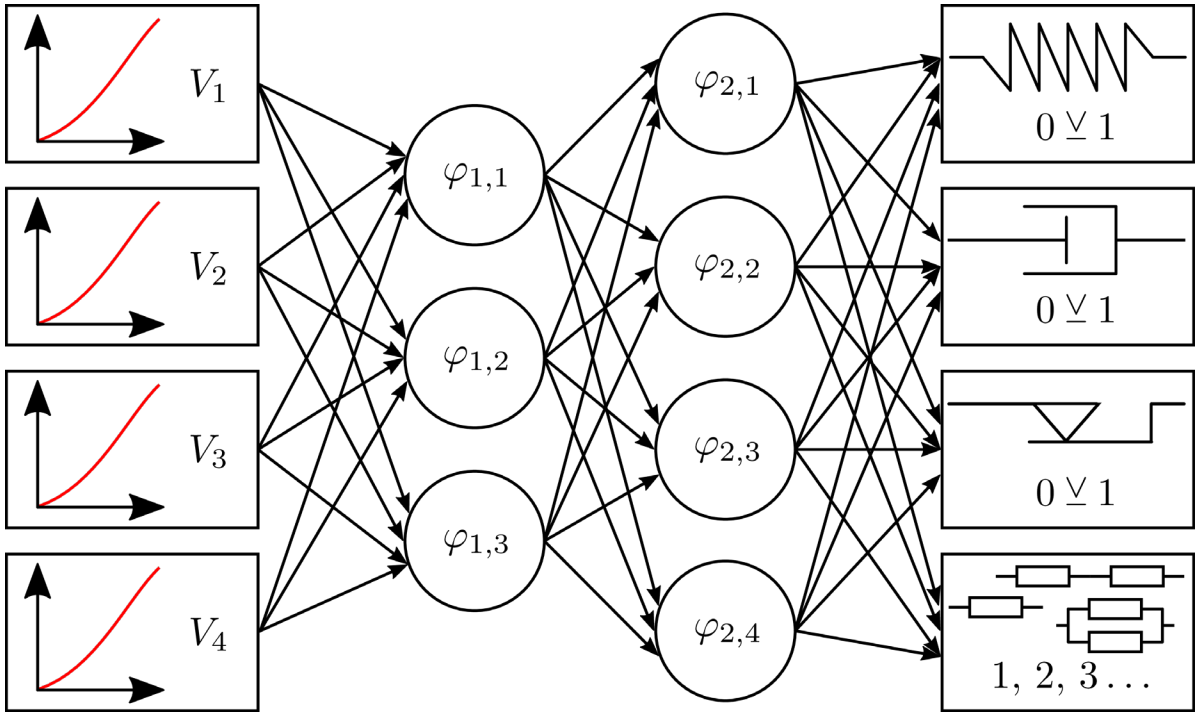
Outlook: Analyzer of the experimental data

Aim:

- *preselection of rheological elements and connection structures*

Idea:

- *definition of a testing directive and analysis with neural networks*



Thank you for your kind attention.

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