The University Of Sheffield.

On the use of Symbolic Regression for Population-Based Modelling of Structures

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OVERVIEW

- Motivation
- Population-based SHM
- Symbolic regression
- Crack-growth application example
- Conclusions

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MOTIVATION

- Scarcity of data
- Motivation from the functionality of physics-based models
- Structures with common physics

- Available data from populations of structures
- Especially in prognosis, damage-evolution data are rare

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POPULATION-BASED SHM

Population-based SHM:

- Motivated from healthcare practices
- Powerful transfer learning techniques
- Reduce the dependence on data
- Discovery of similar patterns in populations
- Often the only way to acquire damage-state data

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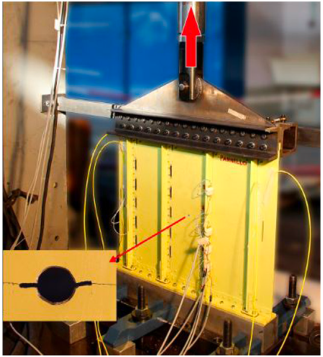
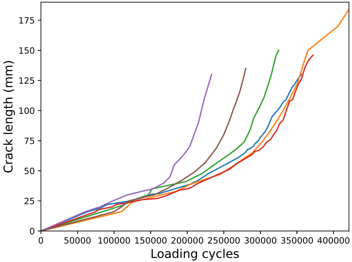
A simple crack-growth population example





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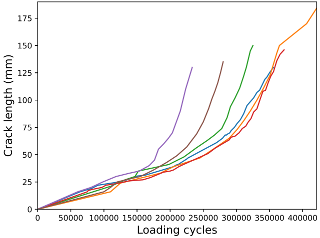
SYMBOLIC REGRESSION

Aims:

- Transfer learning for regression
- Attempt **one-to-one** transfer
- Imitate human inference methodology
- Discovery of common underlying functional form
- Learn an underlying skeleton from a **training** structure
- Fit the trainable parameters to new data from **testing** structure



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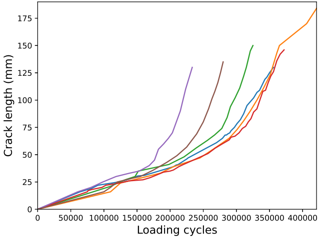
SYMBOLIC REGRESSION

- Pool of candidate functions
- Genetic algorithm to create combinations of the basic functions
- Python implementation PySR [1]
- Impose prior beliefs via the initial function pool
- Human-inference inductive bias of smoothness
- Learn from a **training** structure, test on a **testing** structure



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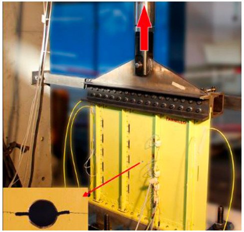
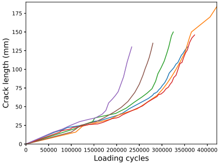
CRACK-GROWTH APPLICATION EXAMPLE

- Six nominally identical aluminium plates
- Cyclic loading
- Initialisation of a small crack
- Monitoring of the crack length as a function of the loading cycles [2, 3]





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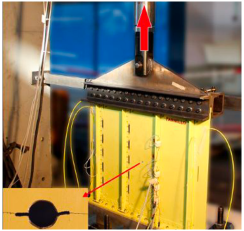
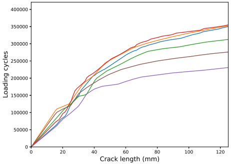
CRACK-GROWTH APPLICATION EXAMPLE

- Six nominally identical aluminium plates
- Cyclic loading
- Initialisation of a small crack
- Monitoring of the crack length as a function of the loading cycles [2, 3]
- Inversion of the input and output variables
- Consider critical crack length of 125mm





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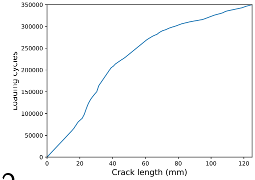
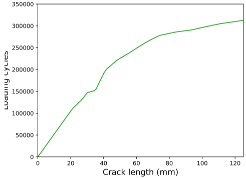
CRACK-GROWTH APPLICATION EXAMPLE

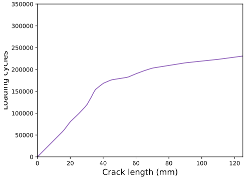
Training plate



Training plate 2



Training plate 1



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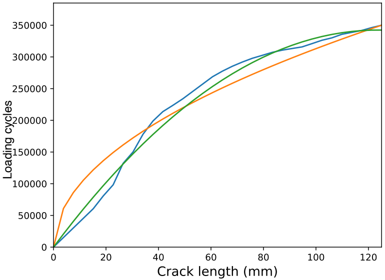
CRACK-GROWTH APPLICATION EXAMPLE

Fitted functions to the training data



$$N_1 = 1.0221437\sqrt{x}$$
$$N_2 = 1.9781963594752x - x^2$$

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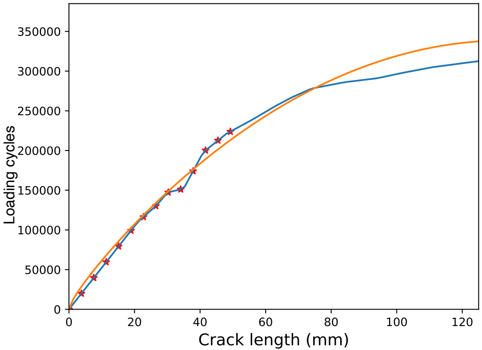
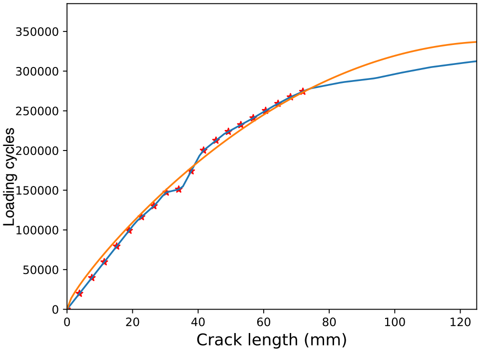
CRACK-GROWTH APPLICATION EXAMPLE

Results 1st testing structure



40% of the curve observed



60% of the curve observed

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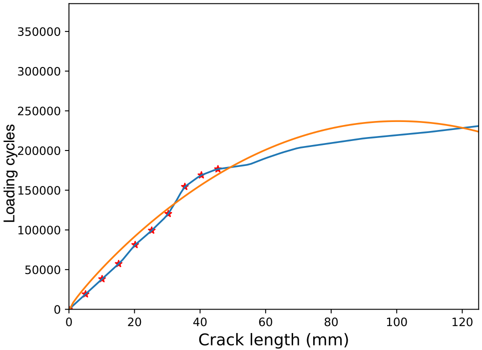
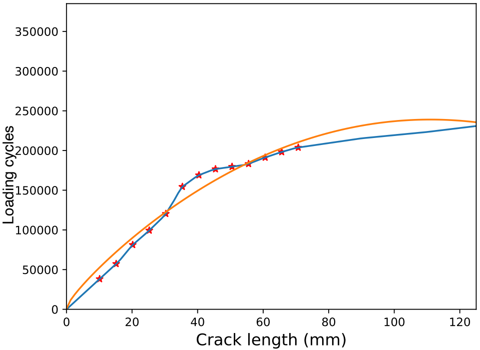
CRACK-GROWTH APPLICATION EXAMPLE

Results 2nd testing structure



40% of the curve observed



60% of the curve observed

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CONCLUSIONS & FUTURE STEPS

- Promising results for one-to-one regression transfer learning
- Some artefacts which could be corrected imposing physical knowledge
- A many-to-one framework could improve the results
- A Bayesian fitting during testing could provide confidence intervals
- New deep-learning promising approaches for symbolic regression that scales could lead to improved resutls

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[3] M. Corbetta et al. "On dynamic state-space models for fatigue-induced structural degradation". In: *International Journal of Fatigue* 61 (2014), pp. 202–219.

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Thank you!