Engineering design of 1D rod and 2D pin-jointed frame structure driven by reinforcement learning and finite element analysis

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1. Introduction

Artificial intelligence is a very powerful tool for inference that is widely used nowadays in many domains of knowledge. One possible application of AI is to engineering design which is a quite tiring process as one needs to make a lot of iterations before resulting in the final design. But this process can be automated by the power of AI. For these models, I combined reinforcement learning with finite element analysis to: (a) optimize cross-sectional area and material in one-dimensional bar, and (b) design pin-jointed frame structure, automatically. Models show some ways on how reinforcement learning can assist in engineering design.

2. Model

For reinforcement learning algorithm, the finite element model represents an environment which you apply actions to. The actions, in this case, are (a) altering values of cross-sectional area and Young's modulus, and (b) moving joint along horizontal axis in the frame. Actions that reduce displacements in a structure, measured by FEA, get rewards. Rewards and FE output then fed to neural network for the next iteration (Figure 1).

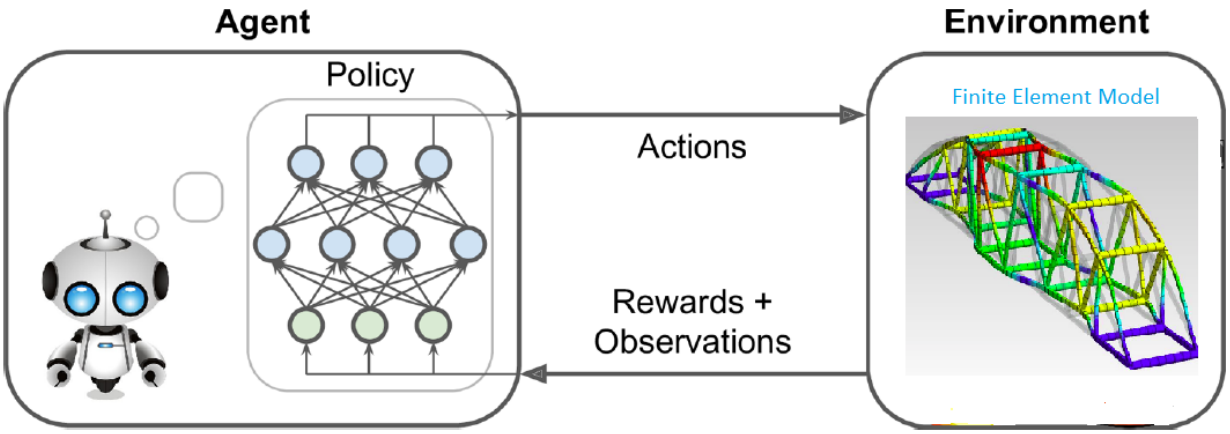

Figure 1. Reinforcement learning to FE model interaction

Model (a) is a 1D bar loaded at its tip (Figure 2). AI tries to find optimal cross-sectional area and Young's modulus, i.e. optimize for geometry and material in the simplest one-dimensional case, in order to have acceptable displacement in tip node (4).

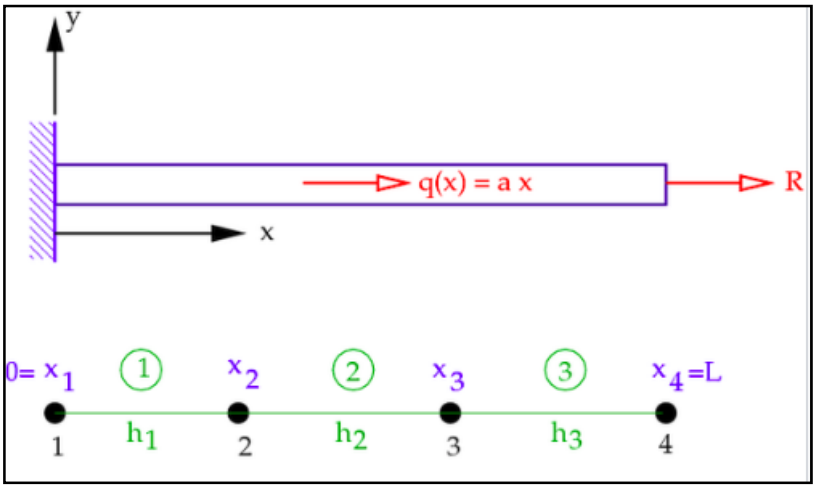

Figure 2. FE model for task (a)

Model (b) is a two-dimensional pin-jointed stricture loaded at node (6) as shown in Figure 3. AI tries to optimize the position of element (3)-(5) by allowing its "asynchronized" movement along horizontal axis in order to minimize displacements in the structure.

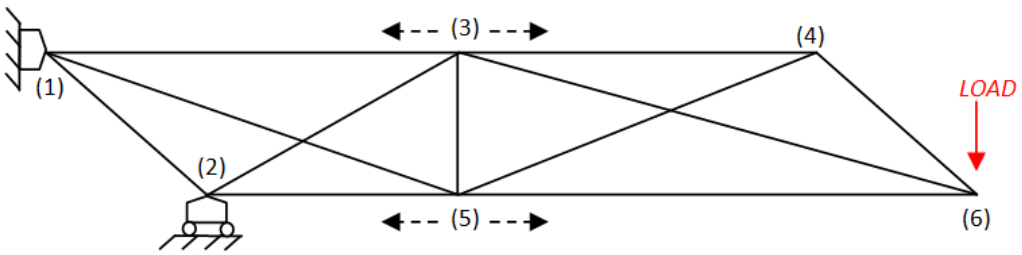

Figure 3. FE model for task (b)

Both, model (a) and (b) optimize to reduce displacements in the structure.

The code for reinforcement learning model is taken from [1]. RL model uses neural network policy gradient algorithm. The algorithm optimizes the parameters of a policy by following the gradients toward higher rewards. The end result of the modeling is a design of (a) bar and (b) pin-jointed frame structure that preserves displacements within acceptable limits.

The code for FE model is taken from [2], Program 4.1 and 4.2.
The source code for the model can be found at [3].

3. Conclusion

AI in general and reinforcement learning in particular is a powerful tool to support engineering design. For this model, I combined RL with FEA in order to get optimal design of structures. The work shows some ways to combine two fields of knowledge: artificial intelligence and finite element analysis. One can experiment with the code at [3].

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4. References

[1] Hands-On Machine Learning with Scikit-Learn and TensorFlow, *Aurŭlien Gŭron*
[2] Programming the finite element method, *I. M. Smith et al*, 5th edition
[3] https://github.com/gigatskhondia/Reinforcement_Learning_and_FEA