A Reinforcement Learning Based Design Method

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Topic of assignment: Developing AI-design guidelines for using reinforcement learning based topology optimization for students of industrial design and mechanical engineering.

Background information: The client was Bojana Rosic, of the Applied Mechanics and Data Analysis group of the MS3 department at the University of Twente. The Applied Mechanics and Data Analysis research group is involved in predictive analysis of engineering systems by creating an interplay between physics based models and data analysis (Applied Mechanics and Data Analysis [AMDA], 2020). The reason for the organization to offer the assignment was because the student inquired for an assignment because he was interested in the possibility of automated design.

Relevance: With a method for automated design using reinforcement learning, topology optimization is applicable on trusses, which are used in various fields, ranging from civil engineering to biomedical engineering and material science. The use of this algorithm significantly improves on efficiency (Hayashi, K., & Ohsaki, M., 2020). In addition, the reinforcement learning based design method is powerful, because it is model-free (Sutton, R. S., & Barto, A. G., 2018), i.e., there is no need to parametrize the design problem.

Main research question: The main research goal is to develop AI design guidelines for the implementation and application of reinforcement learning based topology optimization.

Approach: In order to come up with AI design guidelines for reinforcement learning based topology optimization, literature research is done from an implementation and application point-of-view. Research questions are drawn up in order to discuss a general set-up of the design method, customization of the algorithm for different starting conditions and requirements stemming from application, for the research model see Figure 1. With the knowledge gained from answering the research questions an implementation of the design method is described to make it more concrete. With the concrete implementation it is also made apparent how to customize the algorithm through changing the design parameters.

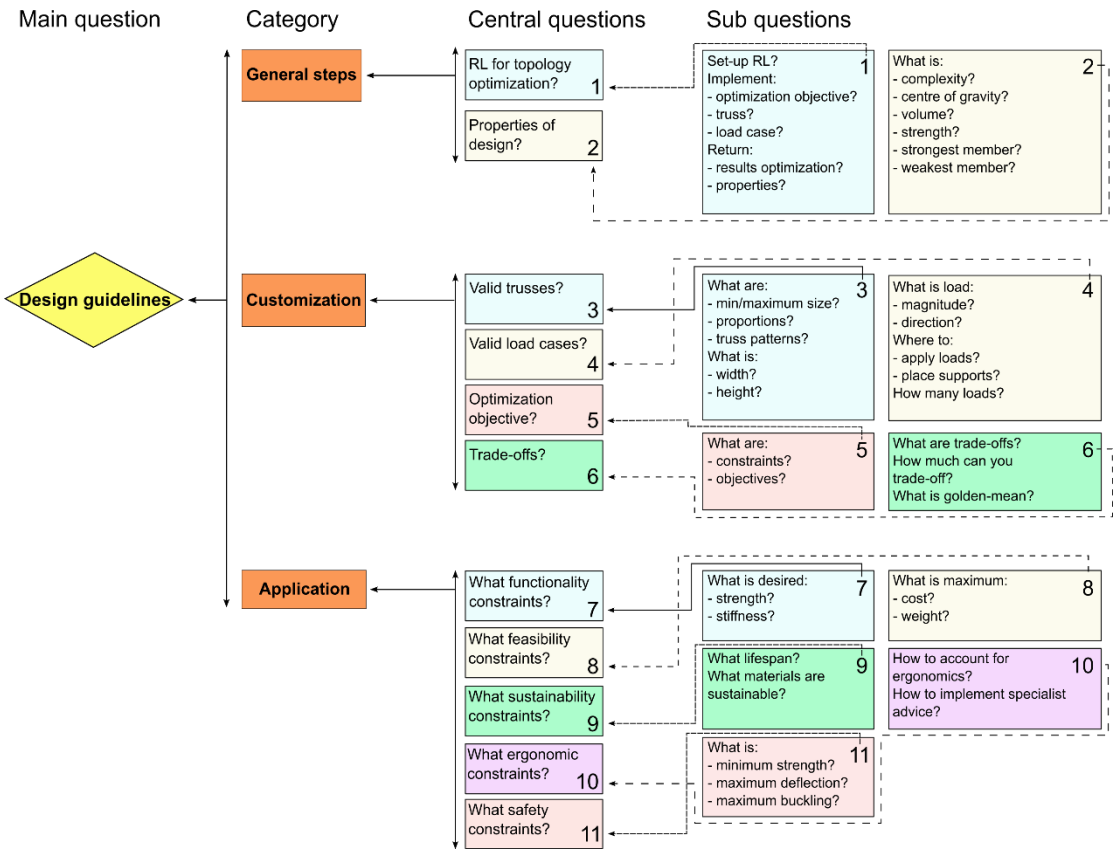

Figure 1: Research model

Results: A general design method is devised based on the literature research on the general set-up and customization steps, and by working out the concrete implementation. This design method is visualized in Figure 2. The designer starts with a problem, an object to be designed, like a bridge. The bridge is then modelled as a ground structure, see for this transformation Figure 3. In addition, optimality criteria are devised based on the design's application. These consist of the objective function, the optimization goal; and the constraints, which describe limits on parameters. Then reinforcement learning is set up, which is visualized in Figure 4. The actions and rewards are implemented by the designer and are defined to reach the objective function. The states are implemented by modelling the ground structure through the Finite Element Method. In addition the agent is implemented to solve the reinforcement learning problem and take into account the constraints. With reinforcement learning set-up, the agent can start learning. After the learning, a solution is found for the design problem, which the designer can evaluate.

Some limitations of the research done is that the implementation of the design method could not be tested. An implementation was practically coded, but it was not possible to make the algorithm work in the time given. Therefore some questions on the customization of the algorithm could not be practically verified, and therefore assumptions were made that rely on literature research.

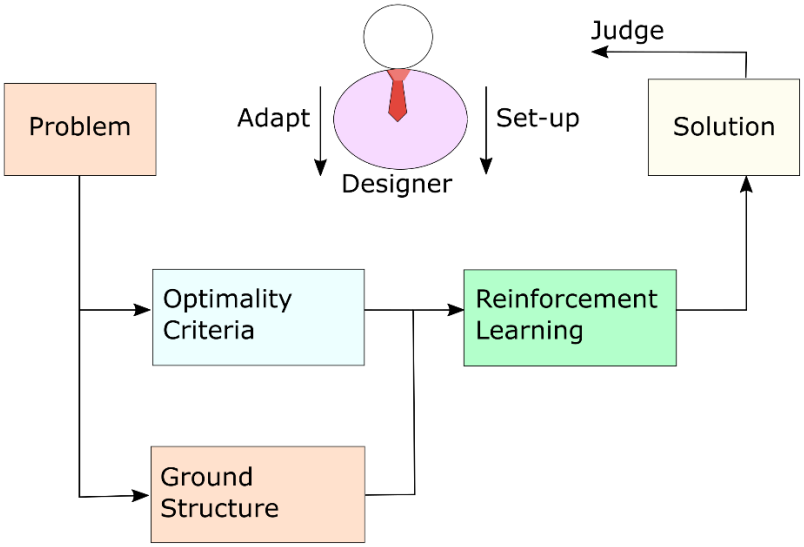

Figure 2: Reinforcement learning based design method

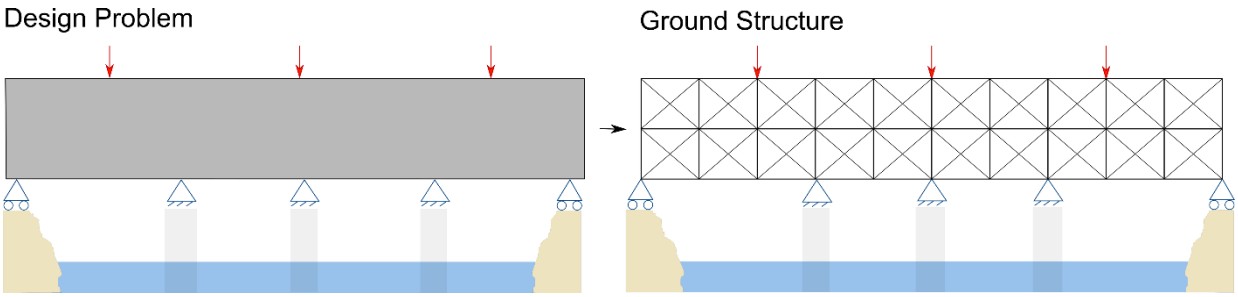

Figure 3: Problem to ground structure

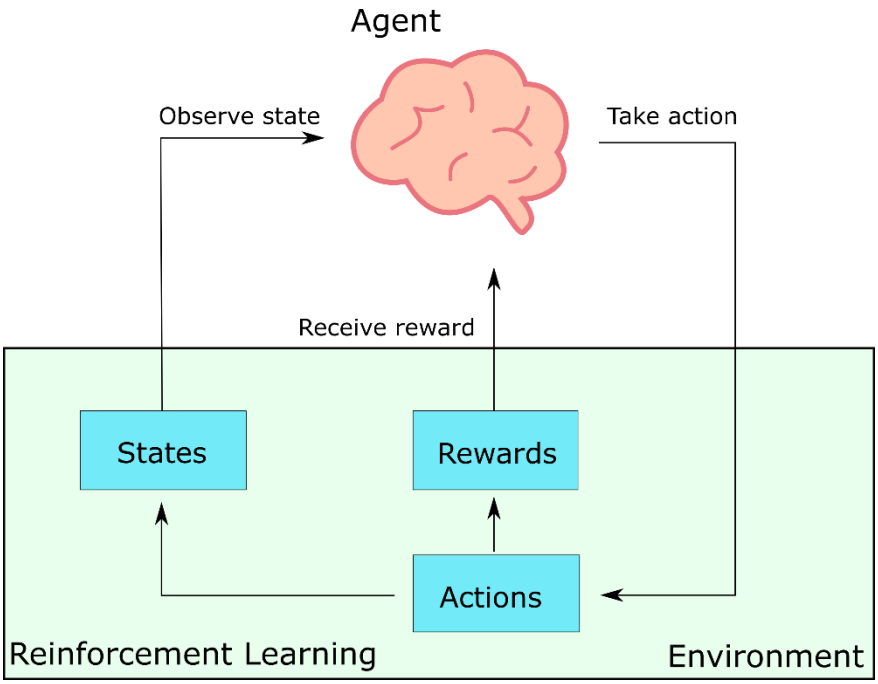

Figure 4: Reinforcement learning set-up

Conclusions and recommendations: Design guidelines have been outlined by discussing the research questions, and by discussing an implementation of the design method. To further improve on the quality of the discussion, an implementation of the design method can be programmed in order to evaluate the effect of changing the design parameters on the design solution. In addition, to improve on the AI design guidelines themselves, theories on design methodologies can be consulted and adhered to, to improve on the accessibility of the design method for students. The design method can be made more systematic and discussions on AI design guidelines can be done for more general use-cases.

References:

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Hayashi, K., & Ohsaki, M. (2020). Reinforcement Learning and Graph Embedding for Binary Truss Topology Optimization Under Stress and Displacement Constraints. *Frontiers in Built Environment*, *6*. https://doi.org/10.3389/fbuil.2020.00059

Sutton, R. S., & Barto, A. G. (2018). *Reinforcement Learning: An Introduction (Adaptive Computation and Machine Learning series)* (second edition). A Bradford Book.