ENSIAS

Truss Structures Optimization Using Neural Networks and Genetic Algorithms

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Overview

Introduction: Optimization

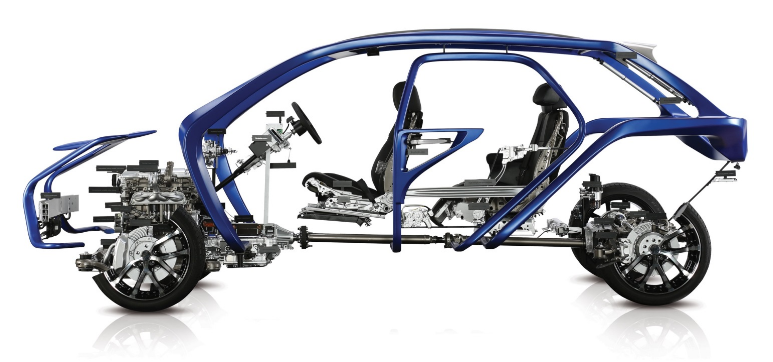
- Optimization is a concern of the various actors in many areas including consultancies in mechanical disciplines.
- An optimization problem seeks to find the better solution to a problem respecting a number of constraints.

Introduction: Structural Optimization

- For shape optimization, the objective is to seek the best structure that ensures efficient performance at minimum cost: minimum weight , minimum volume, minimum deformation energy or other.
- According to G. Allaire [1], we distinguish between three categories of shape optimization problems:
  - One that seeks the best dimensions of a structure.
  - Another that change only the coordinates of the structure borders without changing its topology.
  - And last, gives the possibility to modify the initial topology of the structure without restrictions to find the best possible shape: it is the topology optimization.

- Structural optimization have been used in many real world applications:

Optimizing a car chassis

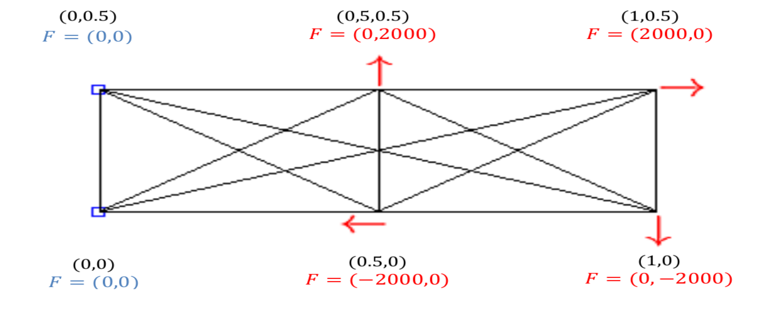


Figur: A Car Chassis

Project Scope: Goal

- The goal of our project is to optimize this truss structure:

Truss Topology



Figur: Truss Structure Topology

- The goal of the optimization is to find the optimal cross section areas of each bar in this structure by utilizing the deformation energy $C(x) = \frac{1}{2}F^tU$ of the structure as the function to minimize, since it is a function of these cross sections.

Problem Formulation

Problem Formulation

$$
\begin{aligned}
\min_{x \in U_{ad}} \quad & C(x) = \frac{1}{2} F^t U \\
\text{s.t.} \quad & K(x)U = F \\
& \sum_{j=1}^{n} l_j x_j \leq V_{max}
\end{aligned}
\tag{1}
$$

Problem Specifications

- The feasible set for the optimization problem, U_{ad}, is given by:

$$U_{ad} = \{x \in \mathbb{R}^n : x_j^{min} \leq x_j \leq x_j^{max}, j = 1, 2, \ldots, n\}$$

- Where x_j^{min} and x_j^{max} are respectively the maximal and minimal cross section areas allowed for the j-th bar.
- m is the number of free nodes of the truss, that is to say, nodes whose displacement is not constrained by the boundary conditions.
- $U \in \mathbb{R}^{2m}$ stands for the displacement vector.
- $F \in \mathbb{R}^{2m}$ stands for the vector of loads applied on the nodes of the structure.
- $K(x)$ stands for the stiffness matrix of the structure.

- Another way of solving the same problem is to approximate the compliance using an artificial neural network and then use the ANN model as the function to minimize:
- The measure of success in our situation, since we have a regression problem,

$$y = C(x) = ANN(x) + \epsilon \tag{2}$$

is the MSE (Mean Squared Error)

$$E = \frac{1}{m}\sum_{i=1}^{m}(ANN(x_i) - y_i)^2.$$

So we need to minimize E to get a good approximation on a training data set and also on a validation dataset in order to avoid over-fitting.

- After training the neural network we will use it as the compliance function that we need to minimize.

$$\min_{x \in \mathbb{R}_n} ANN(x) \tag{3}$$

- We minimized the truss structure using a real valued genetic algorithm that is adapted to constrained optimization problems.

Genetic Algorithms: Definition

- In general, a genetic algorithm is composed out of:
  - Representation (Definition of Individuals):
  - valuation Function (Fitness Function):
  - Population:
  - Parent Selection Mechanism:
  - Variation Operators (Mutation and Recombination):
  - Survivor Selection Mechanism (Replacement):
  - Initialization:
  - Termination Condition:
- Each one of these components can be implemented in many ways.

Genetic Algorithms: Implementations

- In the context of real-valued genetic algorithms these components are presented as follows:
- Representation:
  - The individuals in the context of Real-valued GA needs to be presented by a vector $(x_1, x_2, \ldots, x_n), x_k \in \mathbb{R}$ and $k = 1, 2, \ldots, n.$
- Evaluation function:
  - The evaluation function in our 1 problem is going to be the deformation energy, while in 3 problem it is going to be presented by the approximating ANN.
- population:
- The population is presented by a set of vectors of 13 dimensions that represent the 13 transversal sections of the bars.

- Parent selection mechanism:
  - The parent s are selected randomly according to the uniform distribution.
- Variation operators:
  - In our program the first operation is crossover followed by mutation.
- Crossover:
  - After generating a number (number of population individuals) of parents randomly, crossover will be applied randomly to a $\frac{nc}{2}$ individuals by selecting two random parents x_1 and x_2 and generate new offspring as follow:

$$y_1 = \alpha x_1 + (1 - \alpha) x_2$$

$$y_2 = \alpha x_2 + (1 - \alpha) x_1$$

And α is a random vector. This type of cross-over is called "simulated binary crossover".

- Mutation:
    - Mutation is performed by taking a random individual and changing a number (related to mutation rate) of randomly selected elements in it as follow.
- Survivor Selection Mechanism:
    - After generating a crossed population and mutated population, we combine them with the original population in one big population, sort them using the evaluation function from the individual with the smallest evaluation to the one with the biggest, and take the first size of population individuals from the population, to process the same in the next iteration.
- Termination Condition:
    - The algorithm is terminated after a number of iterations.