Lecture 2

Structural Optimization with Continuous and Discrete Variables

Design parameterization

ME260 Indian Institute of Science

Structural Optimization: Size, Shape, and Topology

G. K. Ananthasuresh

Professor, Mechanical Engineering, Indian Institute of Science, Bengaluru

suresh@iisc.ac.in

Outline of the lecture

Understanding the spirit of optimization

What makes up an optimization problem?

What is structural optimization?

Topology, shape, and size

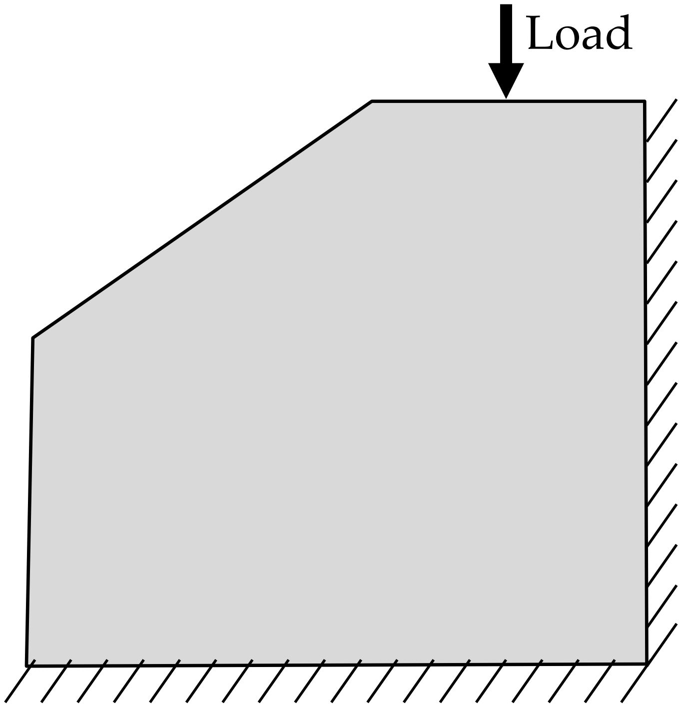
What we will learn:

What is optimization? Philosophically and mathematically?

What is structural optimization? Hierarchy in structural optimization.

How do we distinguish among topology, shape, and size?

Consider a 2D structural optimization problem



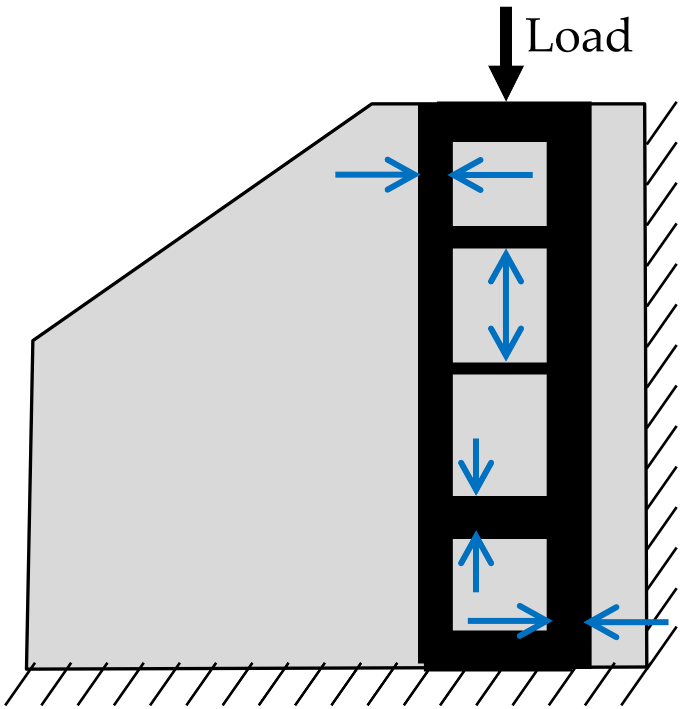
The region shaded in gray color is the design domain. You need to have your structure within that 2D domain.

There is a load. Suppose that you are allowed to fix your structure anywhere on the two edges shown with / / / /. You can have one or more fixed parts on these edges.

Assume that you are asked to minimize the displacement at the point of application of the load. This will be a measure of stiffness. The lower the displacement, the higher the stiffness.

If you have unlimited material with you, you will fill the entire design domain to maximize the stiffness. But, let us say that you can only fill 30% of the domain with material. Now, the problem becomes interesting.

Size optimization of structures



Size optimization implies that you will have a few size-related variables that you can play with. So, you first need to assume topology and size.

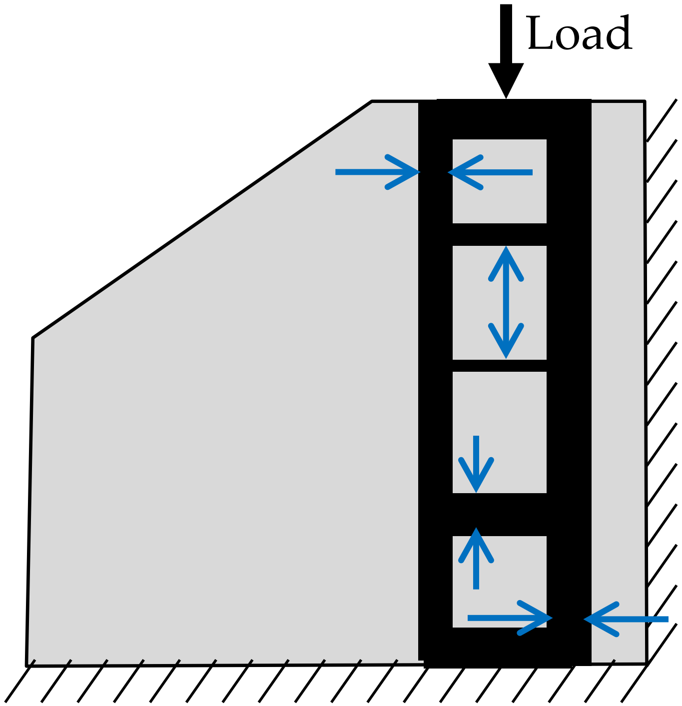
One possibility is shown here with black color. It has four holes (i.e., the topology is chosen). All segments in the structures are straight (i.e., the shape is chosen). What are left now are choosing values for certain sizes: the width of a segment, spacing between segments, etc. Some are shown with blue arrows.

Now, you can use such "size" variables as optimization variables and find the optimal structure.

This is called size optimization. It is the third stage in hierarchical structure optimization.

Size variables can be continuous or discrete. By "continuous", we mean that the size can assume any real number within a given range. By "discrete", we mean that only certain values are allowed, as in the 0.23, 0.48, 54, etc., but not any value. Only continuous variables are amenable for gradient-based optimization methods.

Size optimization of structures



Size optimization implies that you will have a few size-related variables that you can play with. So, you first need to assume topology and size.

One possibility is shown here with black color. It has four holes (i.e., the topology is chosen). All segments in the structures are straight (i.e., the shape is chosen). What are left now are choosing values for certain sizes: the width of a segment, spacing between segments, etc. Some are shown with blue arrows.

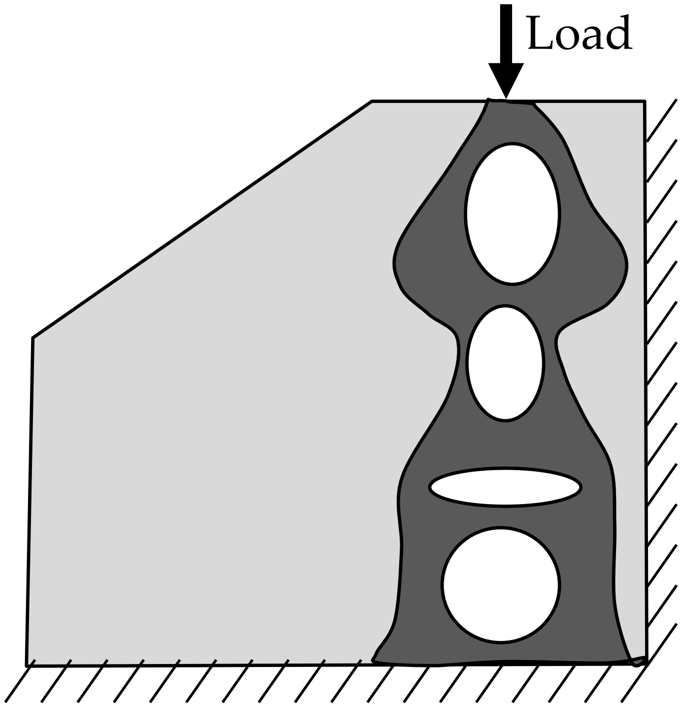
Now, you can use such “size” variables as optimization variables and find the optimal structure.

This is called size optimization. It is the third stage in hierarchical structure optimization.

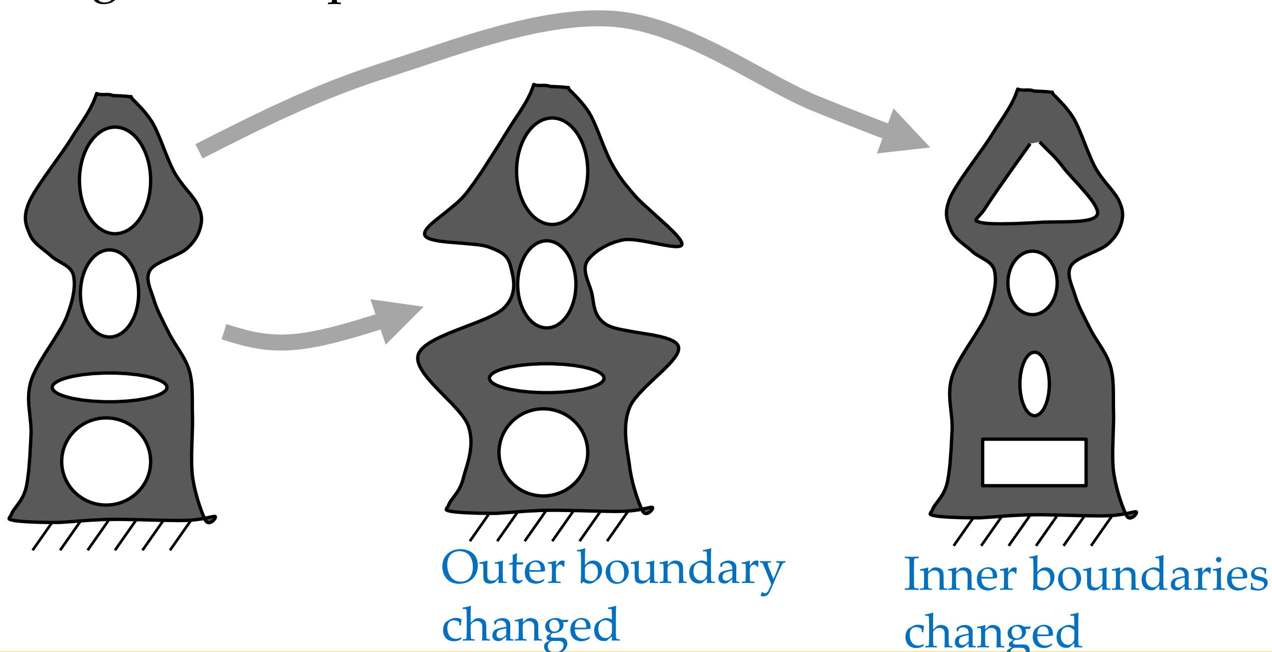
Shape optimization of structures

Here too, we have fixed the topology with four holes. The shapes of the outer curves and the shapes of the holes can be varied to further optimize the structure. This is shape optimization.

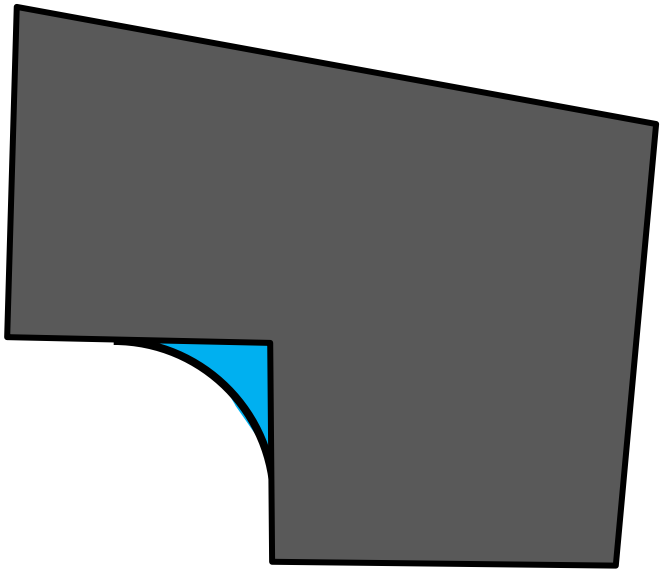
One characteristic of shape optimization is that the 2D domain occupied by the material changes when we change the shape of the curves.



Material domains



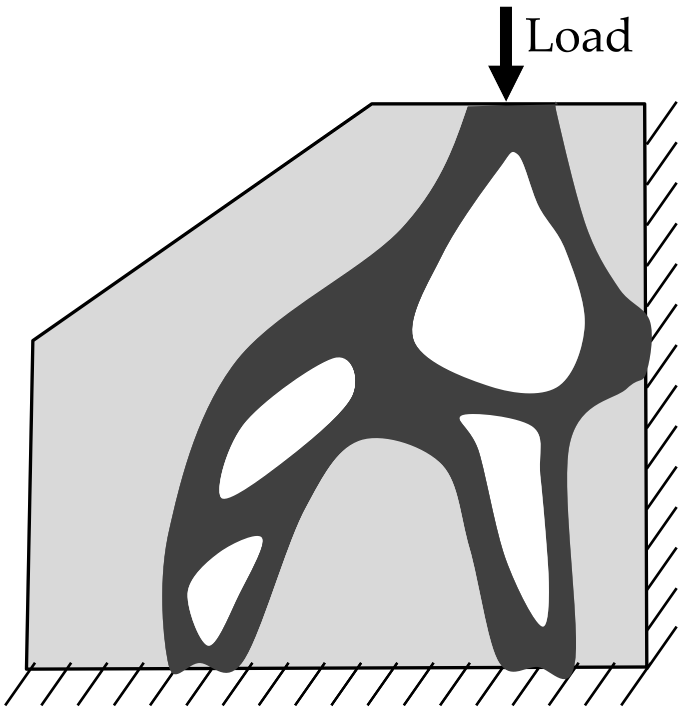
Anytime the domain is changed, it is shape optimization.



Fillet optimization is actually shape optimization as the domain is changed; blue-colored area is now added with the fillet.

In 1D, if we change the length, it is actually shape optimization as we are changing the domain here.

Topology optimization in 2D



Here, we leave the topology open. Any number of holes can be there. That is left to the optimization algorithms.

So, in topology optimization problems, we do not have to assume the topology; rather, it should be determined by the algorithm.

It is important to note that, in topology optimization, the number of holes, their shapes, and sizes—all are determined. So, as implemented, it is actually geometry optimization with all its features, topology, shape, and size.

Optimization and its spirit

Optimization is achieving the best with the available resources while satisfying the constraints.

- We optimize in our daily lives. Nature seems to have optimized almost everything.
  - It is about surviving with what one has and getting the best out of it.
  - Optimization is a way of life!
- Optimization has a lot to do with optimism.
  - Optimists view the proverbial glass half full and not half empty.
  - Given any number of obstacles (i.e., constraints), optimists try to make the best out of the situation.

Optimization hinders evolution!

- It is a witty way of saying the essence of optimization.
- Eventually, everything gets optimized.
  - The fittest and the best survive. The fittest would have used resources in the most effective manner and would have surmounted or circumvented the obstacles.
- But when we optimize at this instant, evolution is not necessary as we have already achieved the best already.
  - So, evolution is hindered.

Everything can be optimized.

- It is not an exaggeration; indeed everything can be optimized.
- It is simply a question of knowing what is the best, what the issues are, and how we can achieve it.

The end note

Structural Optimization

Topology

Topology is the highest level in structural hierarchy.
Topology decides connectivity and the number of holes in a structure.
Identifying the variables that decide the topology is the main challenge.
Topology should be decided first.

Shape

Shape of the segments in a structure.
Shape of a feature in a structure.
Shape of a hole in a structure.
Identifying the variables that decide the shape of a segment, feature, or a hole is easier compared to topology.
Shape optimization follows topology optimization.

Size or **parameter**

Size optimization is the easiest and is the last step.
Parameter (radius of a circular hole) is also a size variable.

All three- topology, shape, and size can be at once too.

Thanks