Mechanics and Machines, Lecture 4

Synthesis of planar mechanisms

INNOPOLIS UNIVERSITY

Difference between Analysis and Synthesis

Analysis

Analysis allows determining whether a given system will comply with certain requirements or not.

During «Theoretical Mechanics» we only analyzed systems. We knew all dimensions and tried to find positions, velocities, accelerations.

Synthesis

Synthesis is the design of a mechanism so that it complies with previously specified requirements.

We know, that it should work on uneven terrain, and we are trying to design the robot with such possibilities.

Types of Synthesis

Structural

This synthesis deals with the **topological** and **structural study** of mechanisms.

It only considers the interconnectivity pattern of the links so that the results are unaffected by the changes in the geometric properties of the mechanisms.

Dimensional

It focuses on the problem of **obtaining the dimensions of a predefined mechanism** that has to comply with certain given requirements.

It will be necessary to define the dimension of the links and the position of the supports, among others.

Question

What the optimal number of legs should be in such robot mover?

Structural Synthesis: Case Study
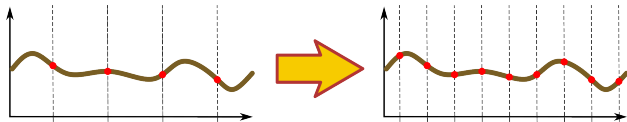
Structural synthesis problem

Question

What the optimal number of legs should be in such robot mover?
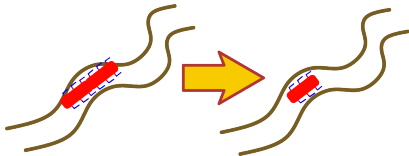
Answer

Robot should have **8-14 legs** in total!
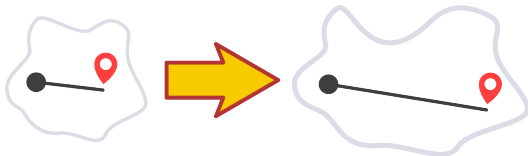
Structural Synthesis: Case Study

Criteria

More legs → higher data discretisation

More legs → longer robot → cannot pass though crooked terrains

Amount of legs nonlinearly correlates of maximal terrain passability

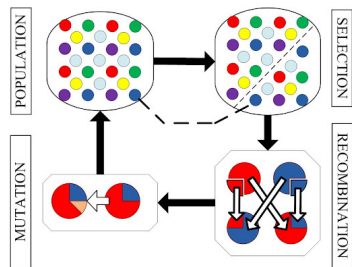# Structural Synthesis: Case Study
Technological stack

Generating terrain approach
(Robot traverse an **artificial
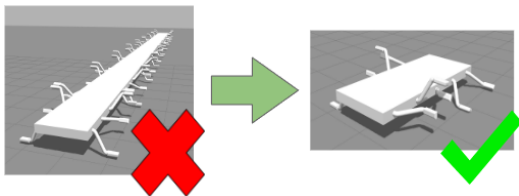terrain** based on **generating
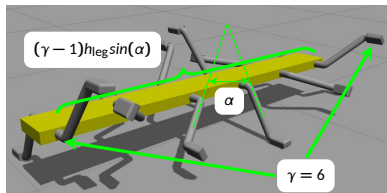parameters**)

Robot simulator

Genetic algorithm
(OpenAI-ES)

Structural Synthesis: Case Study
Proposed solution

$$F \rightarrow max = \beta \left(\omega_1 \cdot \overset{\text{Distance}}{\overbrace{\delta}} + \omega_2 \cdot \overset{\text{Simplified body length}}{\overbrace{\frac{1}{(\gamma - 1)h_{\text{leg}}sin(\alpha)}}} \right) +$$

$$+ (1 - \beta)\delta^{\omega_1} \left(\frac{1}{(\gamma - 1)h_{\text{leg}}sin(\alpha)} \right)^{\omega_2}$$

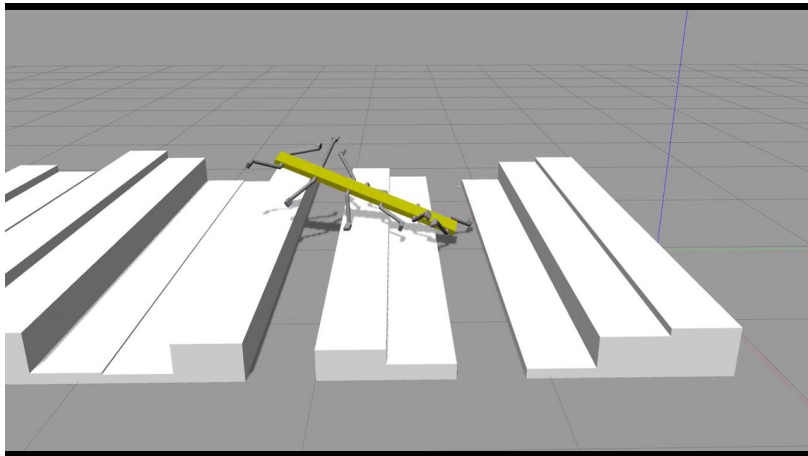**Idea**: Minimize number of legs without losing off-road passability

β is adaptive parameter,

$\omega_{1,2} \in [0..1]$ are the weight coefficients.
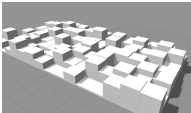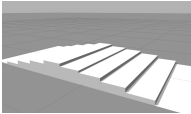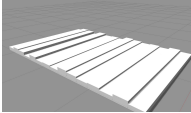
Structural Synthesis: Case Study
Video: The story of one generated robot

Structural Synthesis: Case Study

Particular results: $\omega_1 = 0.6$, $\omega_2 = 0.4$

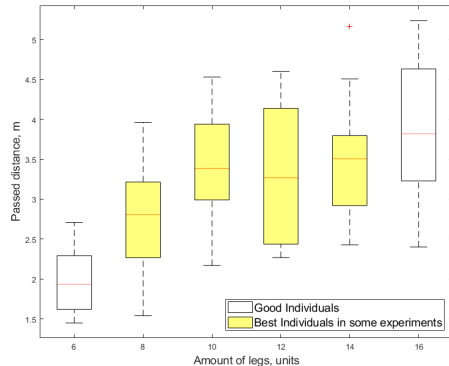|	Terrain types	No. Legs	Angle b/w neighbor legs	No. individuals
Phase 1		12	73	200
		12	72	
Phase 2		10	68	55
		12	77	

Structural Synthesis: Case Study
Global results

Based on fitness function the number of legs range starts from 8 till 14 for different ω values.
It can be explained by static stability criteria.
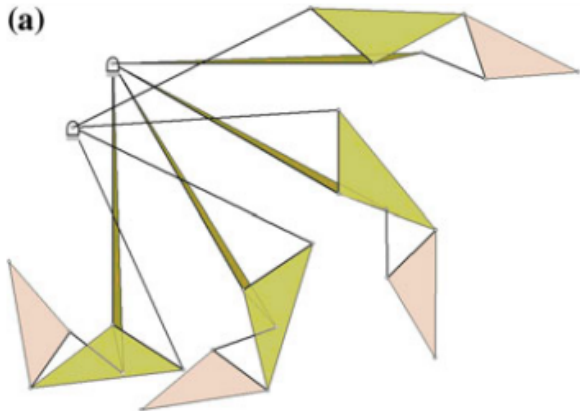In such case 4 legs will touch the ground.

Correlation between amount of legs and passed distance by best robot individuals from several experiments
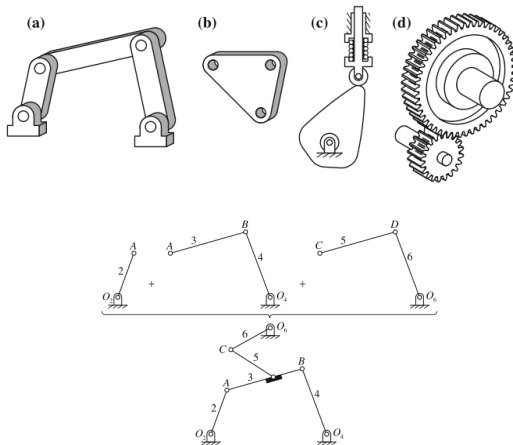
Dimensional Synthesis: Case Study

Structural Synthesis

2 questions, which should be answered

1) Synthesis of type or Reuleaux synthesis: What type of mechanism is more suitable? What type of elements will it be made of? Can it be formed by linkages, gears, flexible elements or cams?

Different configurations are developed according to the pre-established requirements. The criteria to value the different characteristics of the mechanism are set.
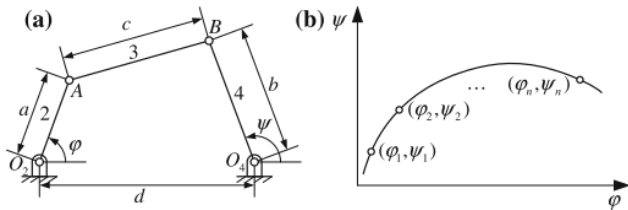
2) Synthesis of number or Grübler synthesis: In the case of a linkage, it determines the number of links and their configuration.

Dimensional Synthesis
Functional Generation

Pre-established conditions refer to the relation between the input and output motions.
These are defined by variables ϕ and ψ, that indentify their positions.
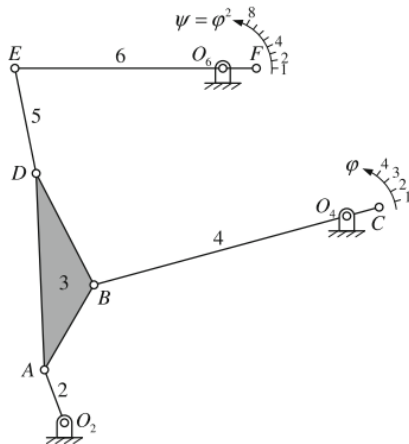
Dimensional Synthesis
Application

Function generation can be used to design mechanisms that carry out mathematical operations: addition, differentiation, integration or a combination of them.
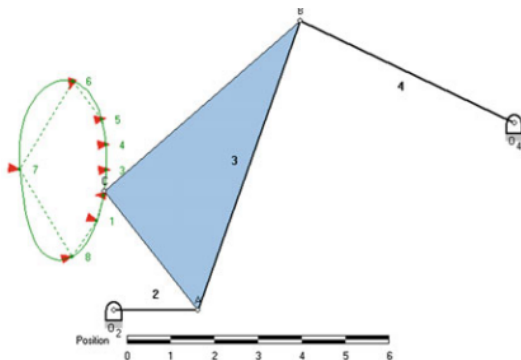
The first computers were mechanical devices based on this type of mechanisms.

Dimensional Synthesis
Trajectory Generation

It studies and provides methods in order to obtain mechanisms in which one of the points describes a given trajectory

Types of solving methods

Graphical

These methods are very didactic and help us to understand the problem in an easy way. However, they offer a limited range of possibilities.

Analytical

They solve the problem by means of mathematical equations based on the requirements.

Optimization-technique-based

They can find the optimal solution to the problem by means of the minimization of an objective function and the establishment of a series of restrictions. Different optimization techniques can be used.

Reference material

1. Synthesis of planar mechanisms (chapter from book)
2. *"Fundamentals of Machine Theory and Mechanisms" book*
3. Collection of applets on the Synthesis of Mechanisms (Geogebra)
4. Mechanics of Machinery (MOM) Module 6 Synthesis of Mechanisms (YouTube)

Deserve "A" grade!

– Oleg Bulichev

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🚪 Room 105 (Underground robotics lab)