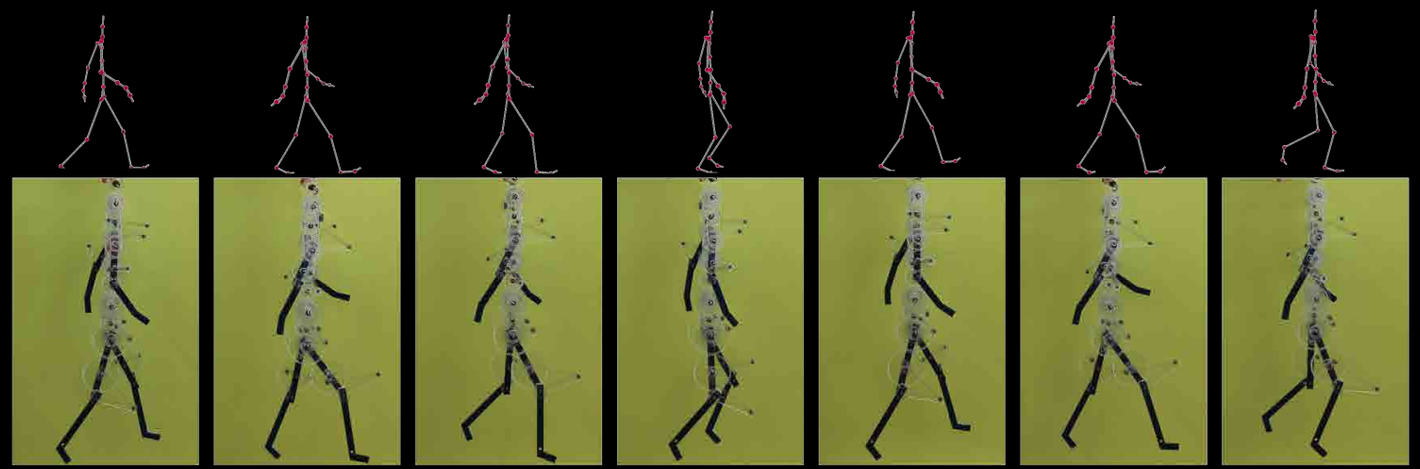
Designing and Fabricating Mechanical Automata from Mocap Sequences



Duygu Ceylan Wilmot Li Niloy J. Mitra

Maneesh Agrawala Mark Pauly

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE · Adobe · UCL · Berkeley UNIVERSITY OF CALIFORNIA

Mechanical Automata

Mechanical Automata

Time Piece - Switzerland

Mechanical Automata

Time Piece - Switzerland

The Writer
(designed by Jaquet-Droz)

Mechanical Automata

Time Piece - Switzerland

The Writer
(designed by Jaquet-Droz)

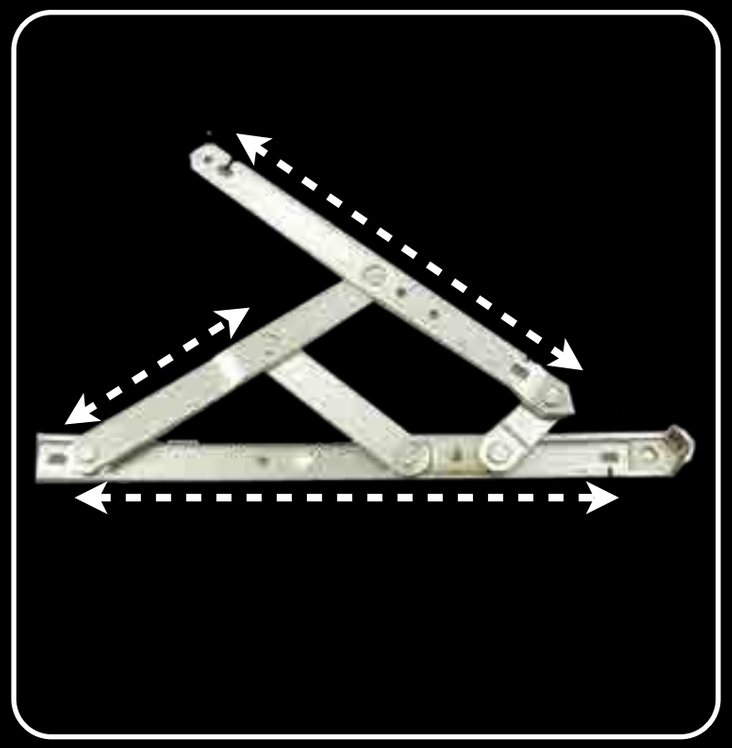
windup toys

Challenges

Conceptual Design

Challenges

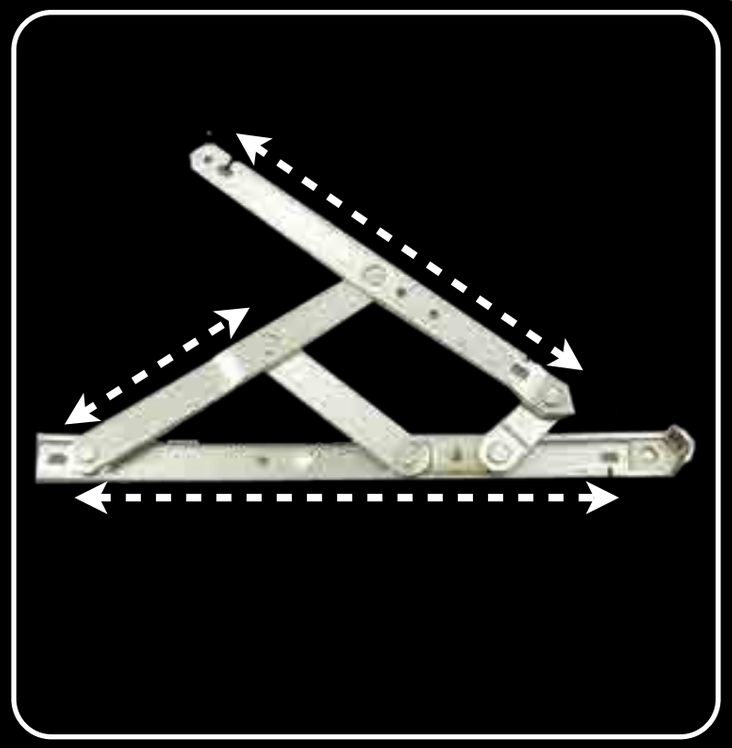
Conceptual Design



Configuration

Challenges

Conceptual Design

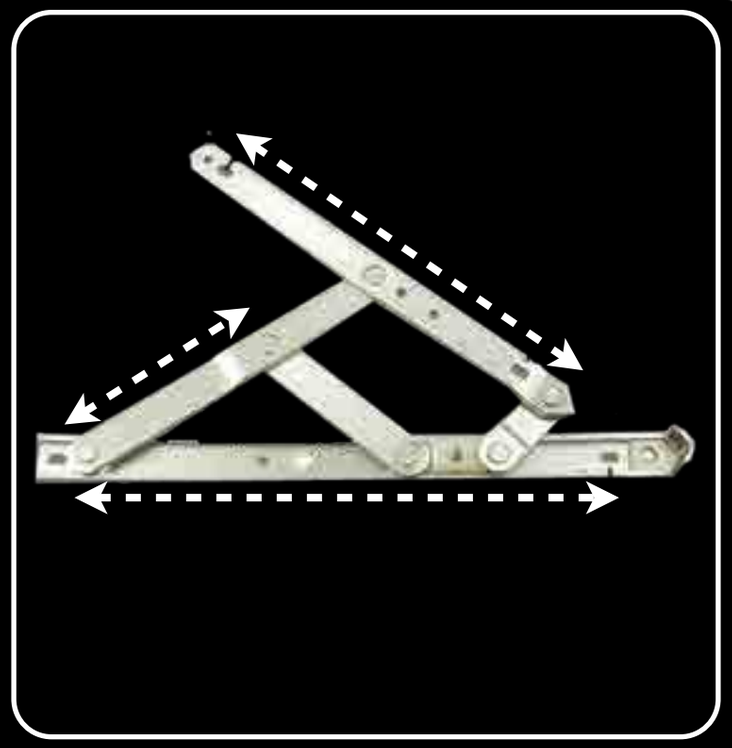


Configuration

Spatial Layout

Challenges

Conceptual Design



Configuration

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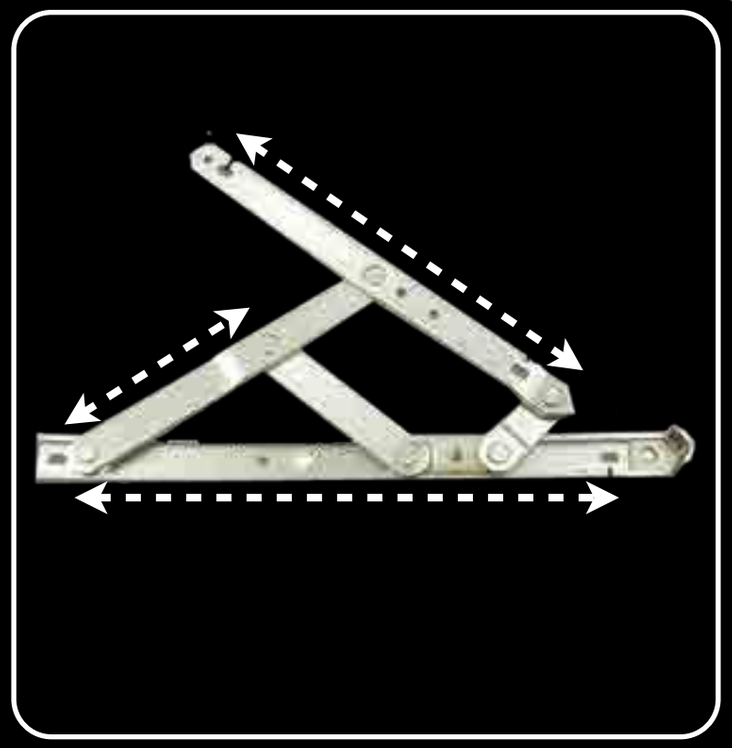


Configuration

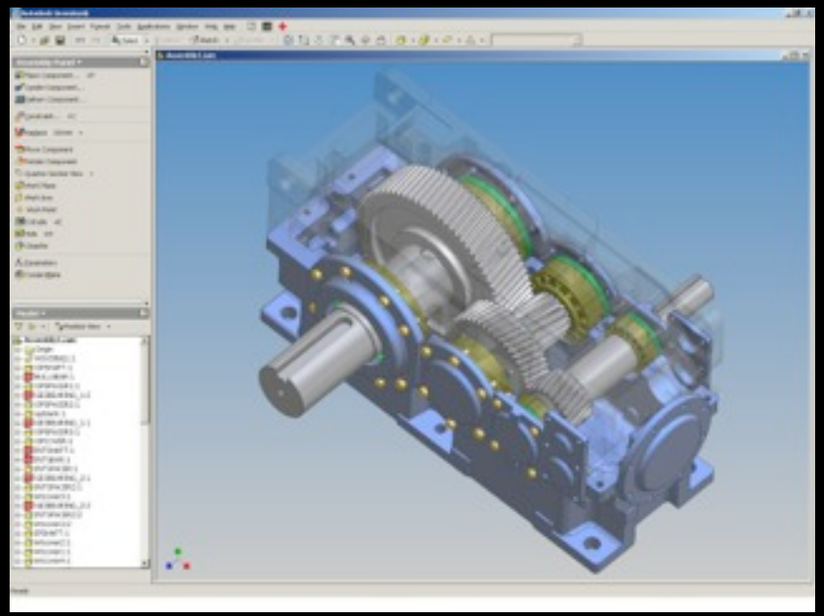
Spatial Layout

How can we automate this process?

Related Work

Related Work

Commercial Solutions



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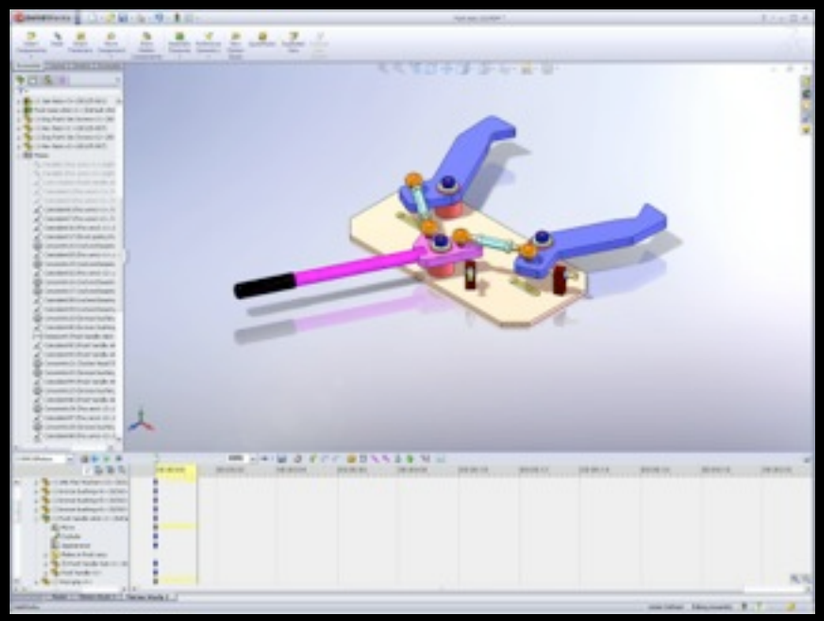

Solidworks

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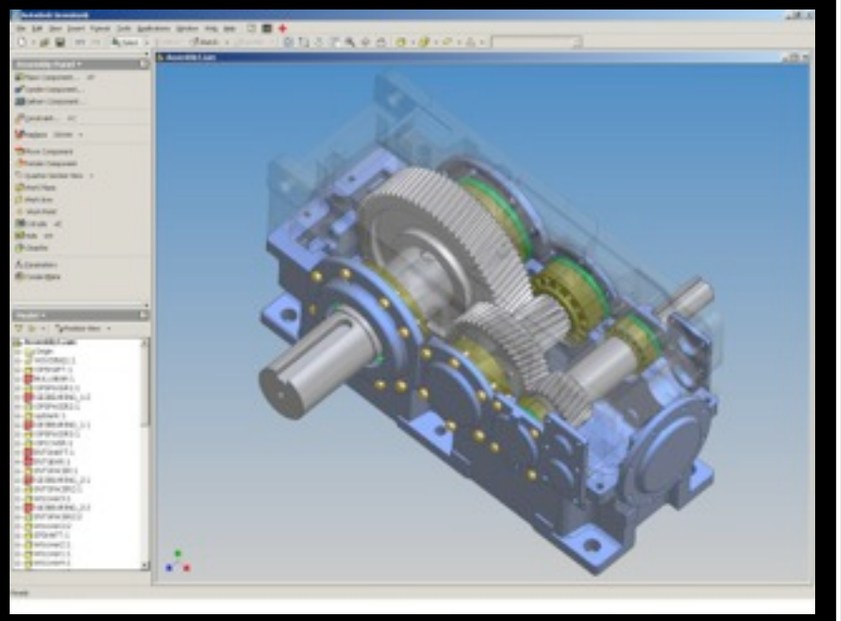

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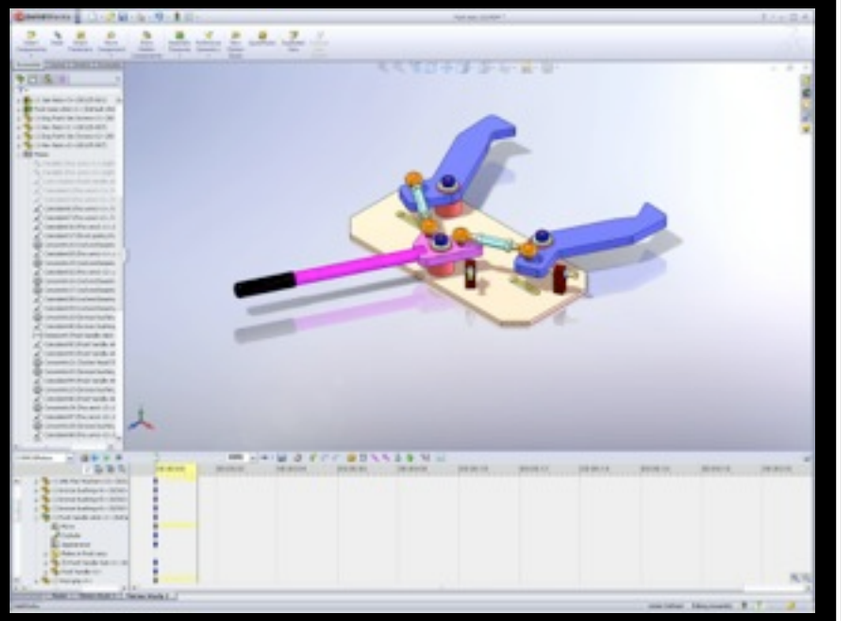

Solidworks

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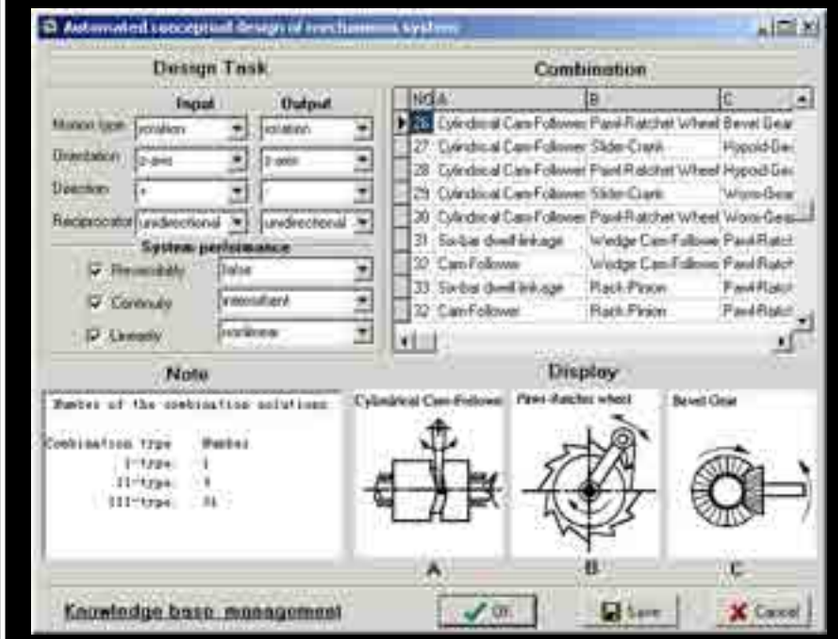

Zu et al. 2008

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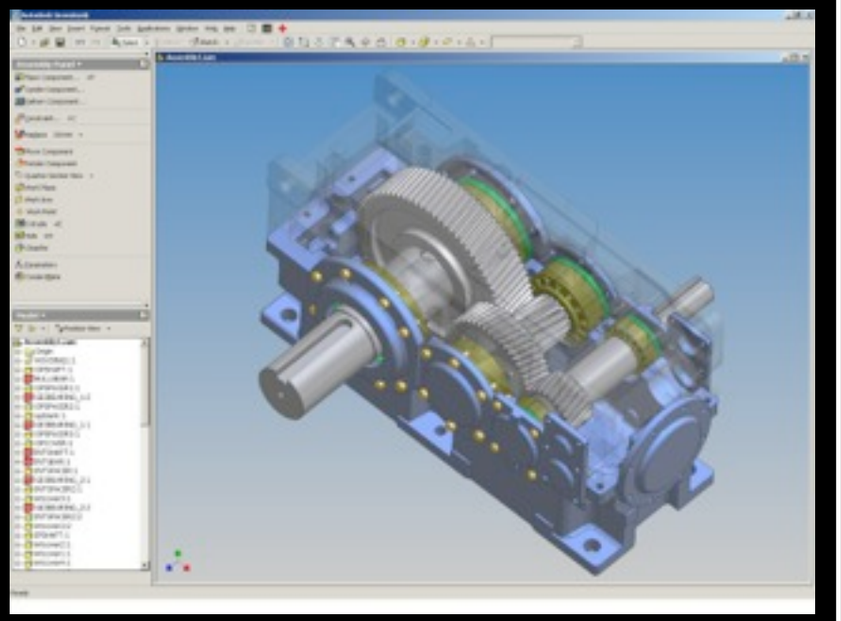

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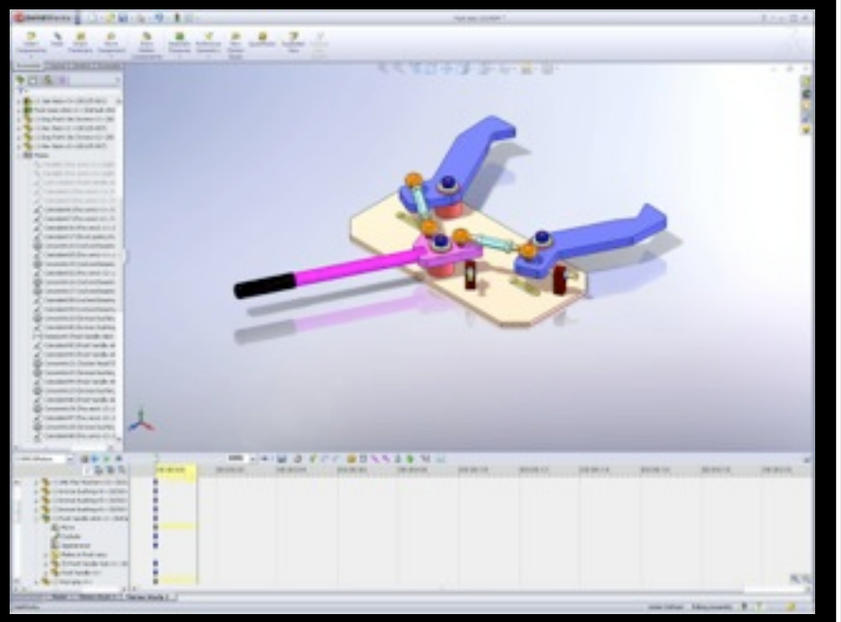

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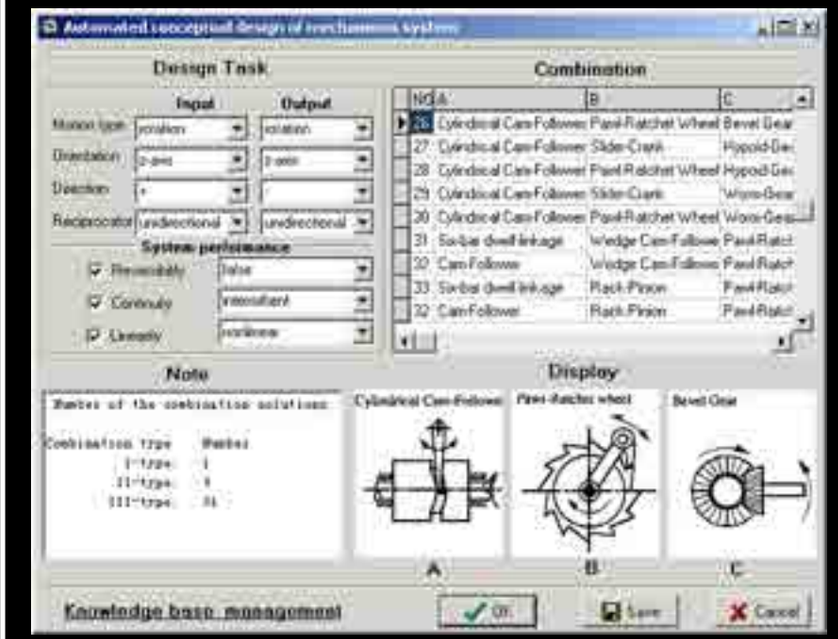

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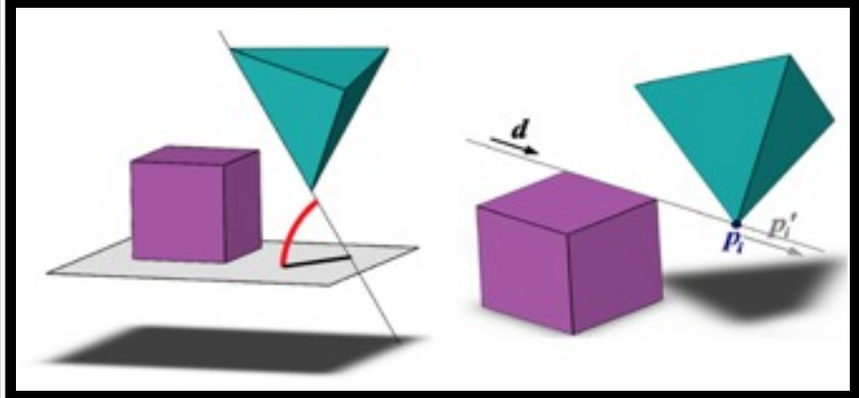

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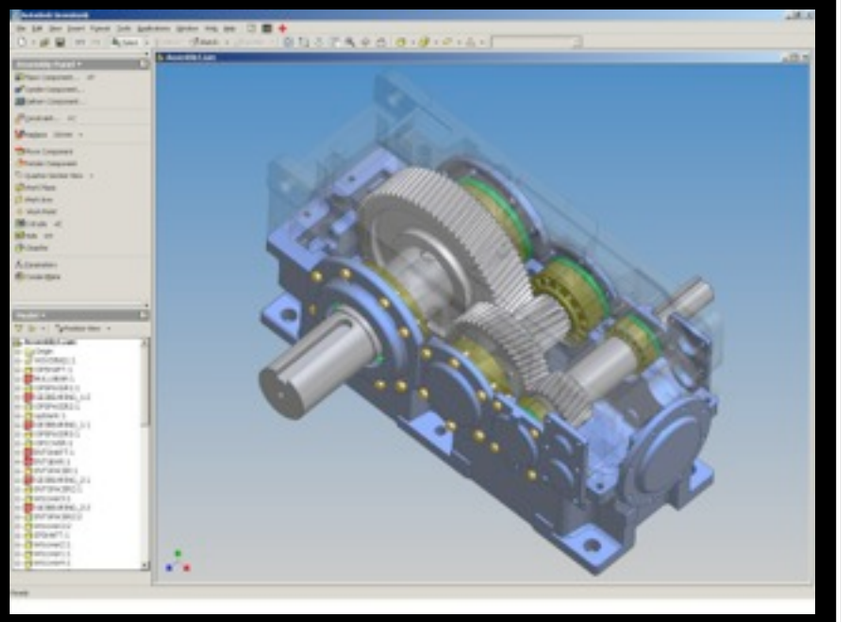

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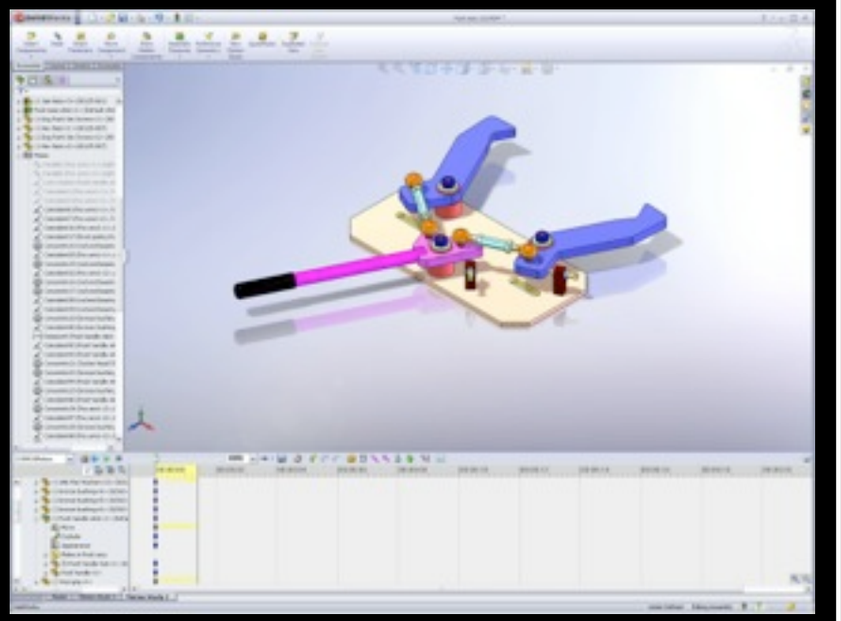

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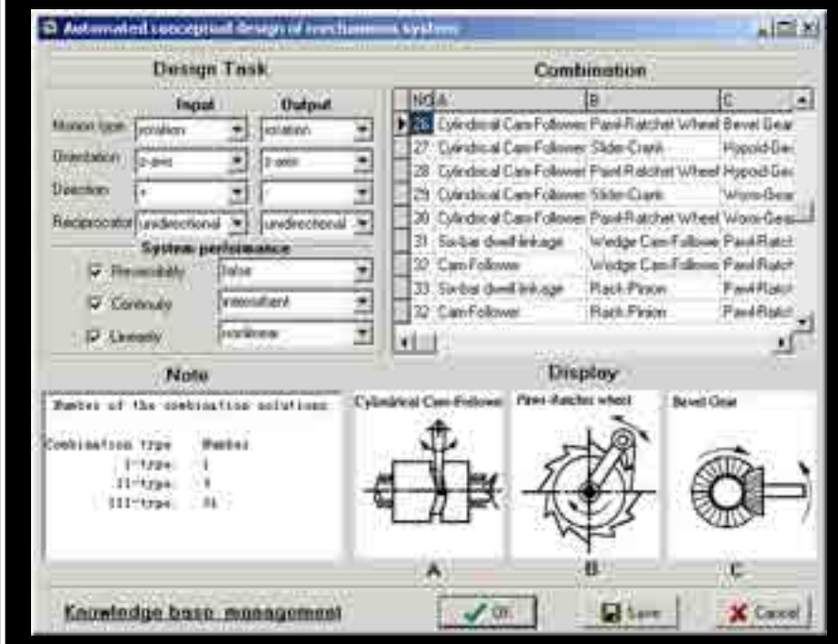

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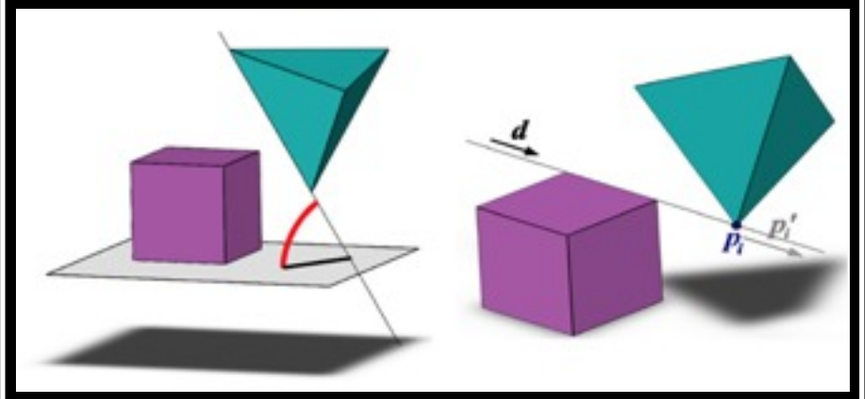

Haller et al. 2009

Automated Mechanism Design

Zhu et al. Sig. Asia 2012

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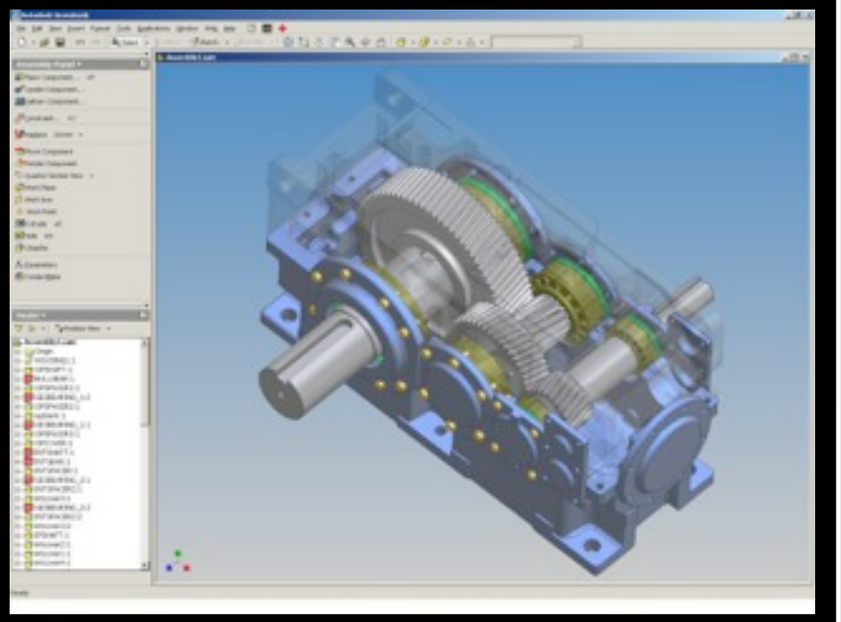

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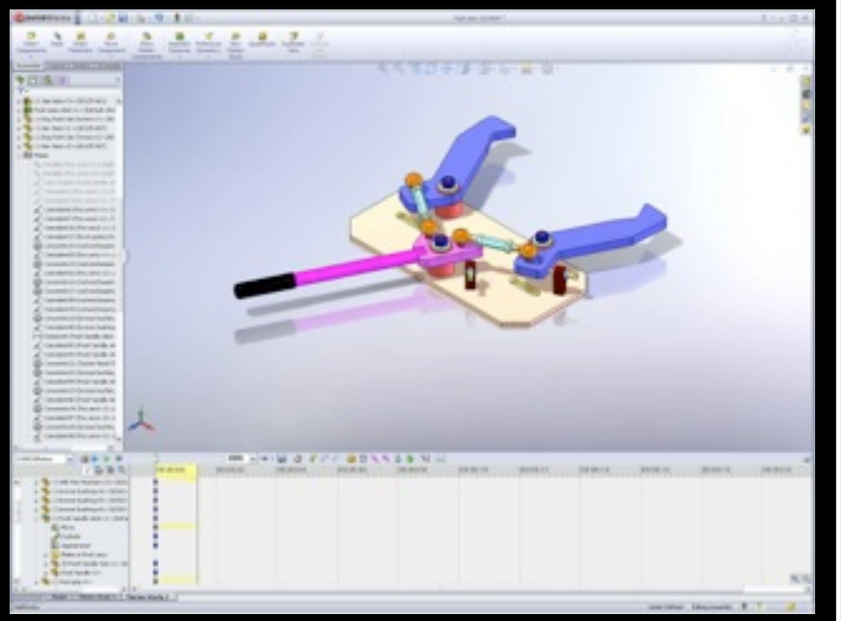

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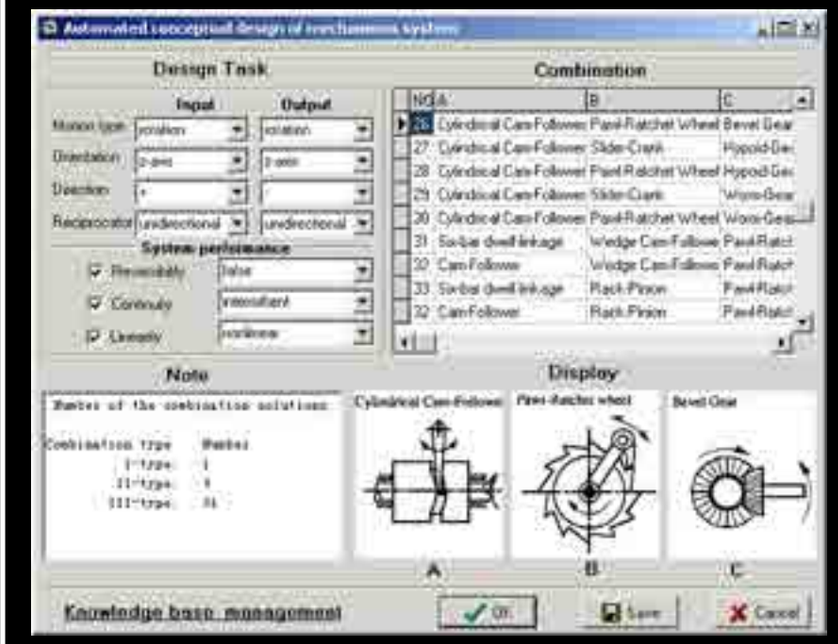

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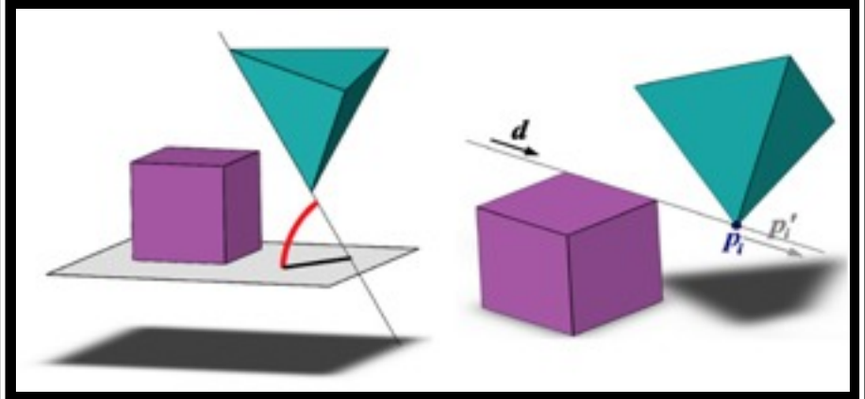

Haller et al. 2009

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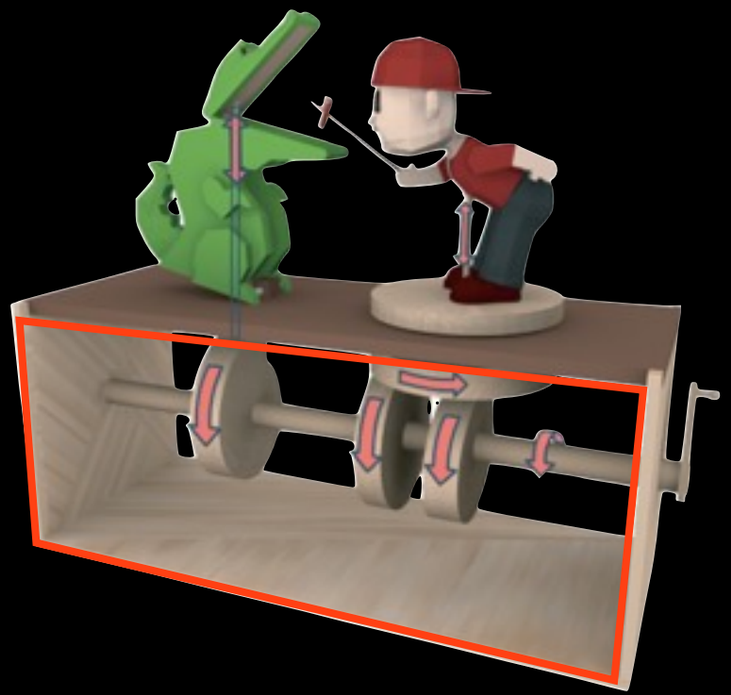

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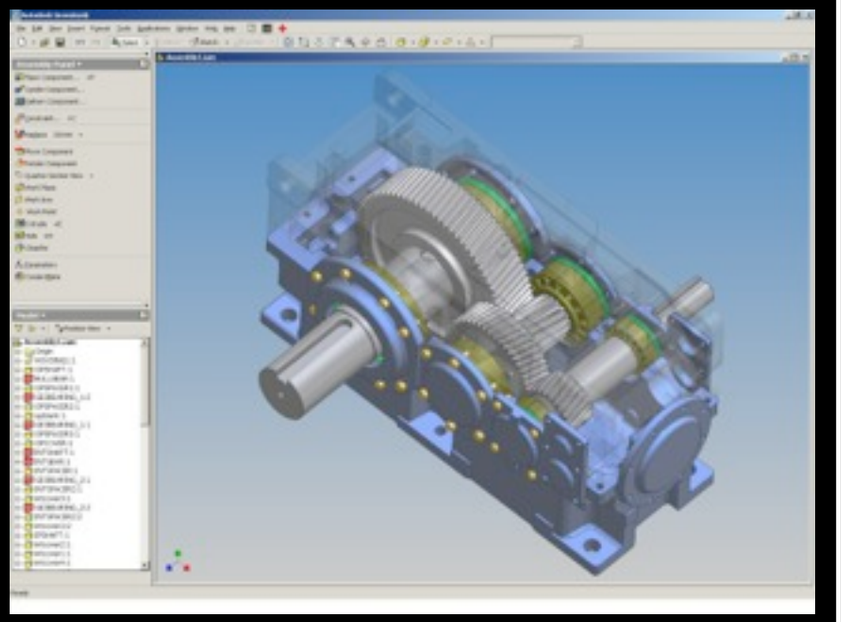

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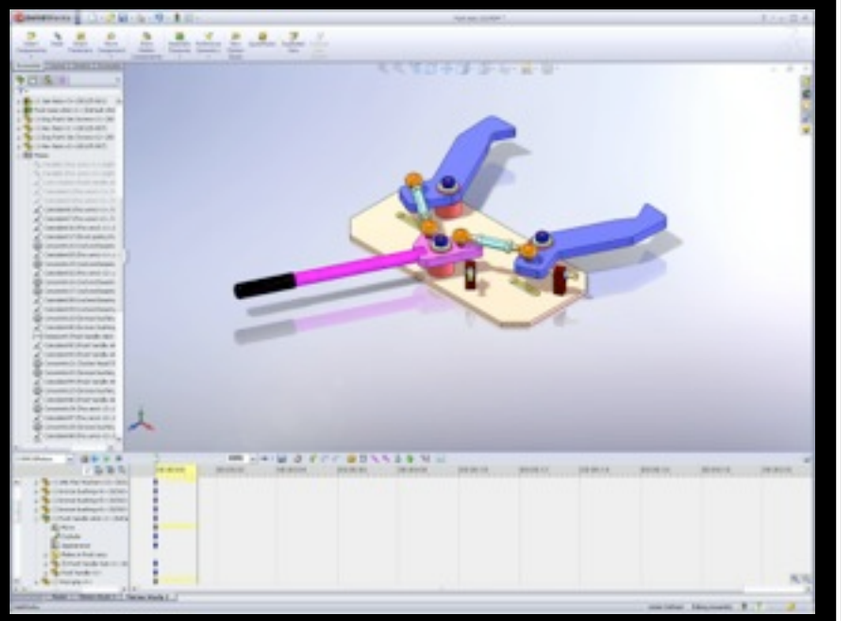

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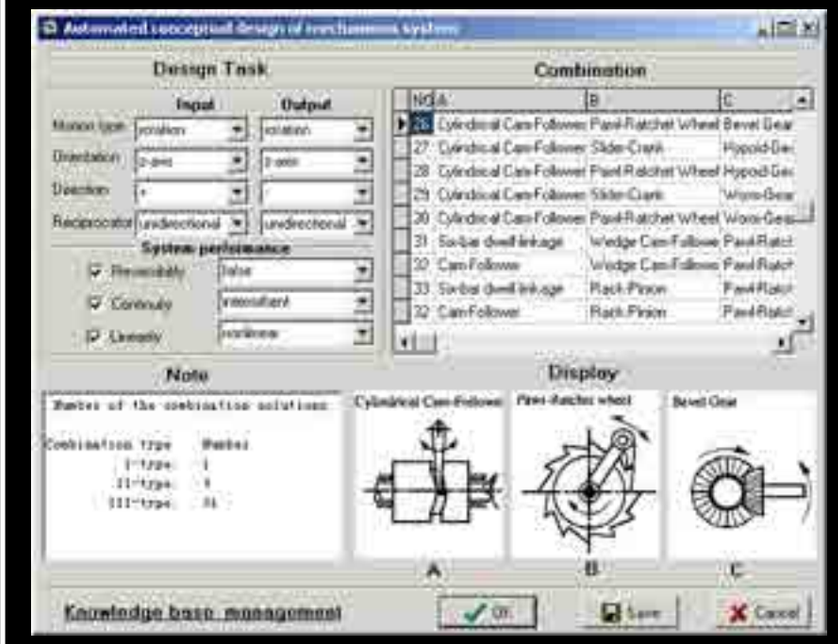

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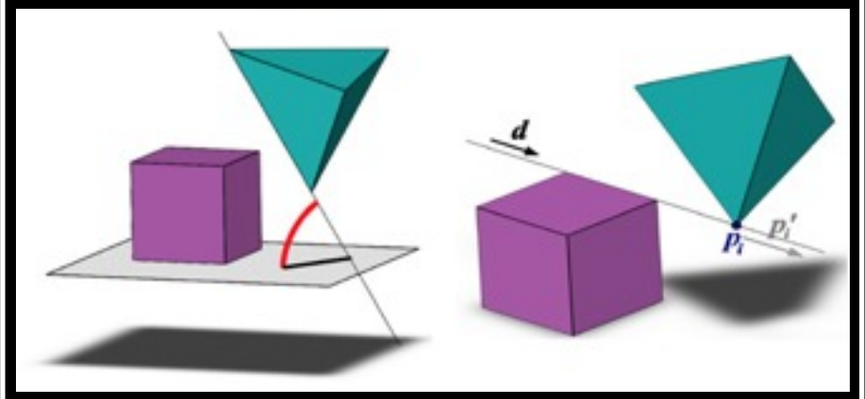

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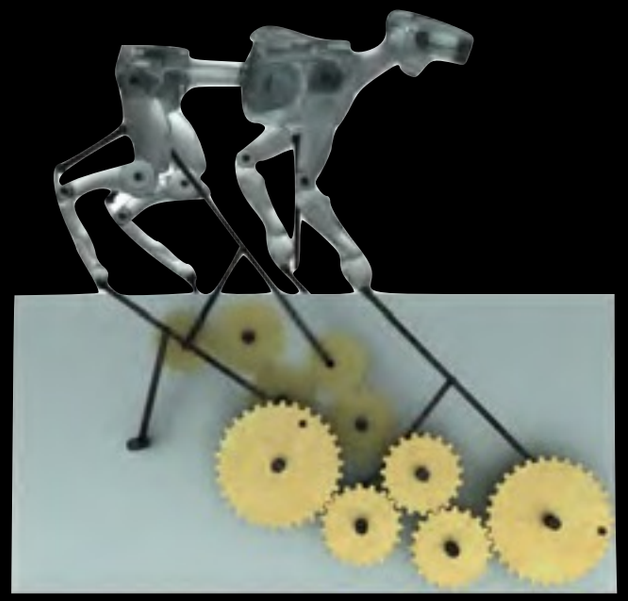

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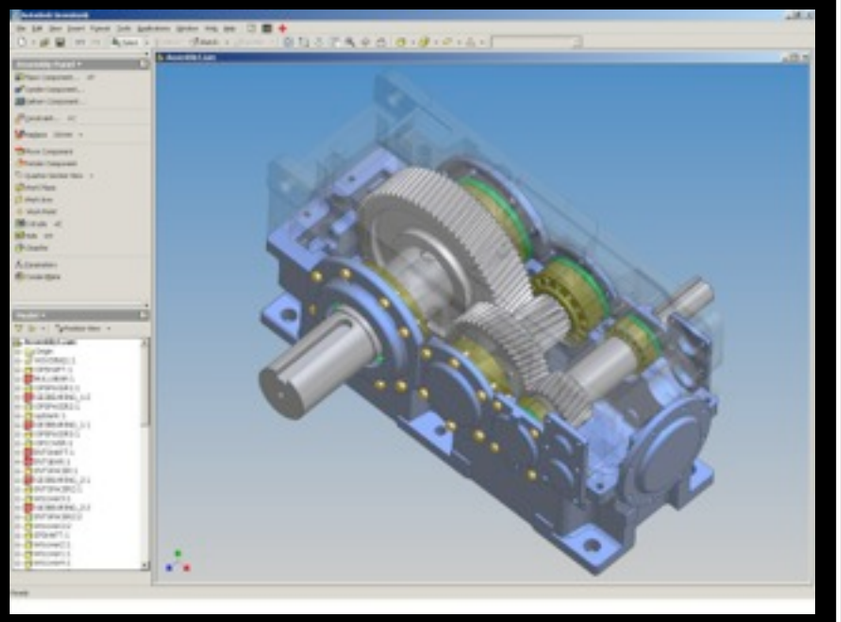

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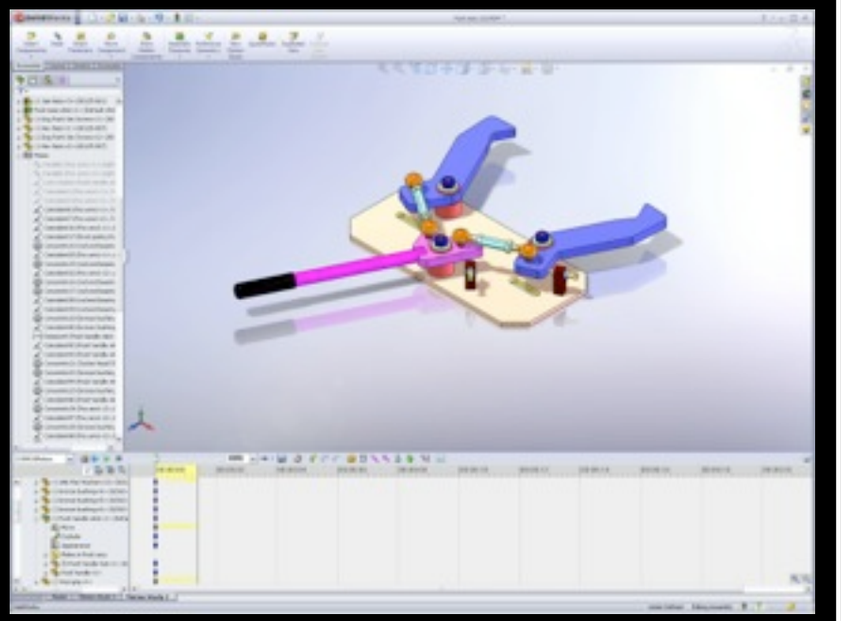

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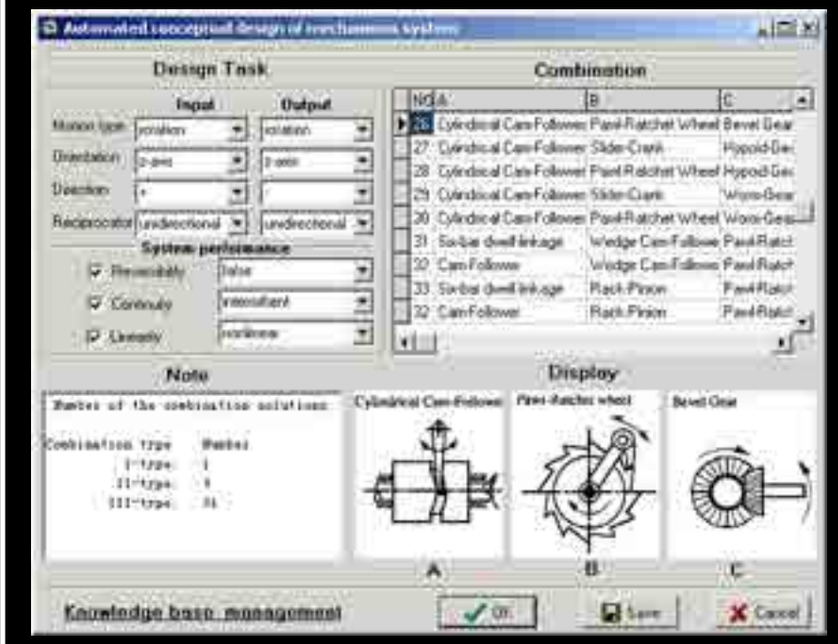

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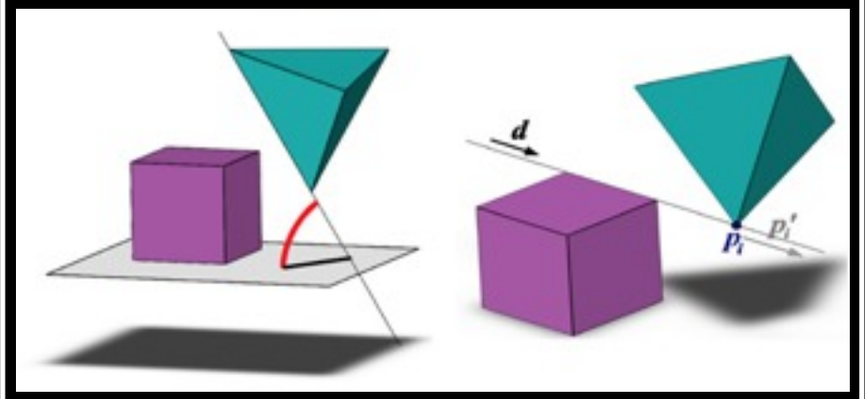

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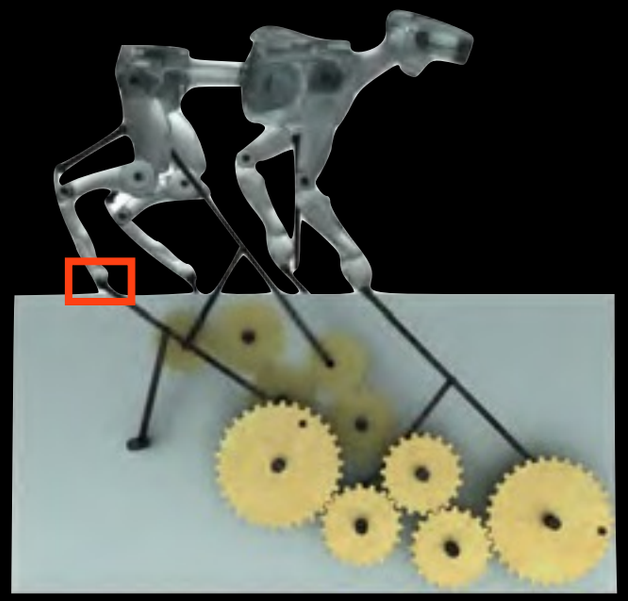

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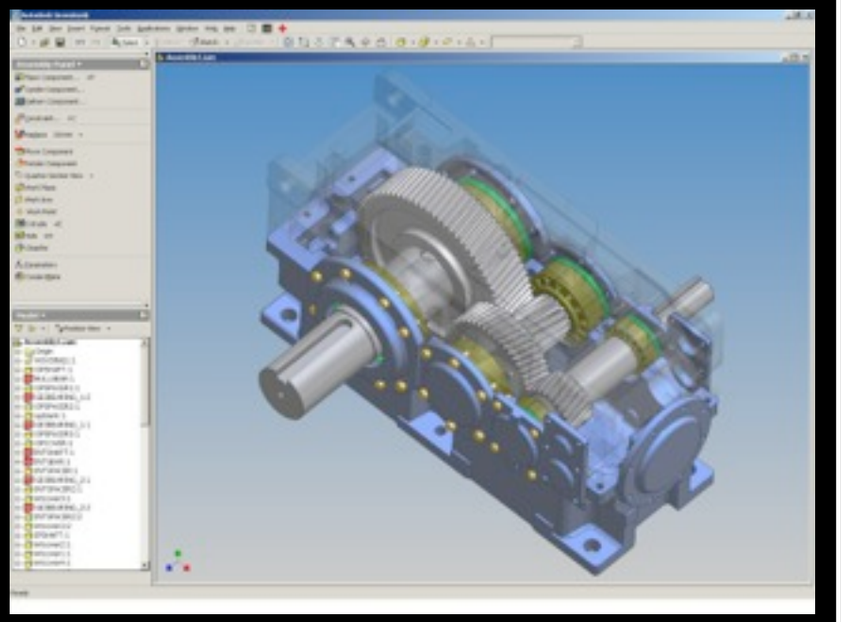
Commercial Solutions



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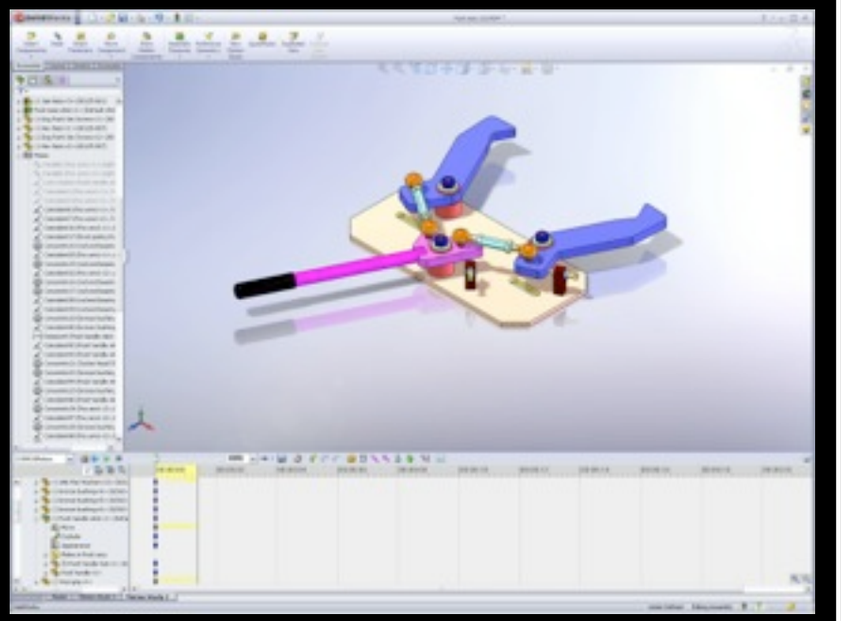

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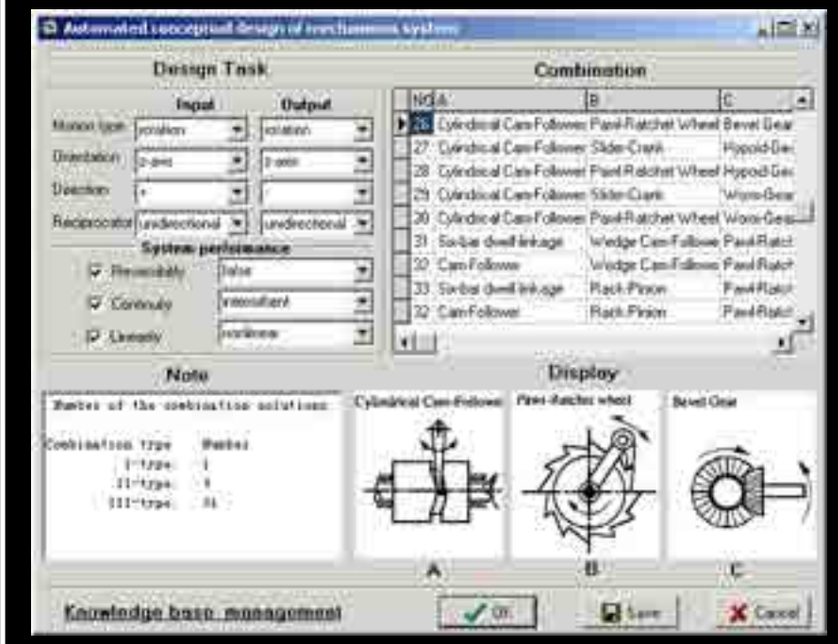

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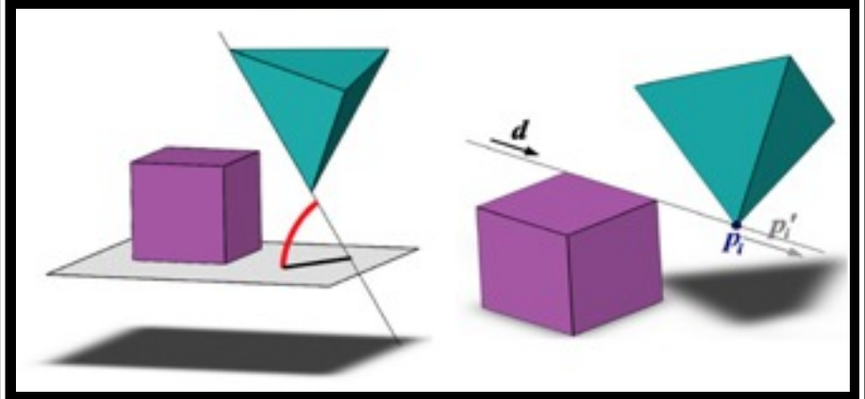

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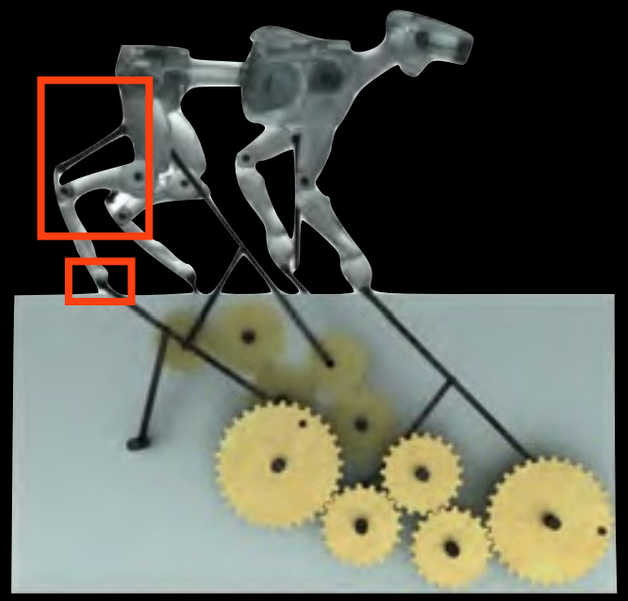


Coros et al. Siggraph 2013

Design Pipeline

Input Motion

Generated Automaton

Design Pipeline

Input Motion

Generated Automaton

Design Pipeline

Input Motion

Generated Automaton

Design Pipeline

Input Motion

Motion Approximation

Generated Automaton

Design Pipeline

Input Motion

Generated Automaton

Motion Approximation

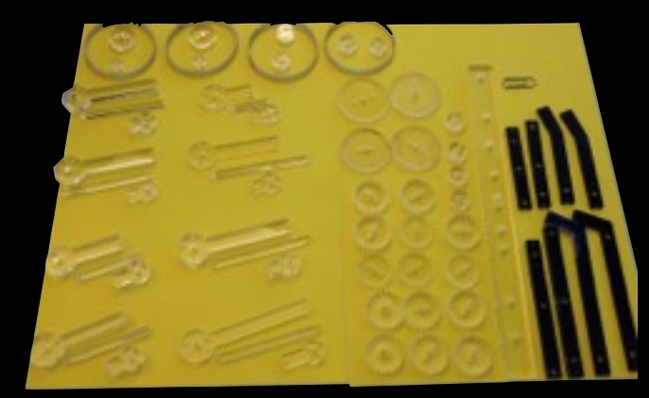
Kinematic chains & layout

Design Pipeline

Input Motion

Motion Approximation

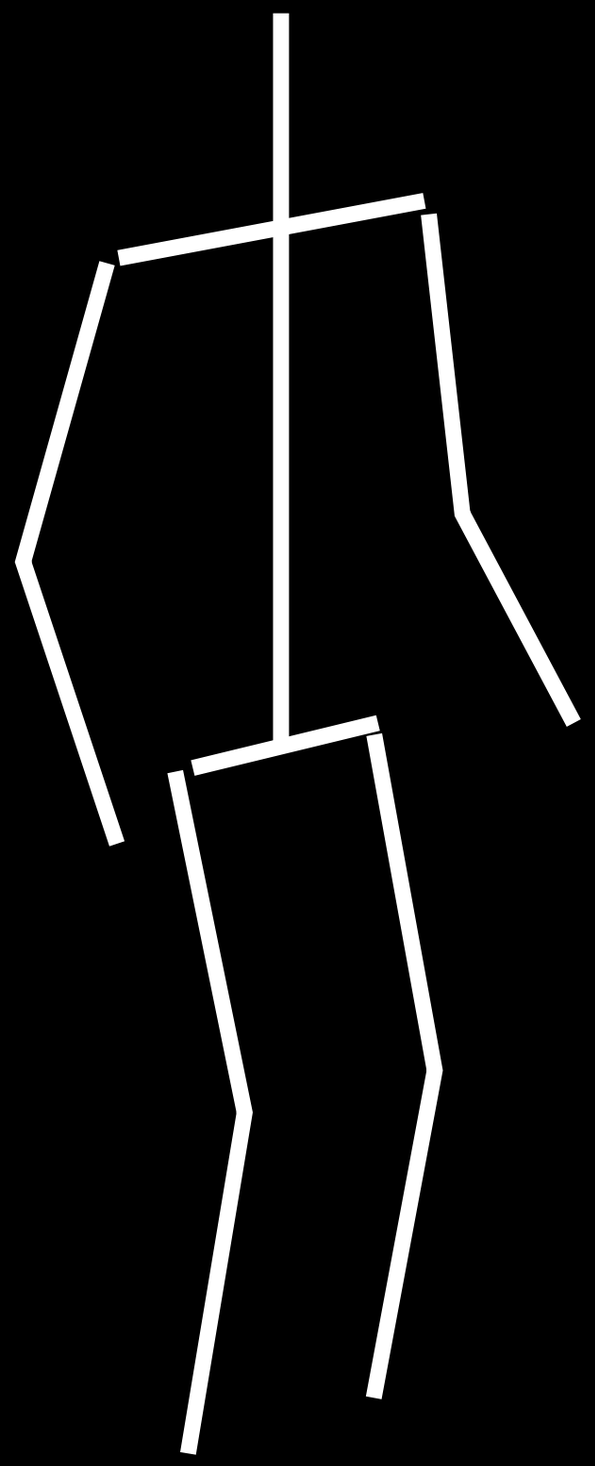
Kinematic chains & layout



Fabrication

Generated Automaton

Automaton Design



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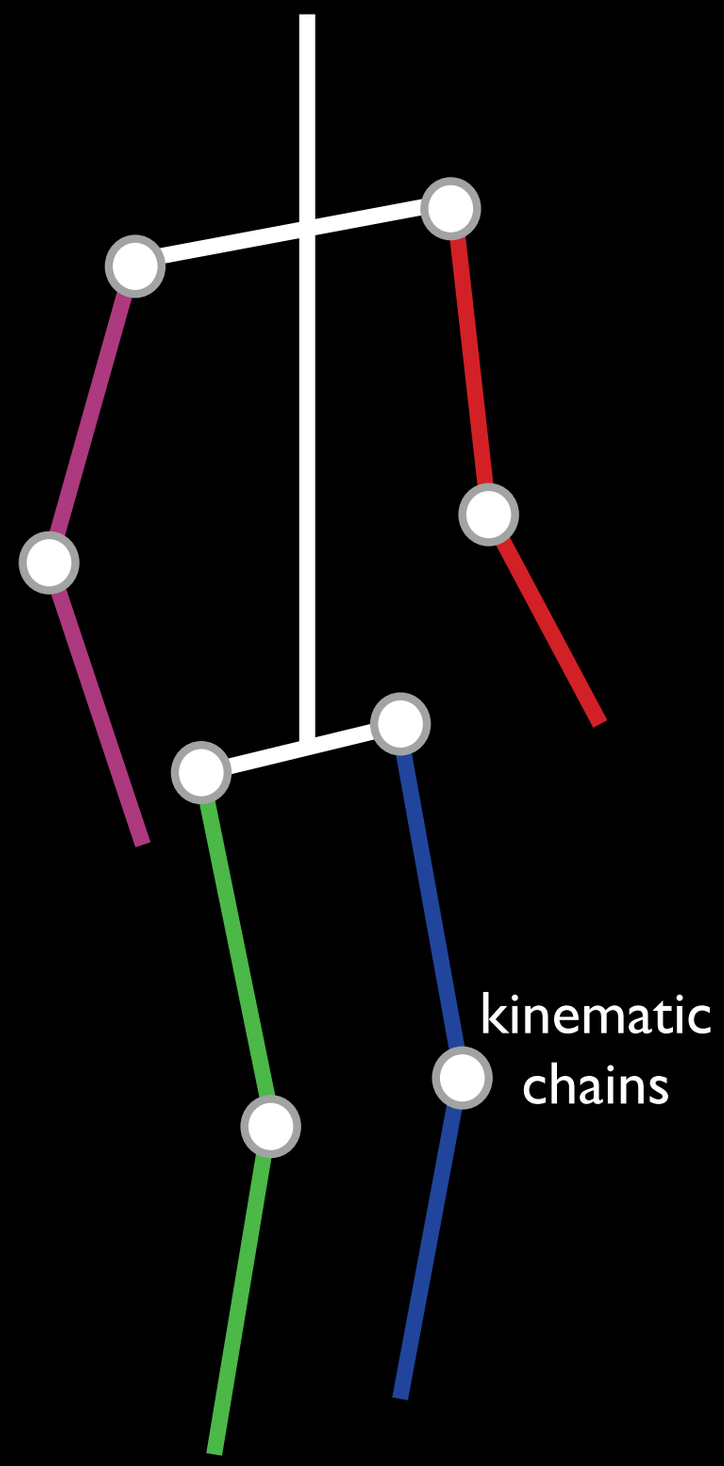

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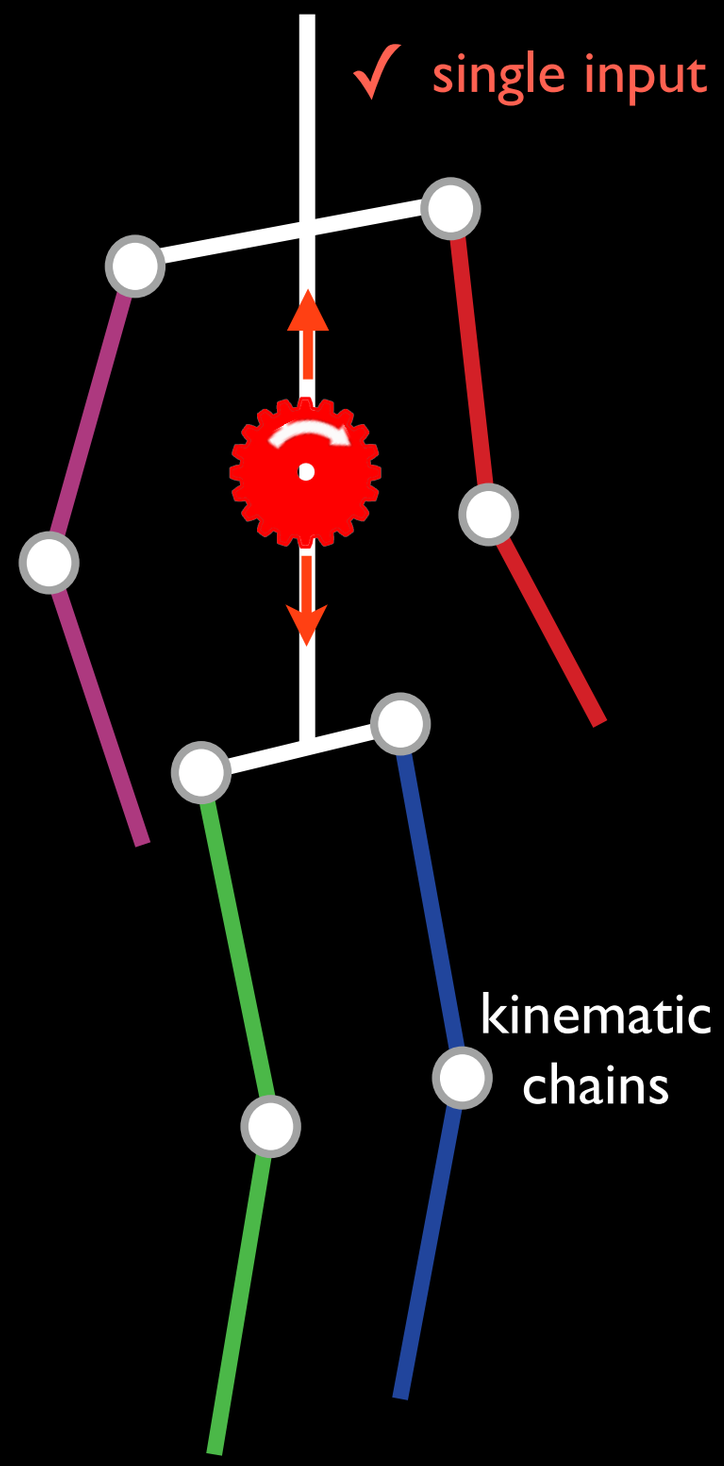

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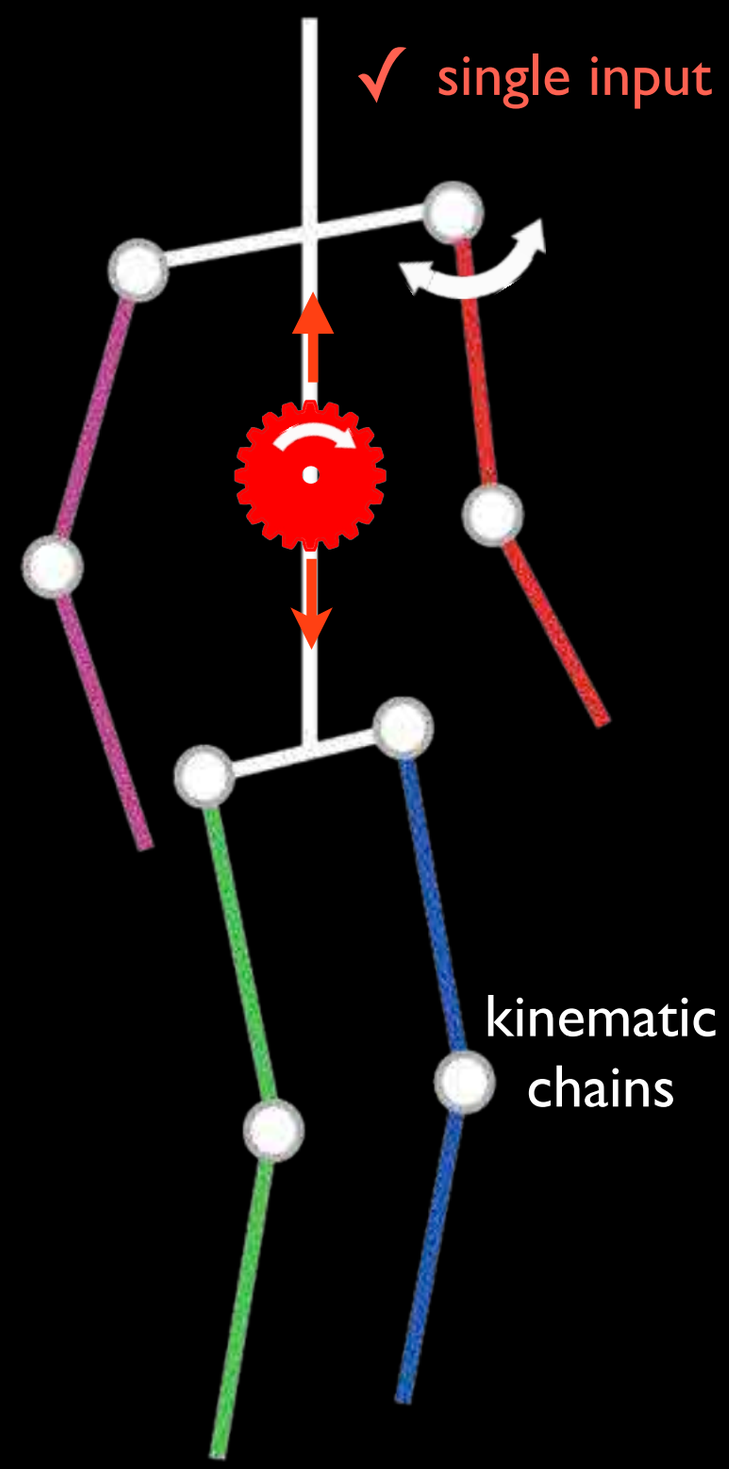

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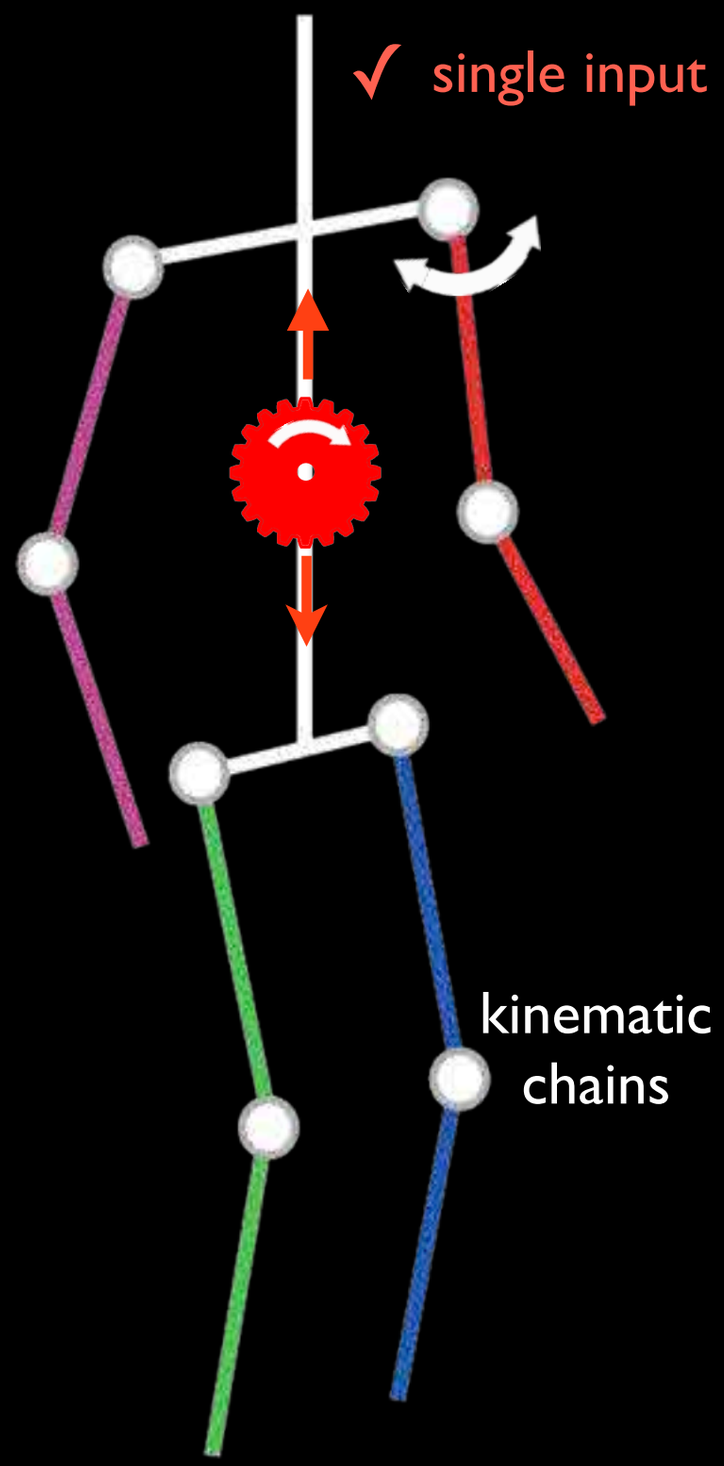

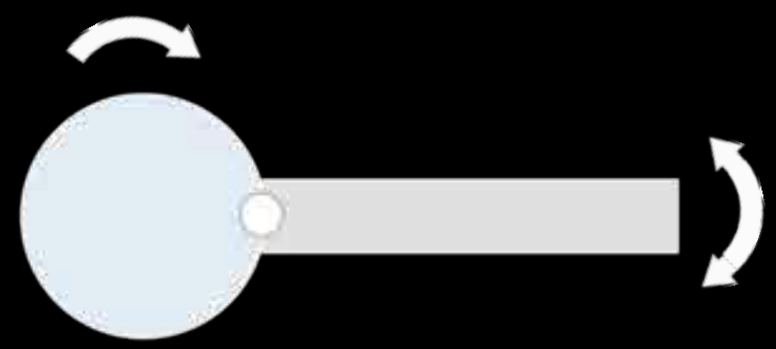

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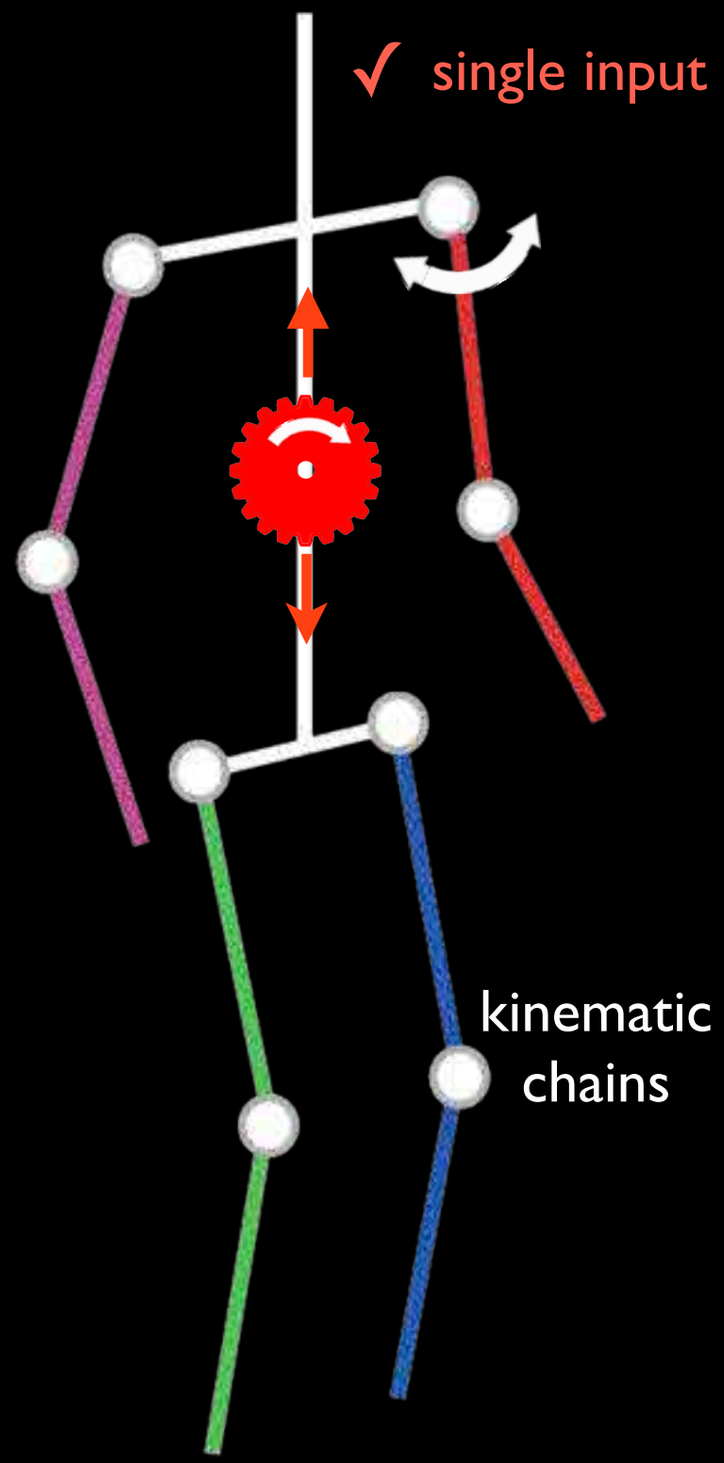

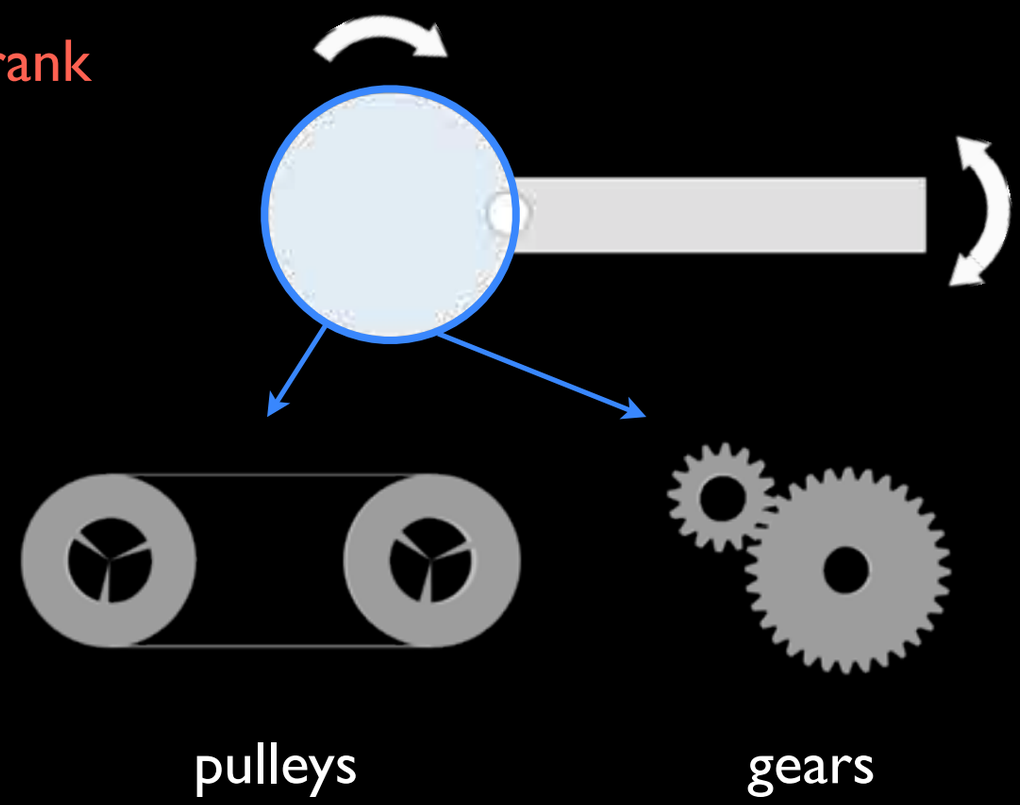

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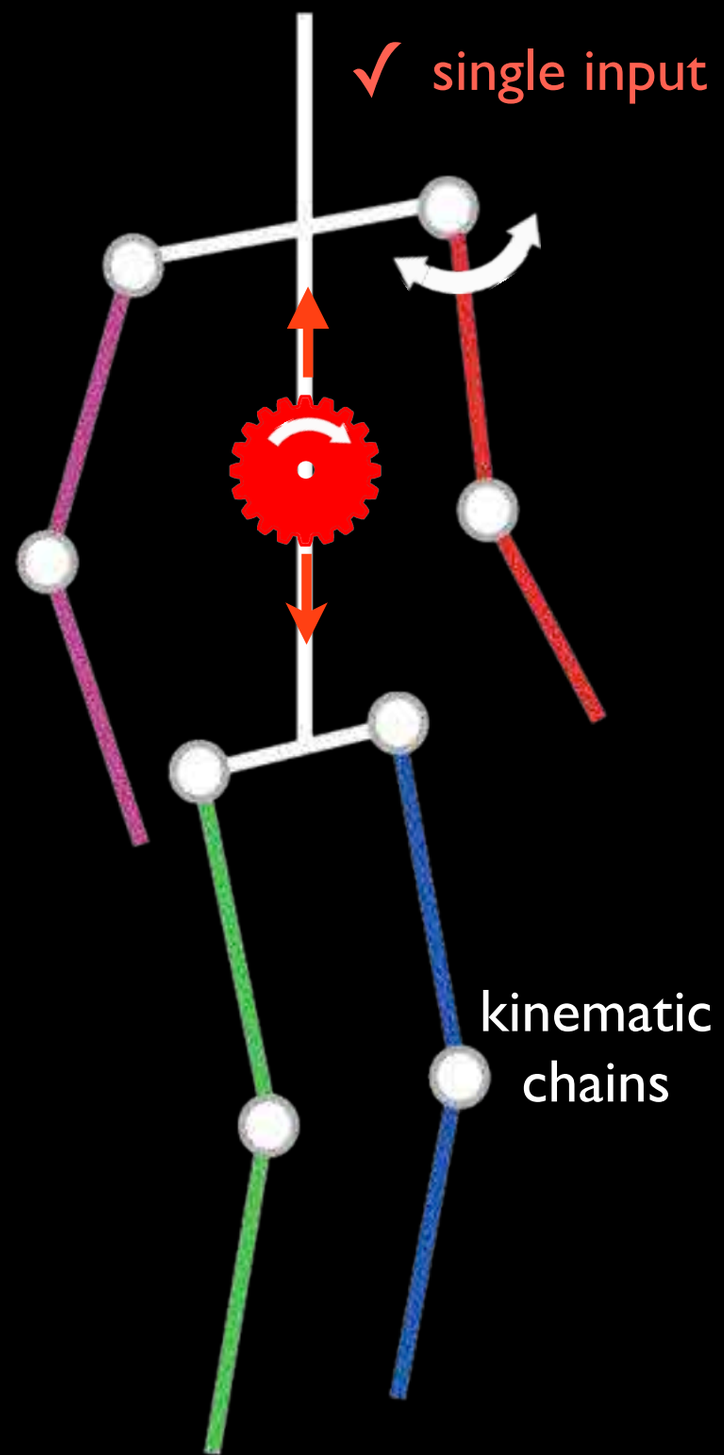
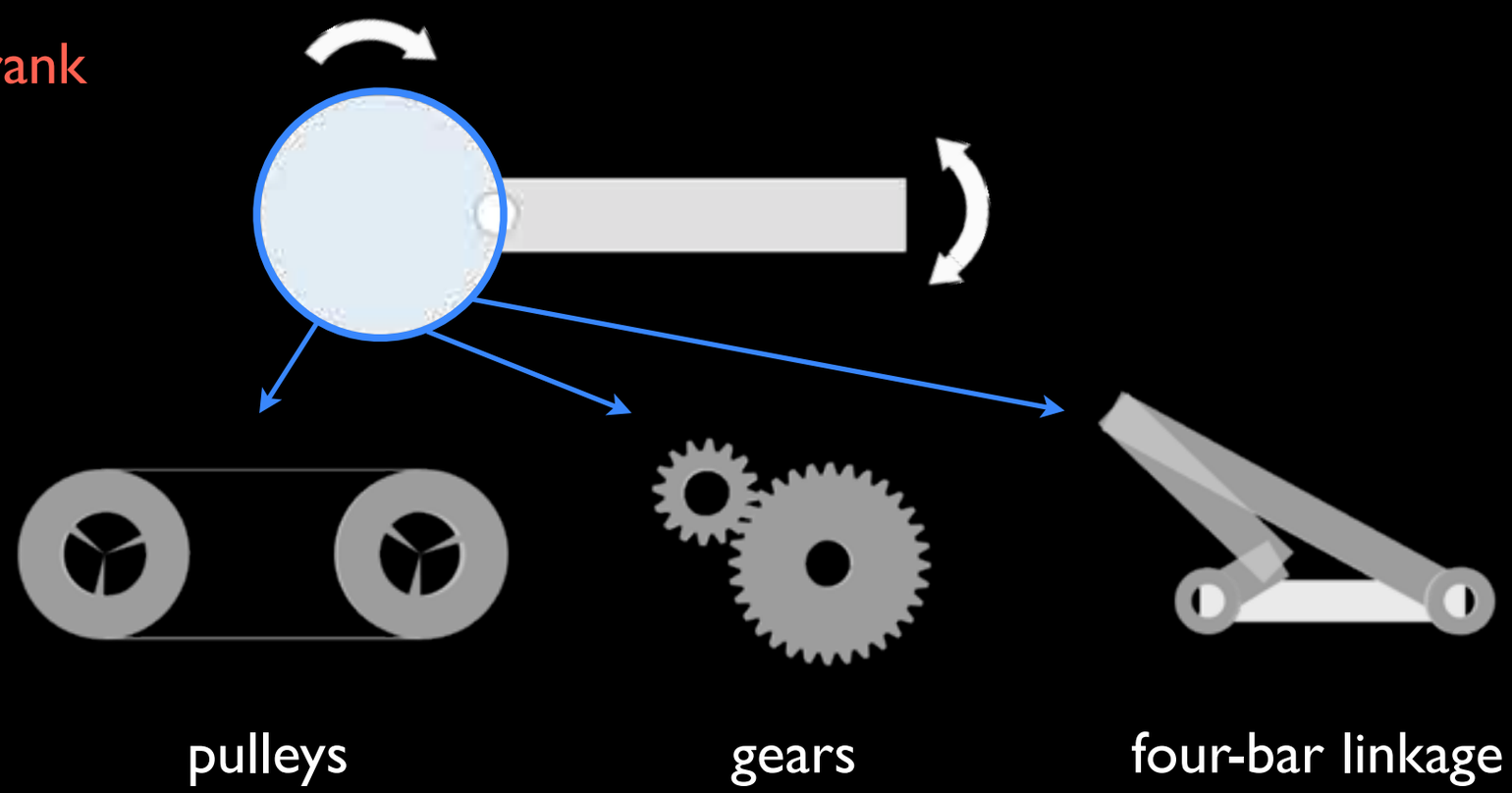
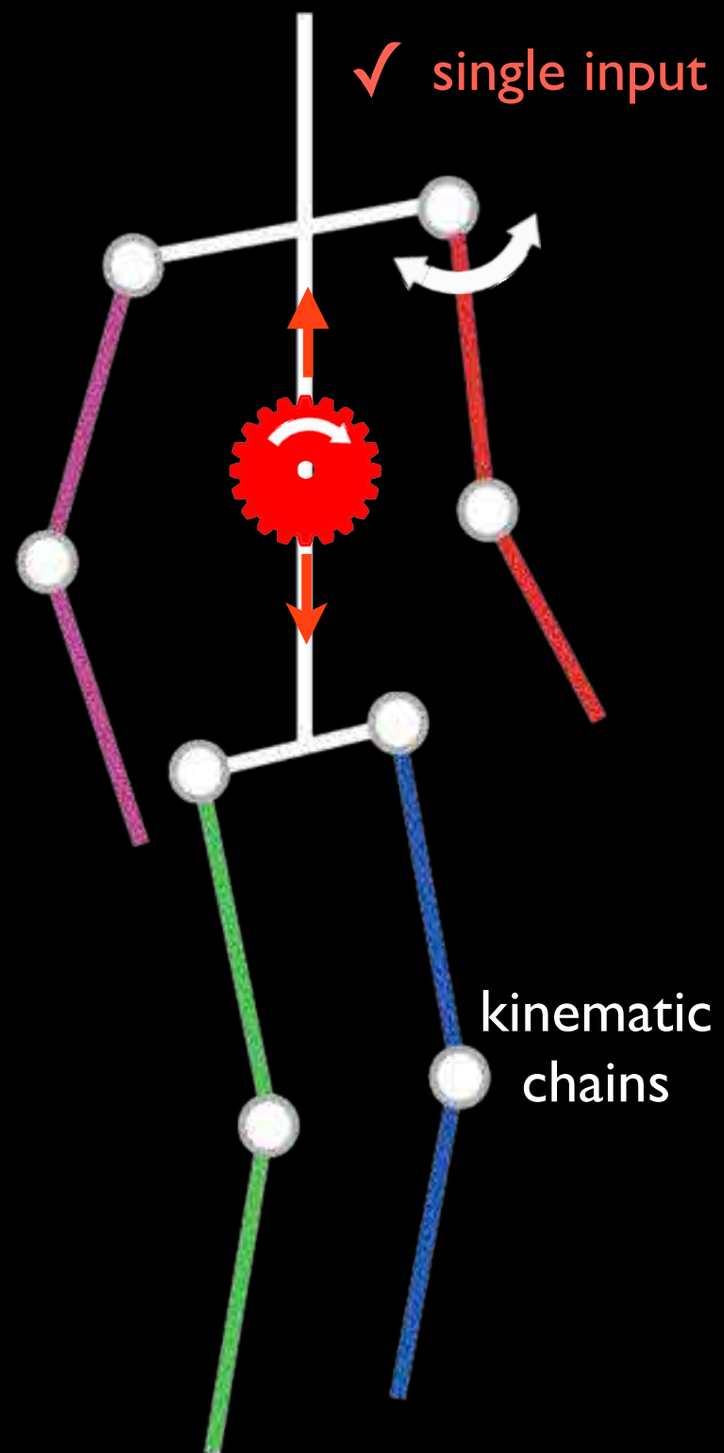
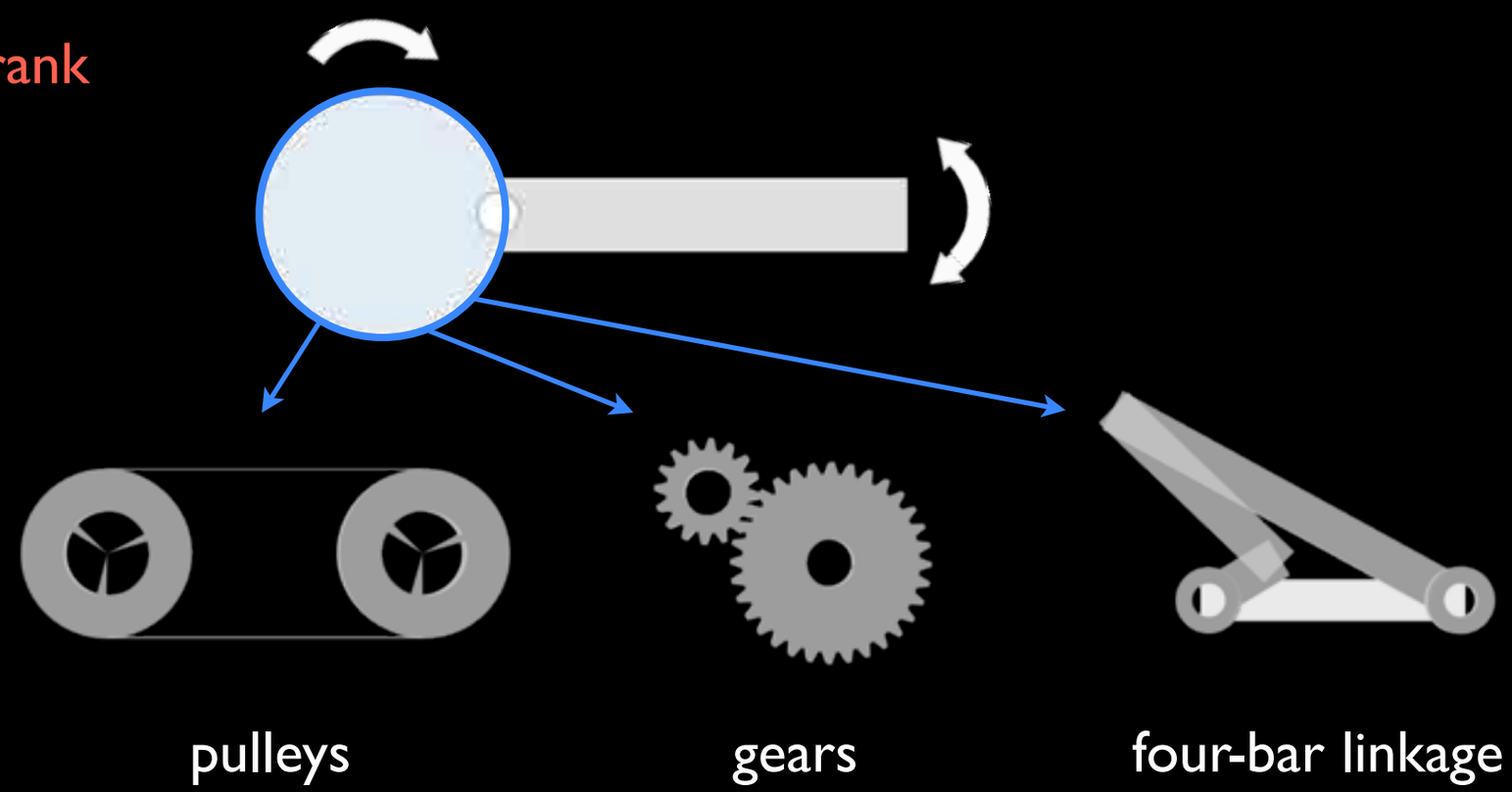




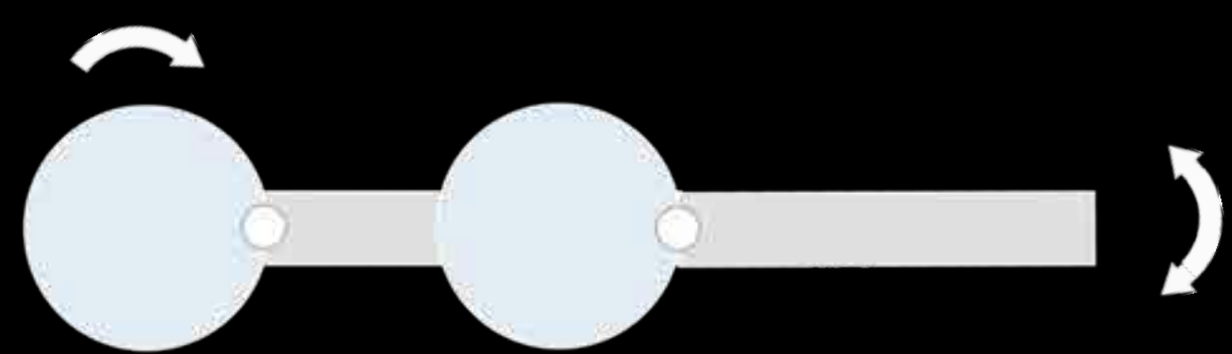
✓ oscillation module: combination of simple mechanisms

Automaton Design



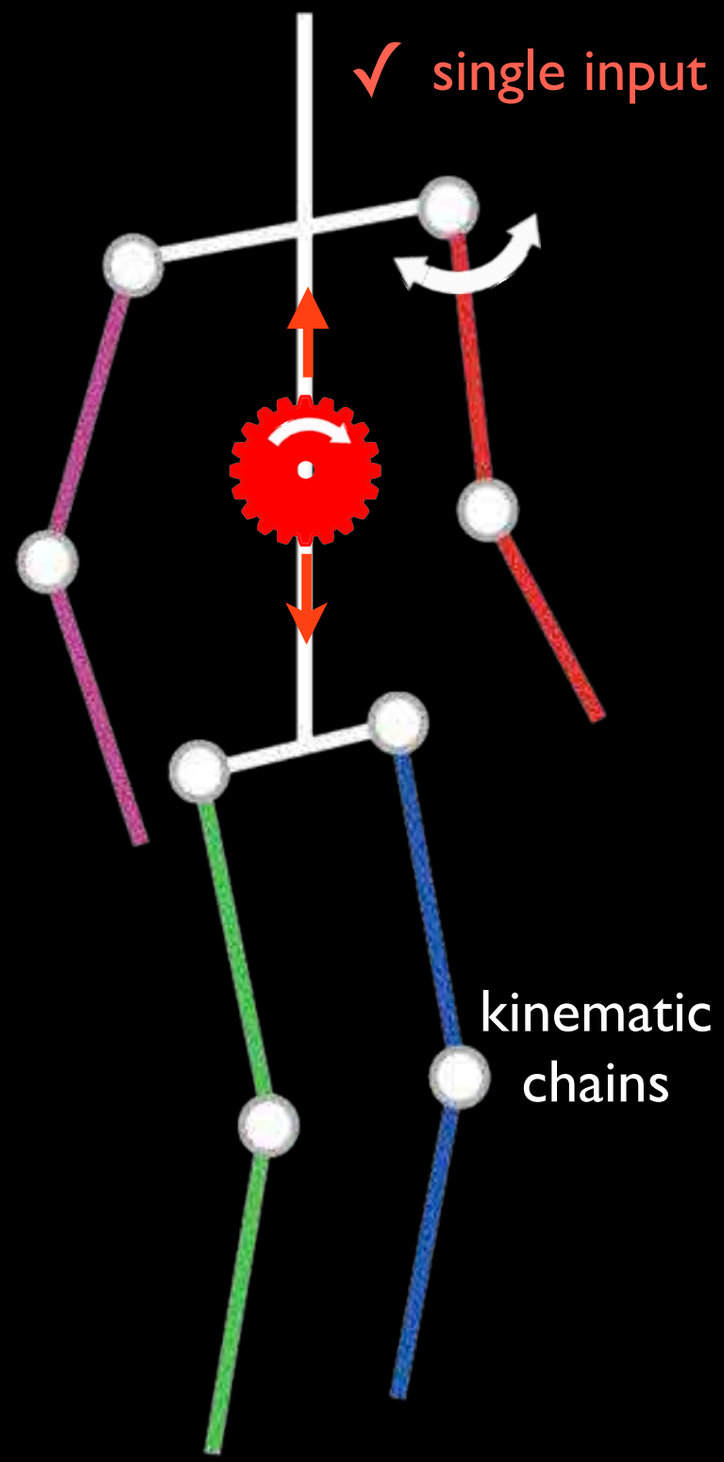


✓ oscillation module: combination of simple mechanisms



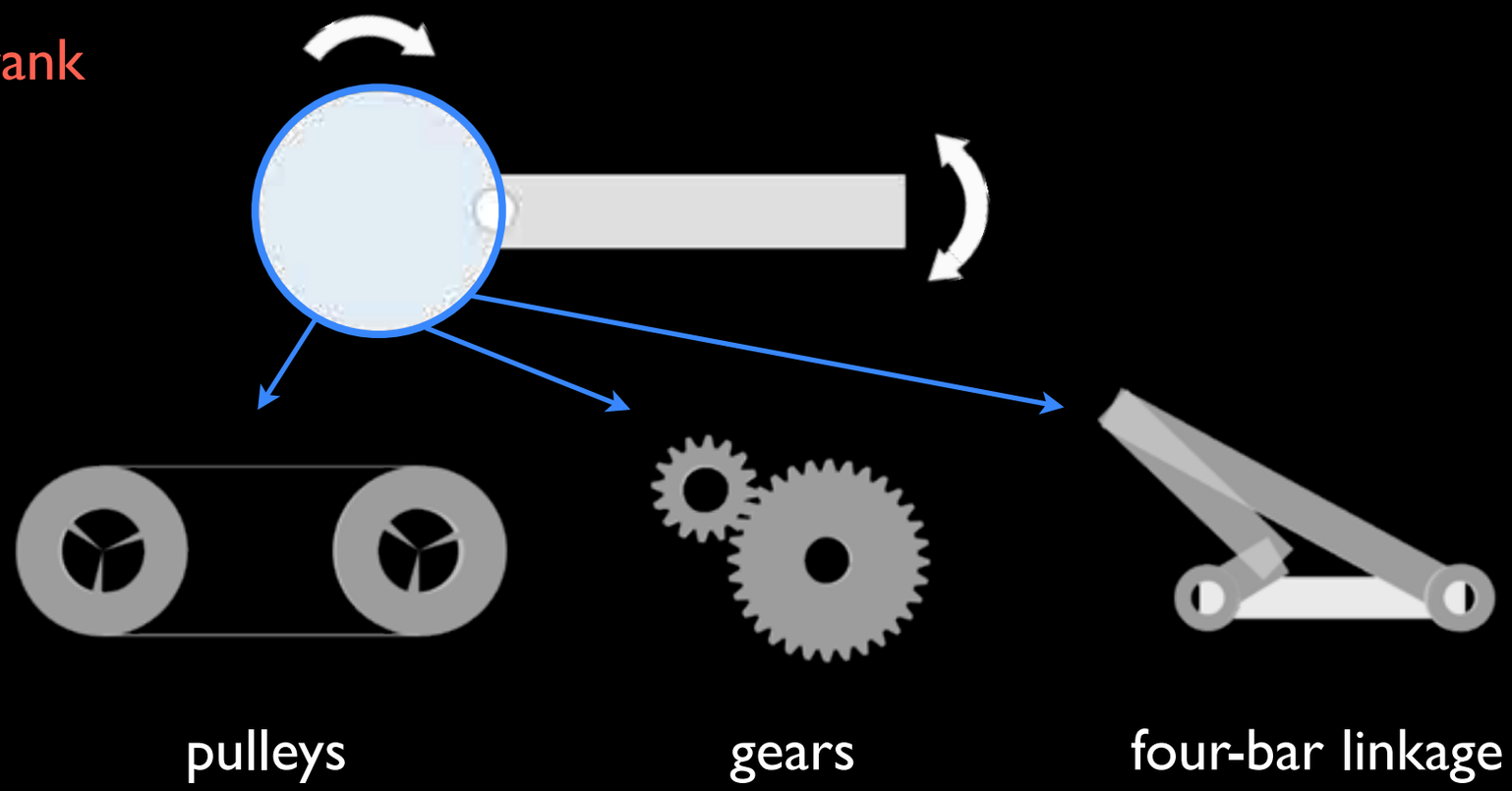
✓ hierarchy of oscillations with varying phase/frequency

Automaton Design

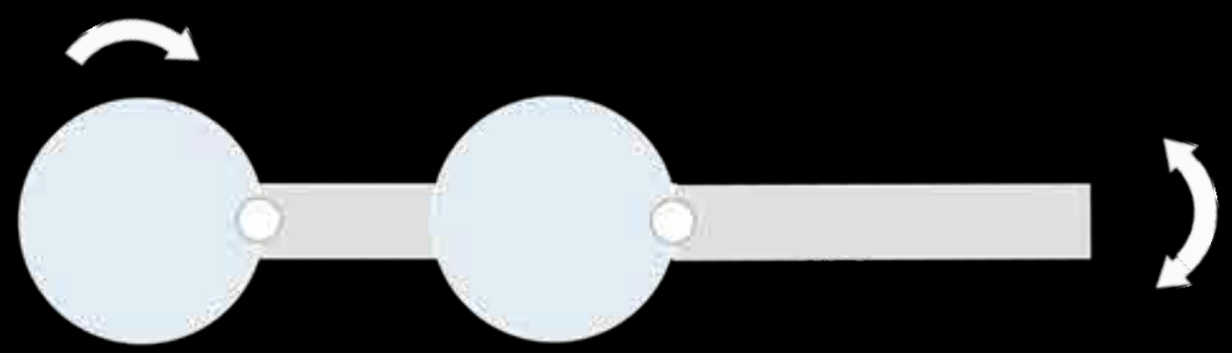


✓ single input crank

✓ free-standing



✓ oscillation module: combination of simple mechanisms



✓ hierarchy of oscillations with varying phase/frequency

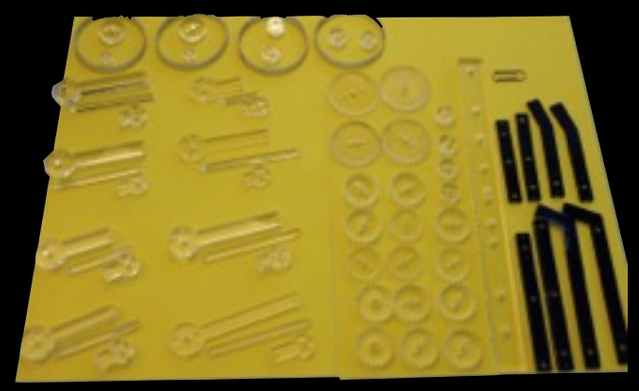
Design Pipeline

Input Motion

Motion Approximation

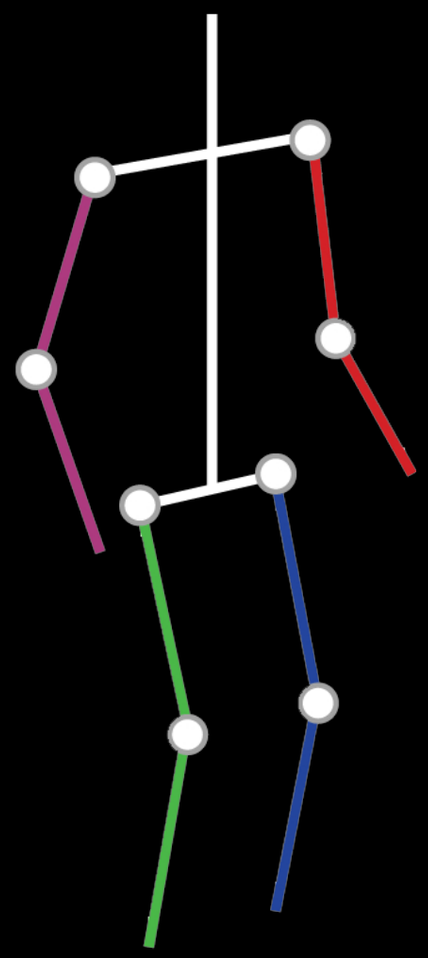
Kinematic chains & Layout

Generated Automaton

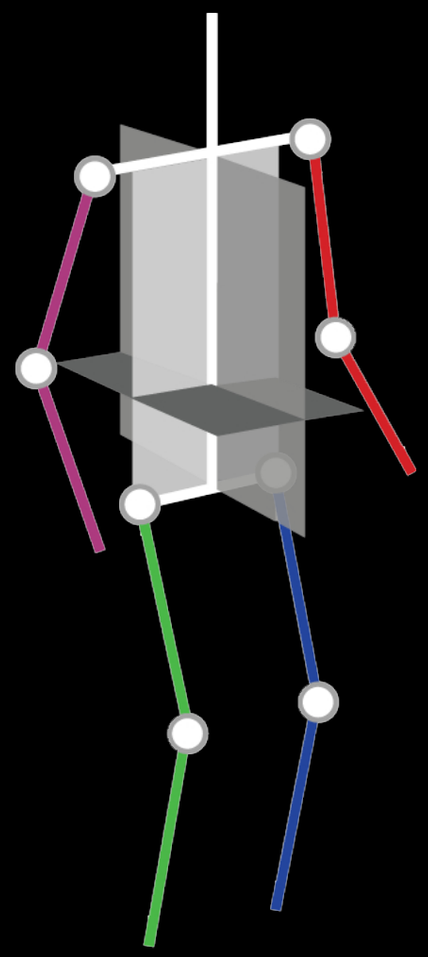


Fabrication

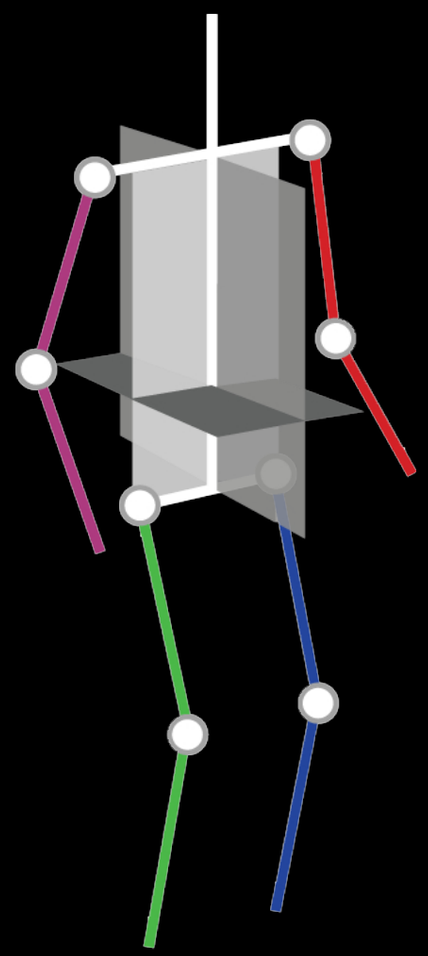
Planar Approximation



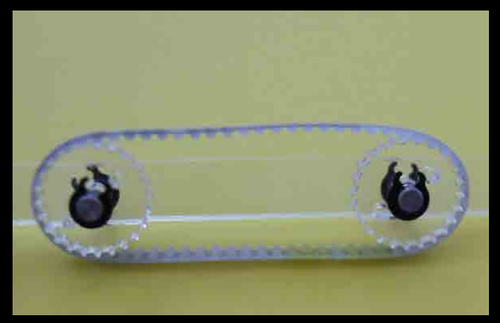
Planar Approximation



Planar Approximation

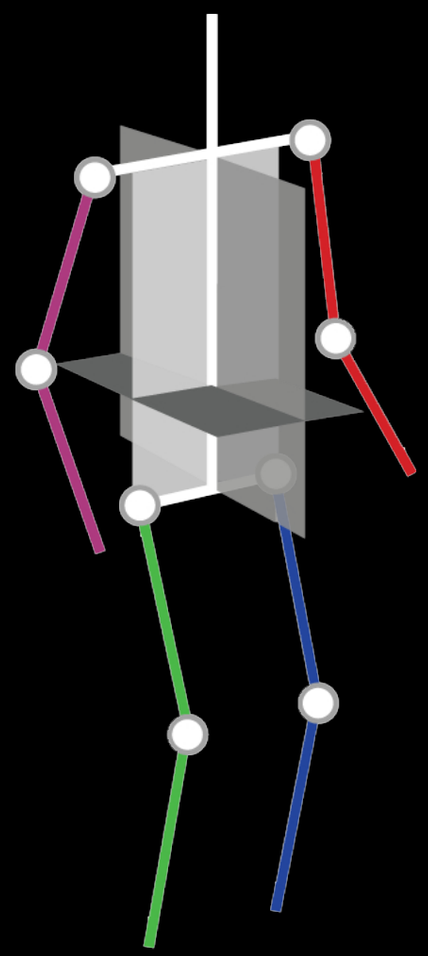


four-bar linkage

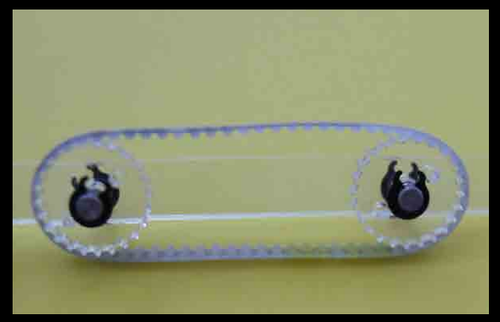


pulleys

Planar Approximation



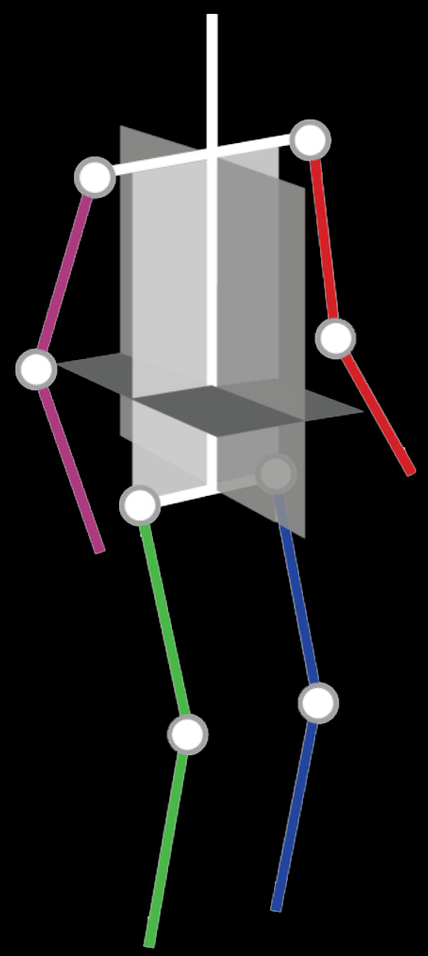
four-bar linkage



pulleys

bevel-gears

Planar Approximation



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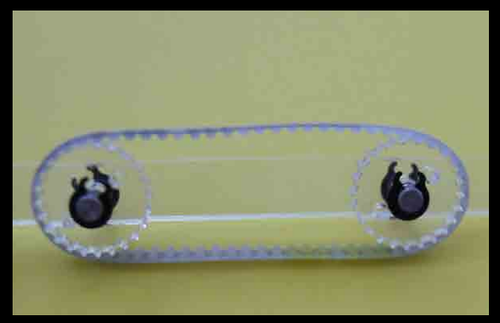
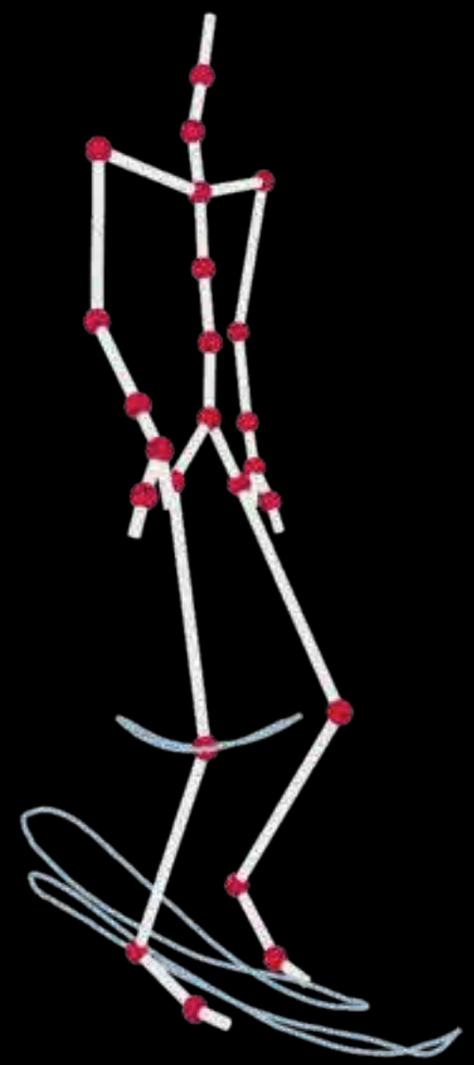
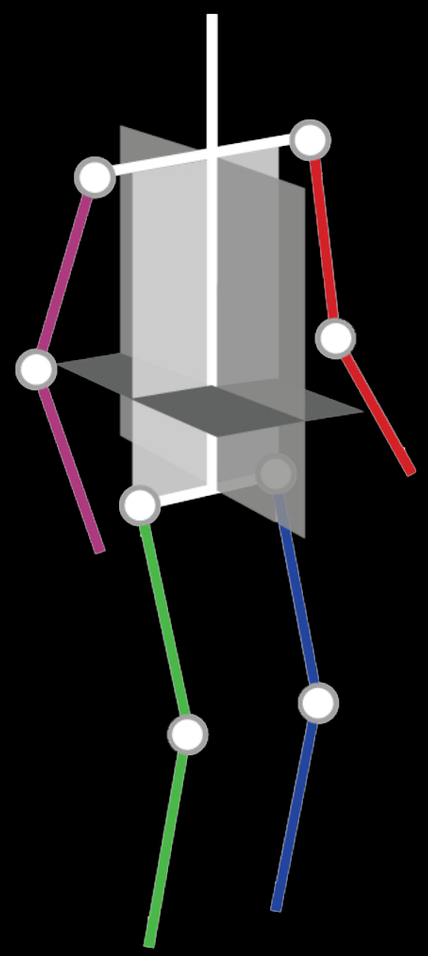


pulleys

bevel-gears



Planar Approximation



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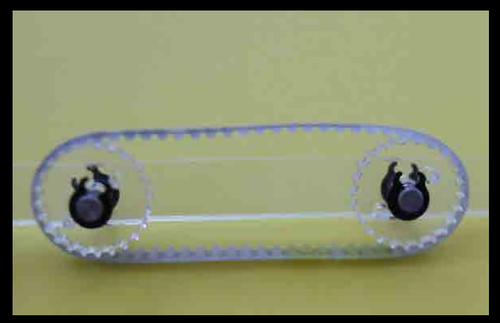

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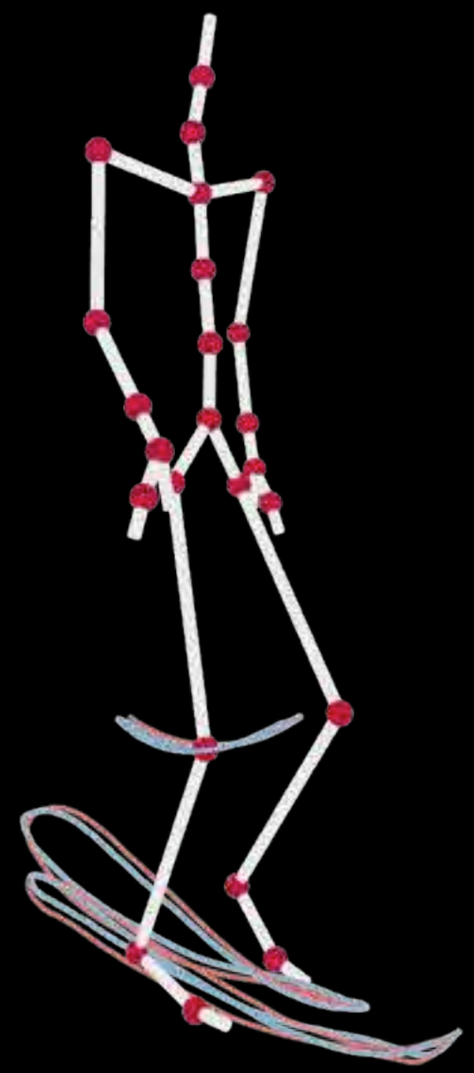
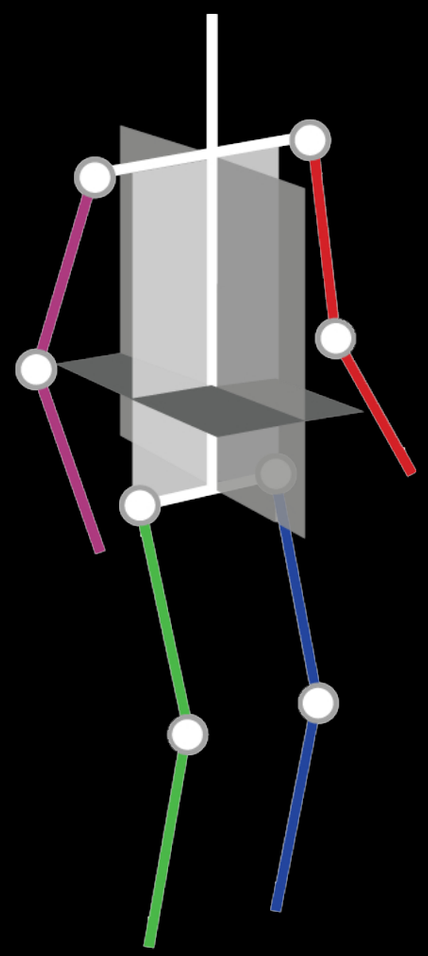
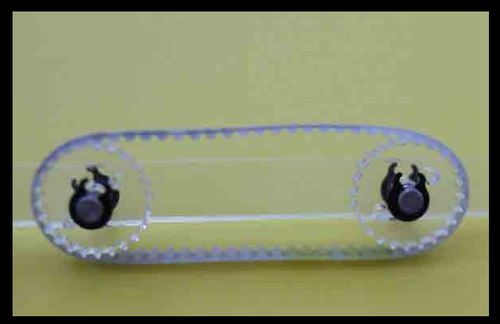


Planar Approximation

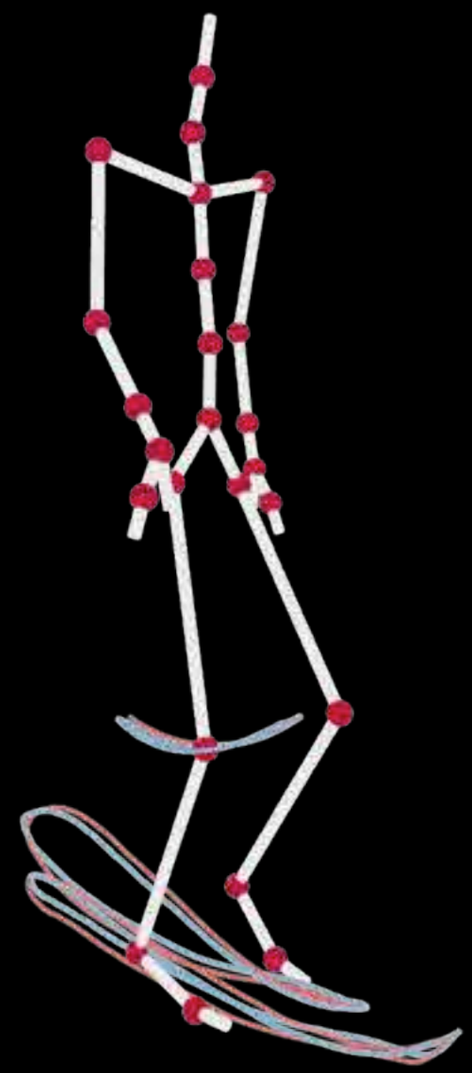


four-bar linkage

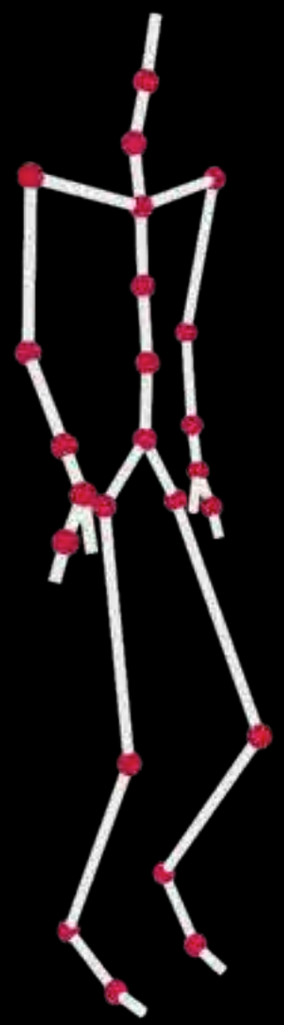


pulleys

bevel-gears

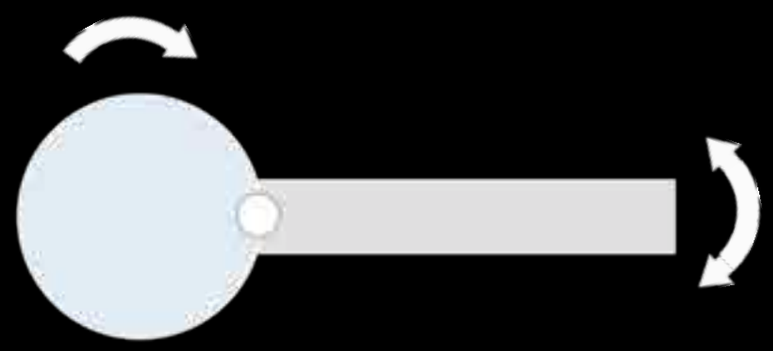


input motion



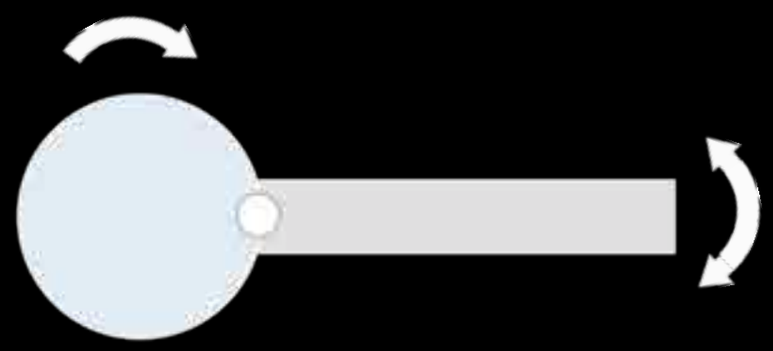
planar motion

Oscillation Module

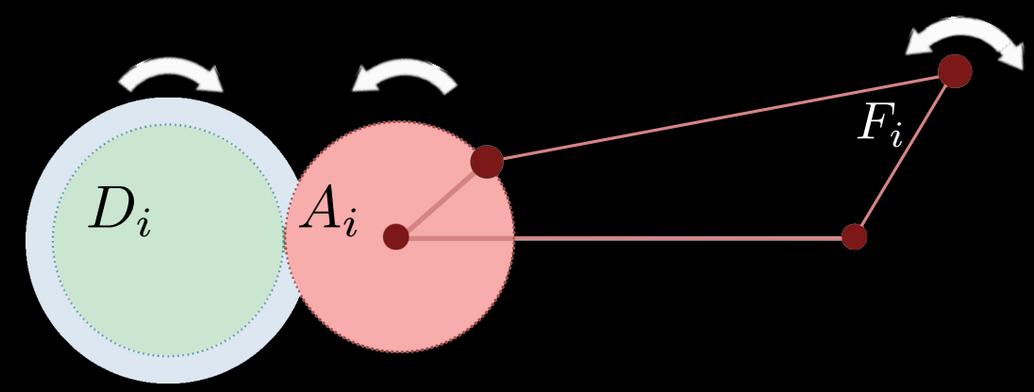


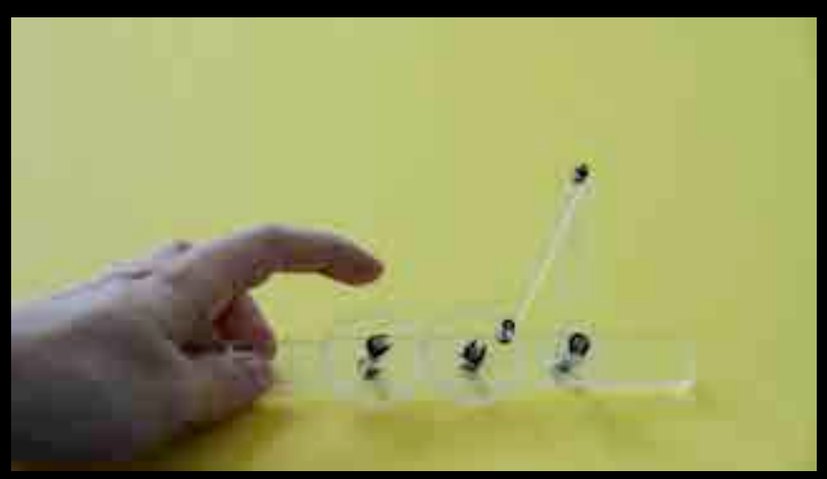
oscillation module

Oscillation Module



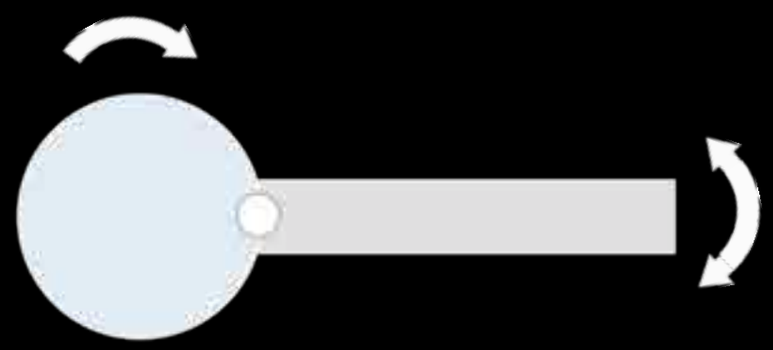
oscillation module



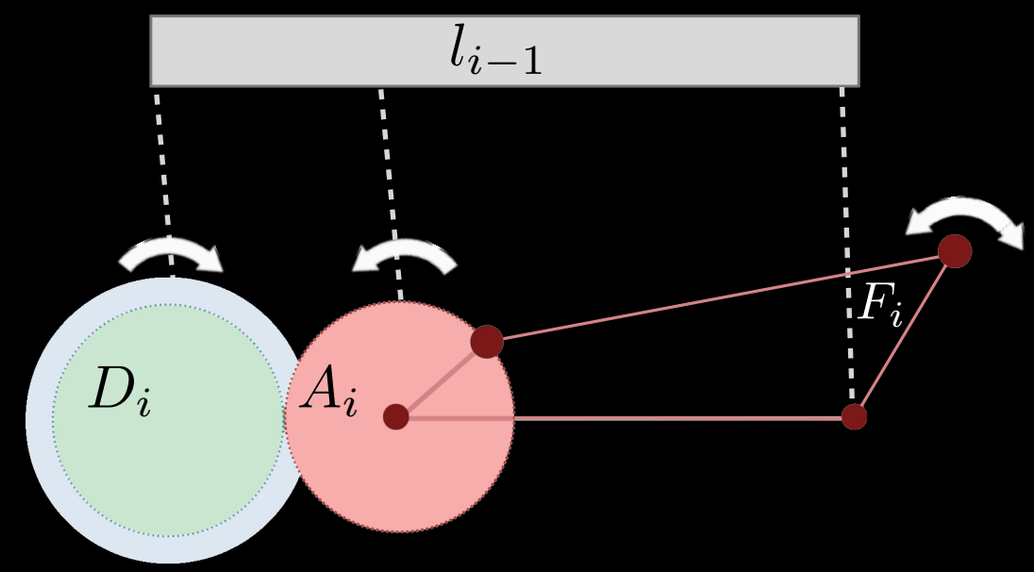


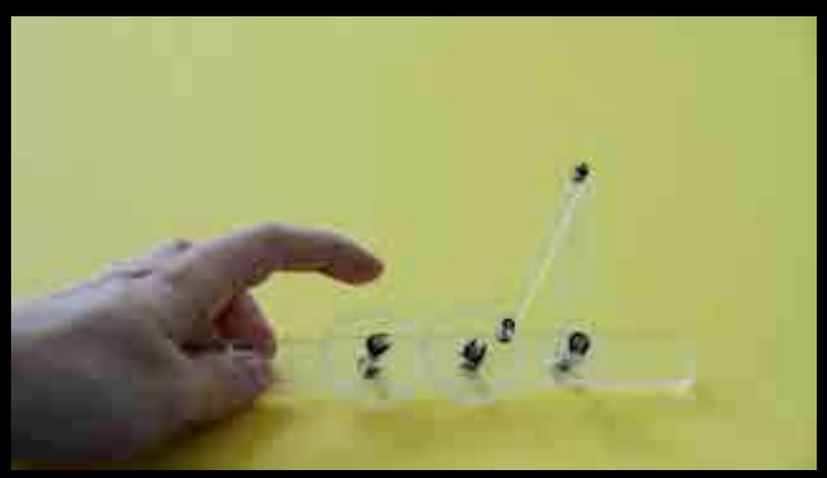
the four-bar linkage converts
uni-directional rotation to oscillation

Oscillation Module



oscillation module





the four-bar linkage converts
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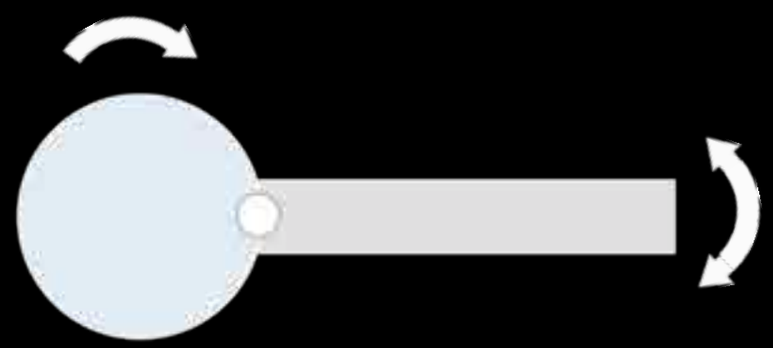
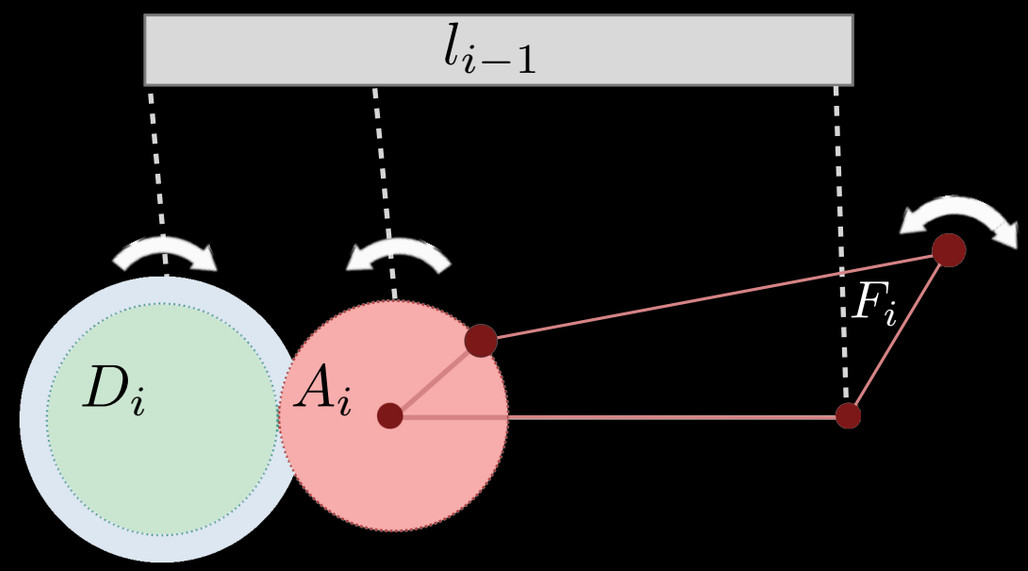
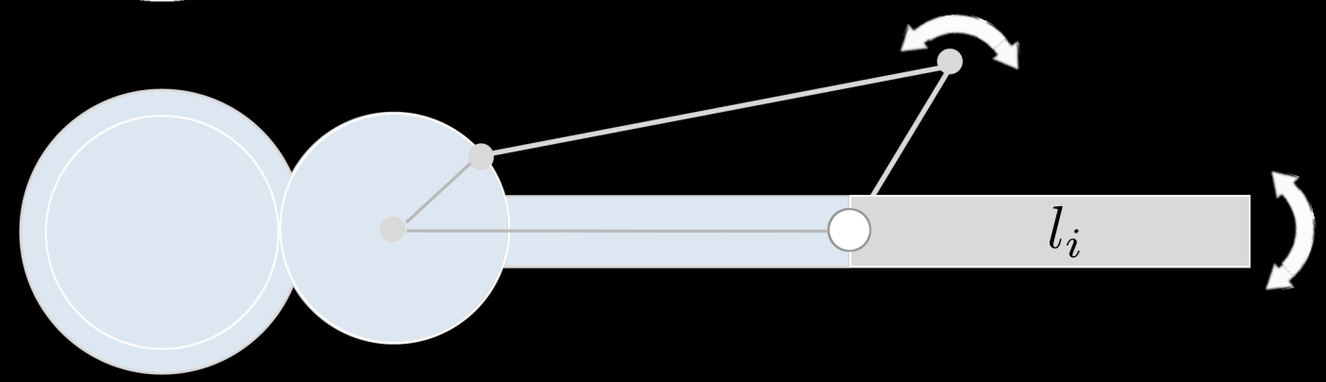
Oscillation Module



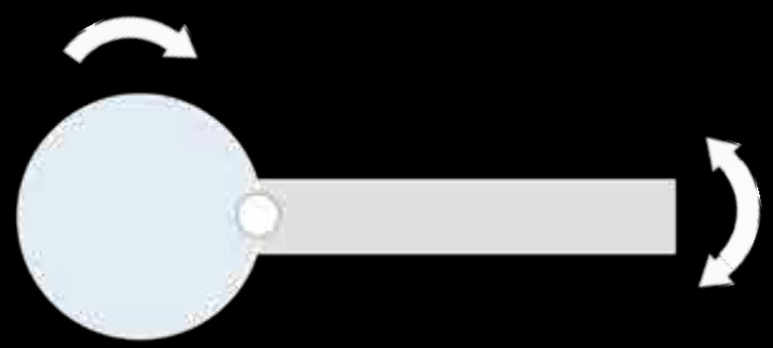
oscillation module



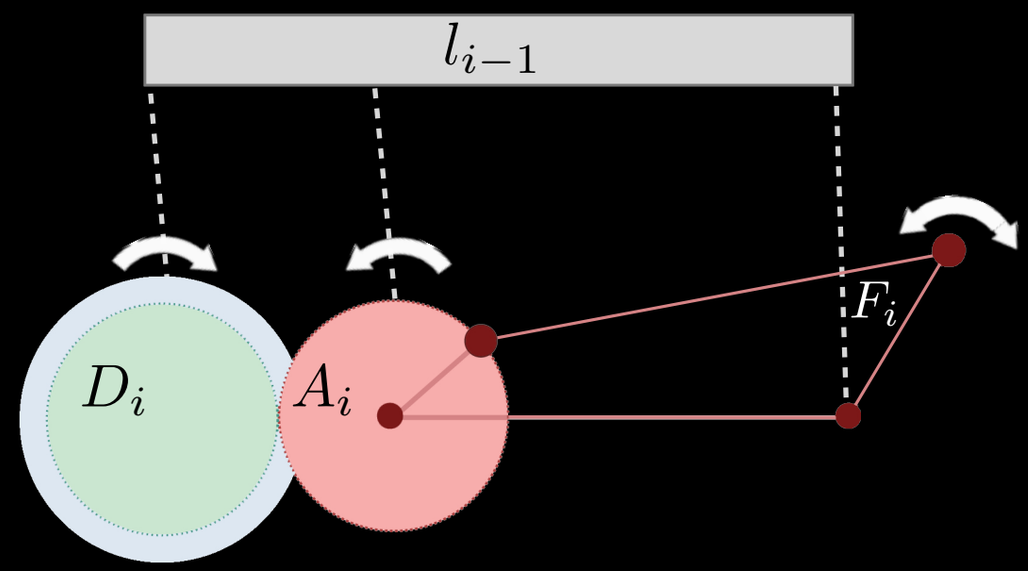


the output crank of the linkage drives the link attached to it

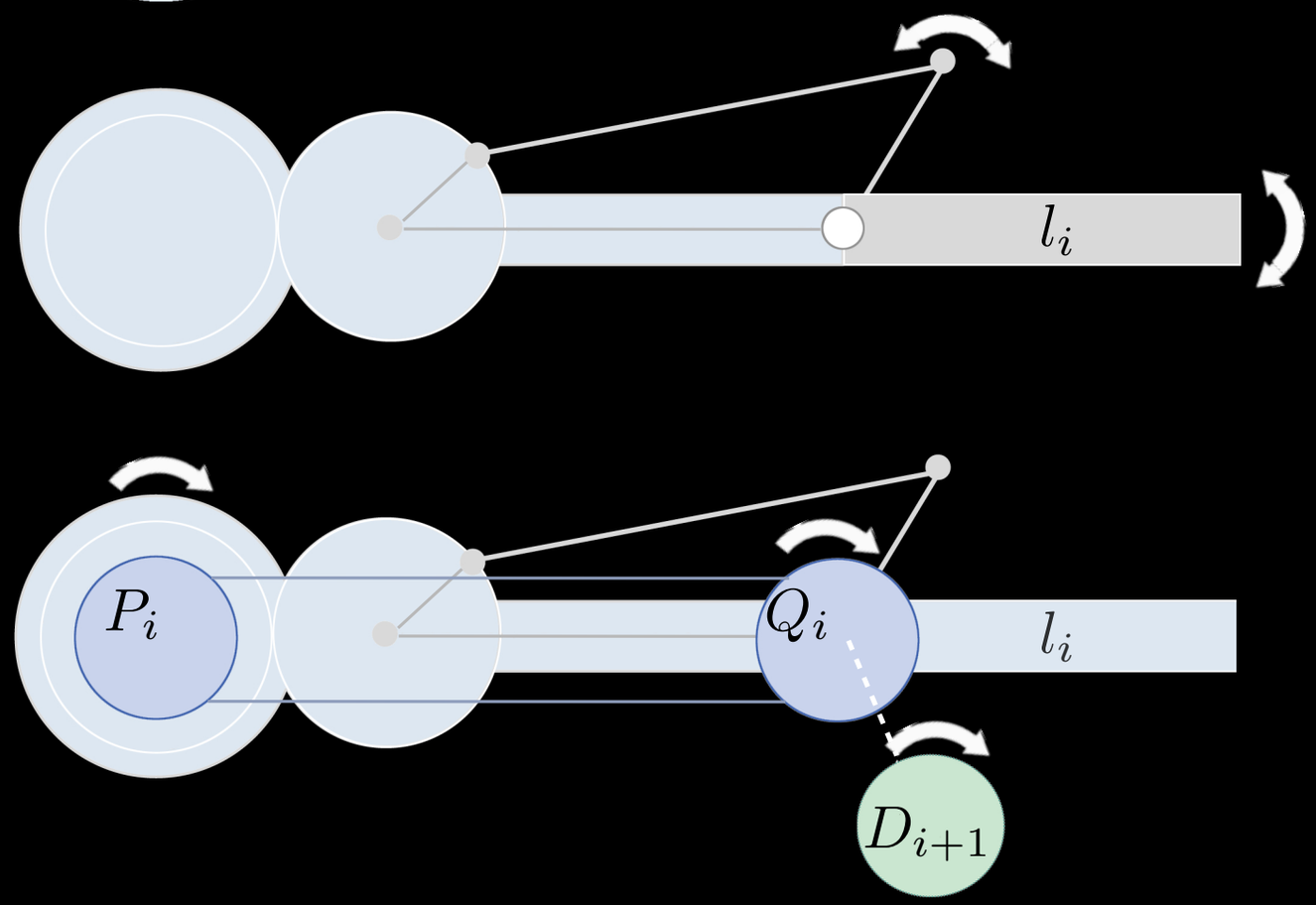
Oscillation Module



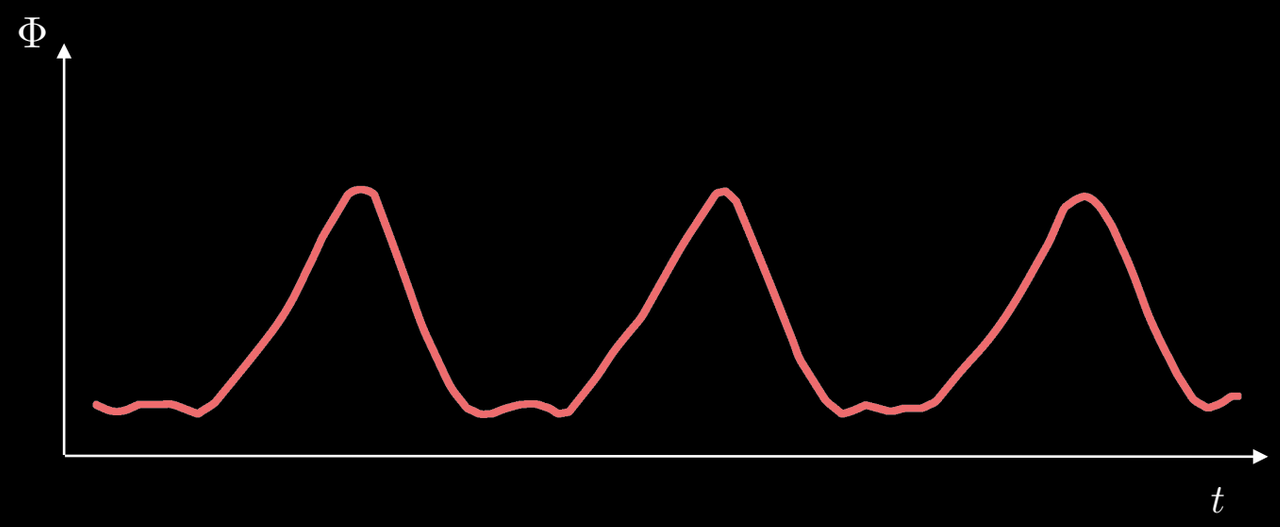
oscillation module



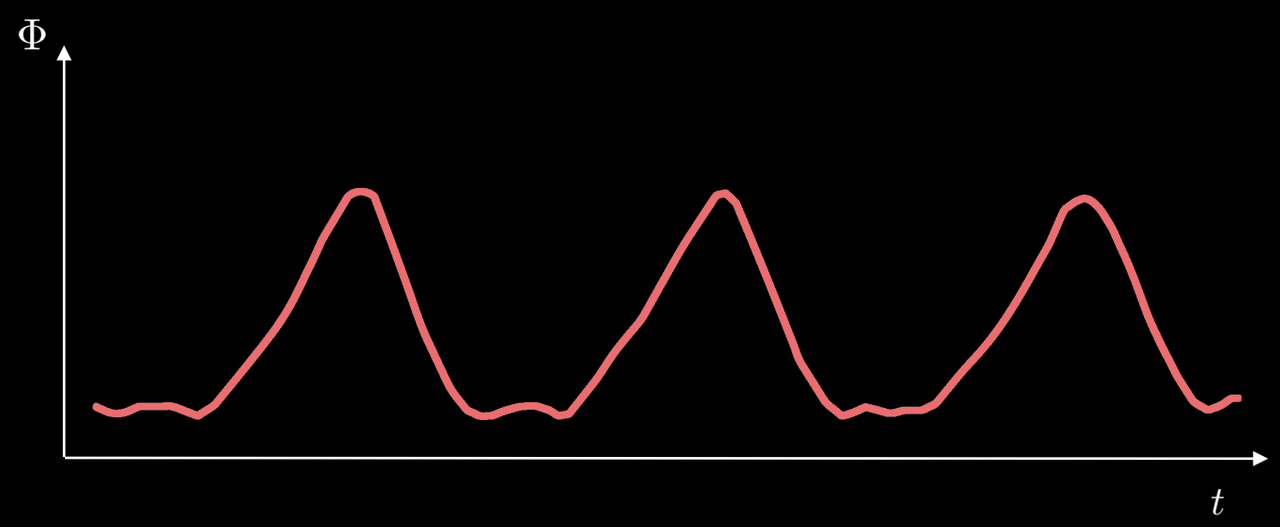
the pulleys propagate the
input rotation to the next link

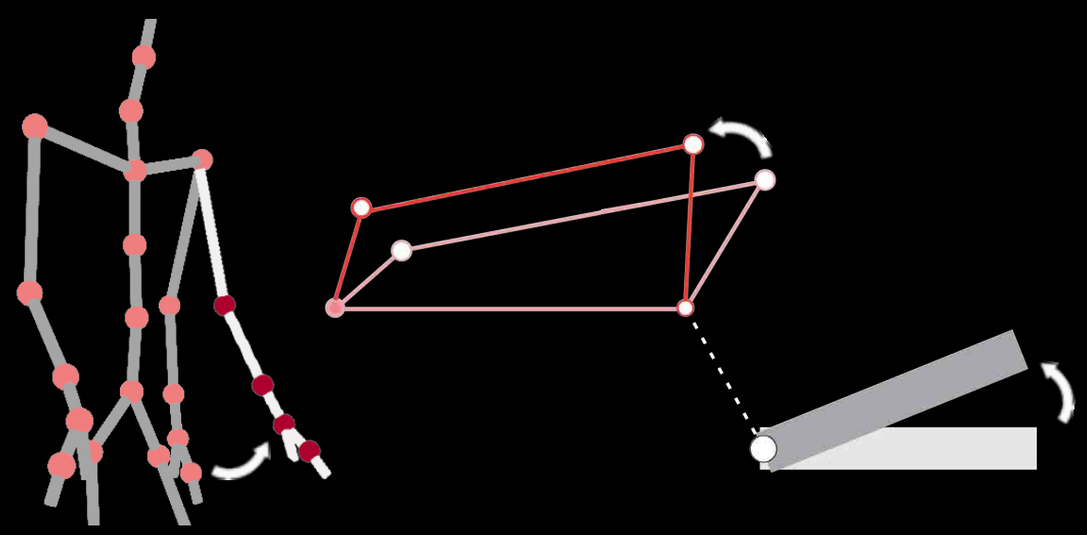


Motion Approximation

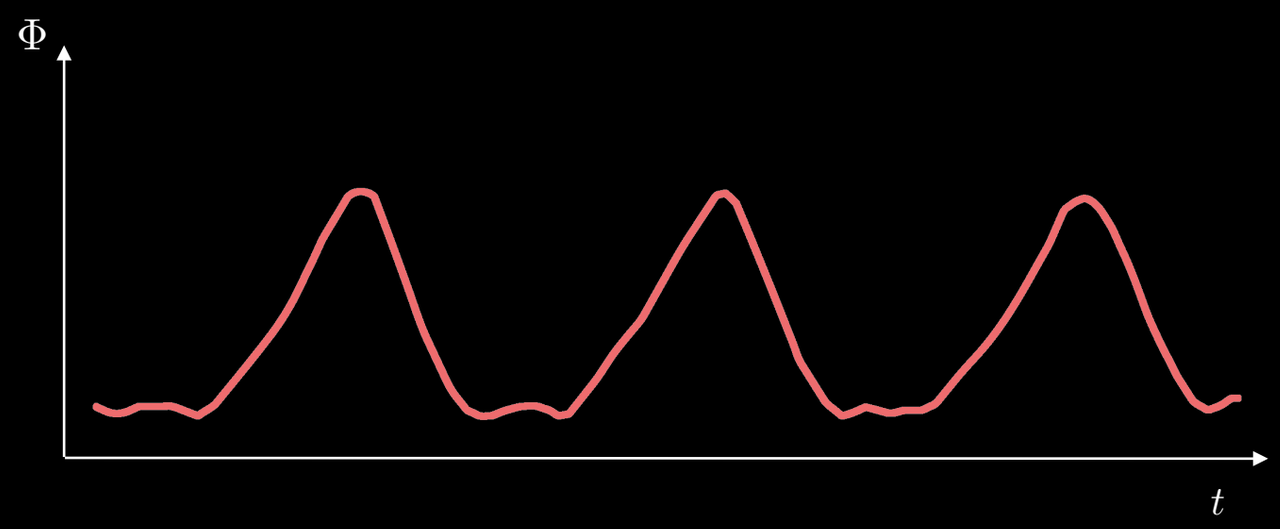


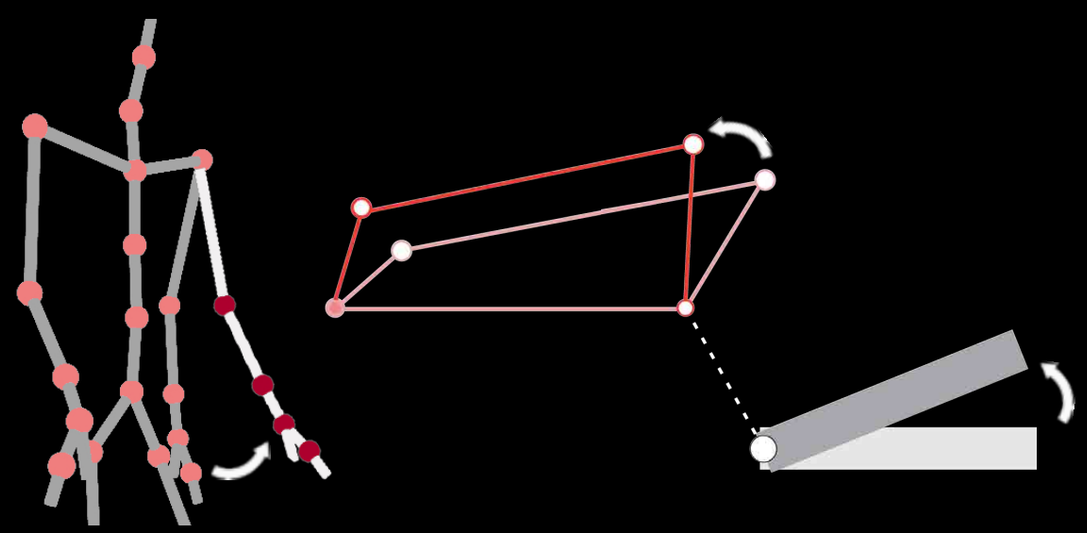
Motion Approximation





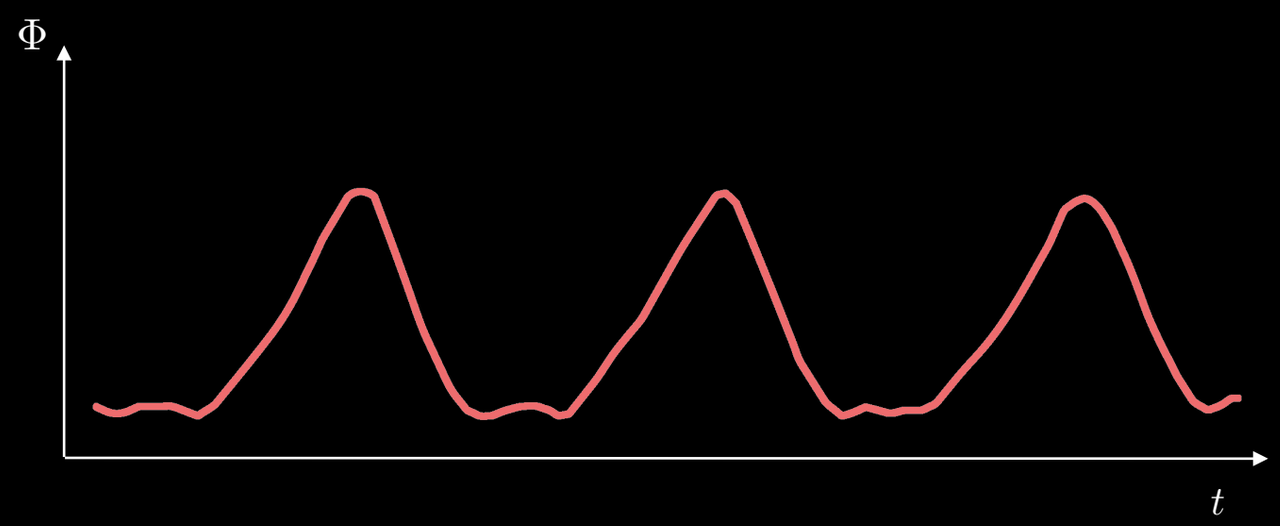
Motion Approximation

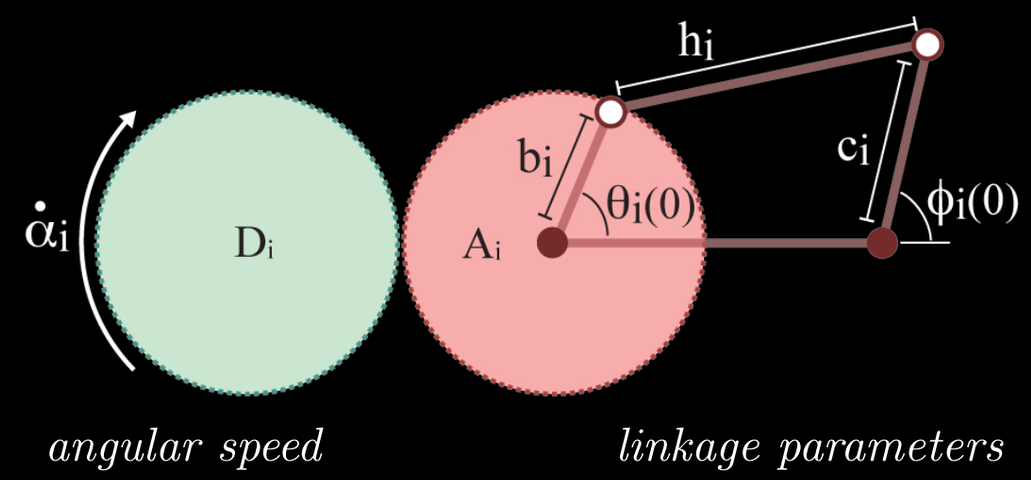


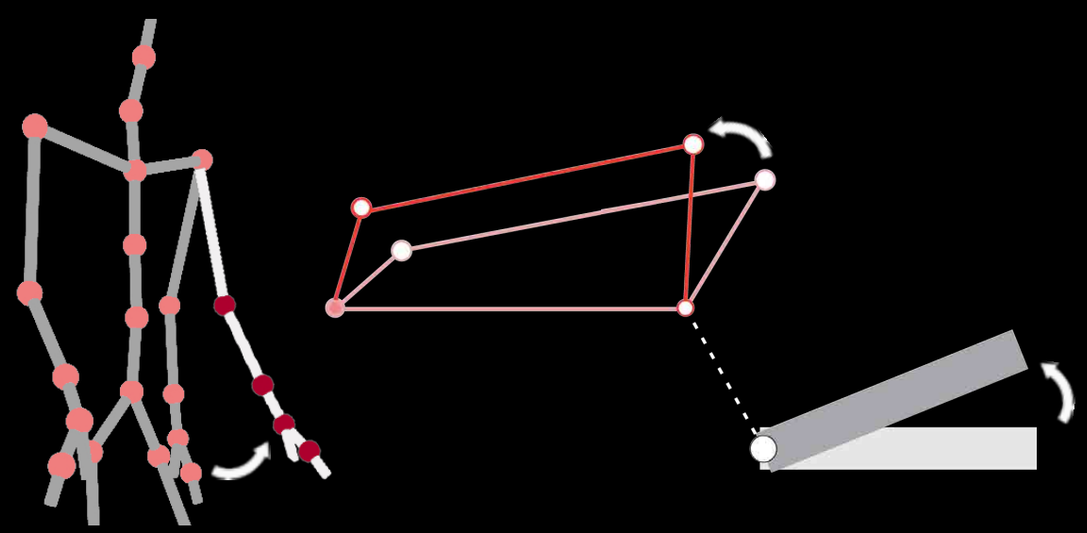


$$E_{\Phi_i} = \sum_{i}^{\#links} \sum_{t}^{\#frames} \left(\sin \frac{\Delta_{\Phi_i}(t) - \Delta_{\phi_i}(t)}{2} \right)^2$$

Motion Approximation







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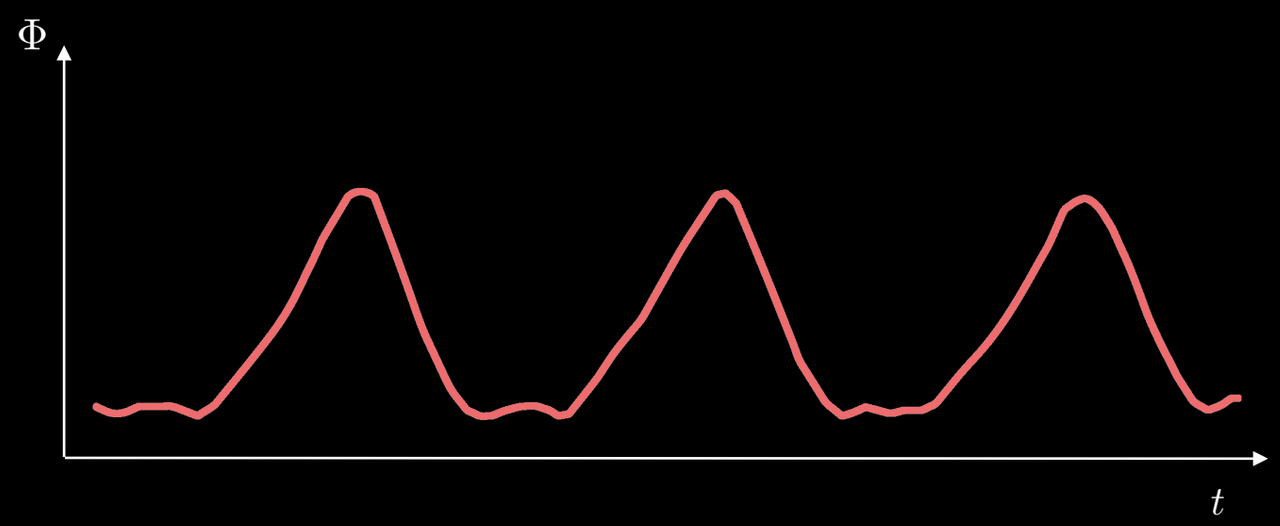
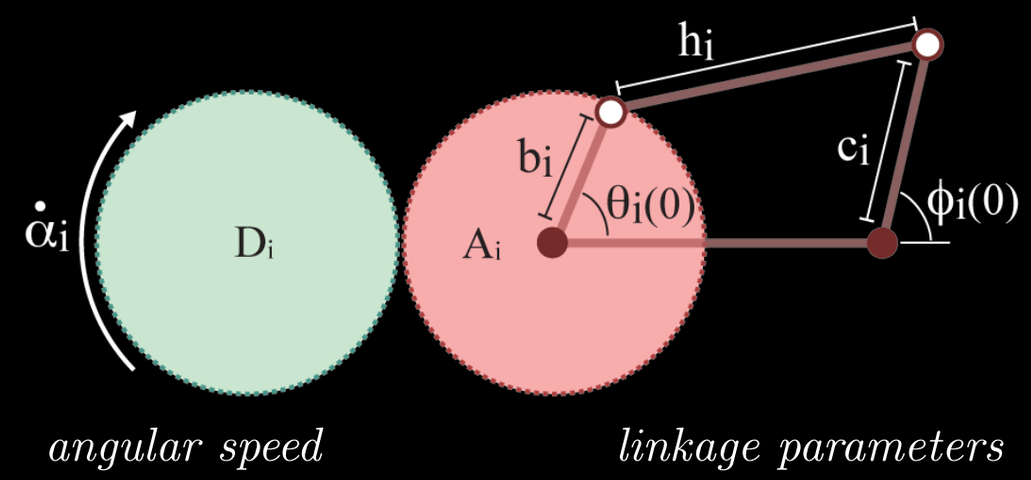
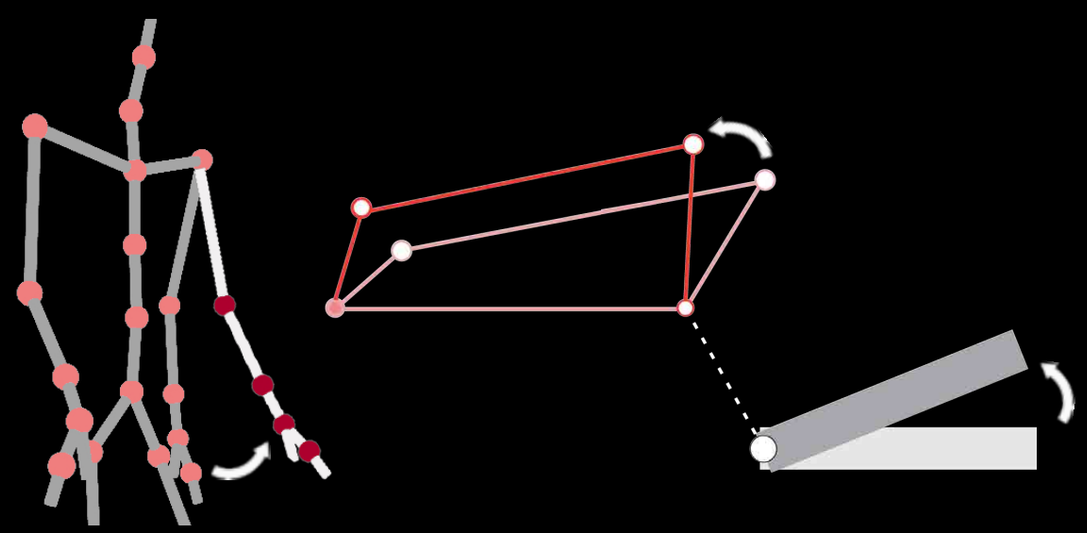
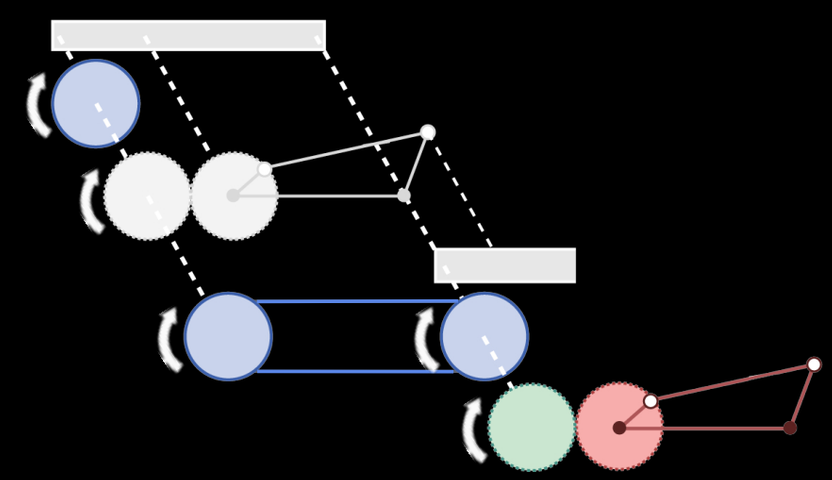
Motion Approximation









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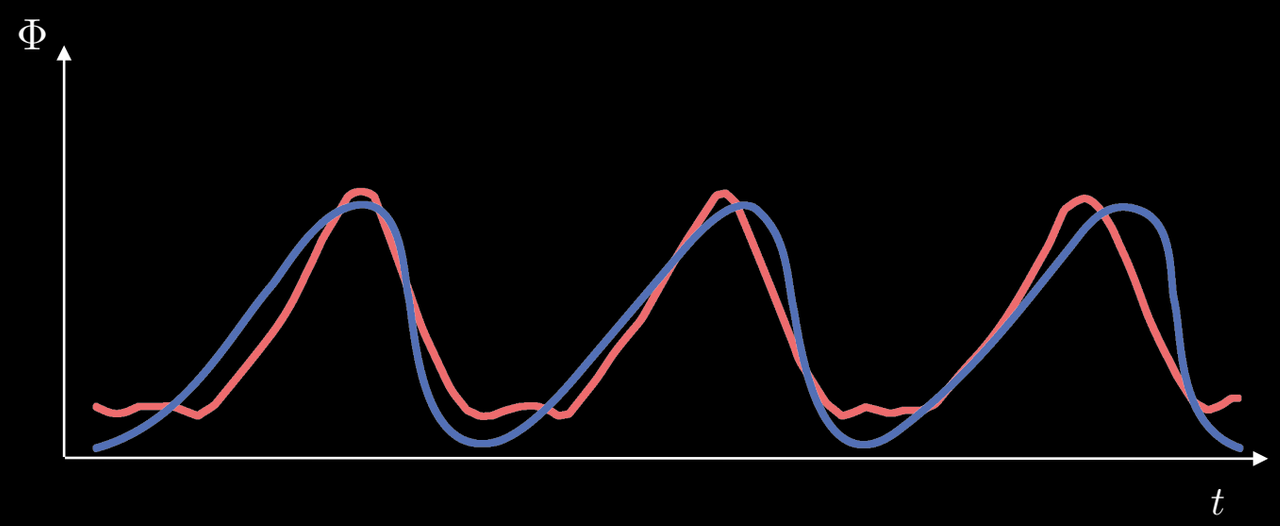
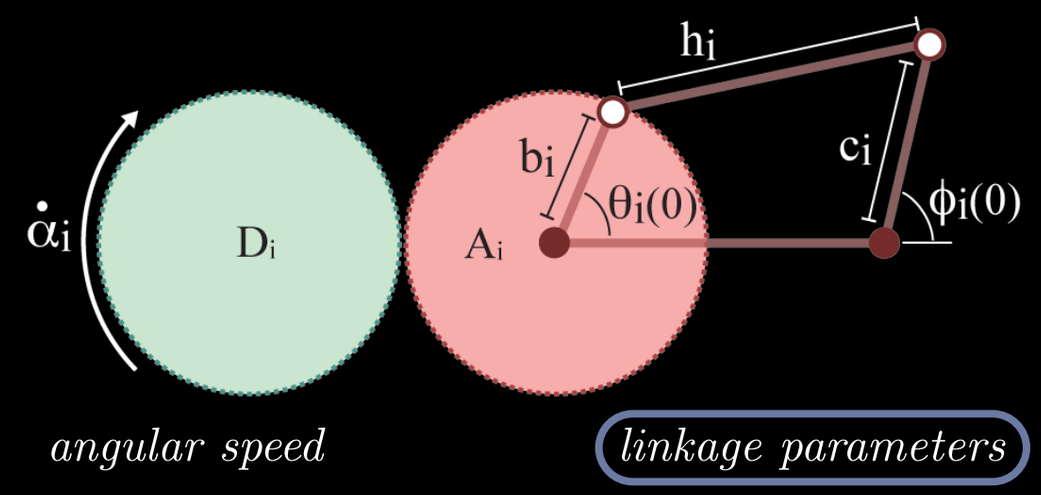
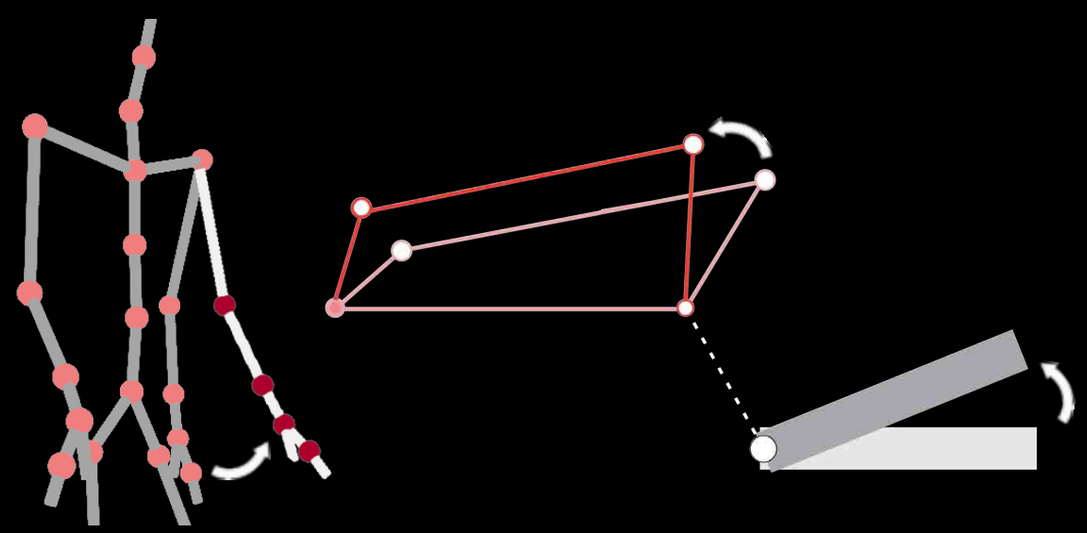
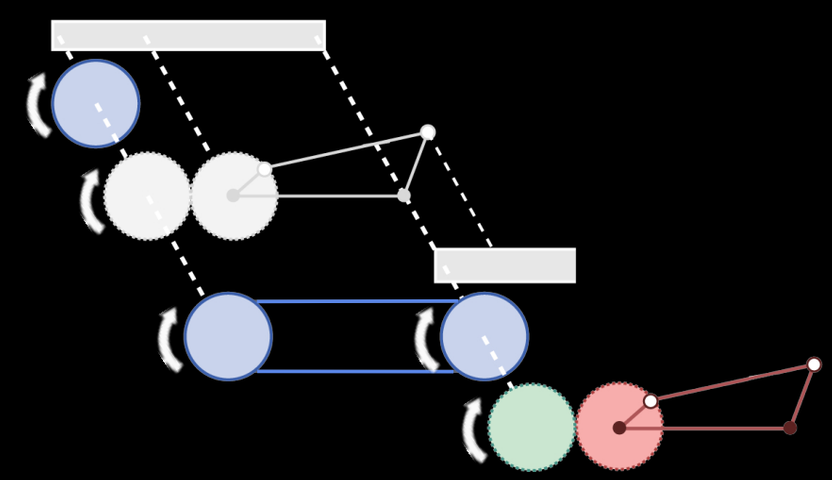
$\dot{\alpha}_i$ depends on input speed & pulley ratios

Motion Approximation









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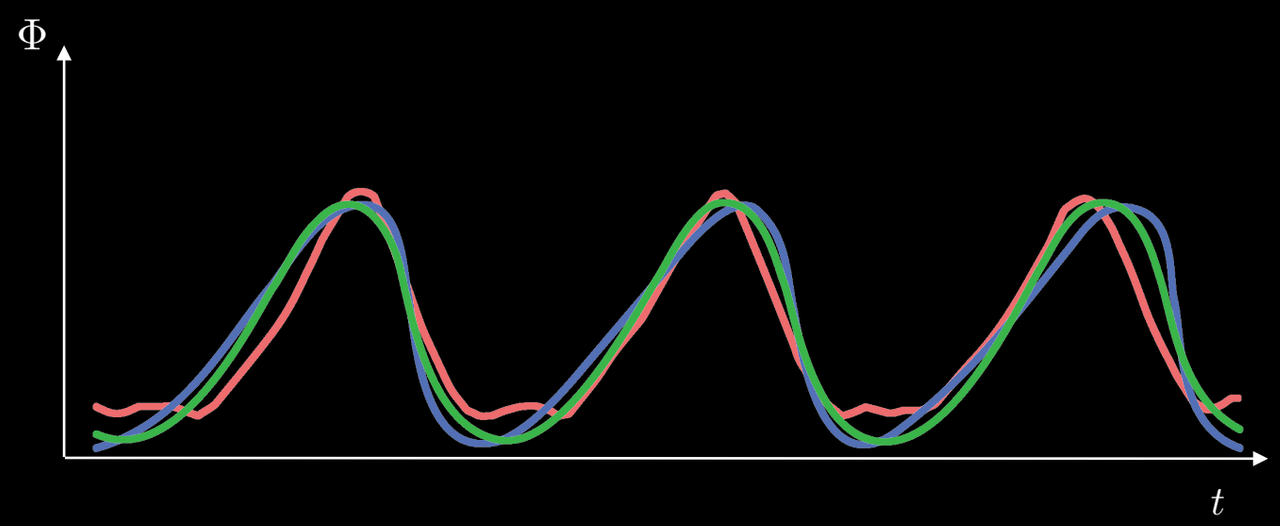
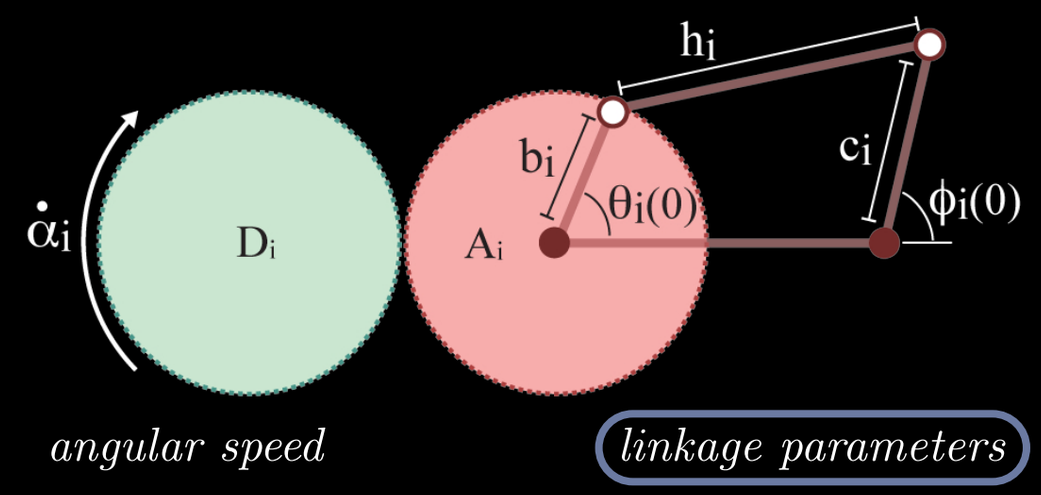
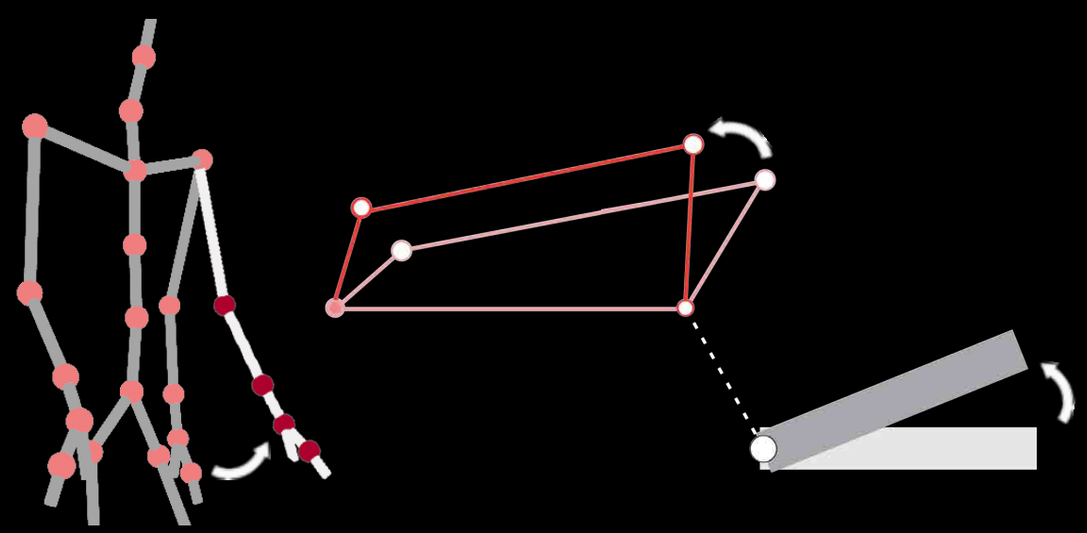
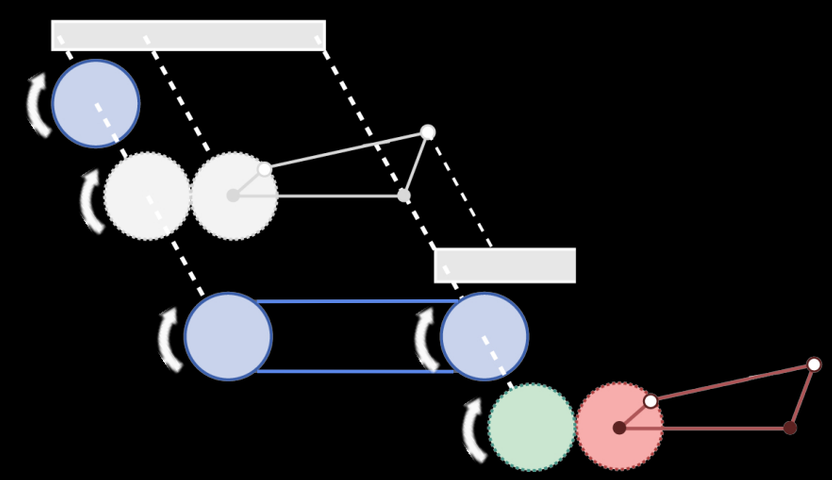
$\dot{\alpha}_i$ depends on input speed & pulley ratios

Motion Approximation





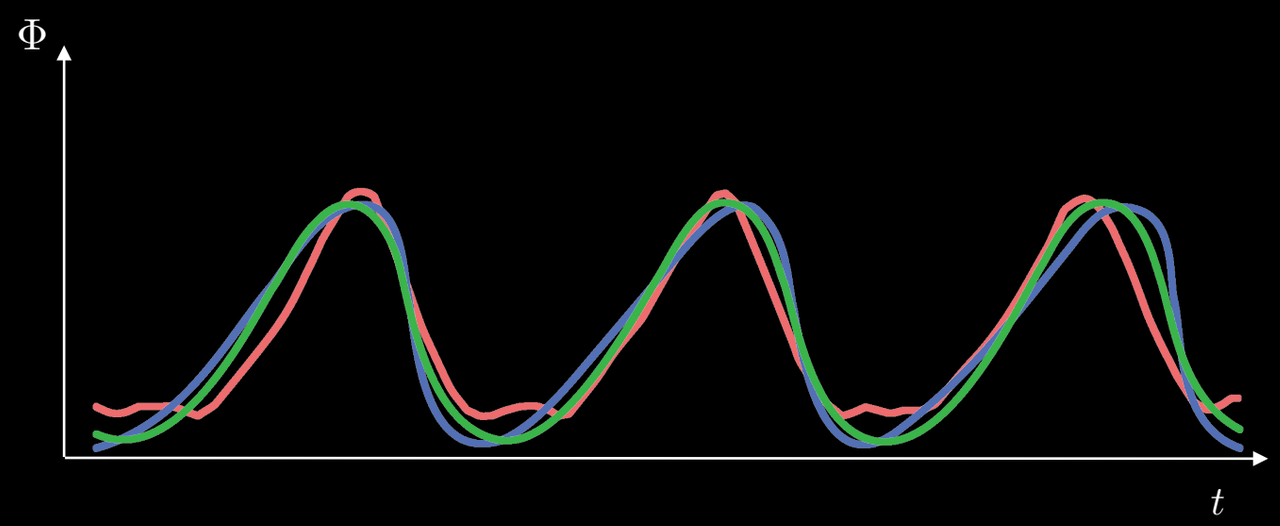


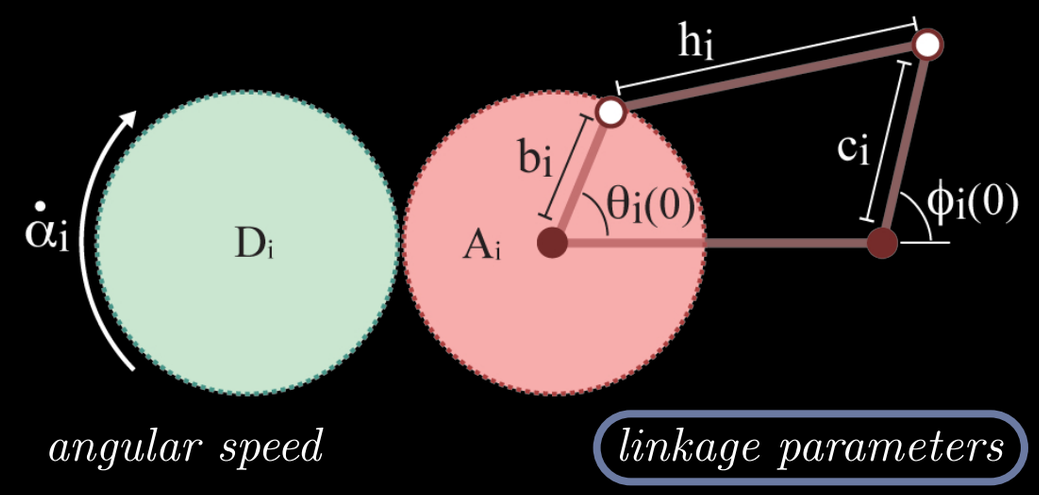


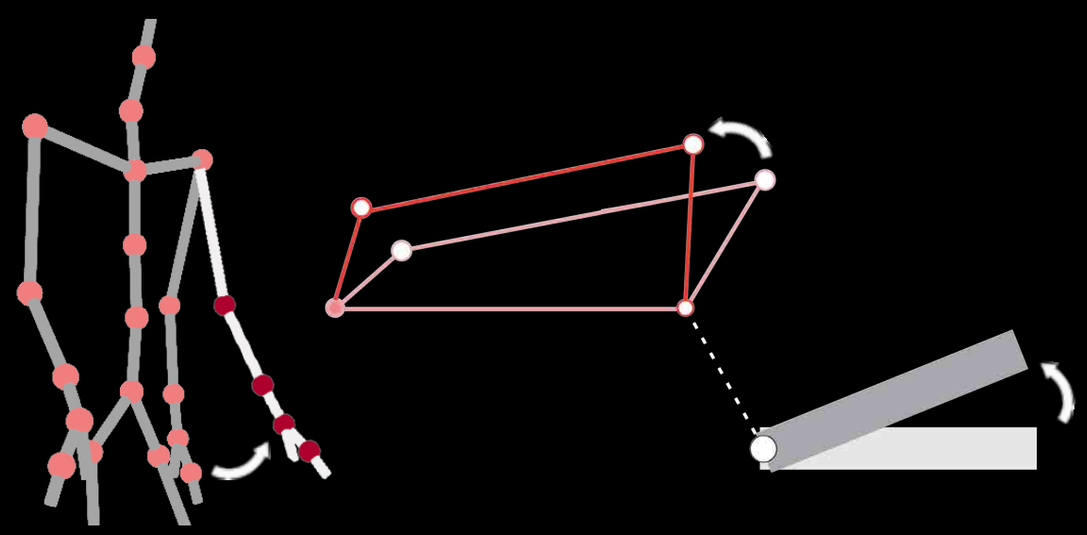
$$E_{\Phi_i} = \sum_{i}^{\#links} \sum_{t}^{\#frames} \left(\sin \frac{\Delta_{\Phi_i}(t) - \Delta_{\phi_i}(t)}{2} \right)^2$$

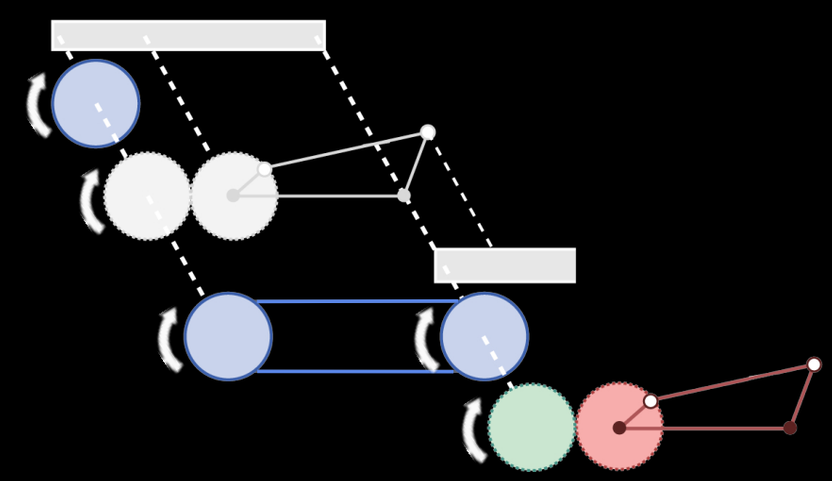
$\dot{\alpha}_i$ *depends on* *input speed & pulley ratios*

Motion Approximation









$$E_{\Phi_i} = \sum_{i}^{\#links} \sum_{t}^{\#frames} \left(\sin \frac{\Delta_{\Phi_i}(t) - \Delta_{\phi_i}(t)}{2} \right)^2$$

$\dot{\alpha}_i$ *depends on* *input speed & pulley ratios*

SQP method in the MATLAB Optimization Toolbox

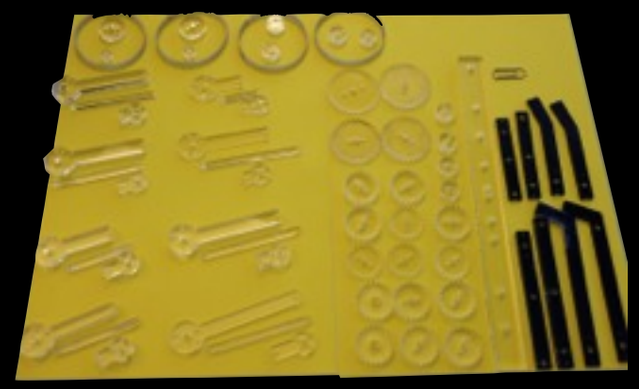
Design Pipeline

Input Motion

Motion Approximation

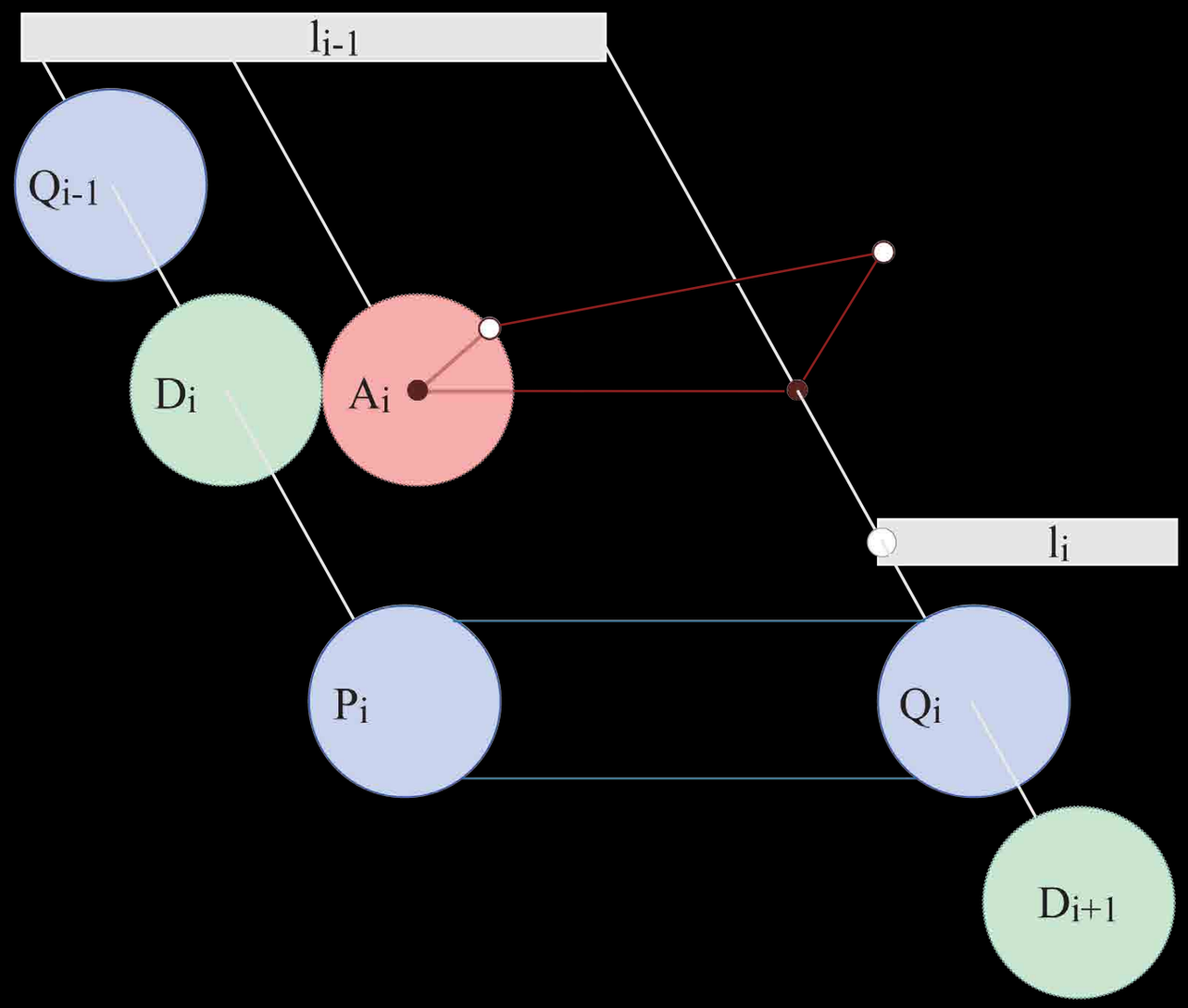
Kinematic chains & layout

Generated Automaton

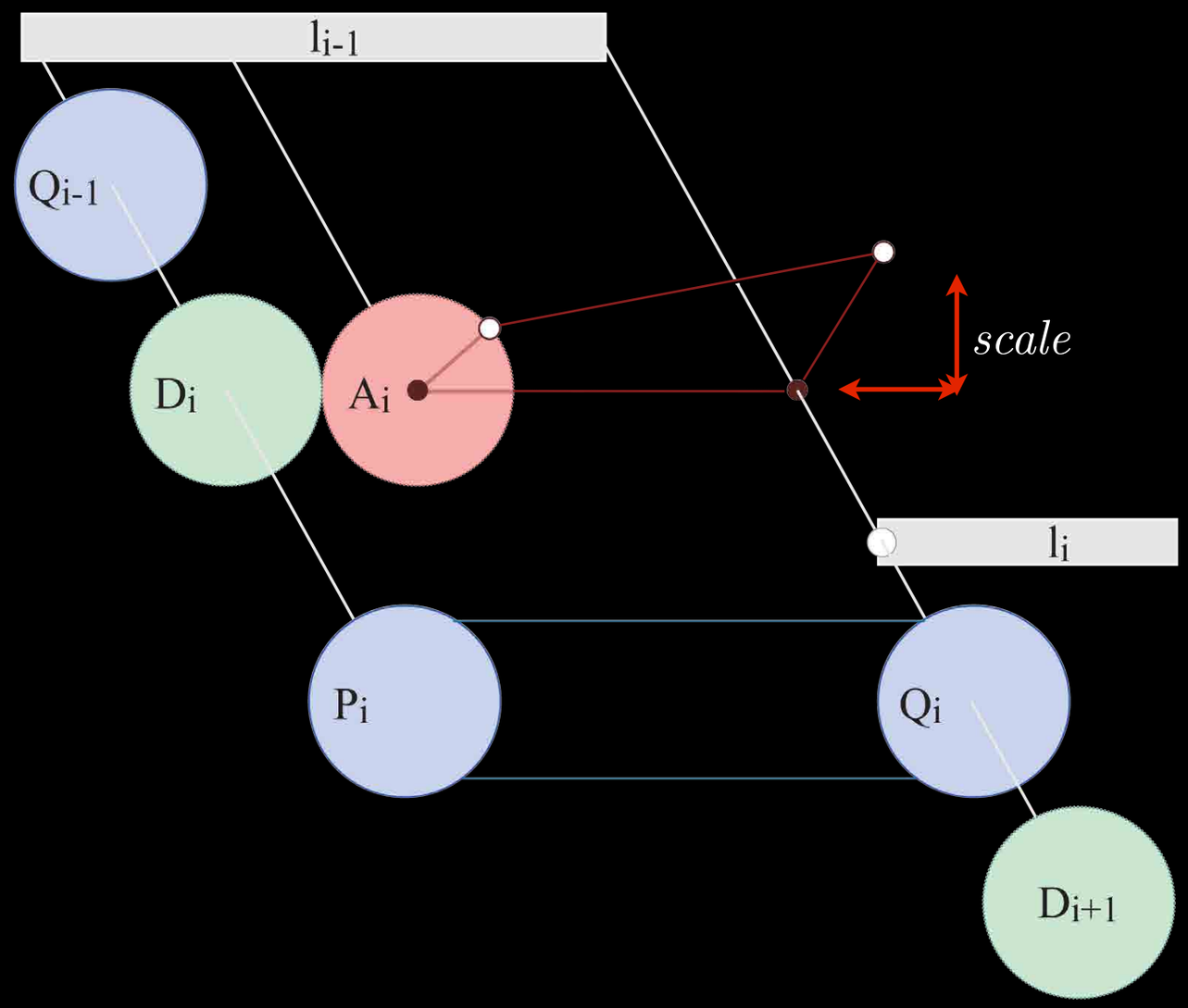


Fabrication

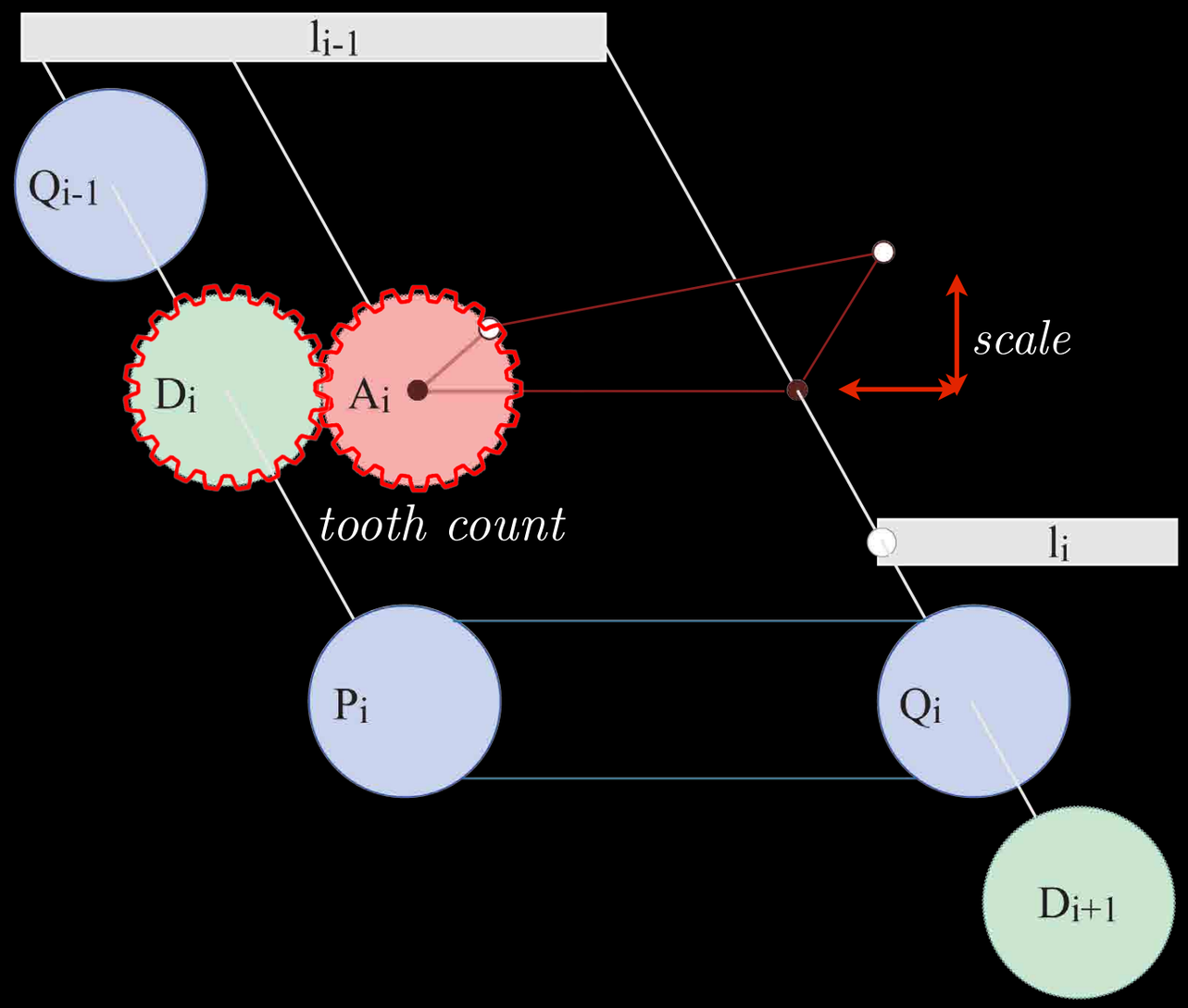
Layout: Kinematic chains



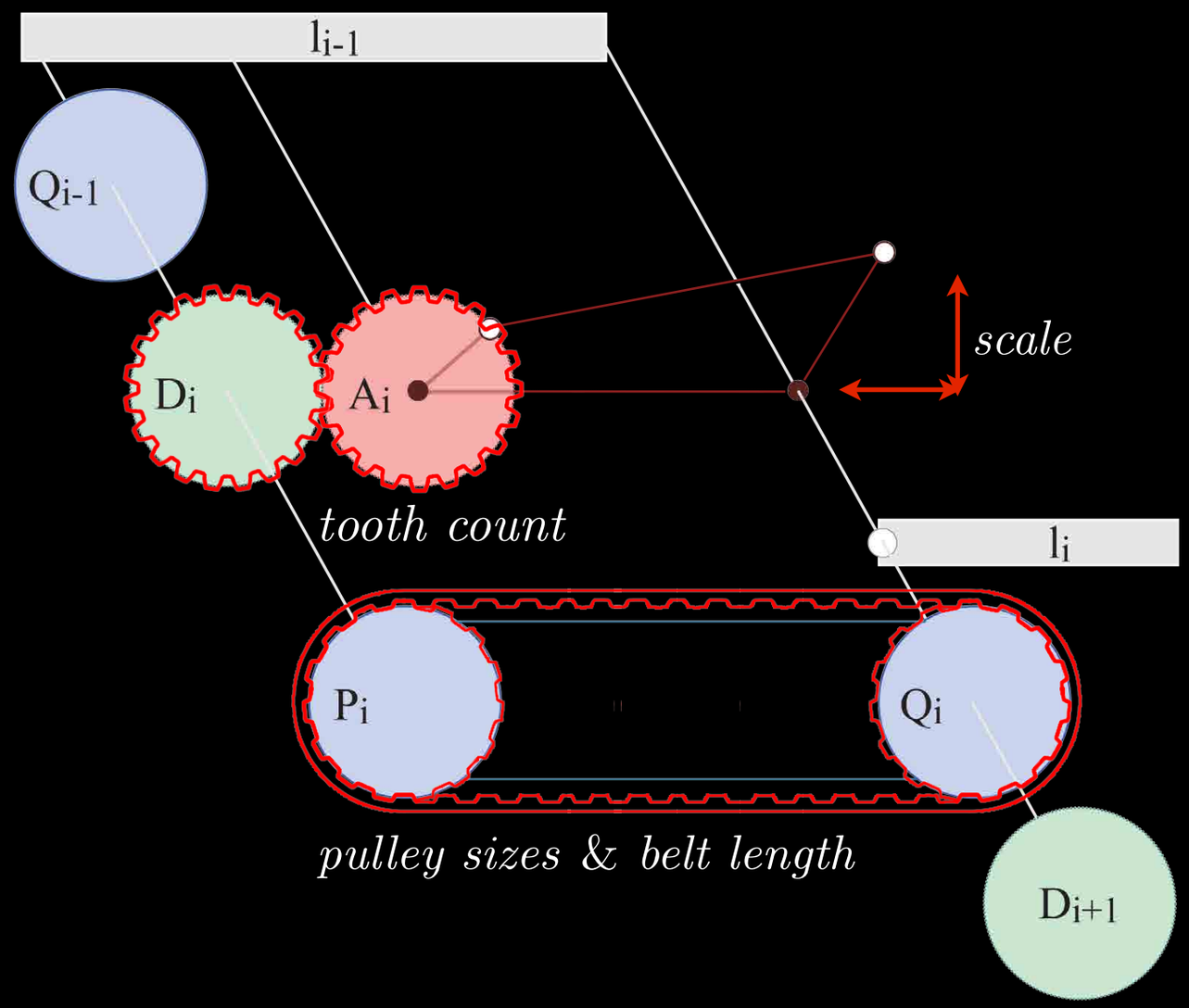
Layout: Kinematic chains



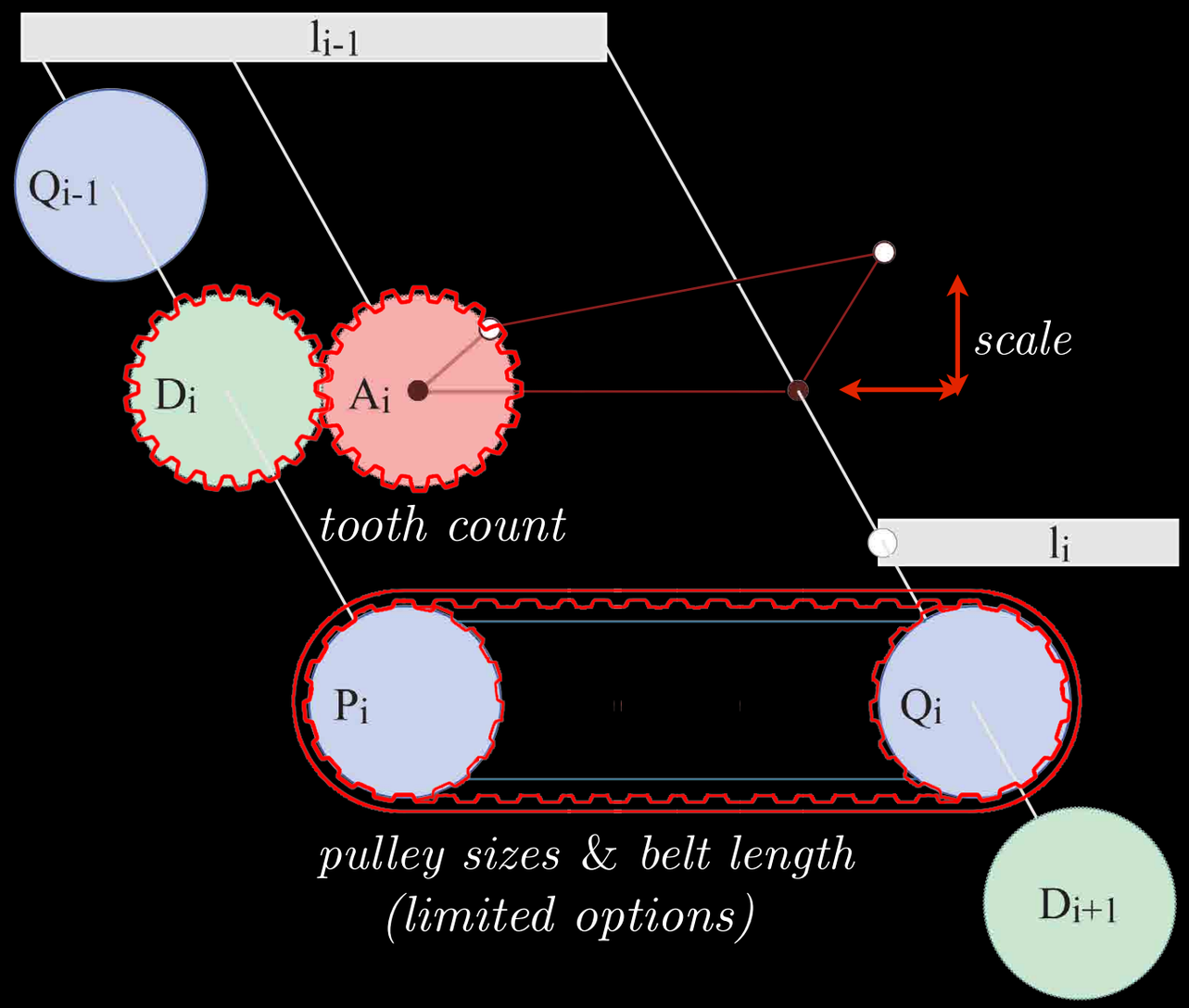
Layout: Kinematic chains



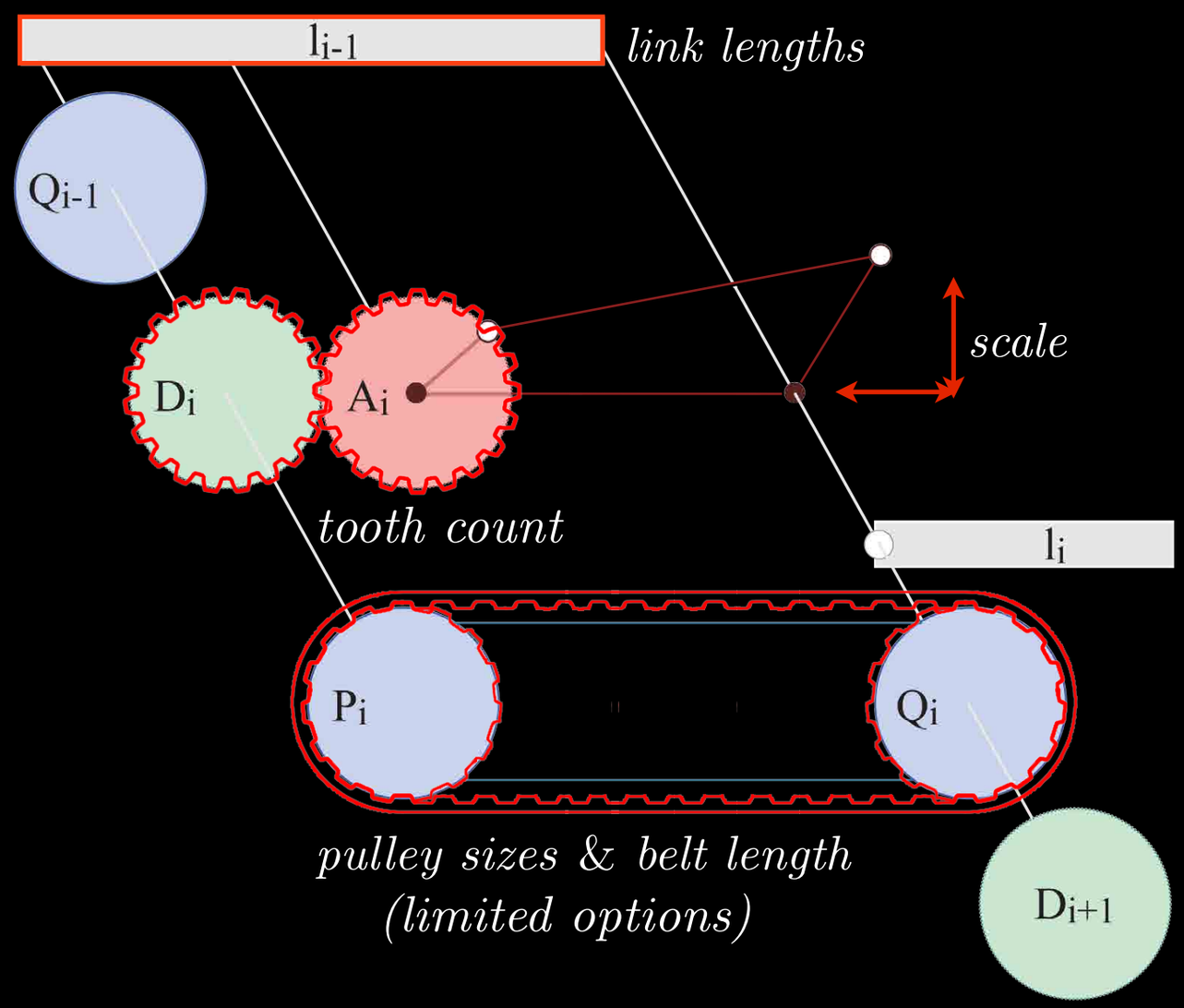
Layout: Kinematic chains



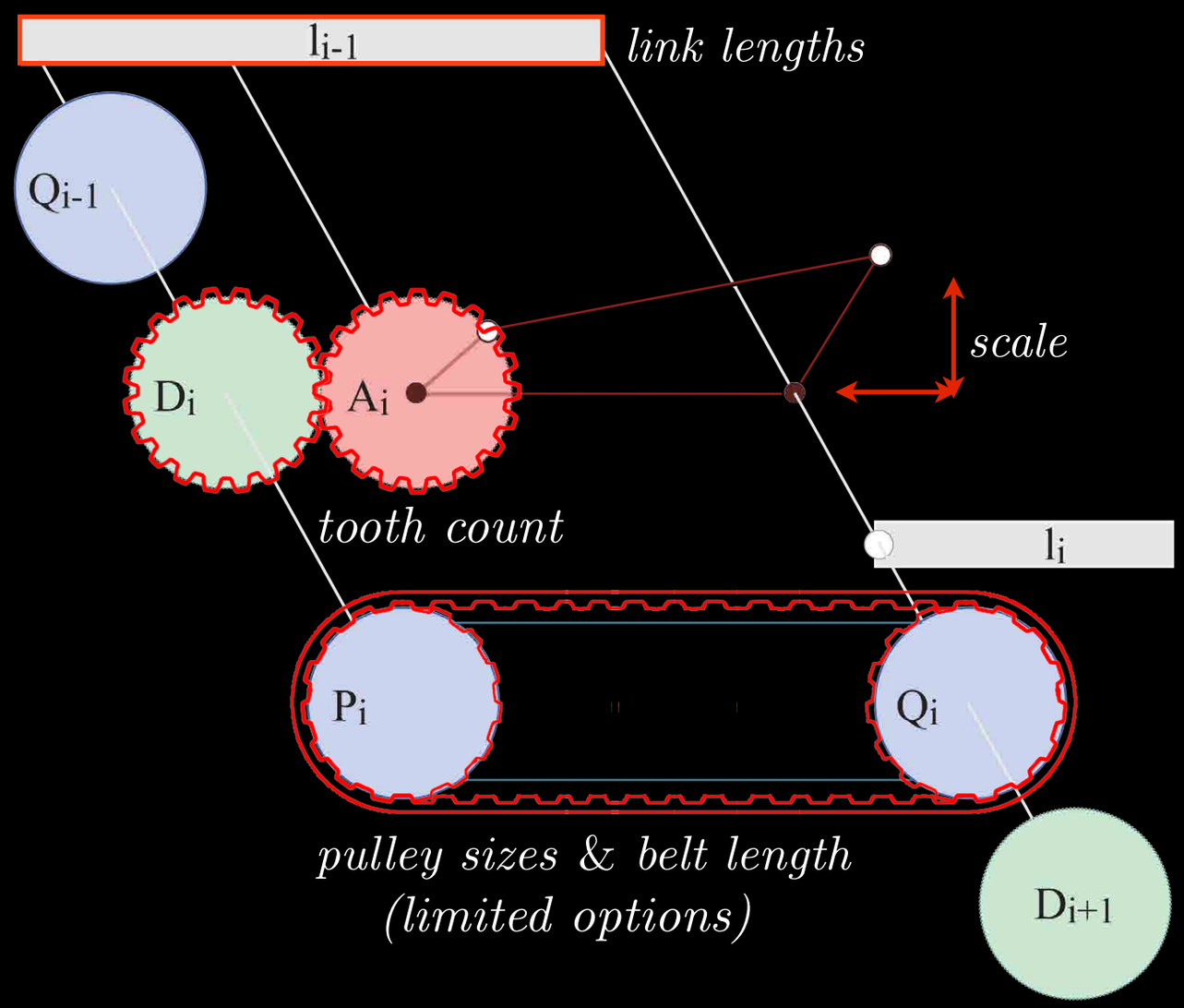
Layout: Kinematic chains



Layout: Kinematic chains

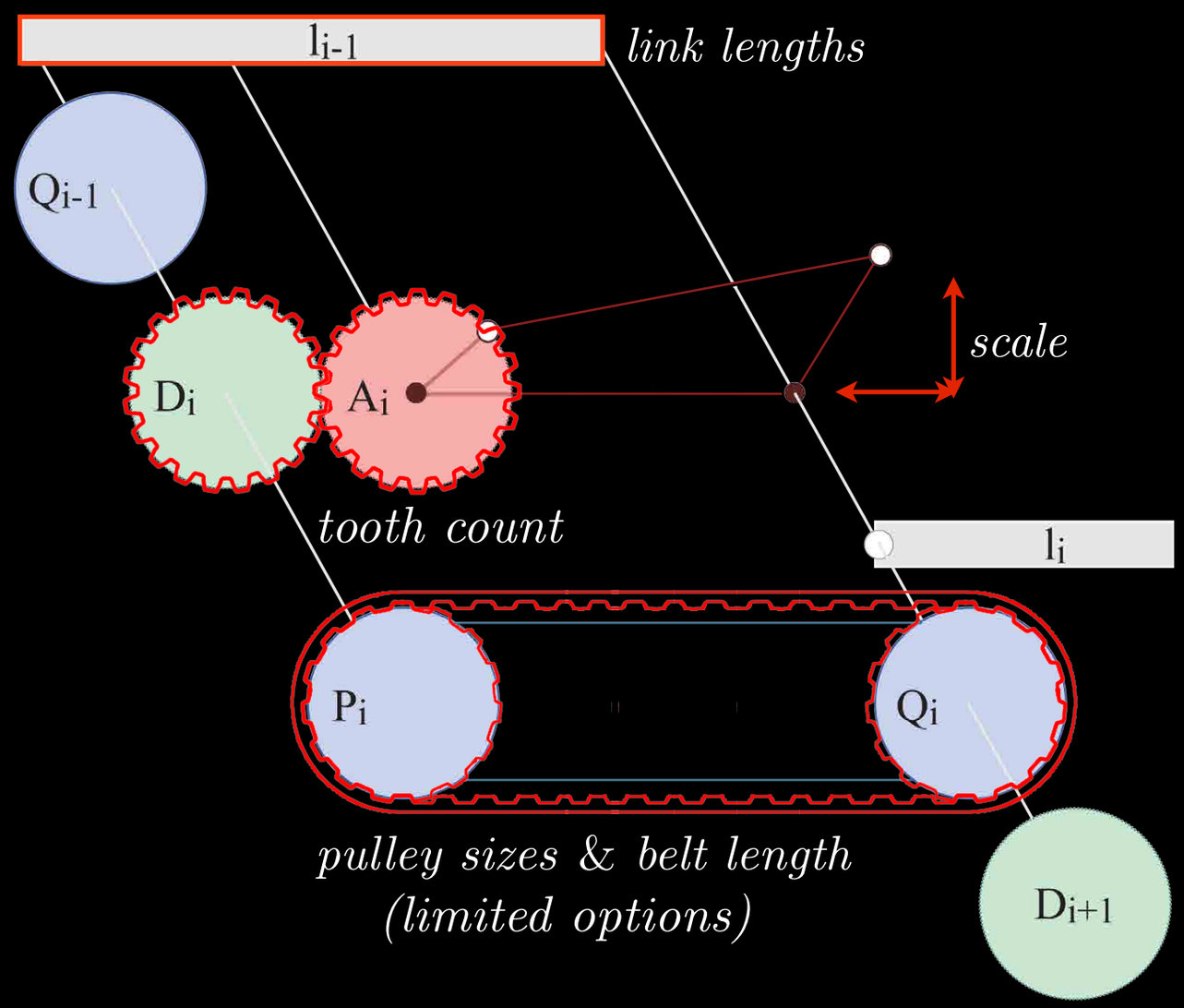


Layout: Kinematic chains



$$E_j = \sum_i w_a * E_{ang} + w_p * E_{pul} + w_s * E_{length}$$

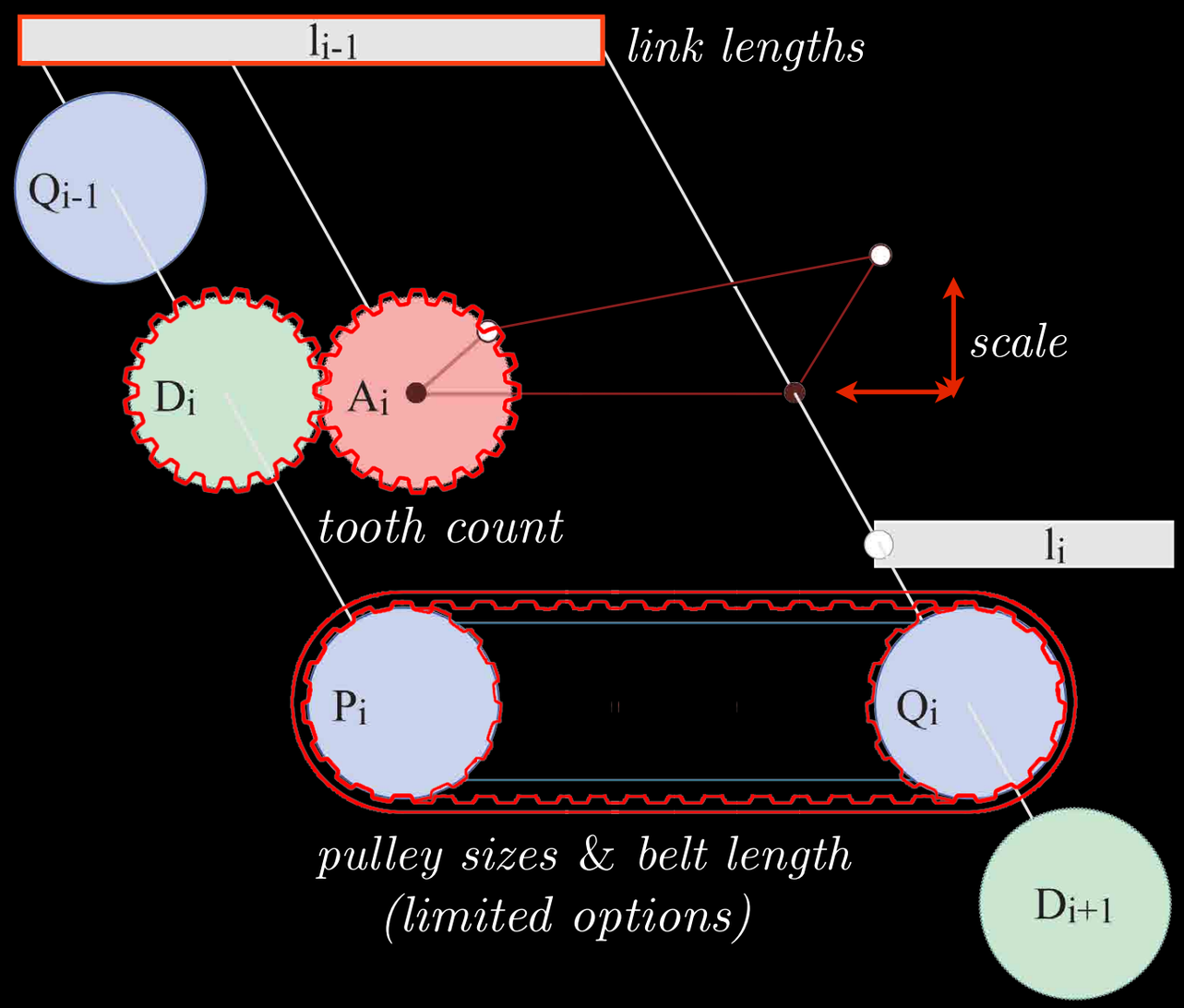
Layout: Kinematic chains



$$E_j = \sum_i w_a * E_{ang} + w_p * E_{pul} + w_s * E_{length}$$

match the desired angular speed of each oscillation module

Layout: Kinematic chains

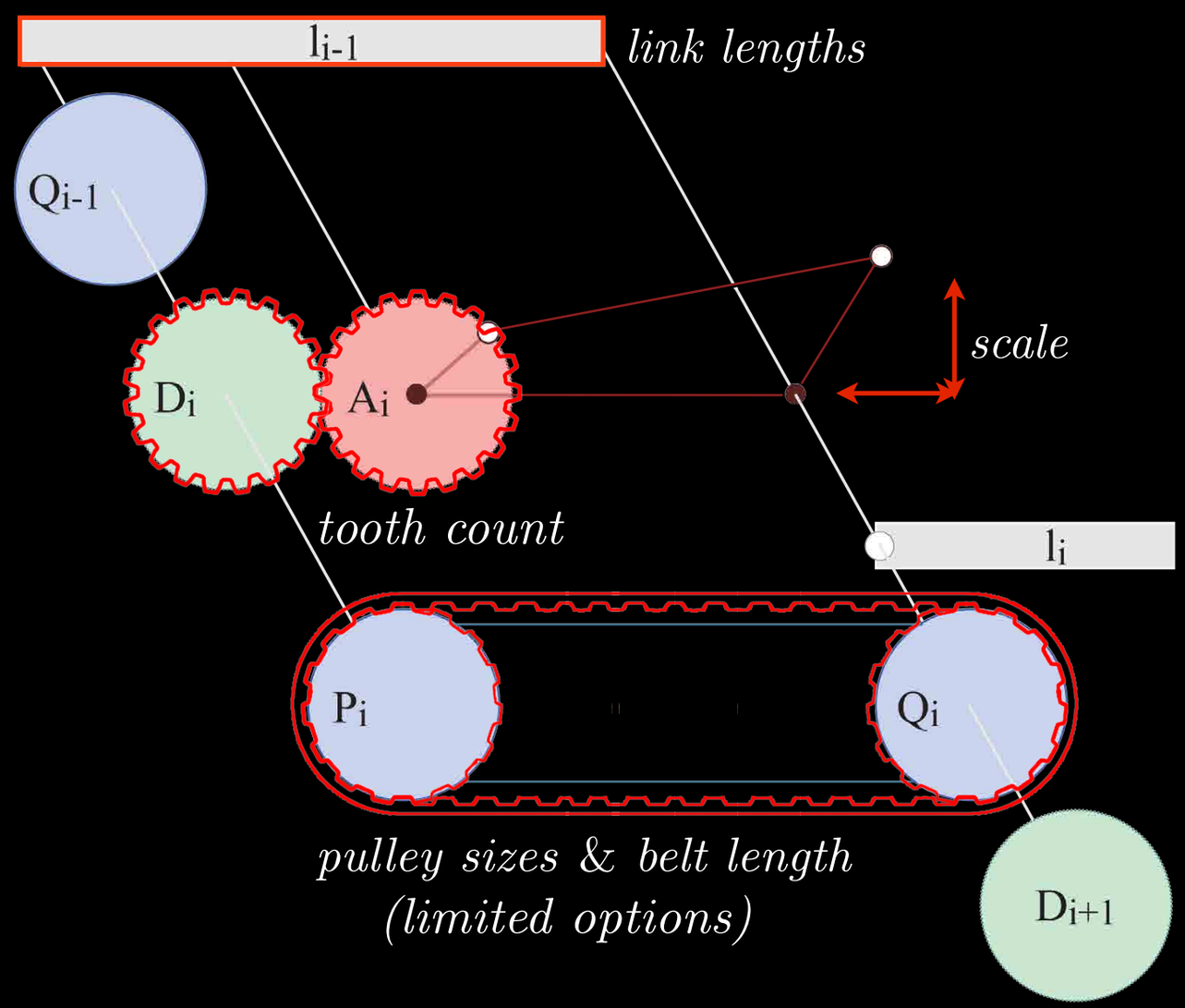


$$E_j = \sum_i w_a * E_{ang} + w_p * E_{pul} + w_s * E_{length}$$

match the desired angular speed of each oscillation module

find the functioning pulley parameters: belt length & wheel radii

Layout: Kinematic chains



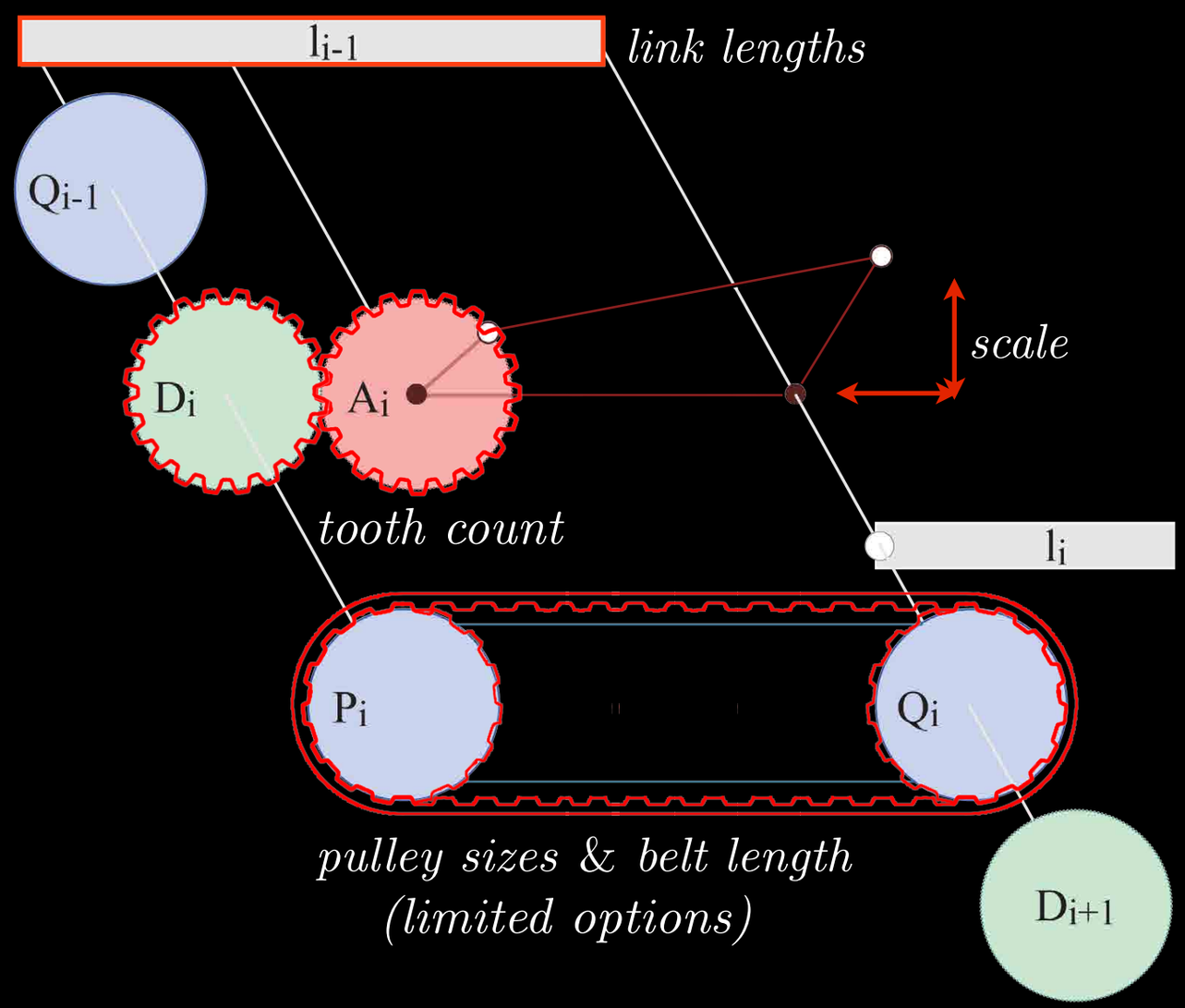
$$E_j = \sum_i w_a * E_{ang} + w_p * E_{pul} + w_s * \boxed{E_{length}}$$

match the desired angular speed of each oscillation module

find the functioning pulley parameters: belt length & wheel radii

preserve the relative bone lengths

Layout: Kinematic chains



$$E_j = \sum_i w_a * E_{ang} + w_p * E_{pul} + w_s * \boxed{E_{length}}$$

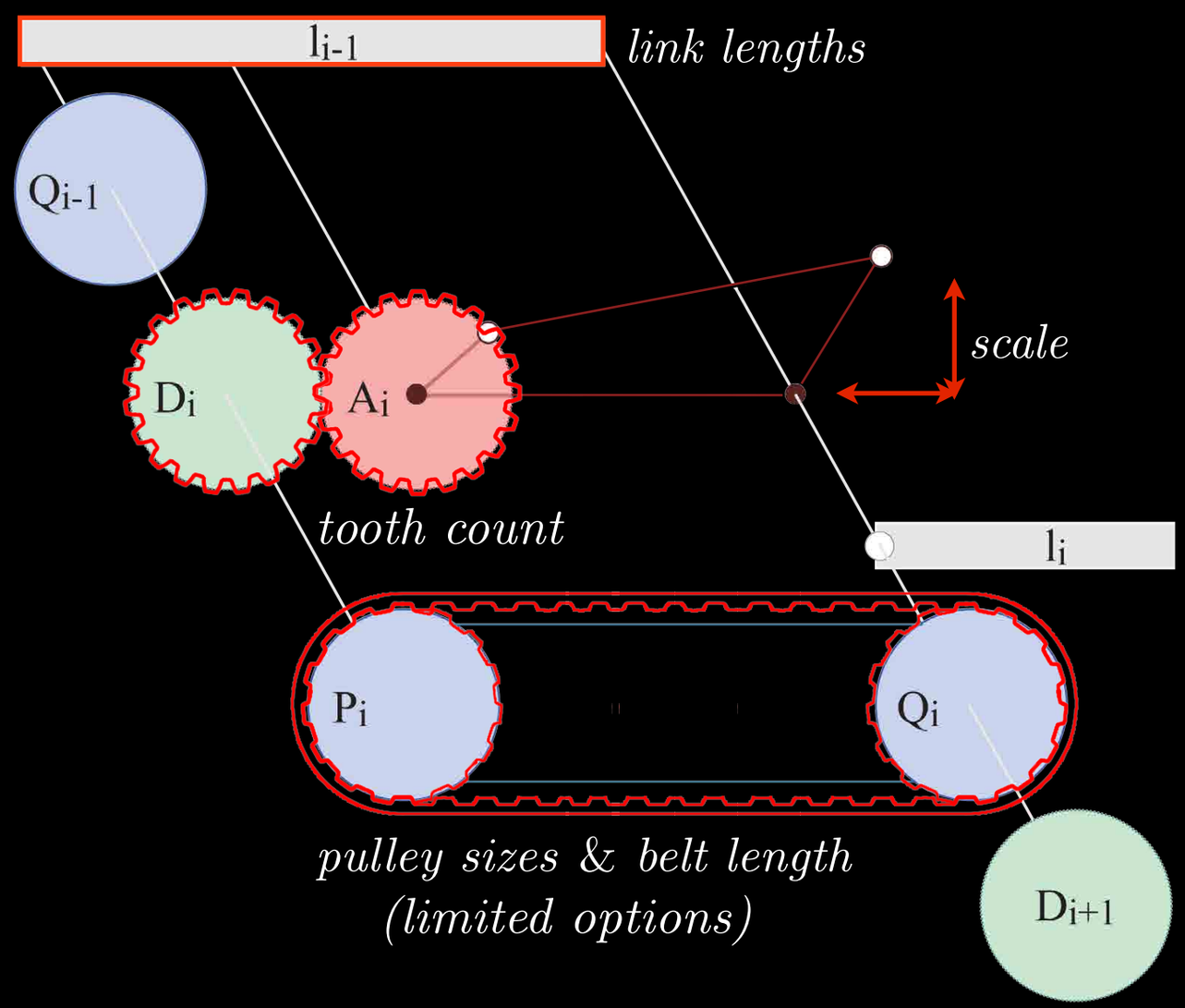
match the desired angular speed of each oscillation module

find the functioning pulley parameters: belt length & wheel radii

preserve the relative bone lengths

$$E = \sum_j E_j + E_{sym}$$

Layout: Kinematic chains



$$E_j = \sum_i w_a * E_{ang} + w_p * E_{pul} + w_s * \boxed{E_{length}}$$

match the desired angular speed of each oscillation module

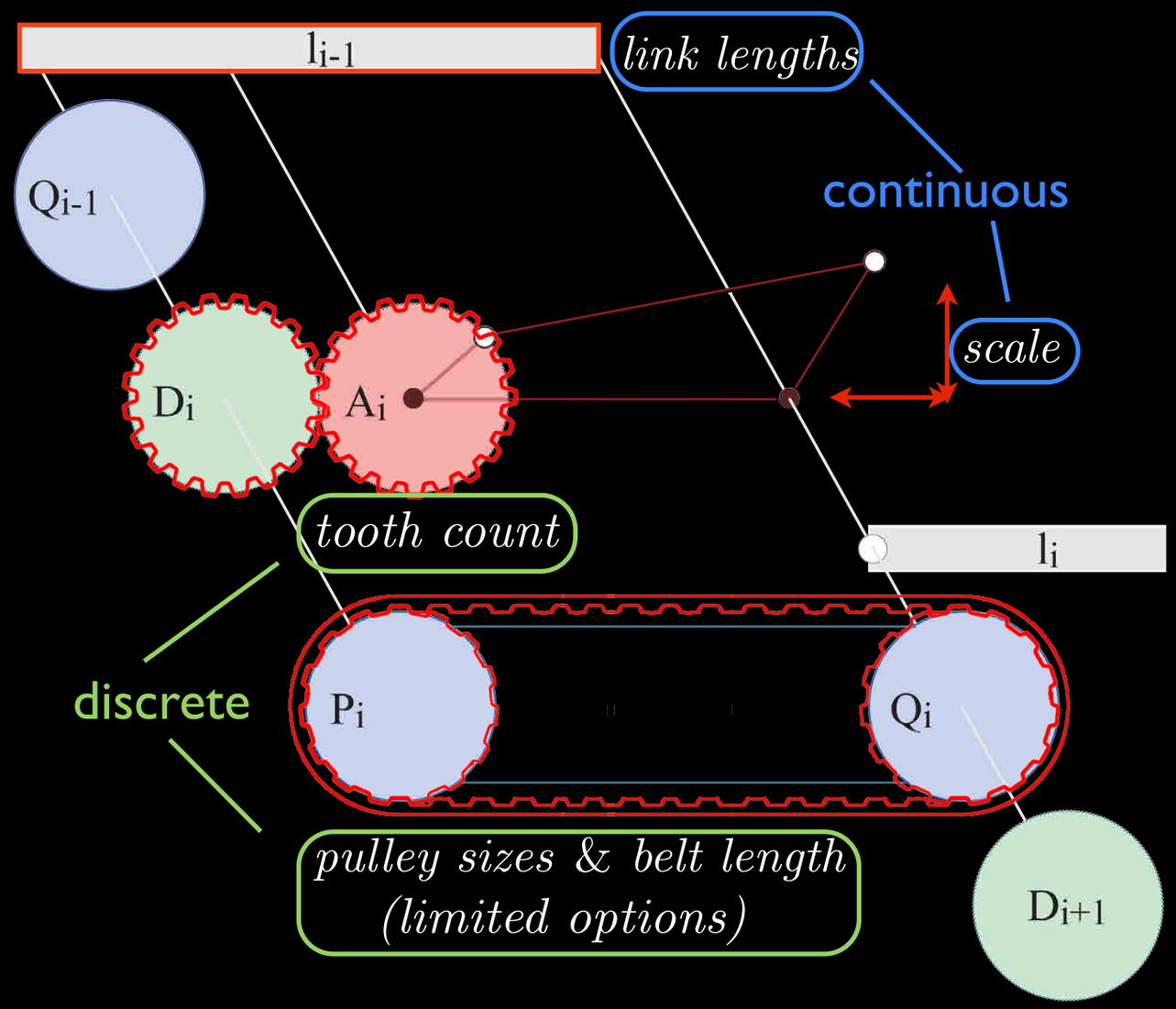
find the functioning pulley parameters: belt length & wheel radii

preserve the relative bone lengths

$$E = \sum_j E_j + \boxed{E_{sym}}$$

assign similar lengths to symmetric link pairs

Layout: Kinematic chains



$$E_j = \sum_i w_a * E_{ang} + w_p * E_{pul} + w_s * E_{length}$$

match the desired angular speed of each oscillation module

find the functioning pulley parameters: belt length & wheel radii

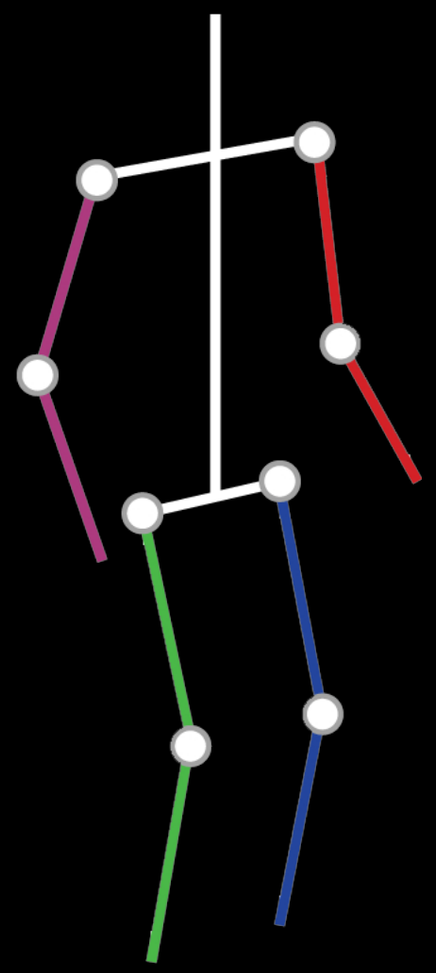
preserve the relative bone lengths

$$E = \sum_j E_j + E_{sym}$$

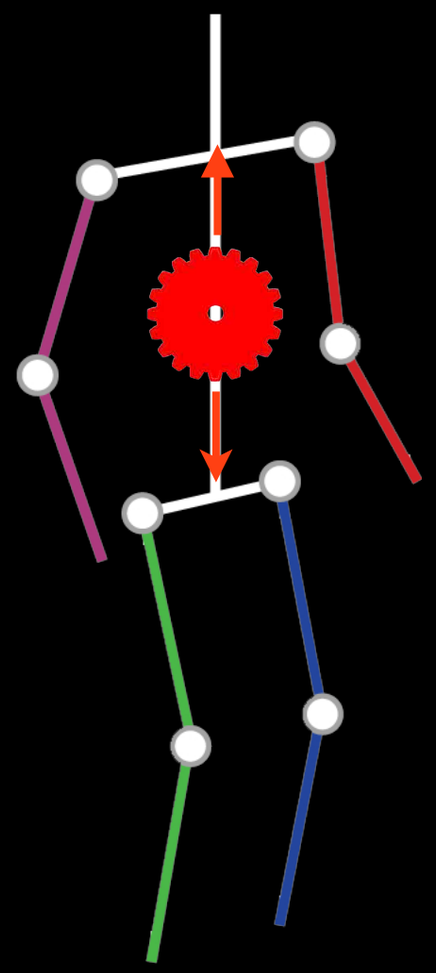
assign similar lengths to symmetric link pairs

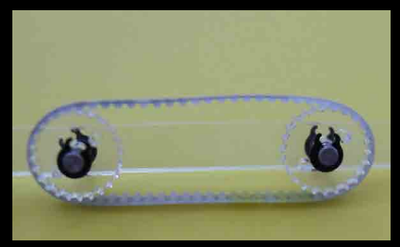
Gurobi, mixed-integer solver

Layout: Unified design

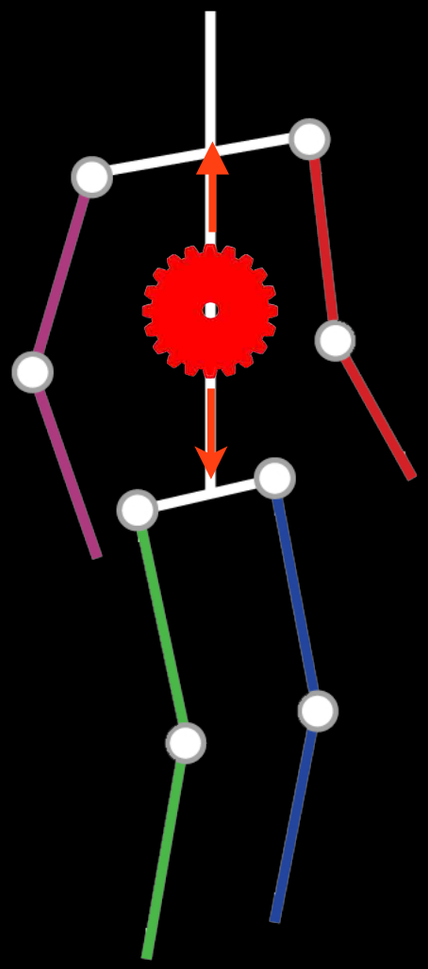


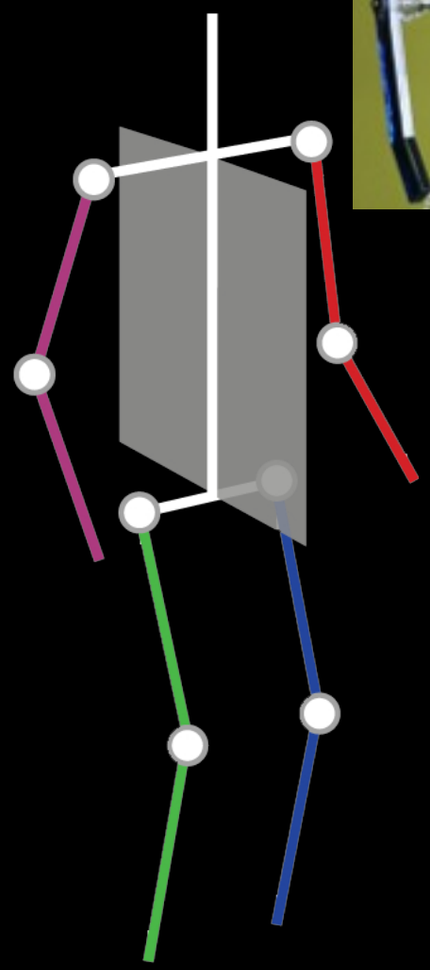
Layout: Unified design

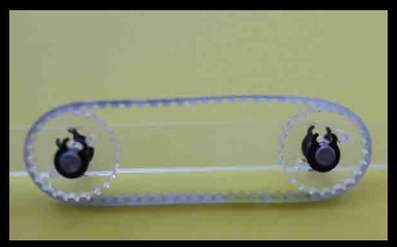




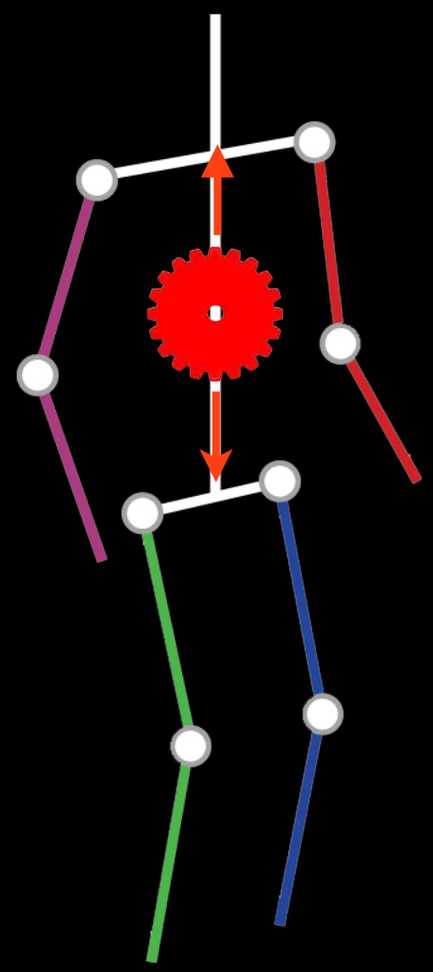
Layout: Unified design

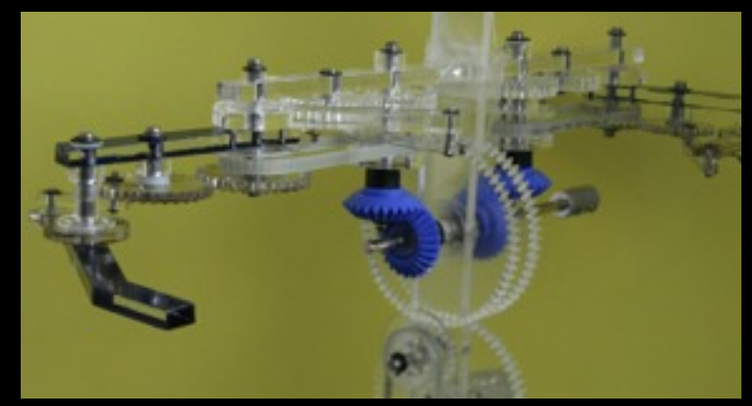


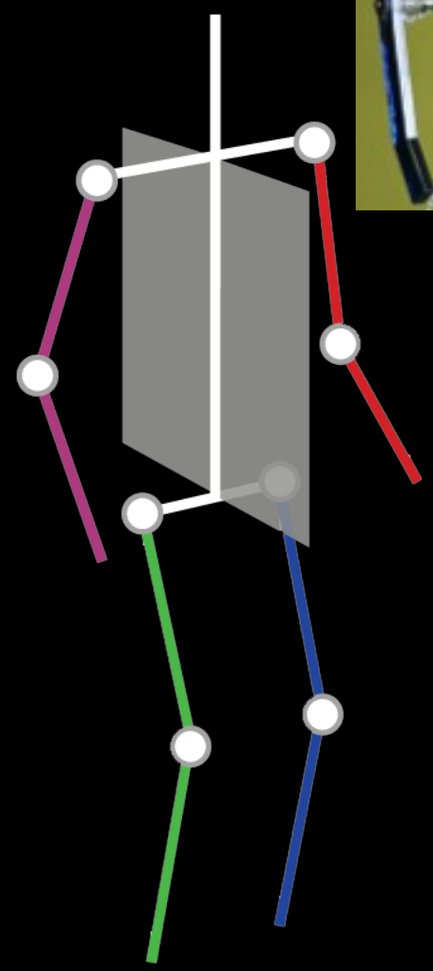


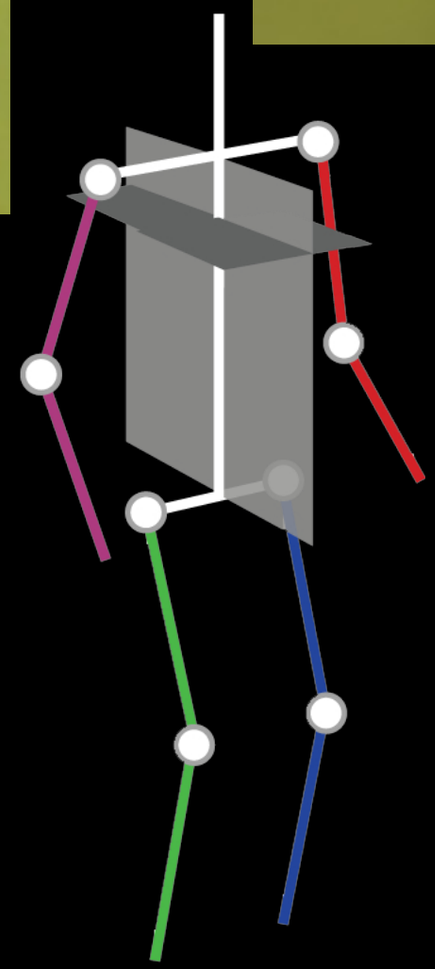


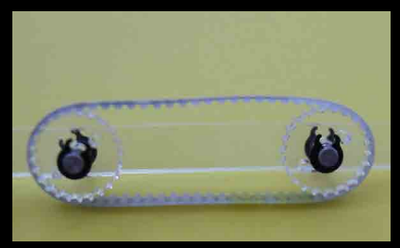
Layout: Unified design











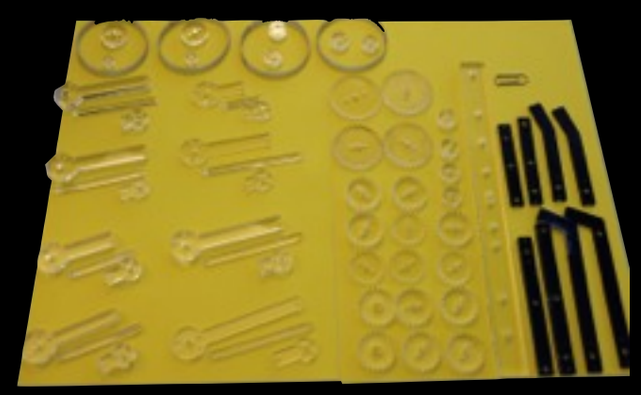
Design Pipeline

Input Motion

Motion Approximation

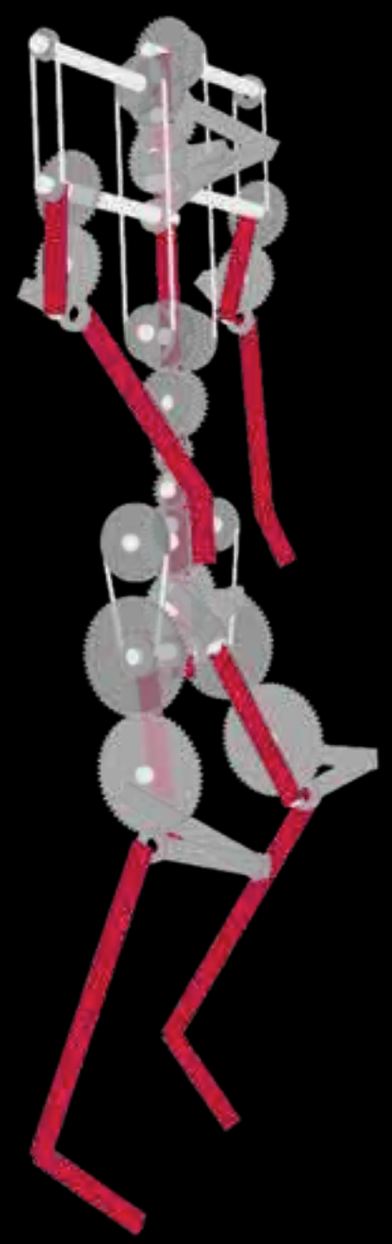
Kinematic chains & layout

Generated Automaton

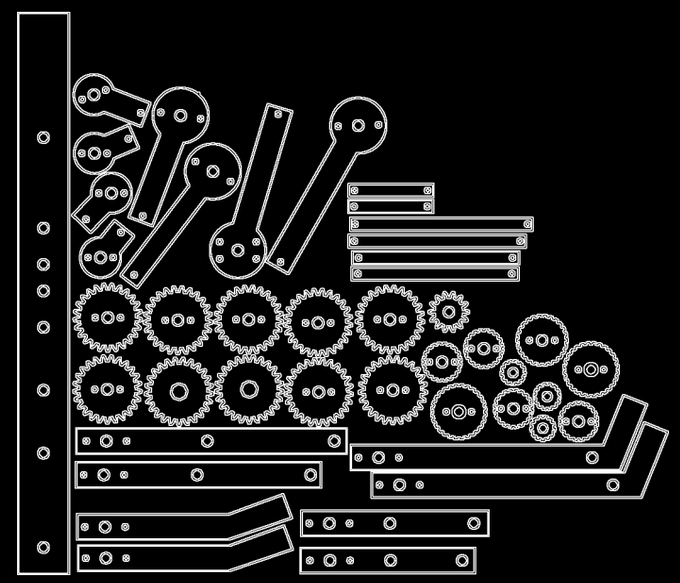


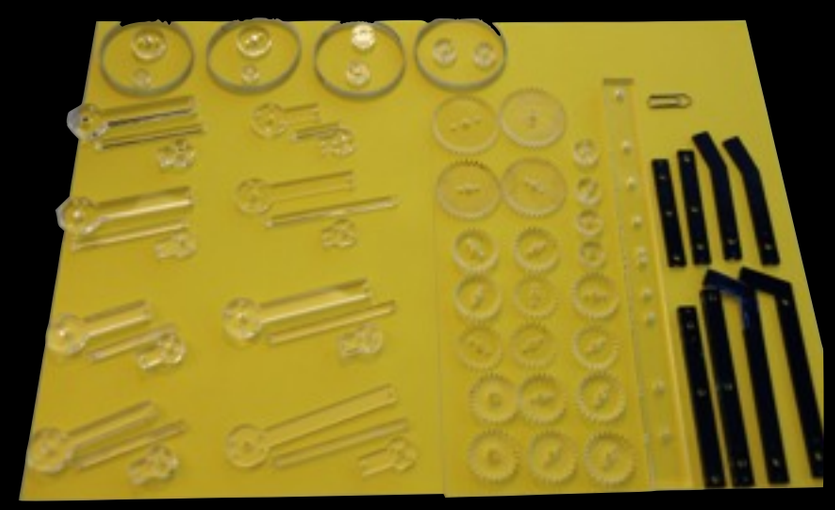
Fabrication

Fabrication



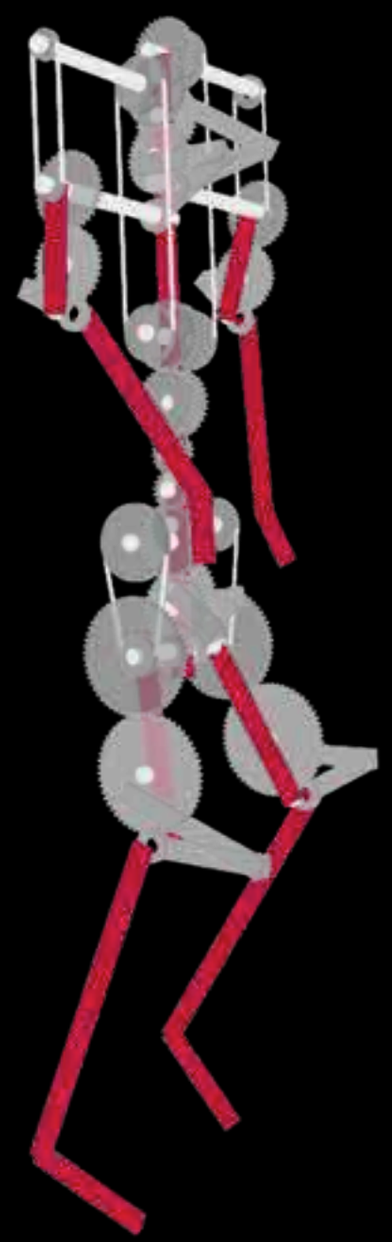
generated automata



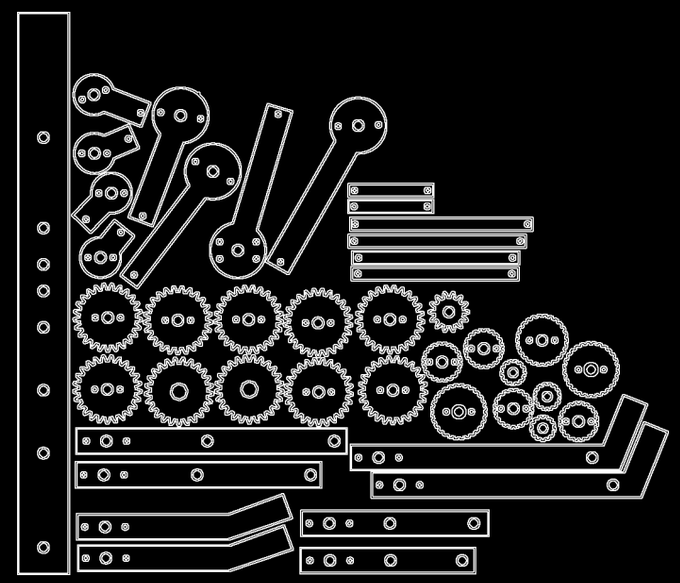


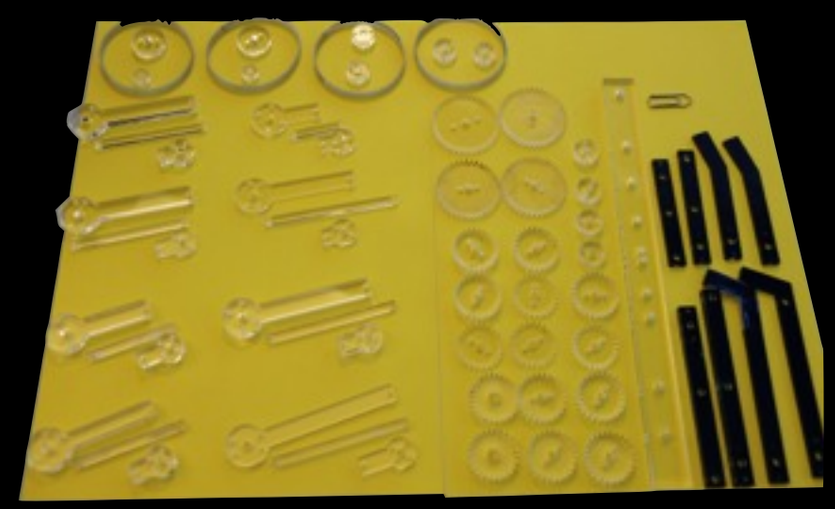
laser-cut & purchased pieces

Fabrication



generated automata

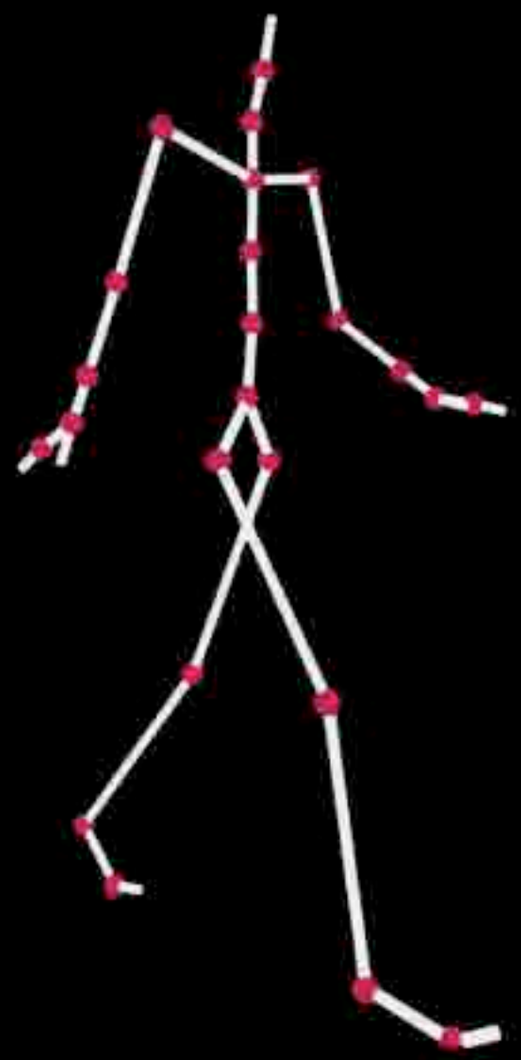




laser-cut & purchased pieces

physical prototype

Results: Walking

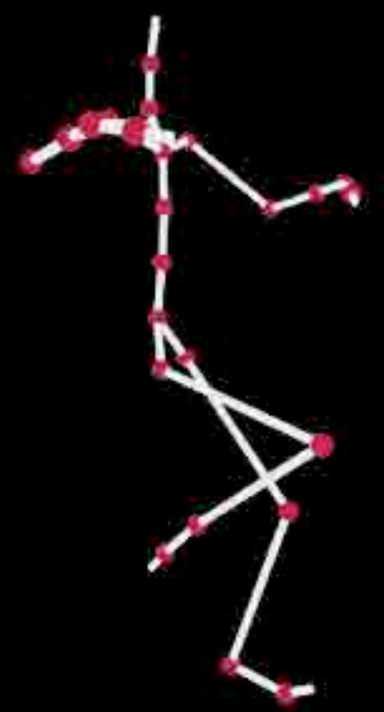


Input Motion

Generated Automaton

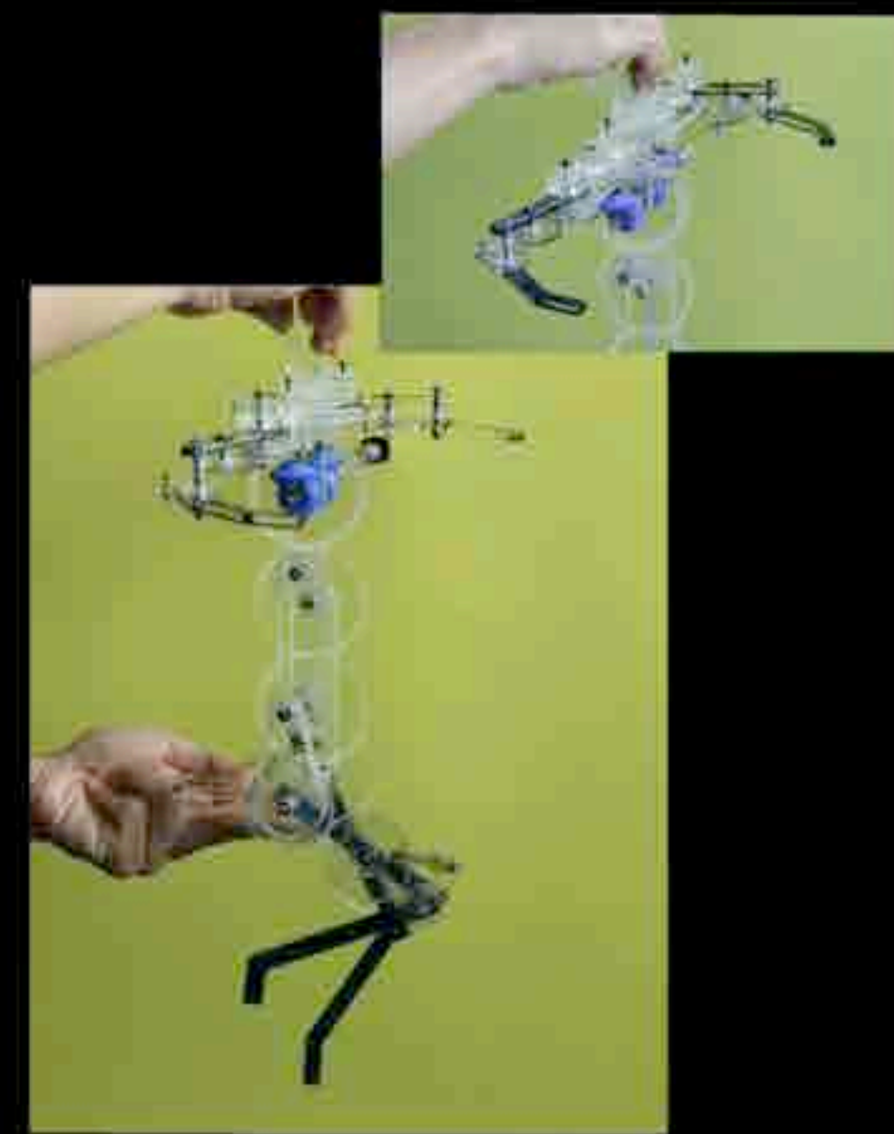
Physical Prototype

Results: Dancing



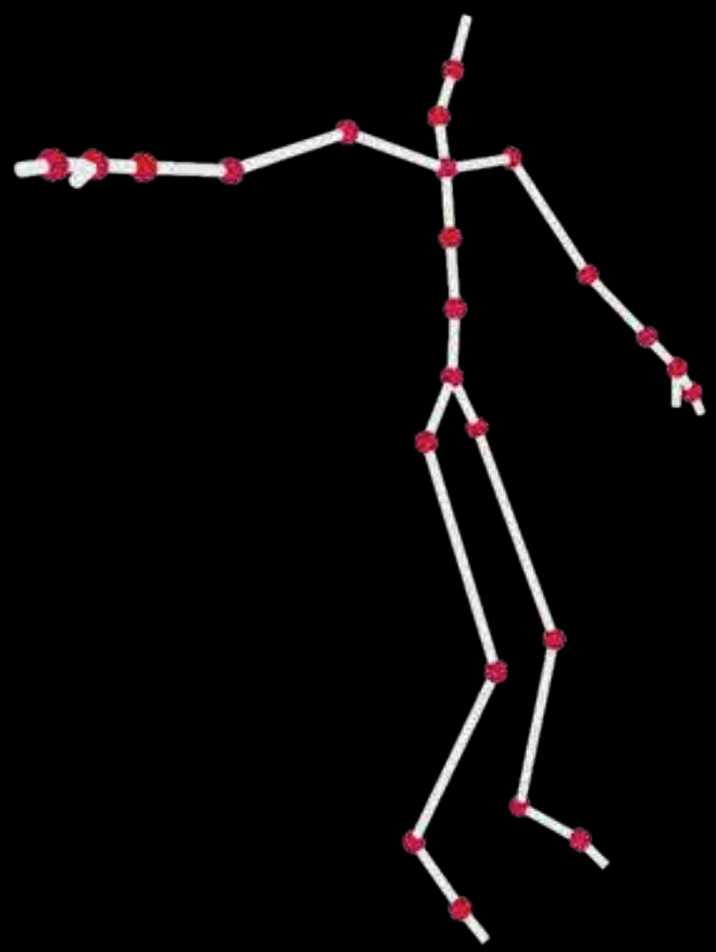
Input Motion

Generated Automaton

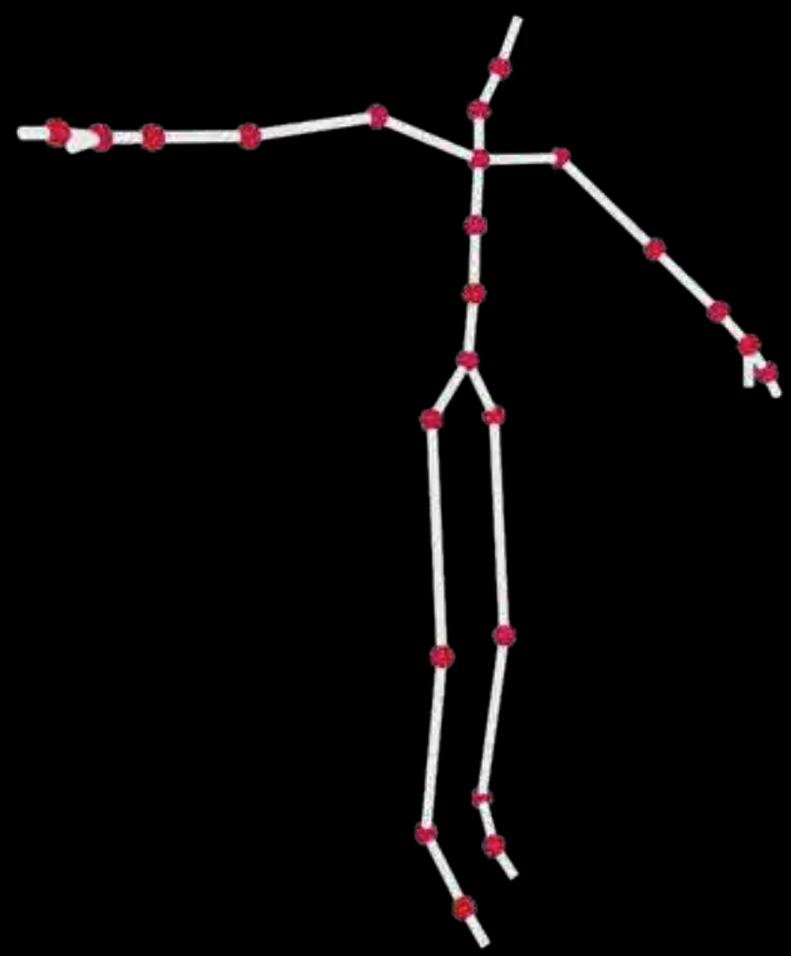


Physical Prototype

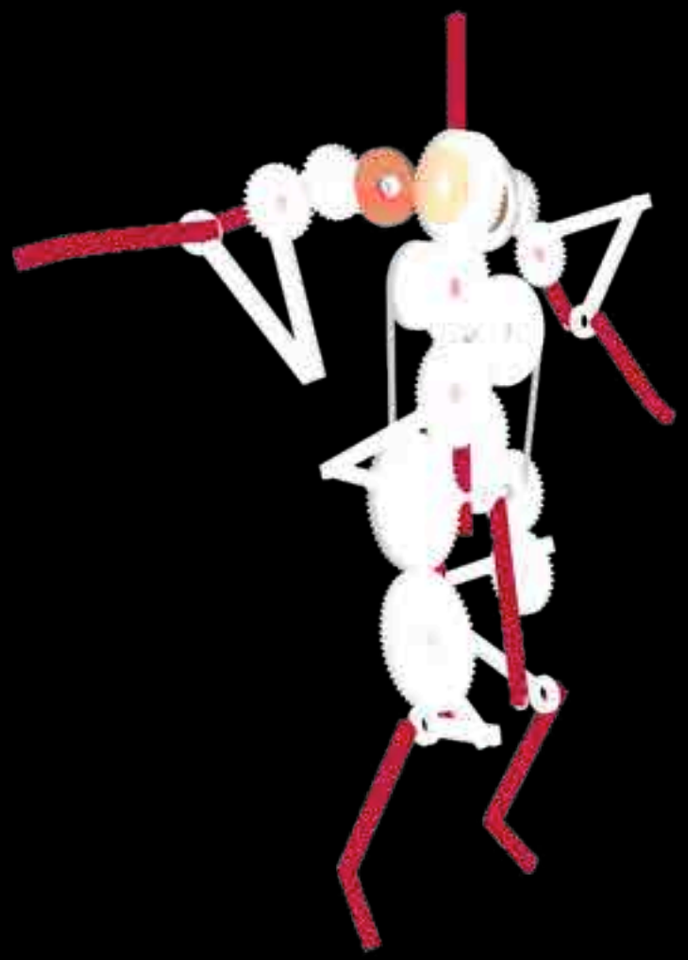
Results: Ballerina



Input Motion



Motion Approximation



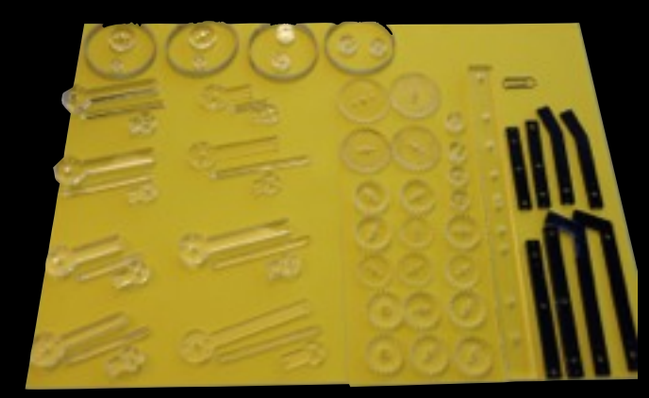
Generated Automaton

Design Pipeline

Input Motion

Motion Approximation

Kinematic chains & layout



Fabrication

Generated Automaton

Design Pipeline

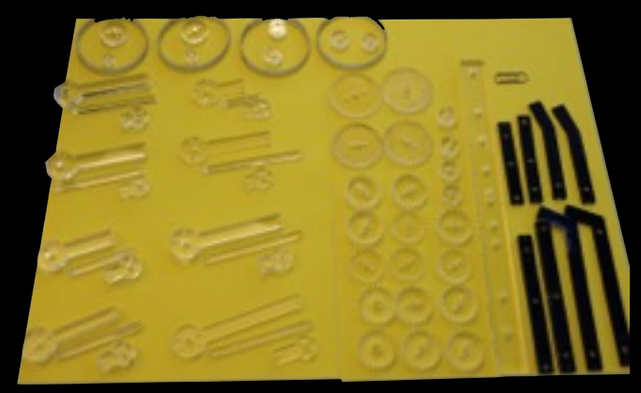
Input Motion

Generated Automaton

oscillation module

Motion Approximation

Kinematic chains & layout



Fabrication

Design Pipeline

Input Motion

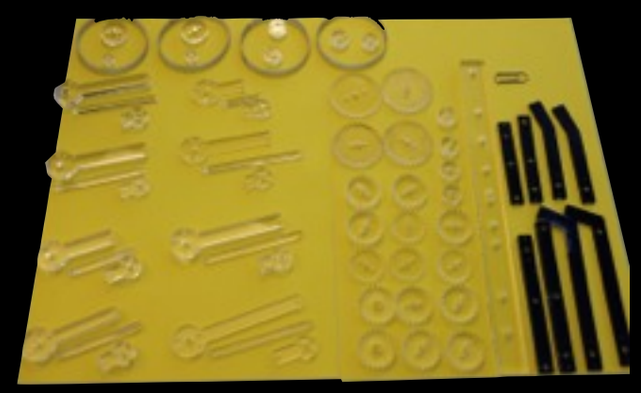
Generated Automaton

oscillation module

Motion Approximation

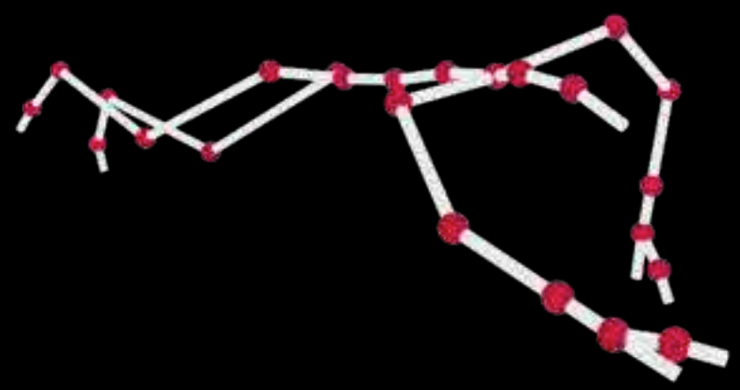
fabrication constraints

Kinematic chains & layout



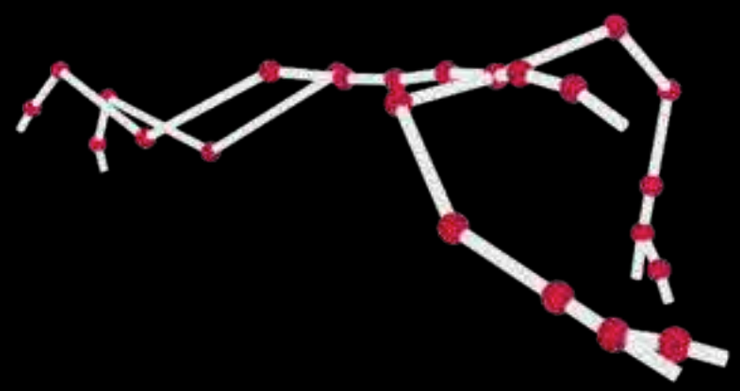
Fabrication

Limitations



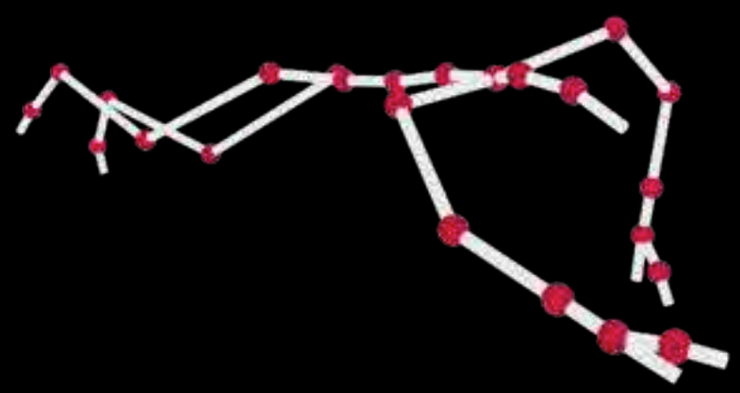
- planar approximation

Limitations



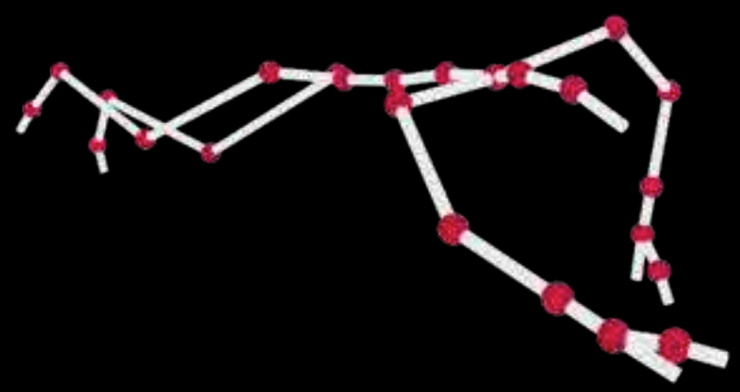
- planar approximation
- single input crank
- simple planar mechanisms

Limitations

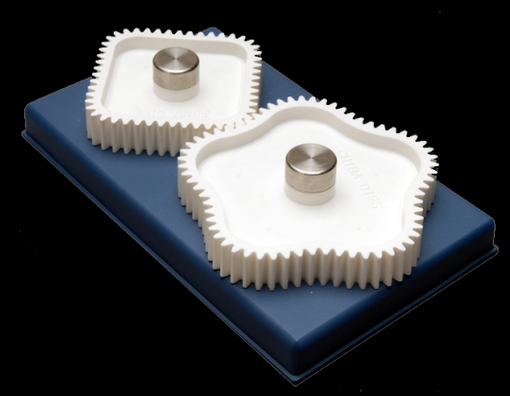


- planar approximation
- single input crank
- simple planar mechanisms

Limitations



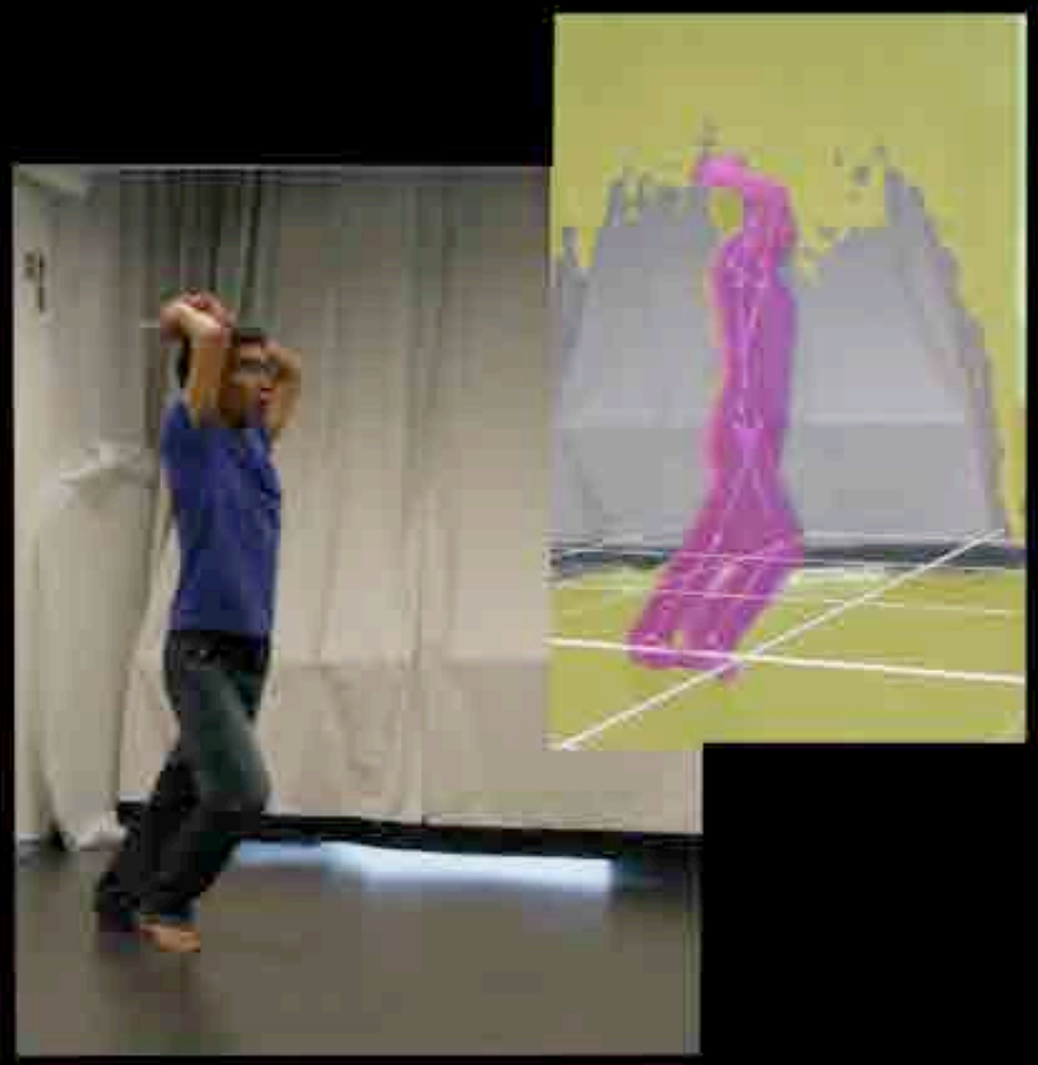
- planar approximation
- single input crank
- simple planar mechanisms



non-circular gears

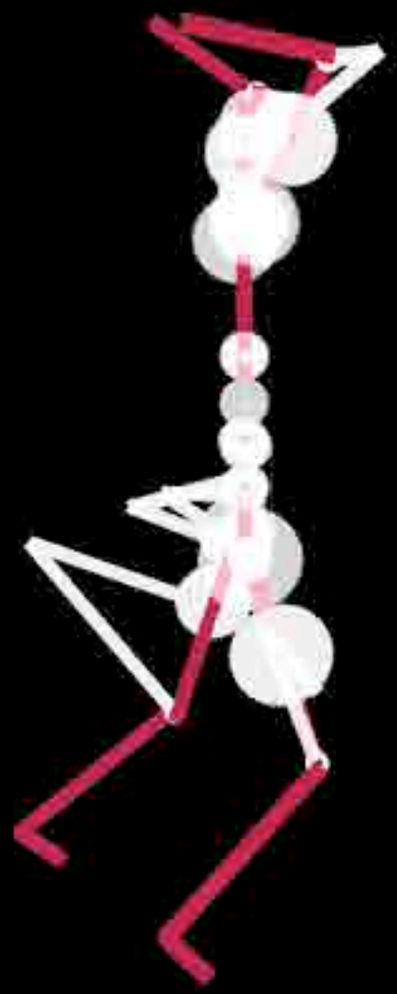
6-bar linkages

What is next?



Motion Capture
with Microsoft Kinect
(tracking by *ipi Soft*)

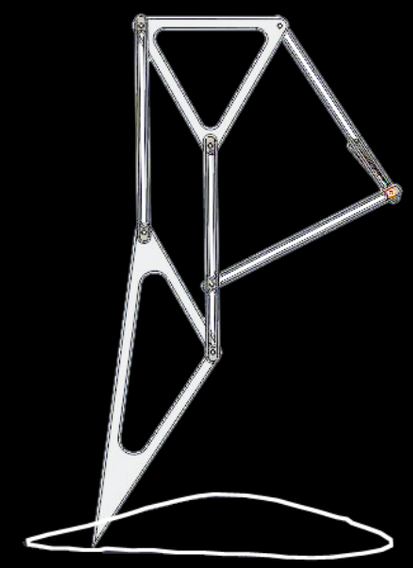
Input Motion



Generated Automaton

What is next?

self-standing automata



other mechanisms

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Thank you...

http://www.duygu-ceylan.com/duygu-ceylan/mechAuto.html