Software and Tools for Computational Engineering

RWTH AACHEN UNIVERSITY

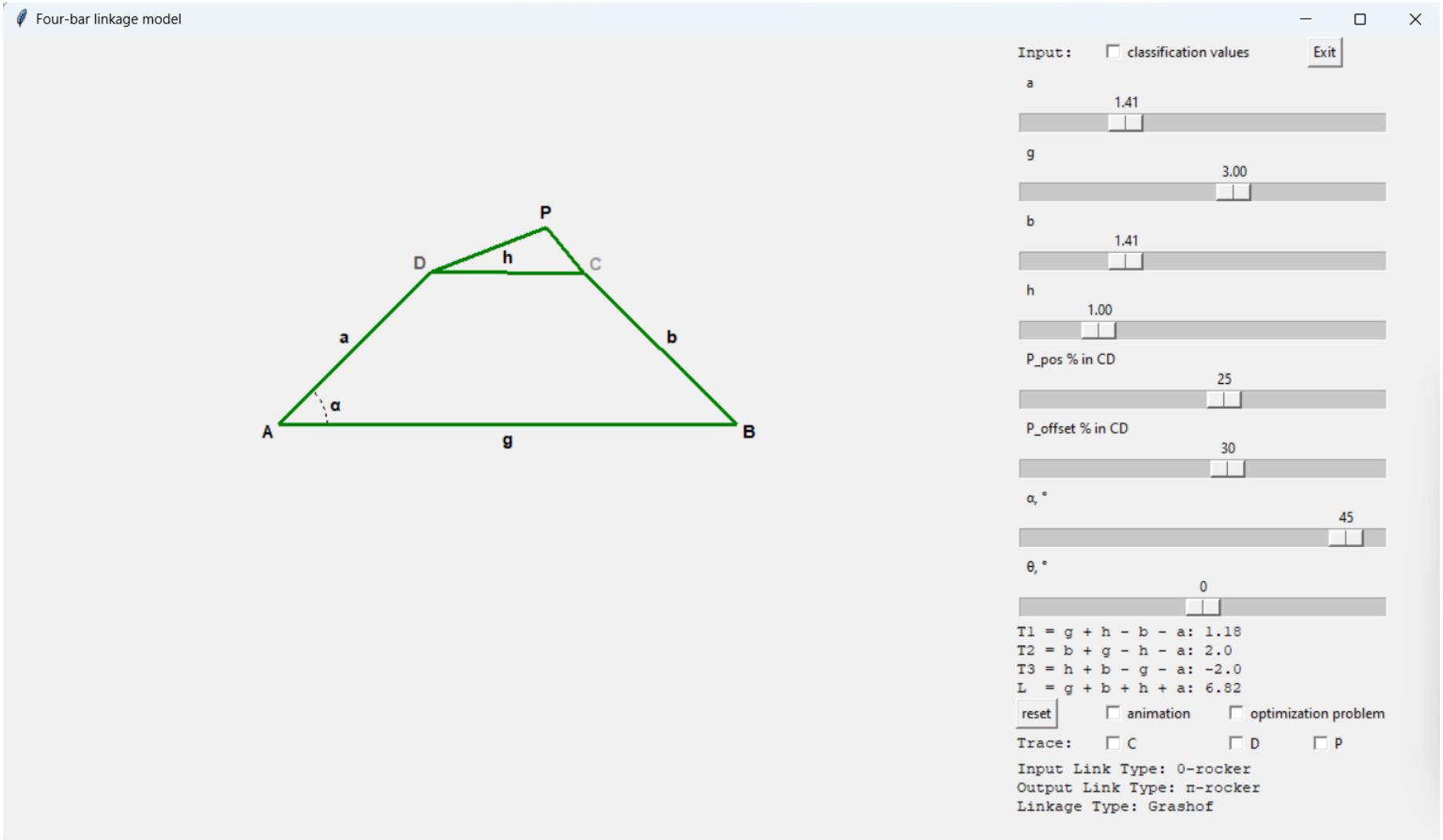
Software Lab Computational Engineering Science

Group 12, Pusher Mechanism

Aaron Floerke, Arseniy Kholod, Xinyang Song and Yanliang Zhu

Informatik 12: Software and Tools for Computational Engineering (STCE)
RWTH Aachen University

Contents


Four-bar linkage model
P
D
h
C
a
b
α
A
g
B
Input:
classification values
Exit
a
1.41
g
3.00
b
1.41
h
1.00
P_pos % in CD
25
P_offset % in CD
30
α, °
45
θ, °
0
T1 = g + h - b - a: 1.18
T2 = b + g - h - a: 2.0
T3 = h + b - g - a: -2.0
L = g + b + h + a: 6.82
reset
animation
optimization problem
Trace:
C
D
P
Input Link Type: 0-rocker
Output Link Type: π-rocker
Linkage Type: Grashof

- **Formular:**

$$M = 3(N - 1 - j) + \sum_{i=1}^{j} f_i$$

  - M: DOF
  - N: Number of links. (4)
  - j: Number of joints. (4 revolute joints)
  - f_i: DOF provided by each joint i, equal 1 for revolute (rotational) joints.
- Calculation for the four-bar linkage:

$$M = \sum_{i=1}^{j} f_i - 3 = 4(1) - 3 = 1$$

- Four-bar linkage has 1 degree of freedom, meaning the mechanism can be fully controlled by a single input. (We use angular velocity as input)

https://en.wikipedia.org/wiki/Degrees_of_freedom_(mechanics)

Grashof's theorem states that a four-bar mechanism has *at least* one revolving link if

$$s + l <= p + q \tag{5-1}$$

and all three mobile links will rock if

$$s + l > p + q \tag{5-2}$$

The inequality 5-1 is **Grashof's criterion**.

All four-bar mechanisms fall into one of the four categories listed in Table 5-1:

Case	l + s vers. p + q	Shortest Bar	Type
1	<	Frame	Double-crank
2	<	Side	Rocker-crank
3	<	Coupler	Doubl rocker
4	=	Any	Change point
5	>	Any	Double-rocker

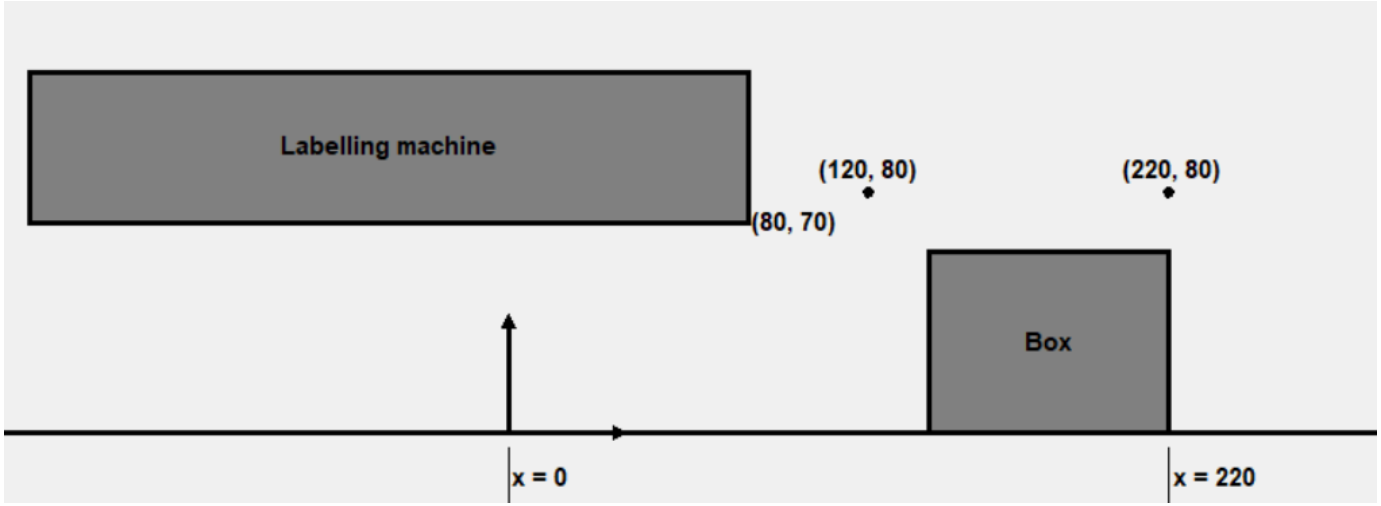
Table 5-1 Classification of Four-Bar Mechanisms

https://www.cs.cmu.edu/~rapidproto/mechanisms/chpt5.html

- Implement 27 motion types of the four-bar linkage with one bar fixed:
  - Classification values:
    - $T_1 = g + h - b - a$
    - $T_2 = b + g - h - a$
    - $T_3 = h + b - g - a$
- Implement GUI with motion animation and the ability to choose geometrical parameters:
  - Length of the bars
  - Position of the coupler
  - Input angle
  - Angle relative to the horizon
  - Classification values as alternative input

No.	T_1	T_2	T_3	T_1T_2	T_1T_3	*a*	*b*
1	+	+	+	+	+	crank	rocker
2	0	+	+	0	0	crank	π–rocker
3	-	+	+	-	-	π–rocker	π–rocker
4	+	0	+	0	+	crank	0–rocker
5	0	0	+	0	0	crank	crank
6	-	0	+	0	-	crank	crank
7	+	-	+	-	+	π–rocker	0–rocker
8	0	-	+	0	0	crank	crank
9	-	-	+	+	-	crank	crank
10	+	+	0	+	0	crank	π–rocker
11	0	+	0	0	0	crank	π–rocker
12	-	+	0	-	0	π–rocker	π–rocker
13	+	0	0	0	0	crank	crank
14	0	0	0	0	0	crank	crank
15	-	0	0	0	0	crank	crank
16	+	-	0	-	0	π–rocker	crank
17	0	-	0	0	0	crank	crank
18	-	-	0	+	0	crank	crank
19	+	+	-	+	-	0–rocker	π–rocker
20	0	+	-	0	0	0–rocker	π–rocker
21	-	+	-	-	+	rocker	rocker
22	+	0	-	0	-	0–rocker	crank
23	0	0	-	0	0	0–rocker	crank
24	-	0	-	0	+	0–rocker	0–rocker
25	+	-	-	-	-	rocker	crank
26	0	-	-	0	0	0–rocker	crank
27	-	-	-	+	+	0–rocker	0–rocker

Figure from "Classification, geometrical and kinematic analysis of four-bar linkages" 10.15308/Sinteza-2018-261-266 by Ivana Cvetkovic et al.

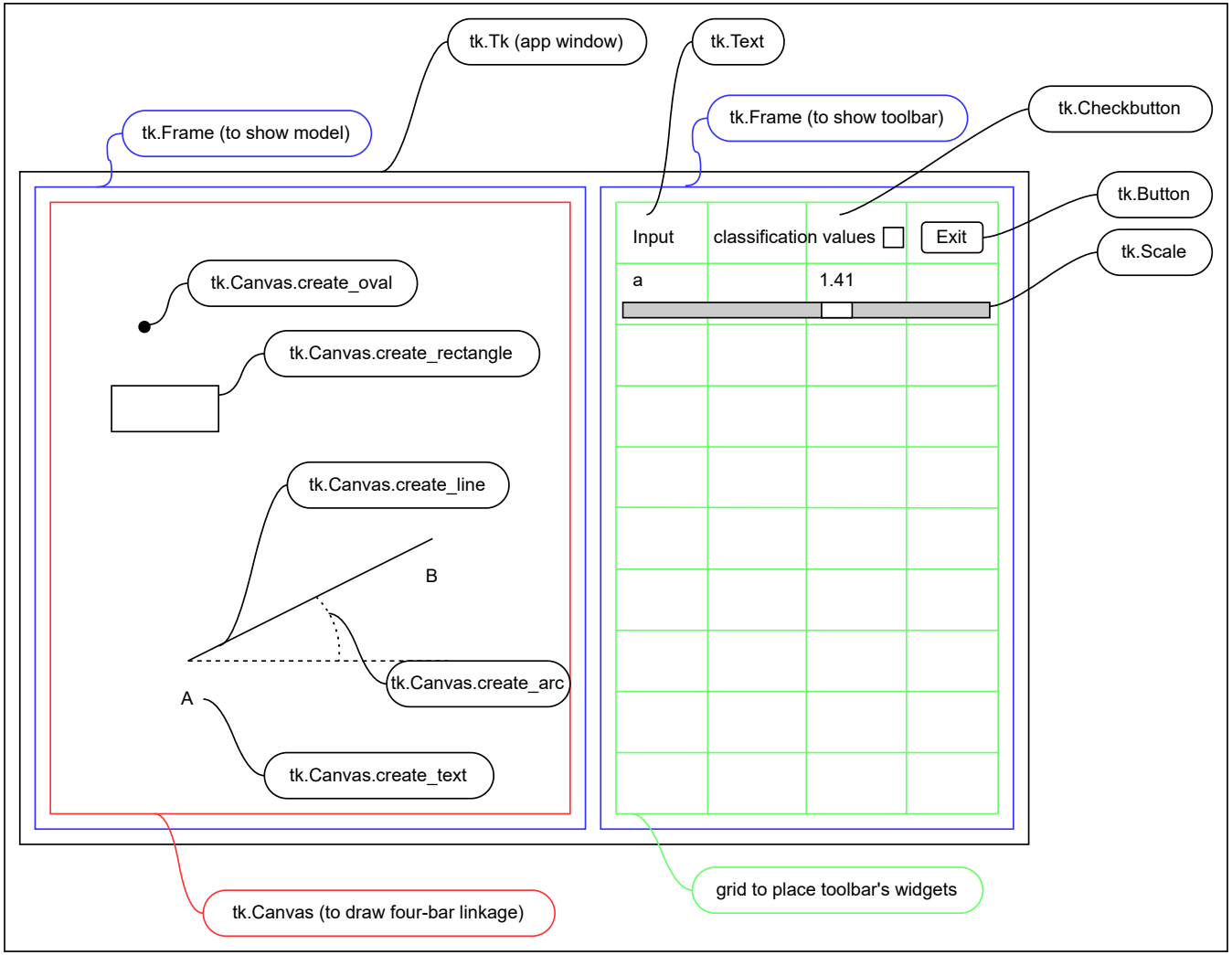


- Solve an optimization problem:
  - Push box with size 80×60 from $x = 220$ to $x = 0$
  - Do not cross the area of the labelling machine (Area with $x < 80$ and $y > 70$).
  - Pass above points $(120, 80)$ and $(220, 80)$

- **Four-bar linkage model**:
  - System simulates all the motion types of the four-bar linkage.
  - System does not crash with any input of geometrical configuration.
- **Tests**:
  - Implement test cases for geometry.
  - Implement test cases with bad input to test system stability.
- **Graphical User Interface**:
  - GUI provides the four-bar linkage visualization and motion animation.
  - User can input geometrical data by moving a point on a slide bar.
  - GUI is coupled with the four-bar linkage model to use implemented motion cases for animation.
  - GUI provides tracing for trajectories of the points.
  - GUI classifies of the linkage.
- **Optimization problem**:
  - It should be possible to find a solution (manually) for the optimization problem using the four-bar linkage model.
  - GUI visualizes the solution.

- **Performance**:
  - The four-bar linkage model is fast enough to provide smooth GUI animations.
  - GUI animations are not slower than 30 frames per second.
- **Usability**:
  - Every essential part of the four-bar linkage model is well documented.
  - GUI is easy to operate and all functionalities are self-explanatory.
  - GUI source code is well documented.

- **1. Operating System:**
  - Xubuntu/Windows
- **2. Developing Environment:**
  - Programming Language: Python.
  - IDE: Spyder/Pycharm.
  - Package Manager: Anaconda.
- **3. Libraries:**
  - Frontend: tkinter, math, numpy
  - Backend: math, numpy
- **4. Version Control System:**
  - GitHub: Remote code repositories for team collaboration, code reviews, and version control.
    `https://github.com/einsflash/Project_Pusher_Mechanism`
- **5. Frameworks:**
  - Pdoc: Used for generating project documentation, helping the team understand and maintain the code better.
  - Makefile: For build management.



- Initiate all tkinter objects inside GUI class and generate app window:

```
GUI().tk.mainloop()
```

Implementation

GUI, Animation

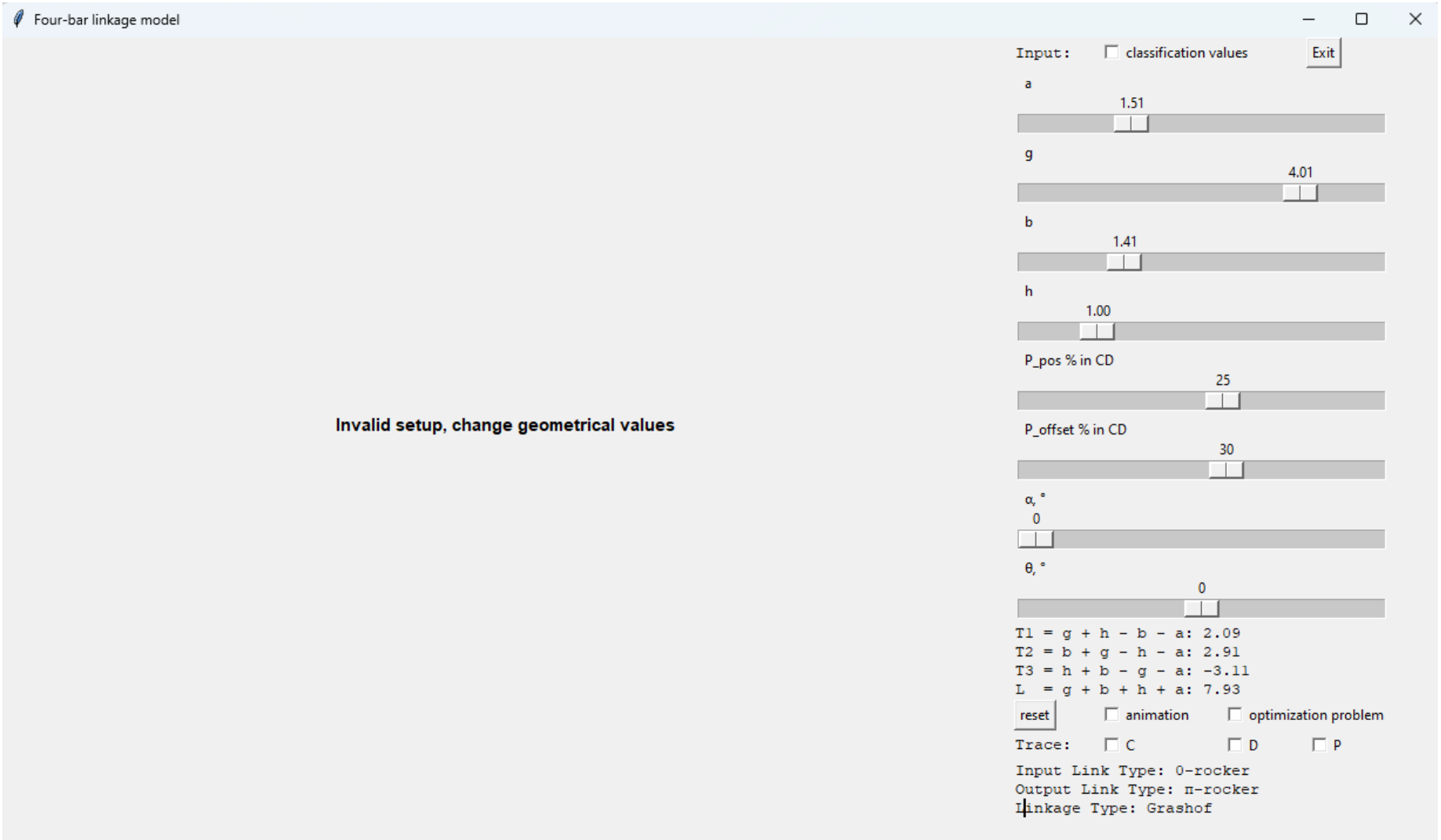
- Update objects in tk.Canvas every animation step using coords and/or itemconfigure for optimization

```
class GUI:
  def __init__(self):
    ...
    self.init_toolbar()
    ...
  def init_toolbar(self):
    ...
    self.enable_animation = tk.IntVar()
    self.animation_button = tk.Checkbutton(self.toolbar_frame, text="animation",
                                           variable=self.enable_animation,
                                           onvalue=1, offvalue=0, command=self.animation)
    self.animation_button.grid(sticky="W", row=10, column=2)
    ...
  def refresh(self):
    ...
    self.linkage.run()
    ...
    self.update_linkage_display()
  def animation(self):
    self.run_animation()
  def run_animation(self):
    if self.enable_animation.get():
      self.linkage.animation_alpha() # alpha = alpha + d_alpha
      self.refresh()
      self.tk.after(25, self.run_animation)
  def update_linkage_display(self):
    ...
    self.model_animation.coords(self.model_animation.AB_line, [A_x, A_y, B_x, B_y])
    ...
```

- To display different modes, some objects have to be hidden or shown.
- For objects in tk.Canvas use itemconfigure:
  - Hide:
    self.model_animation.itemconfigure(self.model_animation.AB_line, state='hidden')
  - Show:
    self.model_animation.itemconfigure(self.model_animation.AB_line, state='normal')
- For widgets like tk.Scale or tk.Text:
  - Hide: self.slider_T1.grid_remove()
  - Show: self.slider_T1.grid()

Implementation

GUI, Invalid Setup Handling



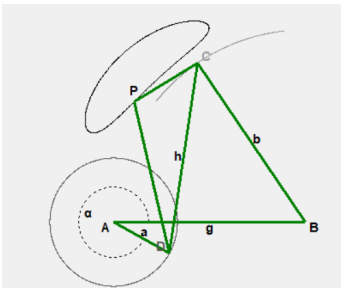
Implementation

GUI, Invalid Setup Handling

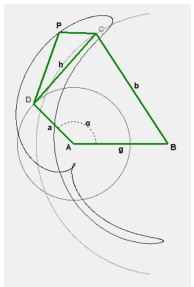

```
class GUI:
  def __init__(self):
    ...
    self.init_linkage_display()
    ...
  ...
  def init_linkage_display(self):
    self.model_animation.invalid_text = self.model_animation.create_text(round(self.model_animation.width/2),
                                                                          round(self.model_animation.height/2),
                                                                          text="Invalid setup, change geometrical values",
                                                                          fill="black", font=('Helvetica 11 bold'))
    self.model_animation.itemconfigure(self.model_animation.invalid_text, state='hidden')
    ...
  ...
  def update_linkage_display(self):
    if self.linkage.geometric_Validity:
      self.show_linkage()
      if self.enable_optimization_problem.get():
        self.show_optimization_problem()
      self.model_animation.itemconfigure(self.model_animation.invalid_text, state='hidden')
    else:
      self.hide_linkage()
      self.hide_optimization_problem()
      self.model_animation.itemconfigure(self.model_animation.invalid_text, state='normal')
      return
    ...
```

Results

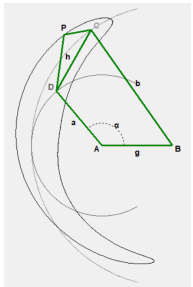
27 movement types



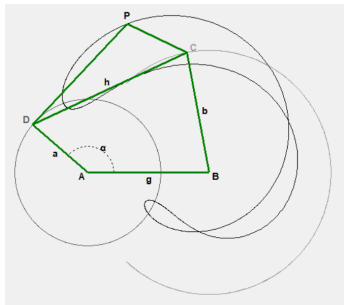
$T_{1,2,3} = 1.0, 1.0, 1.0$



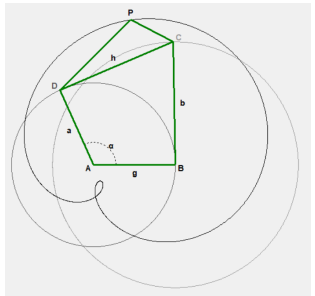
$T_{1,2,3} = 0.0, 1.0, 1.0$



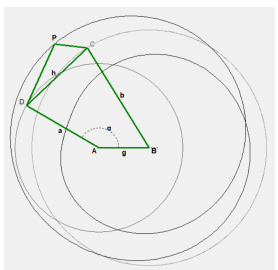
$T_{1,2,3} = -1.0, 1.0, 1.0$



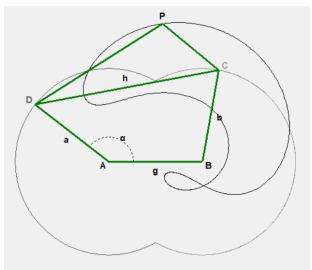
$T_{1,2,3} = 1.0, 0.0, 1.0$



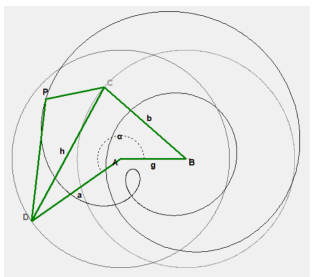
$T_{1,2,3} = 0.0, 0.0, 1.0$



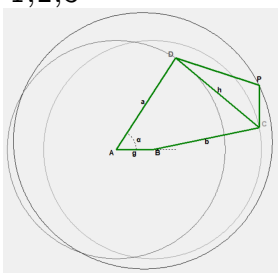
$T_{1,2,3} = -1.0, 0.0, 1.0$



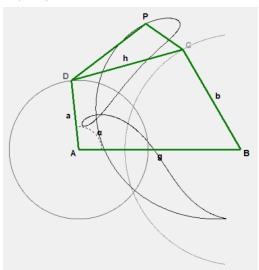
$T_{1,2,3} = 1.0, -1.0, 1.0$



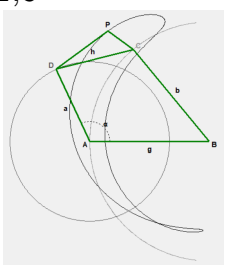
$T_{1,2,3} = 0.0, -1.0, 1.0$



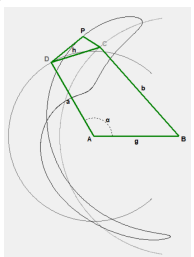
$T_{1,2,3} = -1.0, -1.0, 1.0$



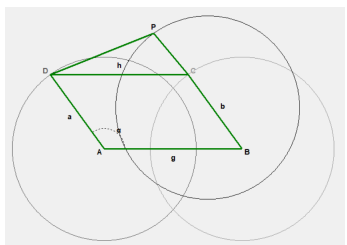
$T_{1,2,3} = 1.0, 1.0, 0.0$



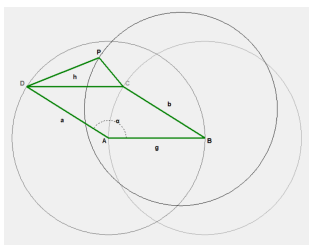
$T_{1,2,3} = 0.0, 1.0, 0.0$



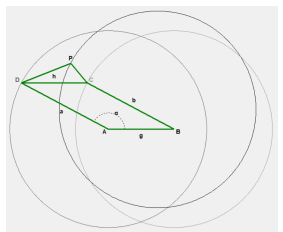
$T_{1,2,3} = -1.0, 1.0, 0.0$



$T_{1,2,3} = 1.0, 0.0, 0.0$



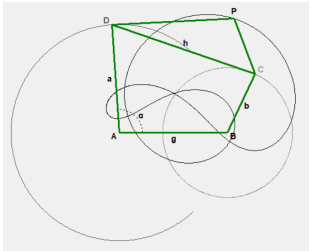
$T_{1,2,3} = 0.0, 0.0, 0.0$



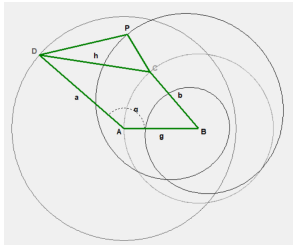
$T_{1,2,3} = -1.0, 0.0, 0.0$

Results

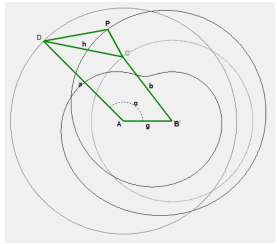
27 movement types



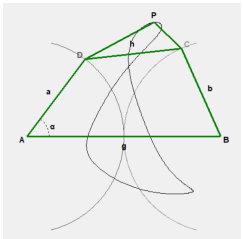
$T_{1,2,3} = 1.0, -1.0, 0.0$



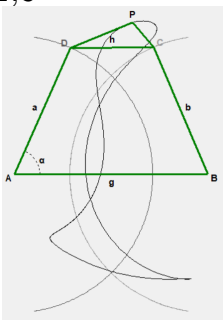
$T_{1,2,3} = 0.0, -1.0, 0.0$



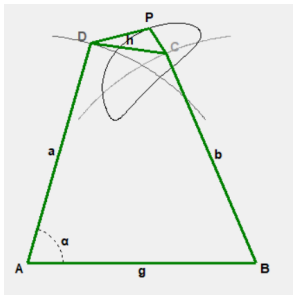
$T_{1,2,3} = -1.0, -1.0, 0.0$



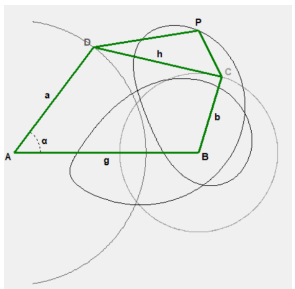
$T_{1,2,3} = 1.0, 1.0, -1.0$



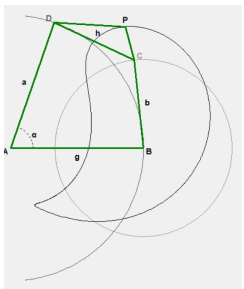
$T_{1,2,3} = 0.0, 1.0, -1.0$



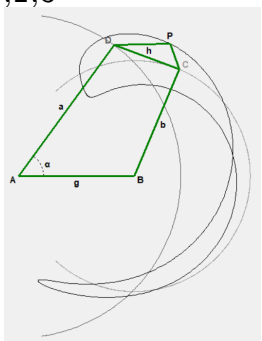
$T_{1,2,3} = -1.0, 1.0, -1.0$



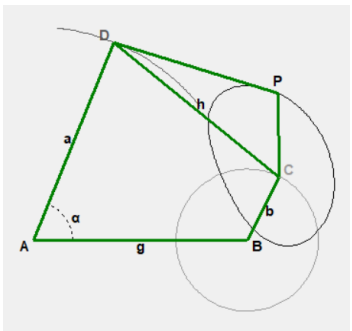
$T_{1,2,3} = 1.0, 0.0, -1.0$



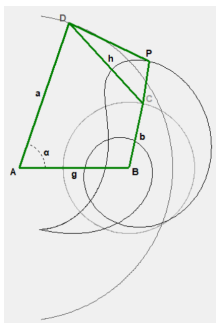
$T_{1,2,3} = 0.0, 0.0, -1.0$



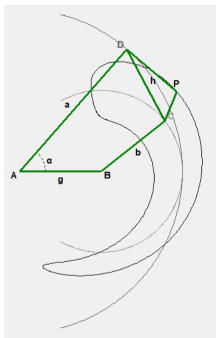
$T_{1,2,3} = -1.0, 0.0, -1.0$



$T_{1,2,3} = 1.0, -1.0, -1.0$



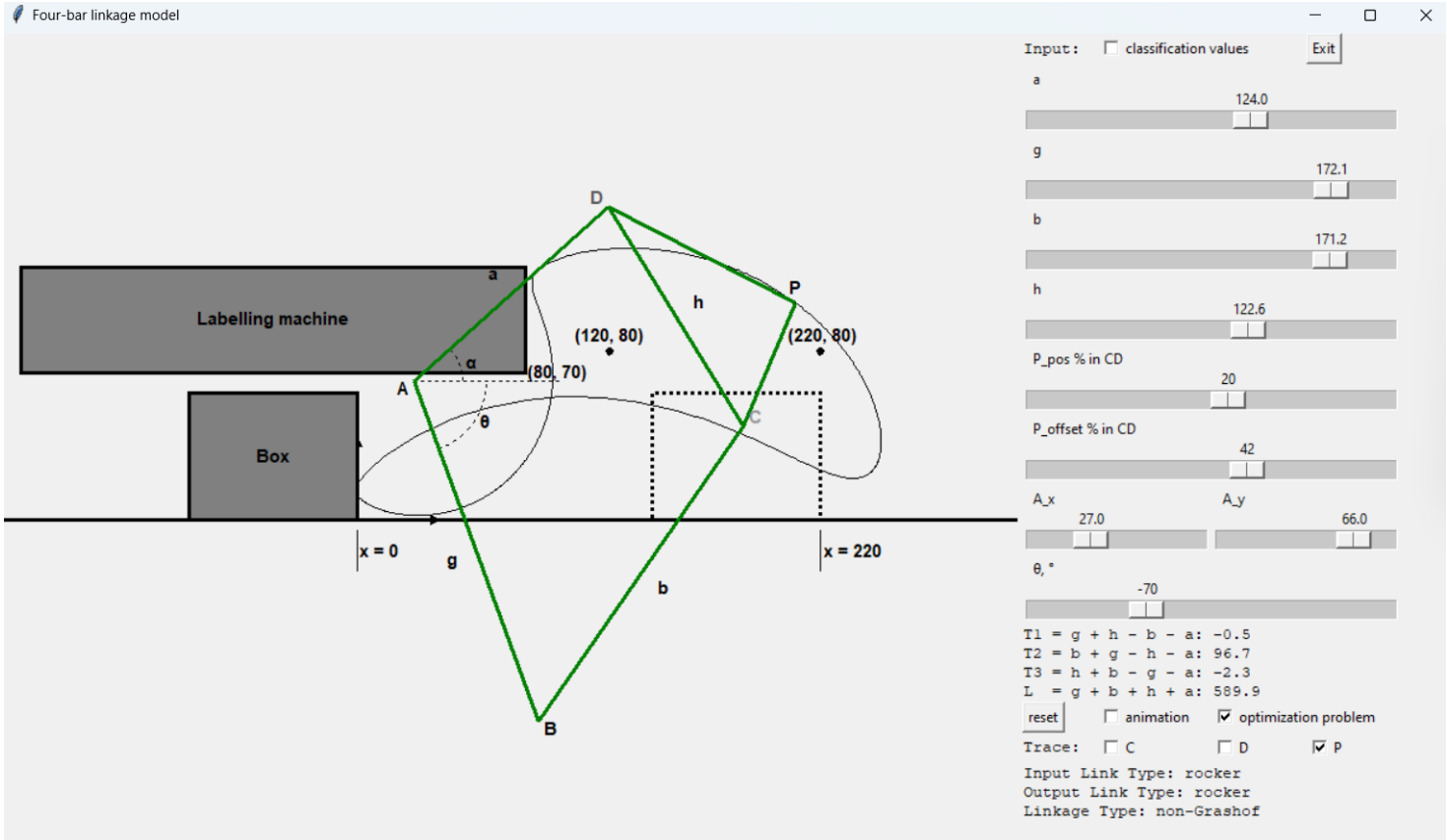
$T_{1,2,3} = 0.0, -1.0, -1.0$



$T_{1,2,3} = -1.0, -1.0, -1.0$

Results

Optimization problem



- 9 degrees of freedom (all lengths in cm):
  - Length of four bars: $a = 124.0$, $b = 171.2$, $g = 172.1$, $h = 122.6$.
  - Coupler position: $P_{pos} = 20.0\%$, $P_{offset} = 42.0\%$ of h.
  - Position of point A: $A_x = 27.0$, $A_y = 66.0$.
  - Angle of ground bar relative to horizon: $\theta = -70.0°$

Documentation for Frontend(GUI)

API Documentation

class GUI
- linkage
- tk
- width
- height
- model_frame
- model_animation
- toolbar_frame
- trace_C()
- trace_D()
- trace_P()
- positions_C
- positions_D
- positions_P
- x_axis
- y_axis
- A_x
- A_y
- pin_box_to_coupler
- prev_coupler_position
- prev_box_position
- init_toolbar()
- init_linkage_display()
- display_classification_values()
- display_bars_values()
- display_information()
- scaling_factor()
- calculate_normalities()
- update_parameter_a()
- update_parameter_g()
- update_parameter_b()
- update_parameter_h()
- update_parameter_p_pos()
- update_parameter_p_off()
- update_parameter_alpha()

gui

▸ View Source

class GUI: ▸ View Source

linkage

tk

width

height

model_frame

model_animation

toolbar_frame

def trace_C(self): ▸ View Source

def trace_D(self): ▸ View Source

def trace_P(self): ▸ View Source

positions_C

positions_D

positions_P

x_axis

y_axis

A_x

A_y

pin_box_to_coupler

prev_coupler_position

prev_box_position

def init_toolbar(self): ▸ View Source

def init_linkage_display(self): ▸ View Source

Documentation for Backend

API Documentation

- class FourBarLinkage
  - FourBarLinkage()
  - AB
  - BC
  - CD
  - DA
  - alpha
  - theta
  - alpha_rad
  - theta_rad
  - coupler_position
  - coupler_offset
  - t
  - alpha_velocity
  - C_mode
  - init_default_values()
  - run()
  - check_Parameter()
  - find_Linkage_Type()
  - calculate_Classification_Value()
  - calculate_Edge_Value()
  - calculate_alpha_lims()
  - calculate_Point_Position()
  - calculate_C_Position()
  - calculate_P_Position()
  - animation_alpha()
  - switch_C2_C1()

built with pdoc

four_bar_linkage

▸ View Source

```
class FourBarLinkage:
```

▸ View Source

```
FourBarLinkage(
    AB,
    BC,
    CD,
    DA,
    alpha,
    theta,
    coupler_position,
    coupler_offset,
    timeinterval,
    alpha_velocity
)
```

▸ View Source

AB

BC

CD

DA

alpha

theta

alpha_rad

theta_rad

coupler_position

coupler_offset

t

alpha_velocity

C_mode

```
def init_default_values(self):
```

▸ View Source

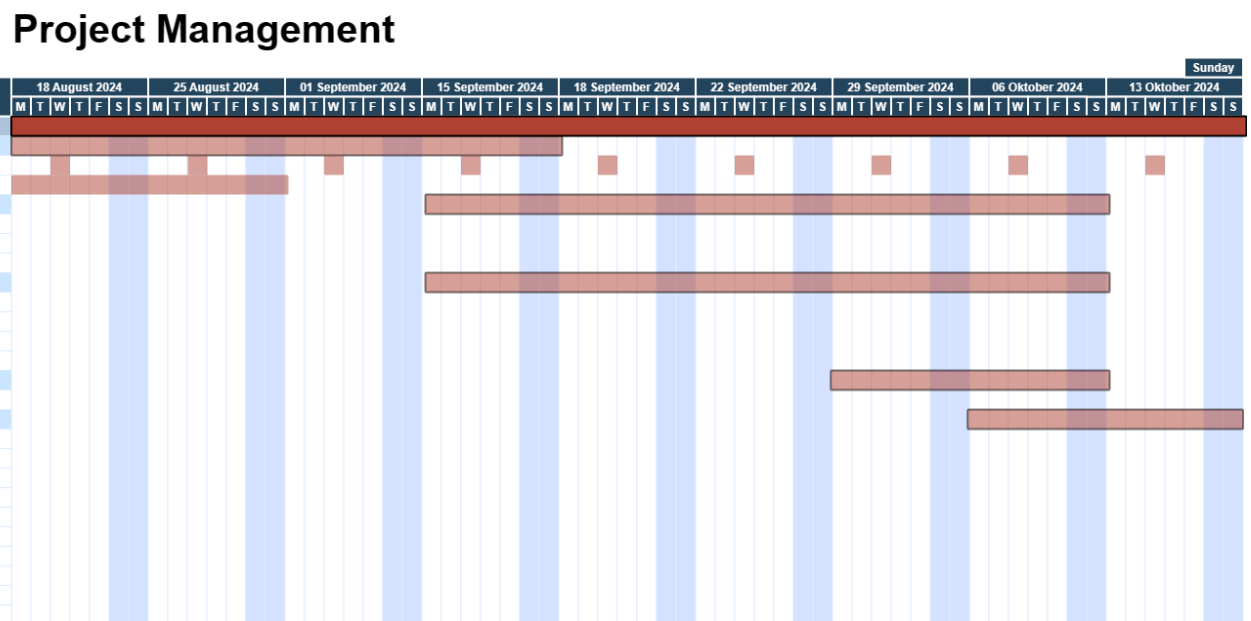
```
def run(self):
```

▸ View Source

- **1.Discuss and Design:**
  - weekly discussion in discord.
  - gathering information / generating ideas for program.
- **2.Frontend:**
  - Design of GUI
  - Implementation
  - Debug
- **3.Backend:**
  - Algorithm for calculating positions and angle extremum
  - Interface for animation
  - Two types of input
  - Display information(Grashof condition, geometric validity)
- **4.Test the motion case:**
- **5.Presentation:**
  - Analysis (user requirements)
  - Frontend
  - Project management
  - Backend
- *The following page outlines the responsibilities of each person.

A = ALL members in group
K = Kholod Arseniy
F = Floerke Aaron Albert
S= Song Xinyang
Z = Zhu Yanliang

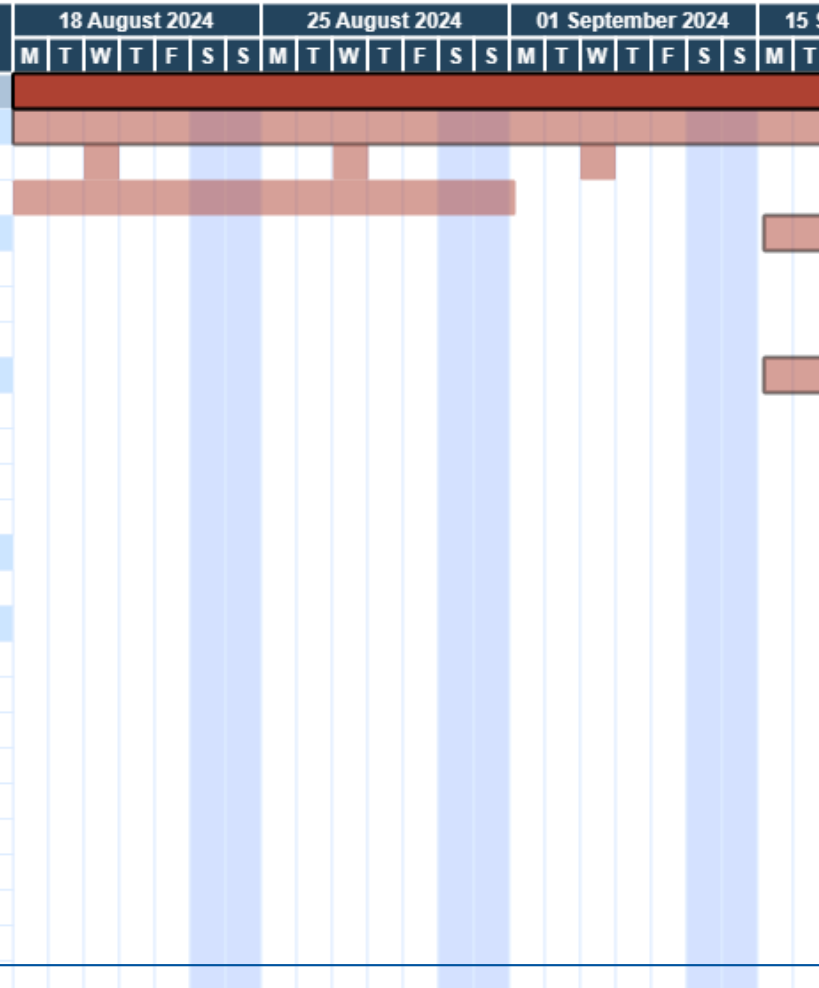
Person	Task	Duration	Start	End
0	Four Bar Linkage Model	62 days	12.08	13.10
1	Discuss and Design	Weekly	12.08	15.09
A	weekly discussion in discord	Wednesday	/	/
A	gathering information / generating ideas for program	14 days	/	/
2	Frontend	35 days	09.09	06.10
K	Design of GUI	/	/	/
K	Implementation	/	/	/
A	Debug	/	/	/
3	Backend	35 days	09.09	06.10
Z	Algorithm for calculating positions and angle extremum	/	/	/
K	Interface for animation	/	/	/
Z	Two types of input	/	/	/
S	Display information(Grashof condition, geometric validity)	/	/	/
4	Test Case	14 days	23.09	06.10
F	Test the motion case			
5	Presentation	14 days	30.09	13.10
A	Task assignment ()			
F	Analysis (user requirements)			
K	Frontend			
S	Project management			
Z	Backend			



A = ALL members in group
K = Kholod Arseniy
F = Floerke Aaron Albert
S= Song Xinyang
Z = Zhu Yanliang

Project Management

Person	Task	Duration	Start	End
0	Four Bar Linkage Model	62 days	12.08	13.10
1	Discuss and Design	Weekly	12.08	15.09
A	weekly discussion in discord	Wednesday	/	/
A	gathering information / generating ideas for program	14 days	/	/
2	Frontend	35 days	09.09	06.10
K	Design of GUI	/	/	/
K	Implementation	/	/	/
A	Debug	/	/	/
3	Backend	35 days	09.09	06.10
Z	Algorithm for calculating positions and angle extremum	/	/	/
K	Interface for animation	/	/	/
Z	Two types of input	/	/	/
S	Display information(Grashof condition, geometric validity)	/	/	/
4	Test Case	14 days	23.09	06.10
F	Test the motion case			
5	Presentation	14 days	30.09	13.10
A	Task assignment ()			
F	Analysis (user requirements)			
K	Frontend			
S	Project management			
Z	Backend			



Live Software Demo

Summary and Conclusion

Literature

- Cvetkovic, Ivana and Stojicevic, Misa and Popkonstantinović, Branislav and Cvetković, Dragan. (2018). Classification, geometrical and kinematic analysis of four-bar linkages. 261-266. 10.15308/Sinteza-2018-261-266.