

# DESIGN AND FABRICATION OF SHAPE MEMORY ALLOY-ACTUATED BUTTERFLY TILES FOR ADAPTIVE THERMAL REGULATION

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Dec 10th, 2025  
M.Eng Project



# BACKGROUND & OBJECTIVE

- Maia Hirsch's bio-inspired thermal regulation suit
- Adaptive tile: shape change → airflow control
- Goal: develop a lightweight, soft, responsive butterfly actuator



*Maia's temperature adaptive suit sketches*



*Maia's previous work - tessellated butterflies*



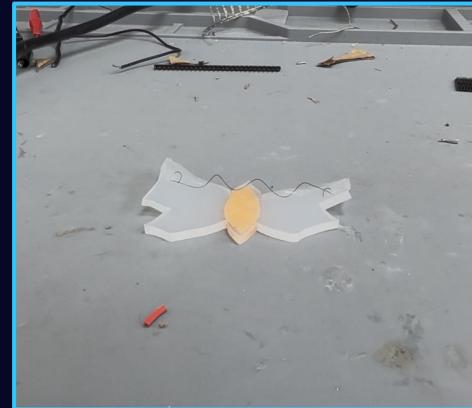
# DESIGN STRATEGY OVERVIEW

Two project approaches:

## 1. Mechanical Linkage



## 2. Shape Memory Alloy Actuation

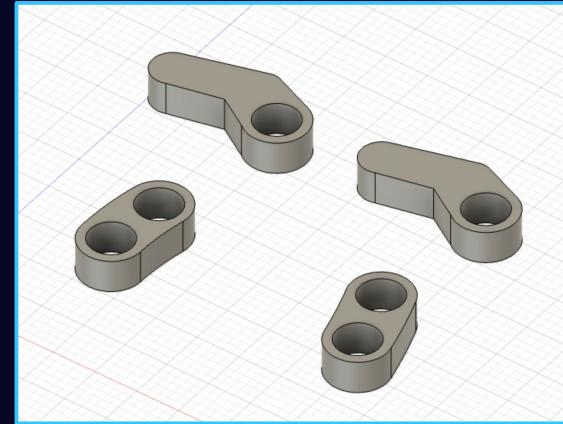
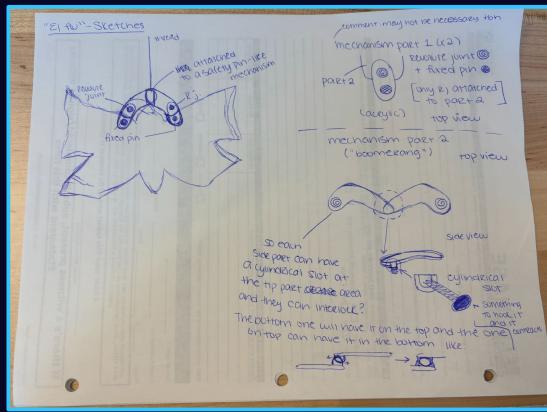


# MECHANICAL LINKAGE: EARLY STAGES

- Retracting-claw concept inspired by Iris Van Herpen's design
- Link-based closing motion imitating wing folding
- Initial sketches

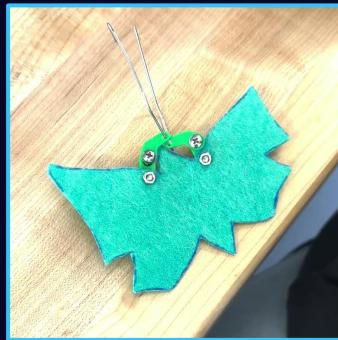


Iris Van Herpen design

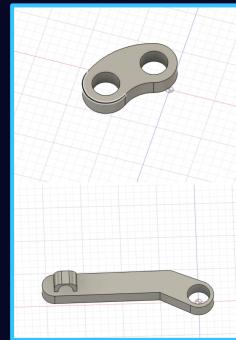


# MECHANICAL LINKAGE: DEVELOPMENT

- Linkage CAD iteration
- Multiple 3d-printed versions
- Verified motion on fabric and resin



*Initial design  
Issue: small lever arm and  
impractical tension-hole  
location*



*Modified: curvature, hole  
location and lever arm  
length*

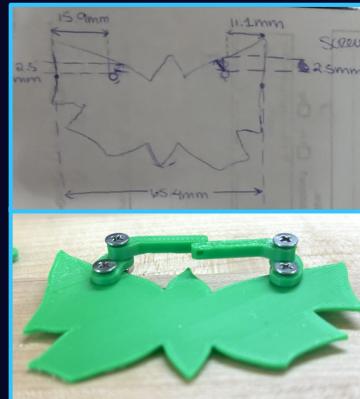
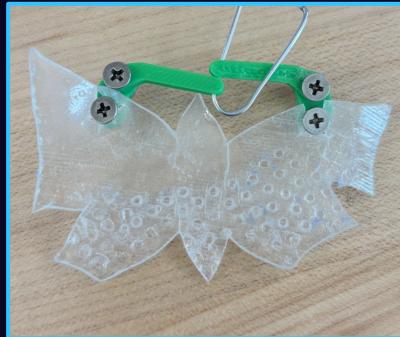


*Modified: hole location and  
material used to model - slightly  
stiffer than actual material*

# MECHANICAL LINKAGE: LIMITATIONS

## Issues observed with resin:

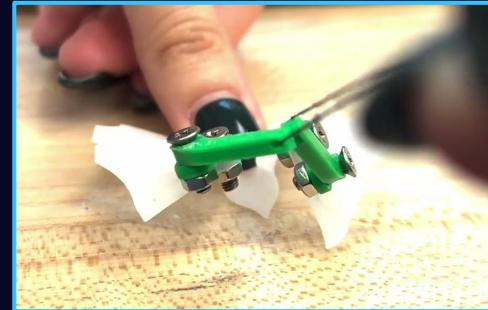
- Resin cracked around screw holes
- Direction of tension didn't match desired fold pattern



Modified: butterfly's CAD to include holes for mechanism and distance of lever arm

## Transition to softer materials:

- Resin was too rigid
- SLA prints kept failing (supports specifics)
- Switched to PLA mold + silicone (Ecoflex)



Issues: mechanism is too heavy on the wings and the ecoflex is too soft for screws  
-> slipping

# ECOFLEX BUTTERFLY FABRICATION

- PLA molds + Ecoflex
- Tested 3 versions, each with a different thickness: 1 mm, 2 mm, 3 mm
- Achieved reliable 3 mm thickness body



PLA molds (1,2,3 mm)



*PLA mold ( $t = 1 \text{ mm}$ ): failed, did not cure after a long time*



*$t = 2 \text{ mm}$  (left): a bit tacky and had a hole  
 $t = 3 \text{ mm}$  (right): fully cured,*



3 mm molds

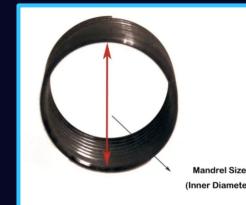
# SHAPE MEMORY ALLOYS

## Introduction:

- Nitinol wire trained to a specific shape via heat + quench
  - Helical springs
- Idea: SMA contracts -> the wing closes

## Characterization:

- Specs: Mandrel (4.75mm), wire size (0.15mm), transition temp (45 C)
- Measured: coil counts (6, 10, 15 loops), resistances, current requirements for activation
- Smallest length with most power: 6 loops

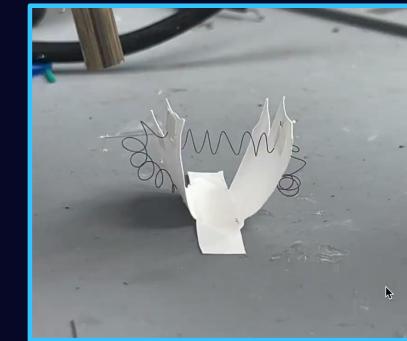
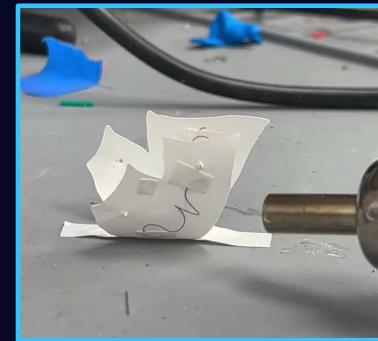
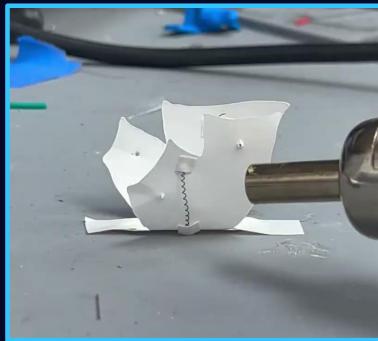
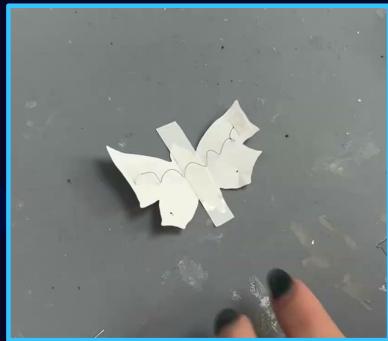


Length	Resistance (ohms)	Voltages (V):	3	5	9	12
6 loops	7	Current (A) =	0.4285714286	0.7142857143	1.285714286	1.714285714
		Power (W) =	1.285714286	3.571428571	11.57142857	20.57142857
10 loops	18.65	Current (A) =	0.1608579088	0.2680965147	0.4825737265	0.6434316354
		Power (W) =	0.4825737265	1.340482574	4.343163539	7.721179625
15 loops	25.2	Current (A) =	0.119047619	0.0283446712	0.3571428571	0.4761904762
		Power (W) =	0.3571428571	0.9920634921	3.214285714	5.714285714

# SMA ACTUATION TESTS

## Paper prototypes:

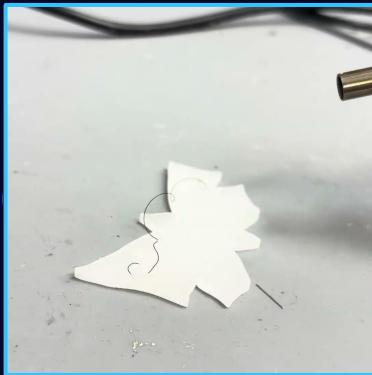
- Proof of motion
- Rapid response when heated
- Demonstrated curling motion similar to initial goal



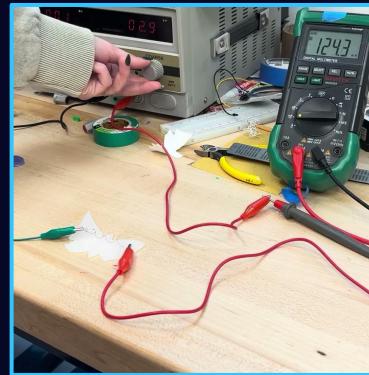
# SMA + ECOFLEX INTEGRATION ATTEMPTS

Challenges:

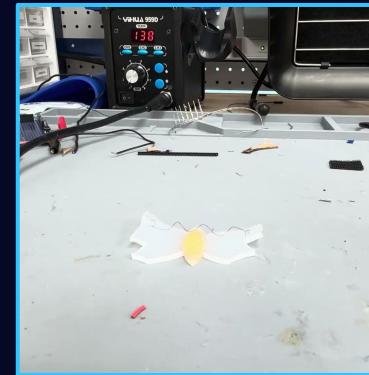
- Center of butterfly was not stable (powder finished butterfly)
- Alligator clips add excessive mass
- Tacky finish reduces sliding motion
- SMA overheating from power supply spikes



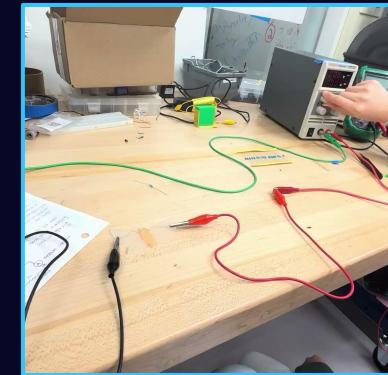
Powder finished



Powder finished



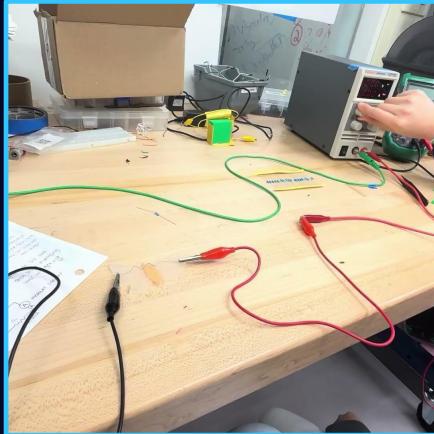
Sticky finished



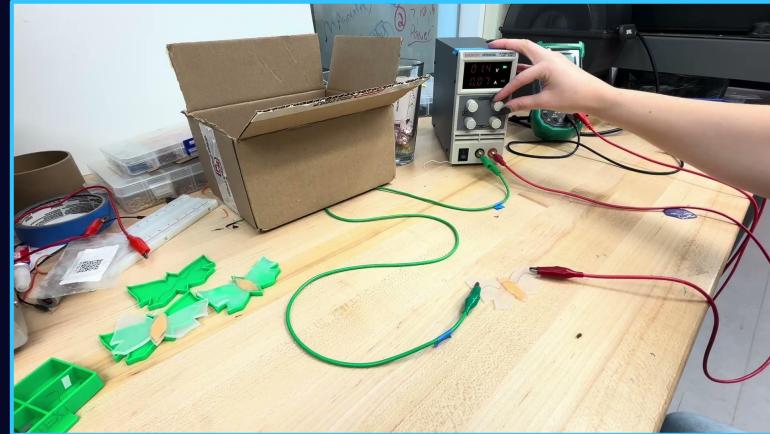
Sticky finished

# SMA: ELECTRICAL FAILURE ANALYSIS

- A SMA wire burned at 7V spike
  - Lost its shape
- Voltage fluctuation when in series with multimeter



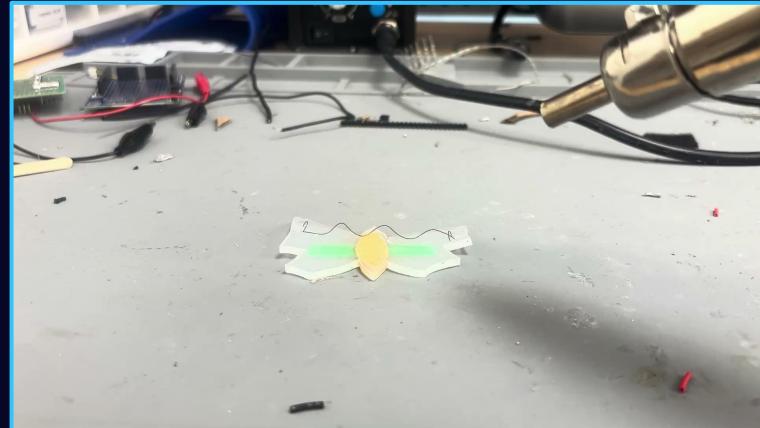
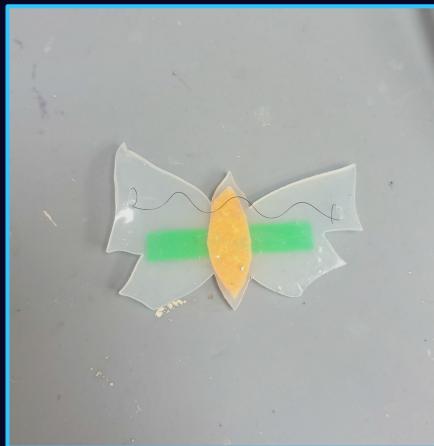
*Sticky finished*



# CURRENT STATE: TRANSITION TO HYBRID DESIGN

Insights that lead to a hybrid solution:

- Ecoflex needs **partial rigid support**
- SMA works **best for pulling**, not pushing
- Central PLA backing gives reliable “default open” posture



# CURRENT STATE

- Butterfly wings default to open state
- SMA contraction pulls edges inward
- System reduces needed actuation force
- Combines soft-rigid + SMA benefits

*Sticky finished*

# CONTINUING WORK

- Thinner PLA piece (0.4 -> 0.2mm)
- Reduce electrical connection weight
- Embed PLA spine into molding
- Add a temperature sensor + push button + Arduino to the circuit



QUESTIONS?



“This is a quote, words full of wisdom that someone important said and can make the reader get inspired”

—SOMEONE FAMOUS



# ONE COLUMN

Do you know what helps you make your point clear? Lists like this one:

- They're simple
- You can organize your ideas clearly
- You'll never forget to buy milk!

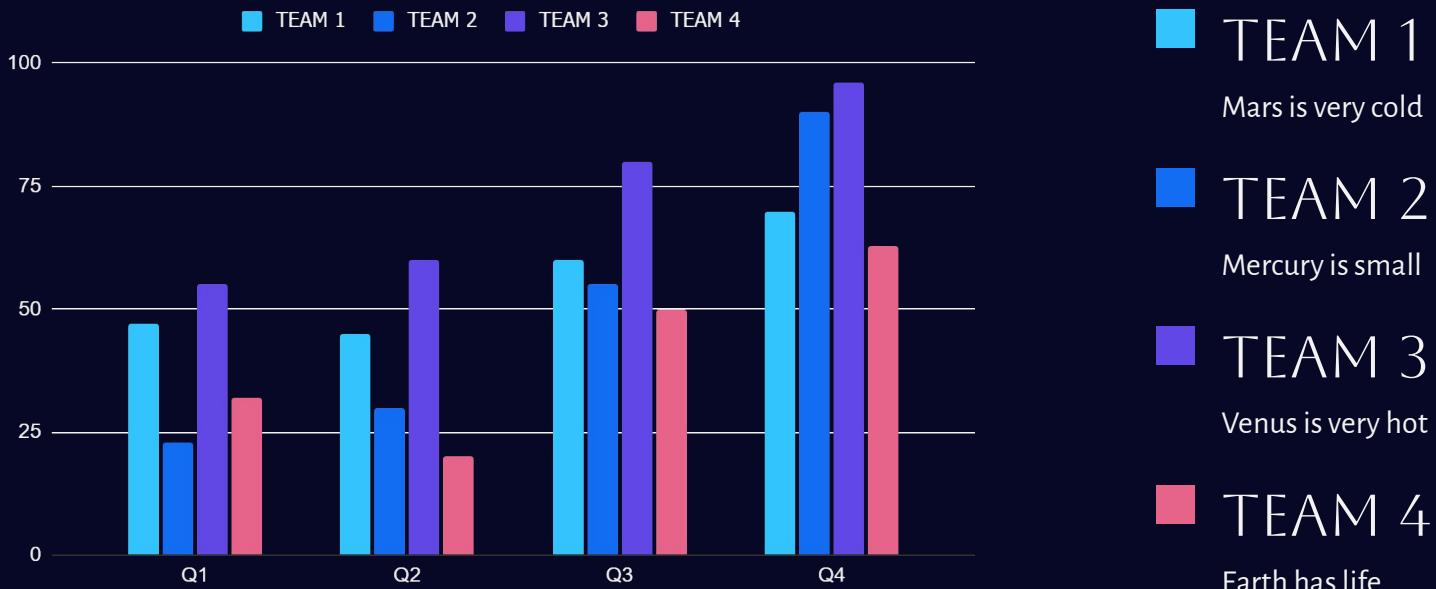
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# 01 SECTION HEADER

# BAR GRAPH

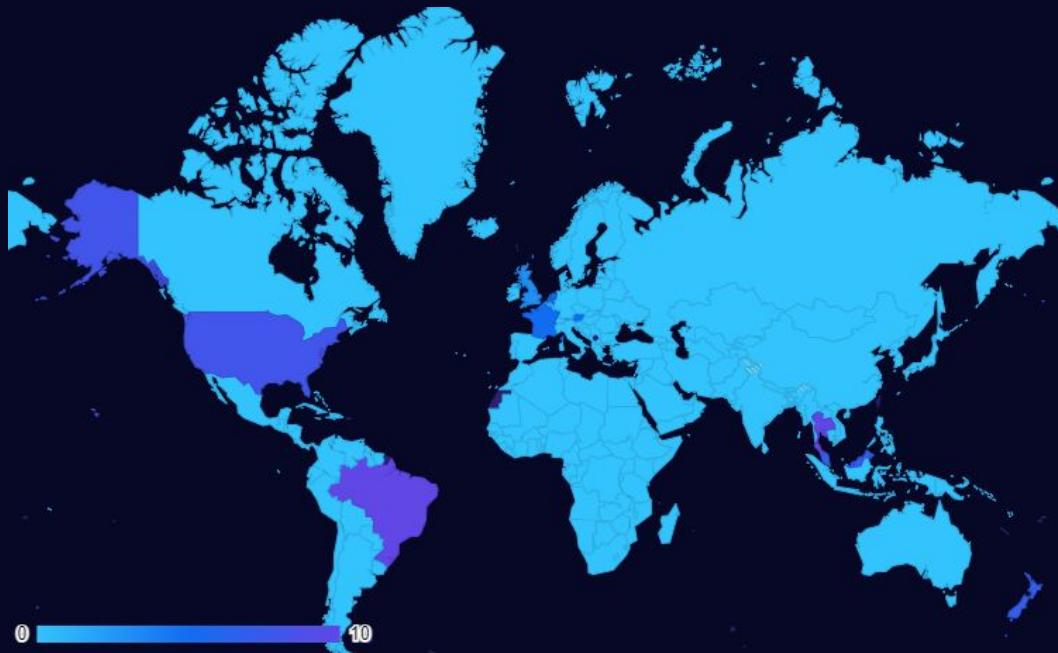


Follow the link in the graph to modify its data and then paste the new one here. [For more info, click here](#)

# MAP

## MARS

Mars is very cold



## MERCURY

Mercury is small

## VENUS

Venus is very hot



Follow the link in the graph to modify its data and then paste the new one here. [For more info, click here](#)

# TABLE

	TEAM A	TEAM B	TEAM C	TEAM D	TEAM E	TEAM F
MERCURY	XX	XX	XX	XX	XX	XX
MARS	XX	XX	XX	XX	XX	XX
SATURN	XX	XX	XX	XX	XX	XX
VENUS	XX	XX	XX	XX	XX	XX
JUPITER	XX	XX	XX	XX	XX	XX
EARTH	XX	XX	XX	XX	XX	XX
MOON	XX	XX	XX	XX	XX	XX

# TIMELINE

01

MARS

Despite being red, Mars is  
a cold place

02

VENUS

Venus is the second planet  
from the Sun

03

NEPTUNE

Neptune is the farthest  
planet from the Sun

04

EARTH

Earth is the third planet  
from the Sun

08

SATURN

Saturn is a gas giant and  
has several rings

07

JUPITER

Jupiter is the biggest  
planet of them all

06

MERCURY

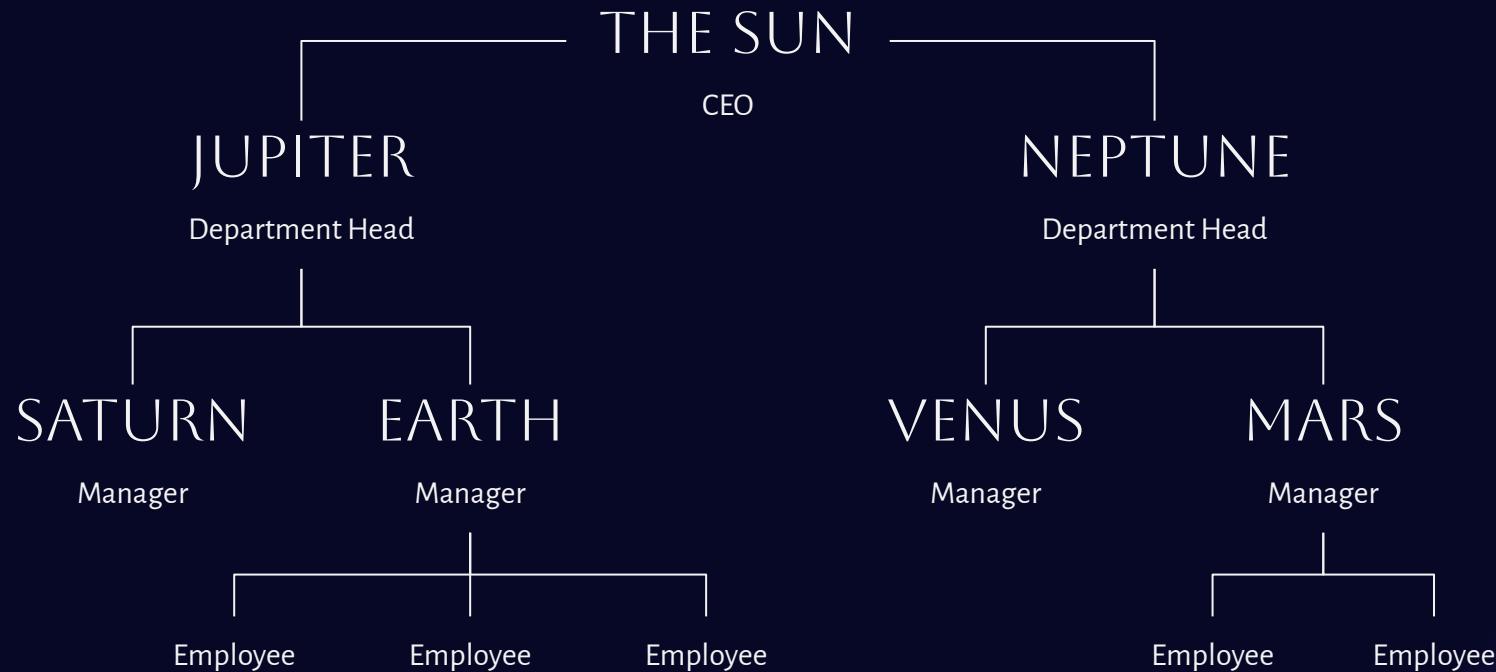
Mercury is the closest  
planet to the Sun

05

MOON

The Moon is Earth's only  
natural satellite

# ORGANIZATIONAL CHART



# ROADMAP INFOGRAPHIC

INITIATIVE	OBJECTIVE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Venus is very hot	Venus has a beautiful name and is the second planet from the Sun		■										
Earth has life	Earth is the beautiful planet on which humans live			■	■								
Mars is very cold	Despite being red, Mars is actually a cold place				■	■	■						
Jupiter is a gas giant	Jupiter is the biggest planet in the Solar System					■	■	■					
Saturn has rings	Saturn is a gas giant and has several rings								■				
Mercury is small	Mercury is the closest planet to the Sun and the smallest one									■			

# THANKS!

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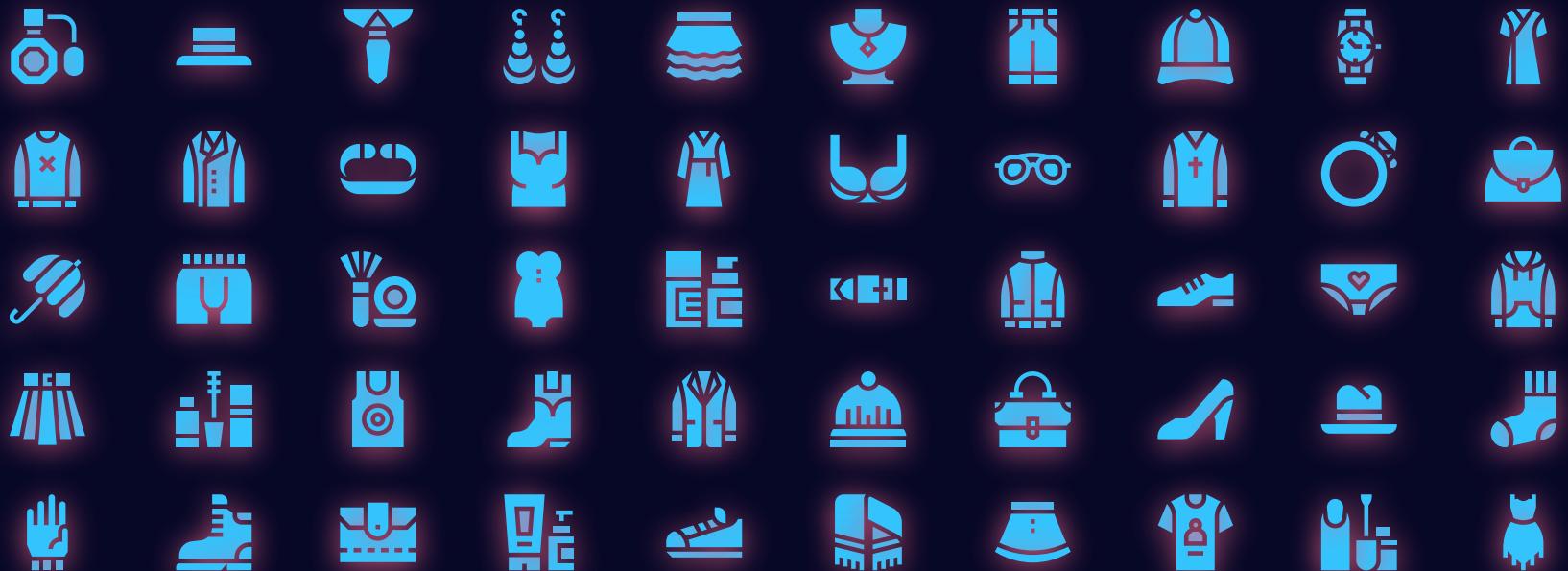


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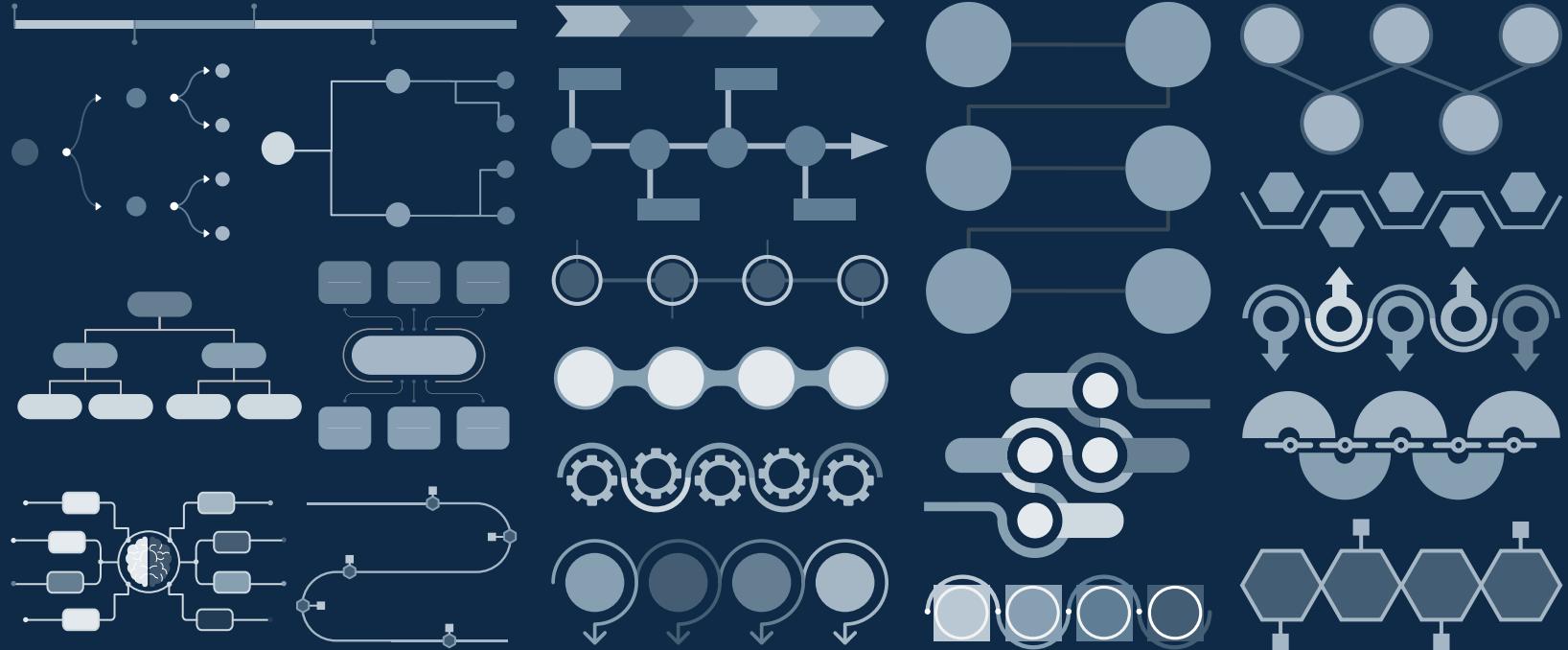
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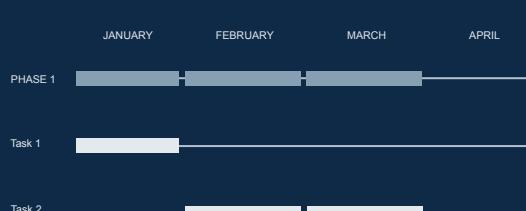
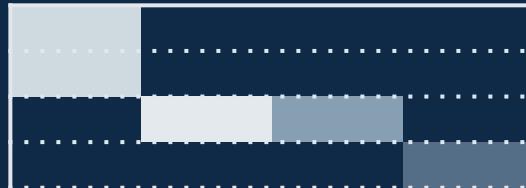
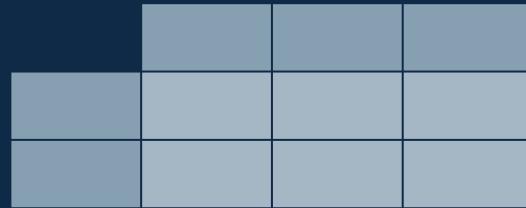
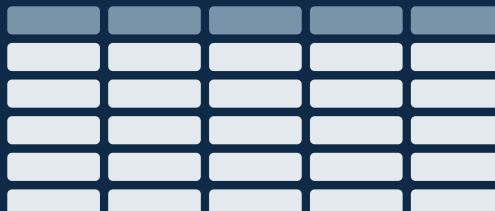
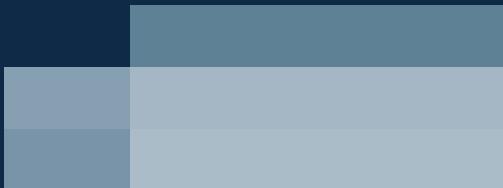
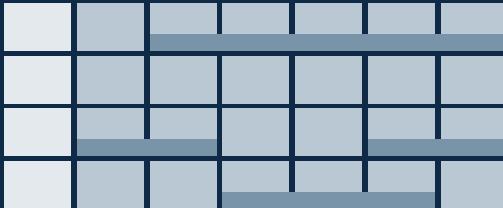
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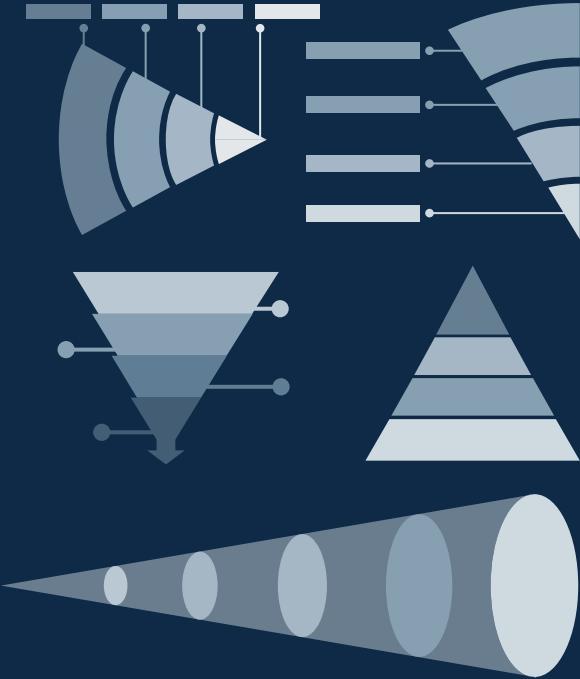
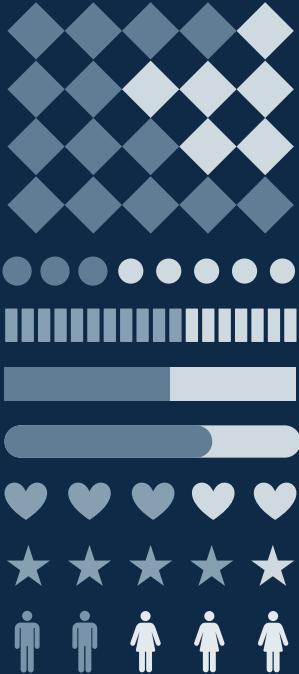
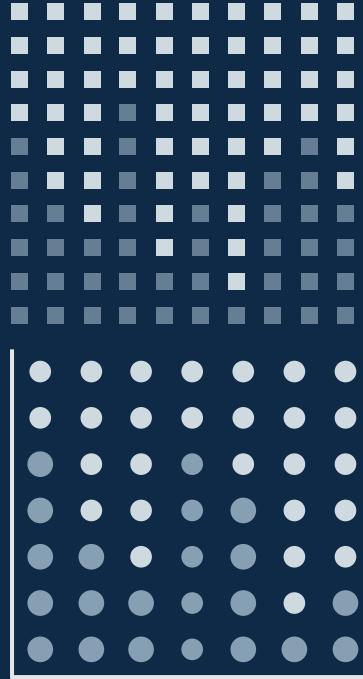












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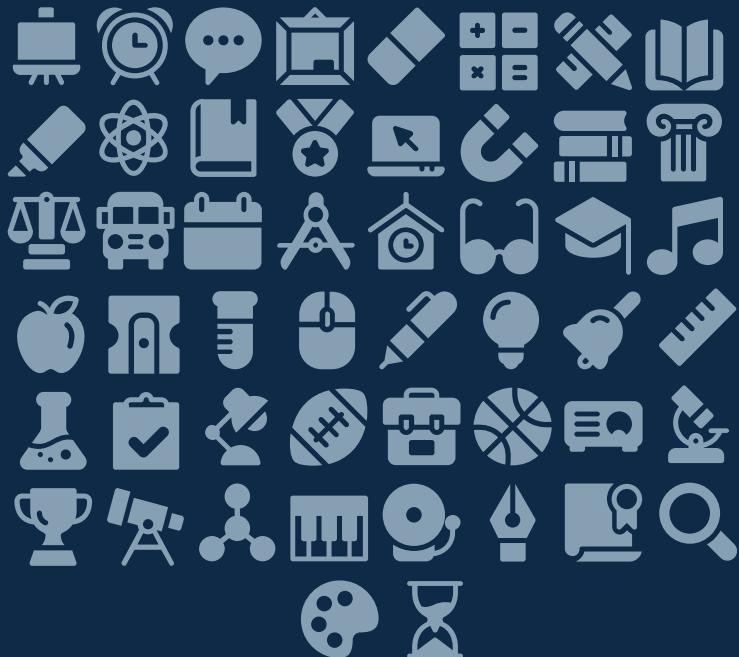
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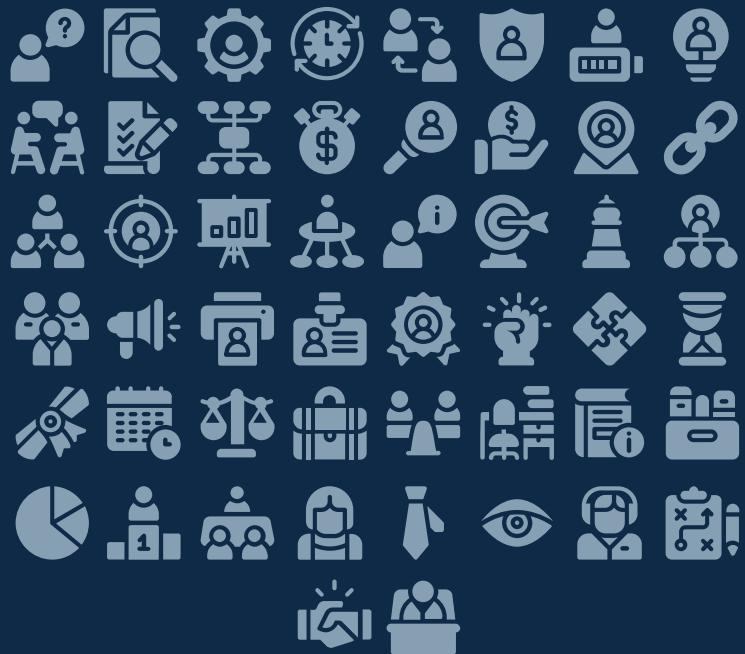
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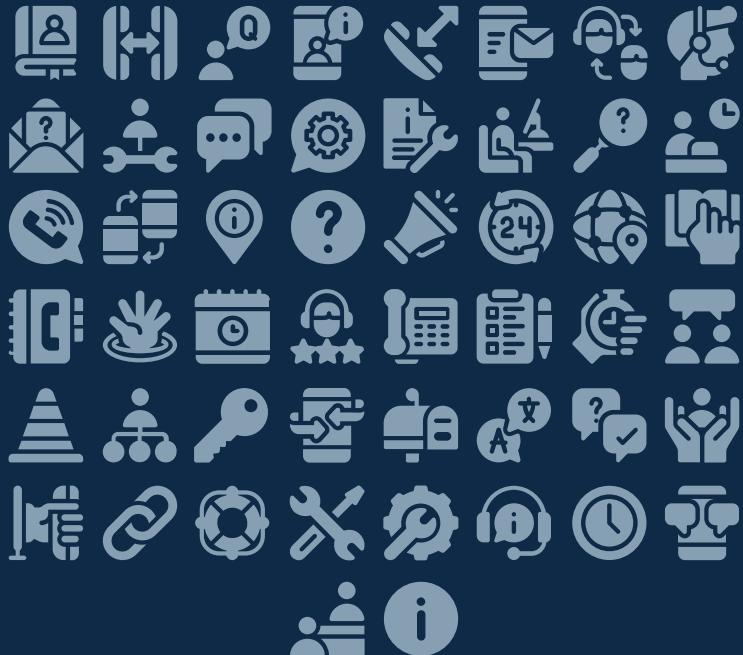
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