



# Garbage Classification

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Class: CAA

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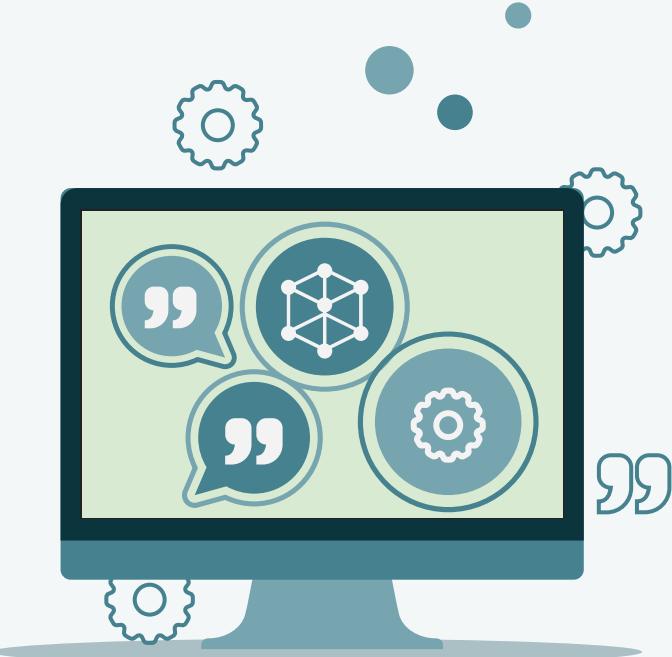
## Conclusion

Best Models, Related Work

# 01

# Introduction

Context and Motivation



# Introduction

## Motivation:

- Waste classification is crucial for recycling & environmental sustainability.
- Traditional methods are labor-intensive; automation can optimize waste management.

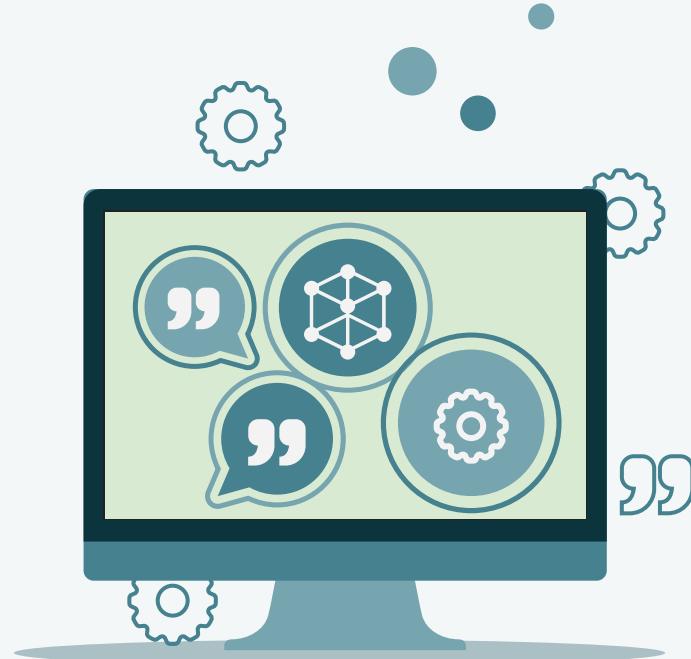
## Goal:

- Classify 6 categories: cardboard, glass, metal, paper, plastic, trash.
- Evaluate ML & DL models: KNN, CNN, DenseNet, ResNet50, VGG16.

# 02

## Dataset

Data and preprocessing



# Dataset

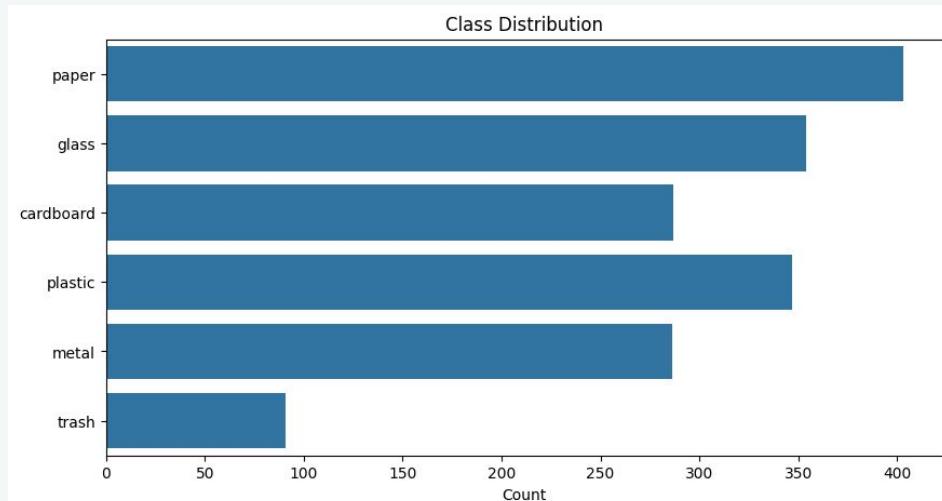
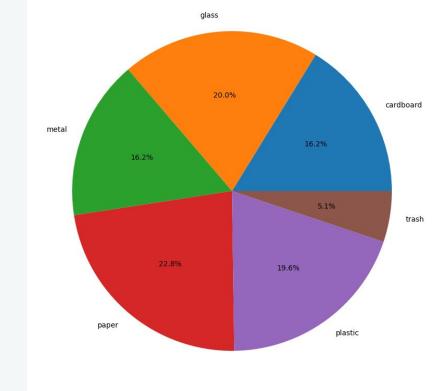
## Dataset:

2,467 images, 6 classes:

- Paper (584)
- Glass (491)
- Plastic (472)
- Metal (400)
- Cardboard (393)
- Trash (127)

## Challenges:

Imbalanced data: Trash only 5%.



# Preprocessing

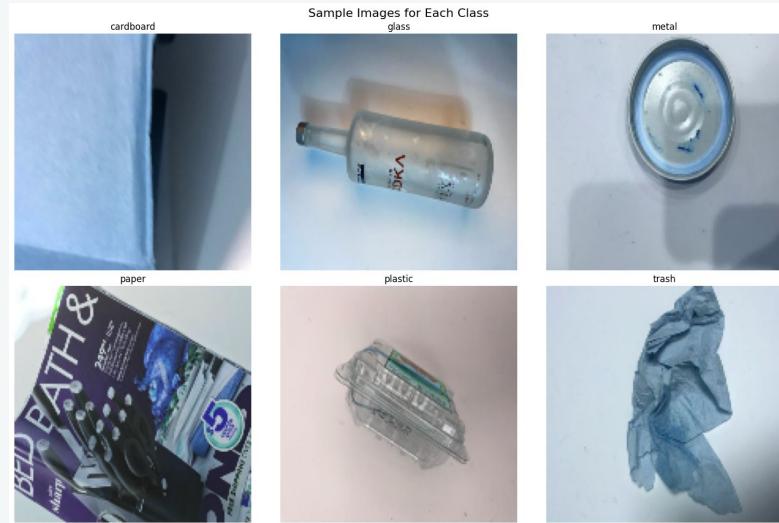
Preprocessing:

- Resizing: 224×224 px.

- Normalization: [0,1] scaling.

Augmentation:

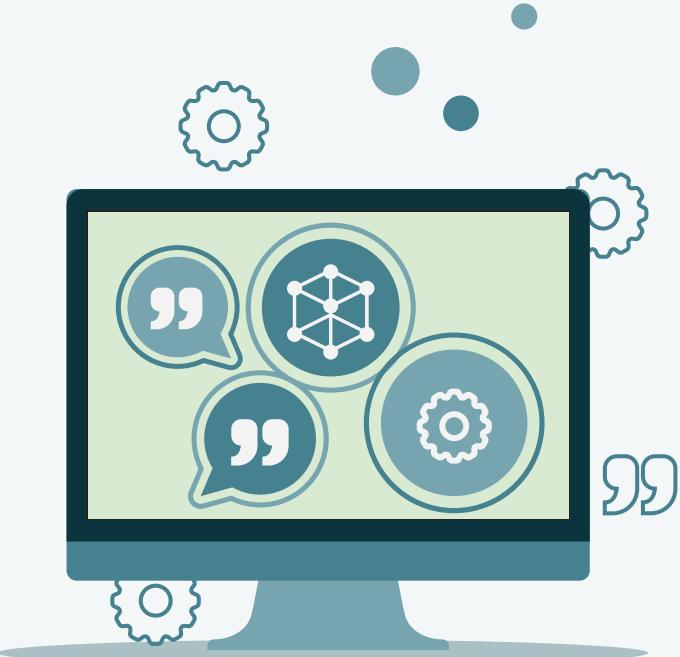
- Random rotations, flips, zoom, brightness shifts.



# 03

# ML Models

ML Models Overview



# ML Models Overview

- KNN: Baseline, simple & interpretable.
- CNN: Custom architecture for feature extraction.
- DenseNet, ResNet50, VGG16: Advanced architectures using transfer learning.

## Optimization Techniques:

- Adam optimizer, L1/L2 regularization, Dropout, EarlyStopping, Dropout+EarlyStopping.

# 04

# Model Training

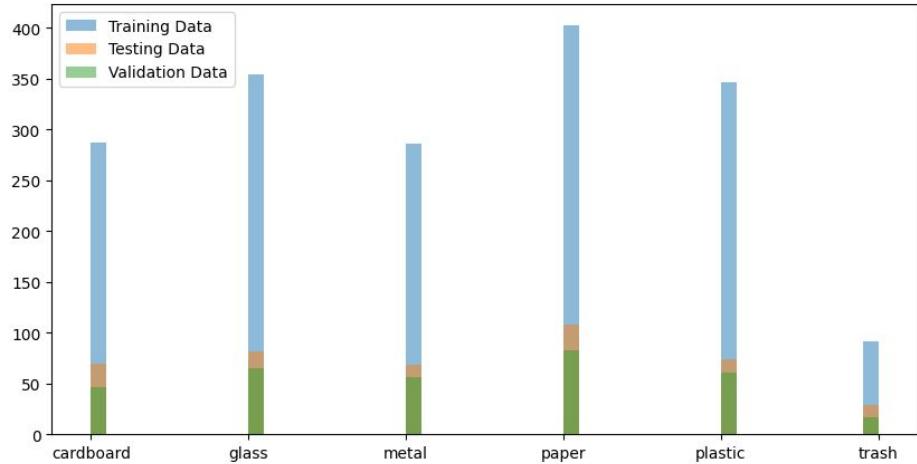
ML Models Overview



# Data Split

- The dataset was already divided into three subsets:

- Training set: used for model training;
- Validation set: used for hyperparameter tuning and early stopping decisions;
- Test set: used for final model evaluation.



# Training Details

## Training Details:

- **Loss:** categorical cross-entropy.
- **Metrics:** accuracy, ROC AUC.

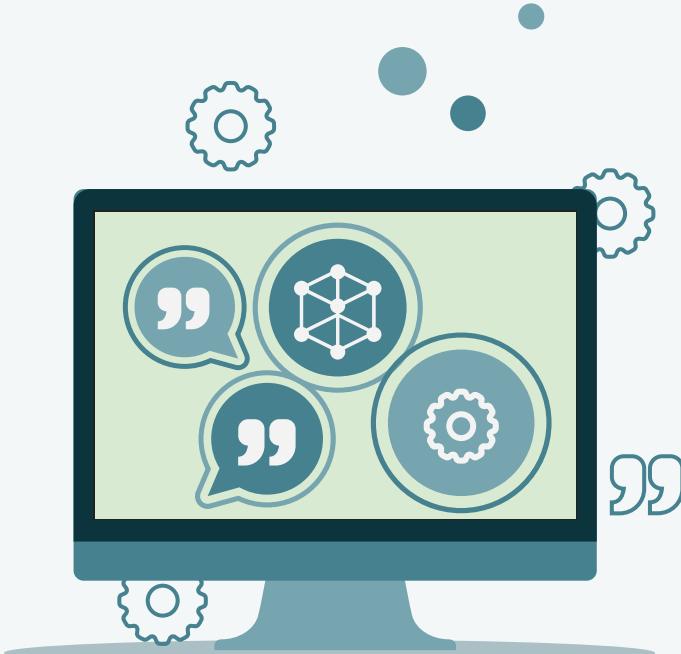
## Hyperparameter Tuning:

- Tested on CNN model and DenseNet.

# 05

# Results

Performance comparison between models



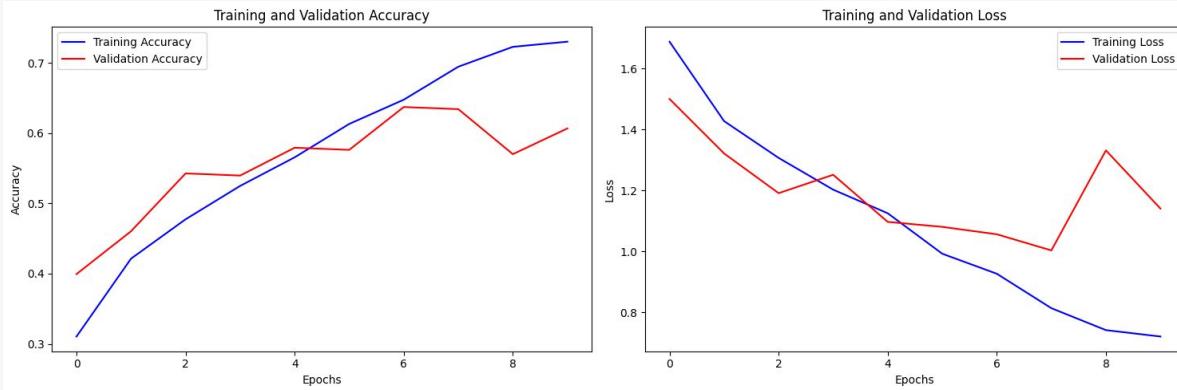
# CNN

CNN model was evaluated using different optimization strategies

We systematically tested six different optimization techniques:

- Adam optimizer (baseline)
- L1 regularization
- L2 regularization, Dropout
- EarlyStopping
- Dropout+EarlyStopping combined

# CNN



CNN Adam Optimizer Training and Validation Accuracy/Loss

## Baseline CNN:

- Train Acc: 73%
- Val Acc: 61%

## Best CNN (Dropout):

- Test Acc: 65%
- but...

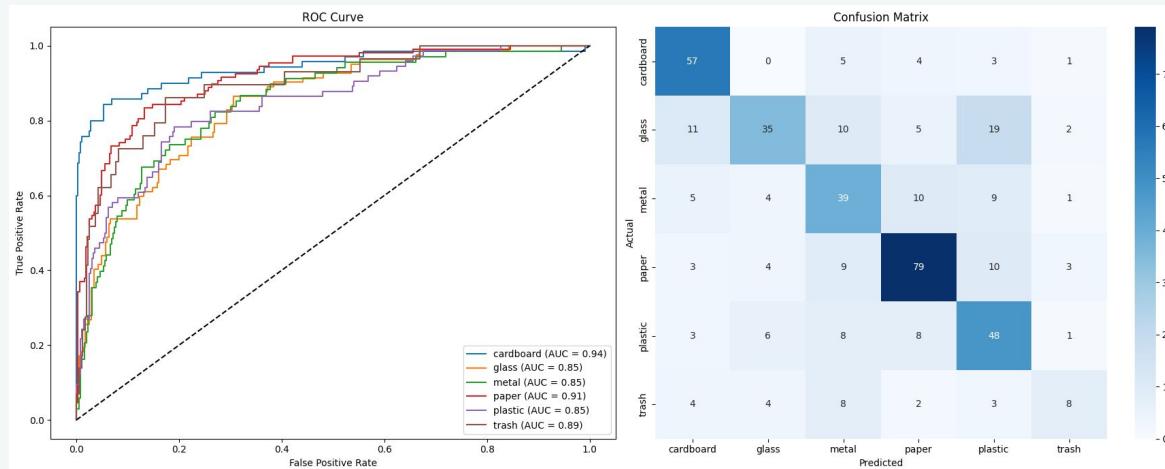
TABLE II  
CNN ACCURACY RESULTS FOR OPTIMIZATION TECHNIQUES

Technique	Train Acc.	Val Acc.	Test Acc.	$ Tr - Ts $
Adam	0.730	0.607	0.617	0.113
L2	0.834	0.588	0.622	0.212
L1	0.404	0.402	<b>0.422</b>	<b>0.018</b>
Dropout	0.734	0.631	0.650	0.084
EarlyStop	0.865	0.576	0.626	0.238
DO + ES	0.765	0.610	0.613	0.152
Hyper	0.771	0.605	0.622	0.149

# CNN

Confusion Matrix: Misclassifications mainly between glass & plastic.

ROC AUC: 0.85–0.94 across classes.



ROC curves and confusion matrix for the CNN model on test data

# CNN Hypertune

## Convolutional Layers

- Number of layers: 2 – 4
- Filters per layer: 32, 64, 96, 128
- Kernel size per layer:  $3 \times 3$  or  $5 \times 5$
- Activation per layer: ReLU or Tanh

## Dense Block

- Units: 64, 128, 192, 256
- Activation: ReLU or Tanh
- Dropout rate: 0.2, 0.3, 0.4, 0.5

## Optimizer & Learning Rate

- Optimizer: Adam, RMSprop, SGD
- Learning rate:  $1 \times 10^{-2}$ ,  $1 \times 10^{-3}$ ,  $1 \times 10^{-4}$

## Best Values Found:

## Convolutional Layers

- Number of layers: 3
- Filters per layer: 32, 32, 96
- Kernel size per layer: 5, 3, 5
- Activation per layer: Tanh, Tanh, ReLU

## Dense Block

- Units: 192
- Activation: Tanh
- Dropout rate: 0.2

## Optimizer & Learning Rate

- Optimizer: Adam
- Learning rate:  $1 \times 10^{-3}$

# CNN

TABLE II  
CNN ACCURACY RESULTS FOR OPTIMIZATION TECHNIQUES

Technique	Train Acc.	Val Acc.	Test Acc.	$ Tr - Ts $
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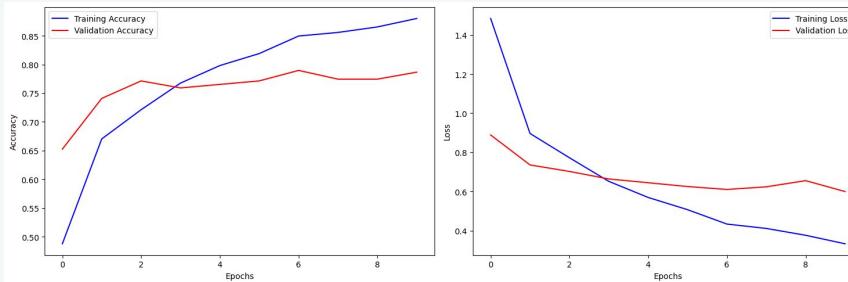
# DenseNet

Best: DenseNet + Adam:

- Test Acc: 82%

TABLE III  
ACCURACY RESULTS FOR DENSENET WITH DIFFERENT OPTIMIZATION  
TECHNIQUES

Technique	Train Acc.	Val Acc.	Test Acc.	$ Tr - Ts $
Adam	0.872	0.784	<b>0.824</b>	<b>0.048</b>
L2	0.998	0.784	0.807	0.191
L1	0.939	0.780	0.803	0.136
Dropout	0.881	0.787	0.817	0.064
EarlyStop	0.976	0.784	0.796	0.180
DO + ES	0.883	0.784	0.798	0.085



DenseNet with Adam Optimizer: Training and Validation Accuracy/Loss

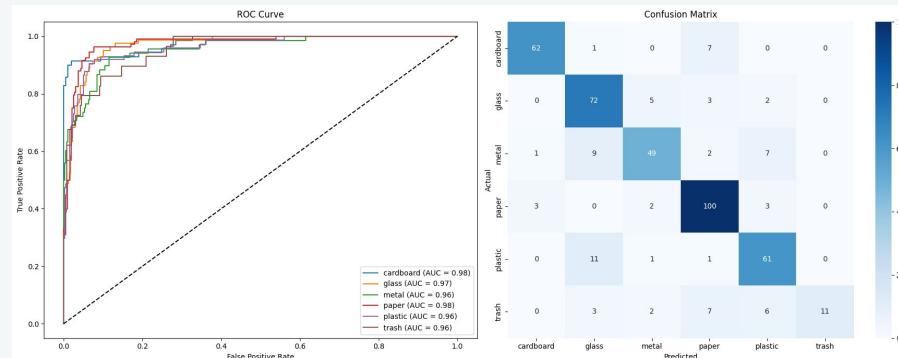
# DenseNet

Best: DenseNet + Adam:

- Test Acc: 82%
- Excellent AUC (0.96–0.98).

Confusion Matrix:

- Very strong on paper & glass; trash remains hardest to classify.



ROC curves and confusion matrix for DenseNet with Adam optimizer

# DenseNet

## Hypertuning

- We tried running but due to computational limits we weren't able to find a viable solution within reasonable time limit

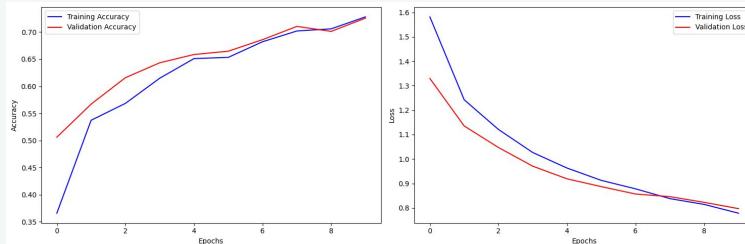
# VGG16

Best: VGG16 + Adam:

- Test Acc: 73%
- AUC: 0.91–0.97.

Advantages:

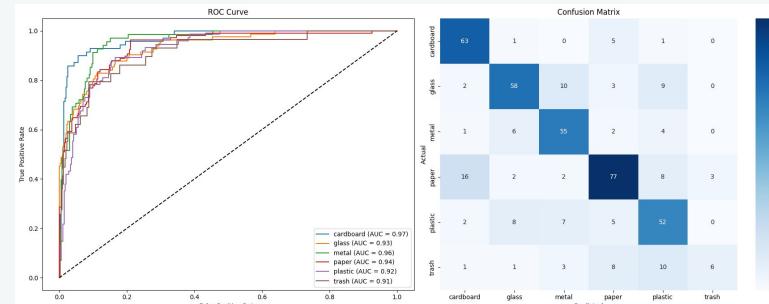
- Simpler architecture, competitive performance.



VGG16 with Adam Optimizer: Training and Validation Accuracy/Loss

TABLE V  
ACCURACY RESULTS FOR VGG16 WITH DIFFERENT OPTIMIZATION TECHNIQUES

Technique	Train Acc.	Val Acc.	Test Acc.	$ Tr - Ts $
Adam	0.728	0.726	<b>0.722</b>	<b>0.006</b>
L2	0.860	0.750	0.763	0.097
L1	0.727	0.668	0.694	0.033
Dropout	0.848	0.750	0.763	0.085
EarlyStop	0.909	0.744	0.766	0.143
DO + ES	0.840	0.753	0.775	0.065



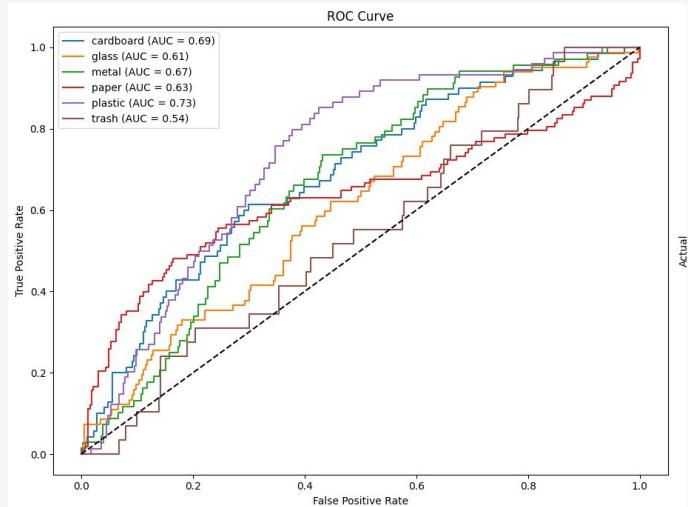
ROC curves and confusion matrix for VGG16 with Adam optimizer

# ResNet50

- Underperformed in all optimization techniques (29% acc best)
- Likely due to over-regularization.

TABLE IV  
ACCURACY RESULTS FOR RESNET50 WITH DIFFERENT OPTIMIZATION TECHNIQUES

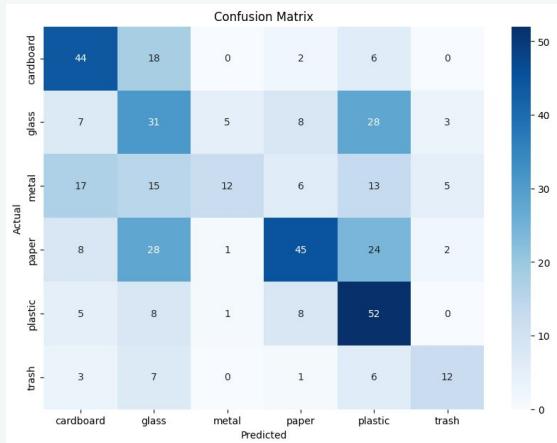
Technique	Train Acc.	Val Acc.	Test Acc.	$ Tr - Ts $
Adam	0.241	0.299	0.318	0.077
L2	0.329	0.253	0.295	0.034
L1	0.272	0.293	<b>0.290</b>	<b>0.018</b>
Dropout	0.287	0.308	0.329	0.042
EarlyStop	0.434	0.427	0.404	0.030
DO + ES	0.267	0.280	0.302	0.035



ROC curves and confusion matrix for ResNet50 with L1 regularization

# KNN

- Test Acc: 45%, struggles with high-dimensional data.



Confusion matrix for KNN classification

TABLE VI  
PERFORMANCE METRICS FOR KNN

Class	Precision	Recall	F1-Score	Support
Cardboard	0.52	0.63	0.57	70
Glass	0.29	0.38	0.33	82
Metal	0.63	0.18	0.28	68
Paper	0.64	0.42	0.51	108
Plastic	0.40	0.70	0.51	74
Trash	0.55	0.41	0.47	29
<b>Accuracy</b>			0.45	431
<b>Macro Avg</b>	0.51	0.45	0.44	431
<b>Weighted Avg</b>	0.51	0.45	0.45	431

# Data Augmentation



# Impact of Data Augmentation

Augmentation reduced overfitting!!

- DenseNet + Adam + Augmentation:

- Test Acc: 78.9% (best overall).

- VGG16 + L2 + Augmentation:

- Test Acc: 73.8%.

Conclusion: Improves generalization, especially on imbalanced data.

TABLE VIII  
COMPARISON OF DENSENET TEST ACCURACY AND OVERTFITTING WITH  
AND WITHOUT DATA AUGMENTATION

Technique	Test Accuracy		$ Tr - Ts $	
	Original	Augmented	Original	Augmented
Adam	<b>0.824</b>	<b>0.789</b>	<b>0.048</b>	<b>0.002</b>
L2	0.807	0.824	0.191	0.054
L1	0.803	0.782	0.136	0.047
Dropout	0.817	0.831	0.064	0.043
EarlyStop	0.796	0.775	0.180	0.055
DO + ES	0.798	0.794	0.085	0.009

TABLE X  
COMPARISON OF VGG16 TEST ACCURACY AND OVERTFITTING WITH AN  
WITHOUT DATA AUGMENTATION

Technique	Test Accuracy		$ Tr - Ts $	
	Original	Augmented	Original	Augmented
Adam	<b>0.722</b>	0.715	<b>0.006</b>	0.082
L2	0.763	<b>0.738</b>	0.097	<b>0.005</b>
L1	0.694	0.710	0.033	0.065
Dropout	0.763	0.742	0.085	0.006
EarlyStop	0.766	0.780	0.143	0.007
DO + ES	0.775	0.749	0.065	0.022

# Performance Comparison

Model	Absolute Test Accuracy	Test Accuracy (by minimum Overfit)
DenseNet	83% (Aug+Dropout)	79% (Aug+Adam)
VGG16	78% (Aug+ES)	74% (Aug+L2)
CNN	65% (Og+ES)	49% (Aug+Adam)
ResNet50	40% (Og+ES)	29% (Aug+DO+ES)
KNN	45%	---

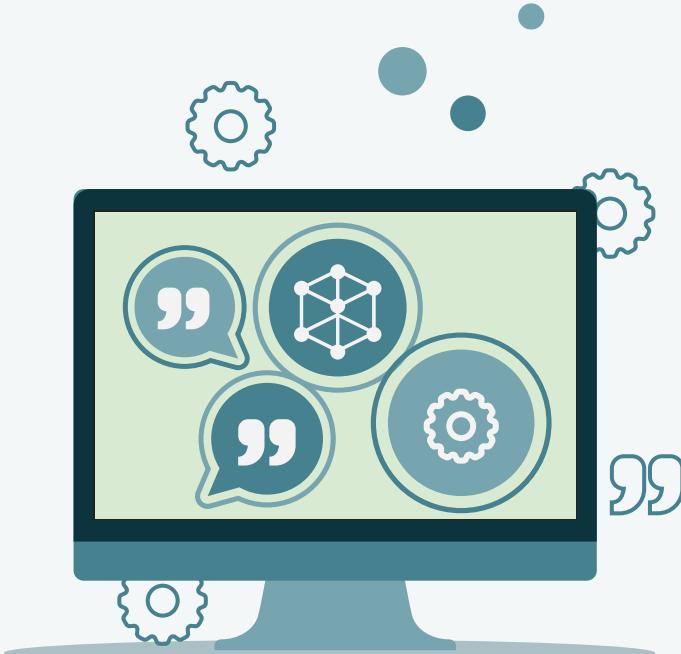
# Extra (YOLO)



# 06

# Discussion

Best Model and findings



# Discussion

**Best Precision Model:** DenseNet + Dropout + Aug.

**Less Overfitted Model:** DenseNet + Adam + Aug.

## Challenges:

- Trash category hard to classify (low data, high variability).
- Glass/plastic confusion due to visual similarity.

# Related Work

“Recyclenet: Intelligent waste sorting using deep neural networks” by Bircanoglu

Bircanoglu et al.:

- DenseNet121 (fine-tuned): 95% accuracy
- InceptionResNetV2: 87-90% accuracy
- DenseNet121 from scratch: 83-85%

Our Results:

- DenseNet: 83% (Aug+Dropout)
- DenseNet: 79% (Aug+Adam)

# Conclusion

- Deep learning outperforms traditional ML.
- DenseNet is highly effective due to feature reuse.
- Data augmentation is key for generalization.
- VGG16 offers a good trade-off between simplicity & performance.

# Thanks!

Do you have any questions?  
[alexandrecotorobai@ua.pt](mailto:alexandrecotorobai@ua.pt)  
[andreaoliveira@ua.pt](mailto:andreaoliveira@ua.pt)

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# Resources

- G. H. Sakr, E. Mokbel, A. Darwich, M. N. Khneisser, and A. Hadi, “Comparing deep learning and support vector machines for autonomous waste sorting,” in 2016 IEEE International Multidisciplinary Conference on Engineering Technology (IMCET), 2016, pp. 207–212.
- asdasdasdas, “Garbage Classification Dataset,” Kaggle, 2019. [Online]. Available: <https://www.kaggle.com/datasets/asdasdasdas/garbage-classification/data>. [Accessed: May-2025].

**9h 55m 23s**

Jupiter's rotation period

**333,000**

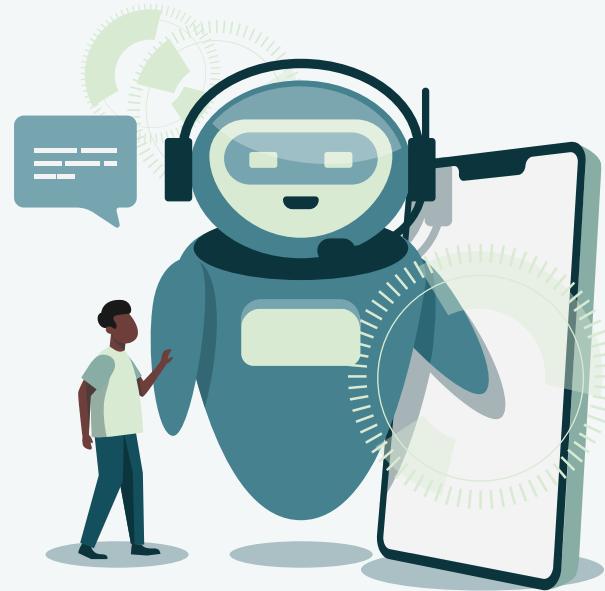
The Sun's mass compared to Earth's

**386,000 km**

Distance between the Earth and the Moon

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

—Someone Famous



# Introduction to AI



## Definition

Mercury is the closest planet to the Sun and the smallest in the Solar System—it's a bit larger than the Moon



## Advantages

Venus has a beautiful name and is the second planet from the Sun. It's hot and has a poisonous atmosphere

# AI and ethics



## Transparency

Mercury is the closest planet to the Sun and the smallest one of them all



## Privacy

Venus has a beautiful name and is the second planet from the Sun



## Legal

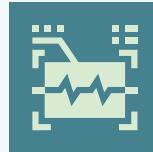
Despite being red, Mars is actually a cold place. It's full of iron oxide dust

# AI and society



## Impact

Despite being red,  
Mars is very cold



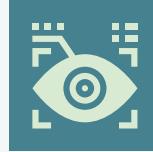
## Healthcare

Neptune is the  
smallest planet



## Education

Jupiter is the biggest  
planet of them all



## Government

Saturn is a gas giant  
and has several rings

# Examples



## Business

Mercury is the closest planet to the Sun and the smallest one of them all

## Entertainment

Venus has a beautiful name and is the second planet from the Sun

## Social

Despite being red, Mars is actually a cold place. It's full of iron oxide dust

# AI and business



## Applications

Despite being red,  
Mars is very cold



## Models

Venus is the second  
planet from the Sun



## Role of data

Neptune is the farthest  
planet from the Sun



## Ethics

Mercury is the closest  
planet to the Sun



## Customer

Saturn is a gas giant  
and has several rings



## Future

Jupiter is the biggest  
planet of them all

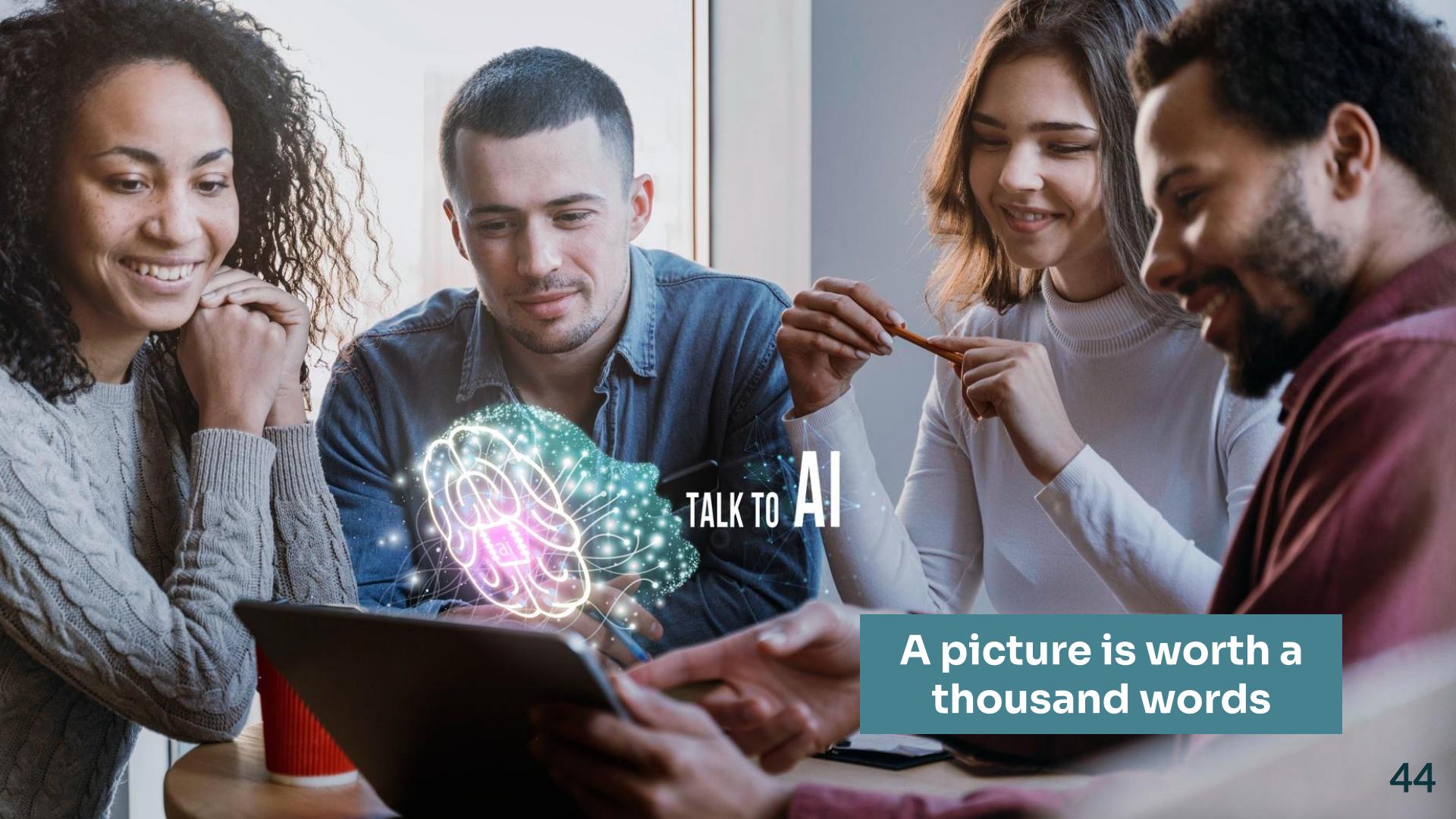


## A picture always reinforces the concept

You can give a brief description of the topic you want to talk about here. For example, if you want to talk about Mercury, you can say that it's the smallest planet in the entire Solar System

**4,498,300,000**

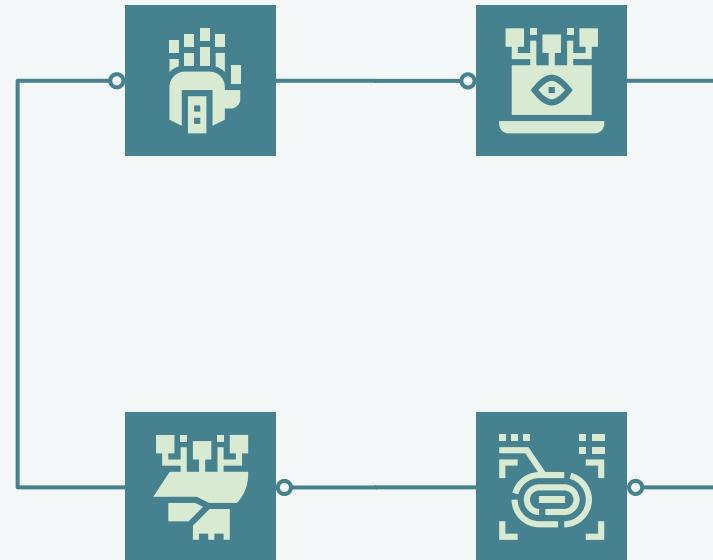
Big numbers catch your audience's attention



A picture is worth a  
thousand words

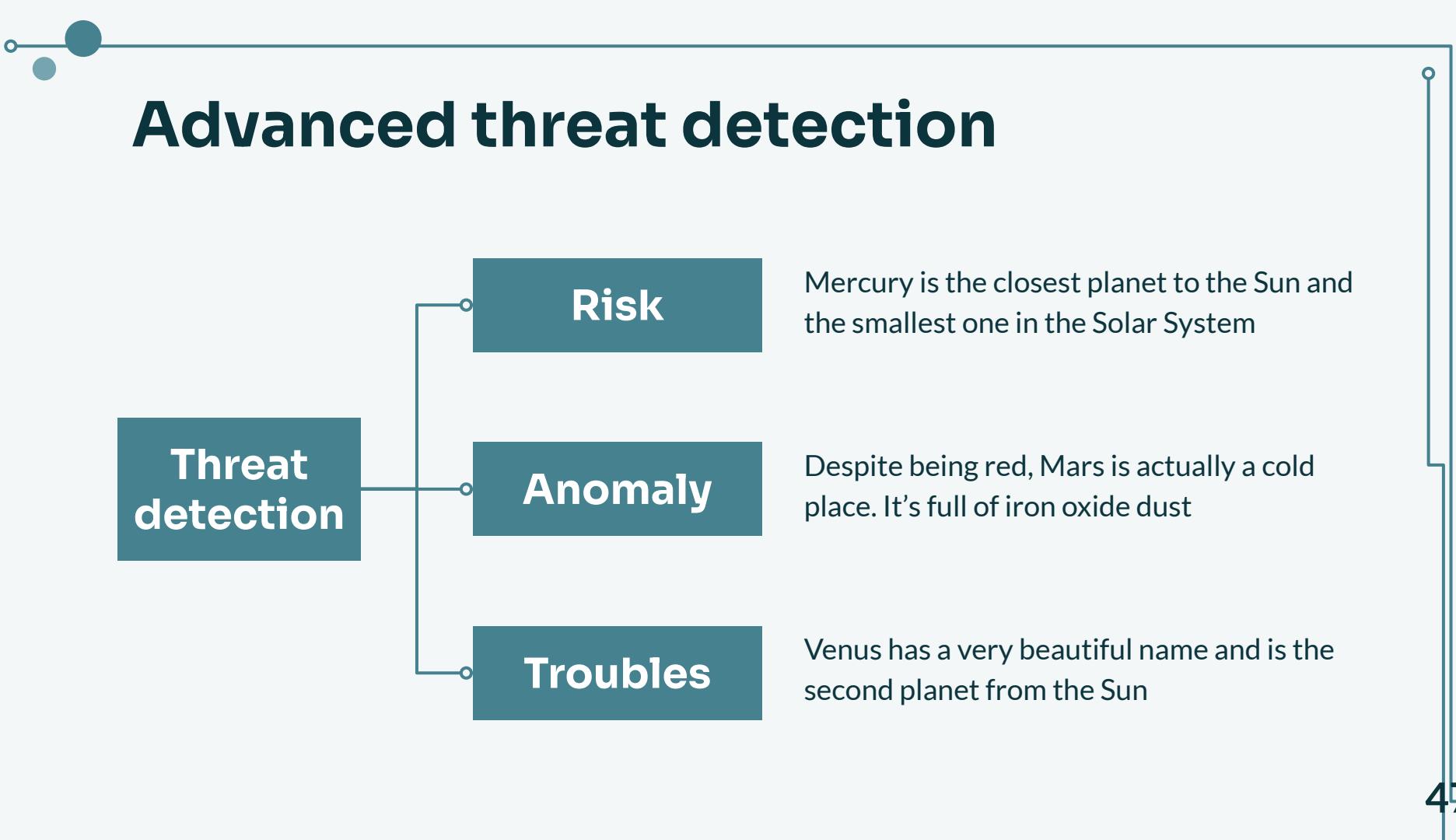
# Improve your cybersecurity for AI

1. Mercury is the closest planet
2. Mercury is very small
3. Mercury has a thin atmosphere
4. Mercury takes 59 Earth days

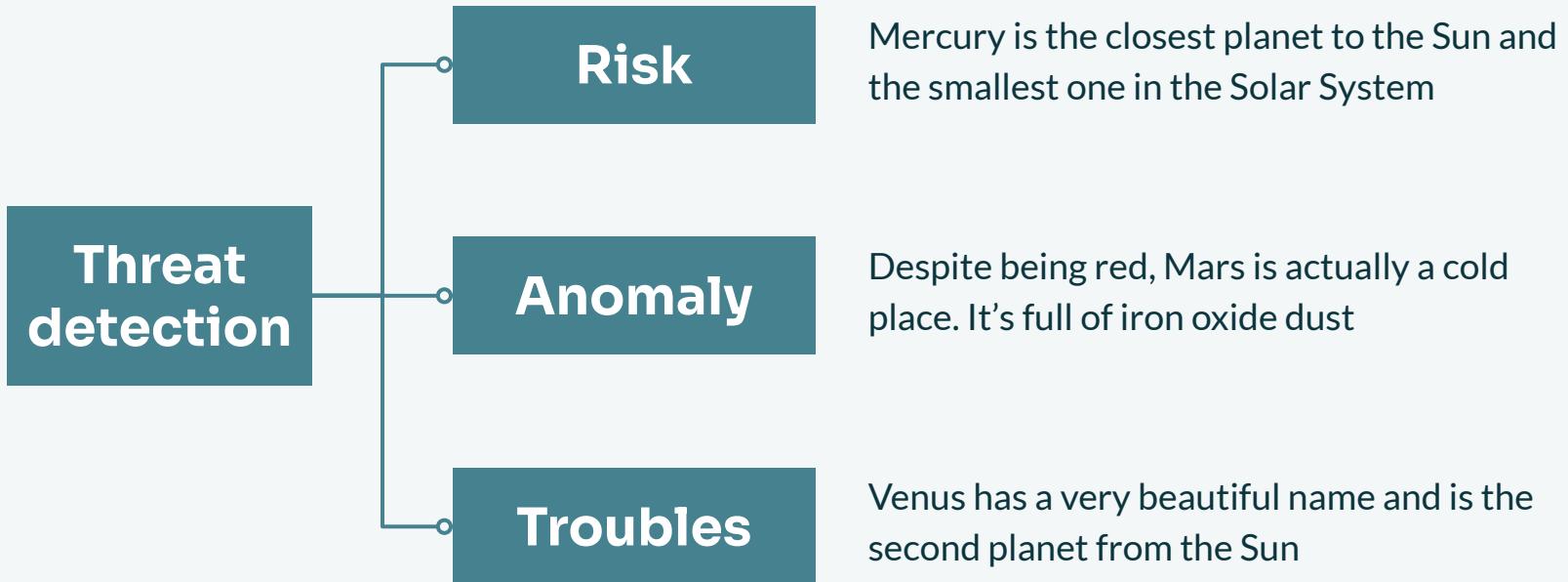


# KWL (brainstorming)

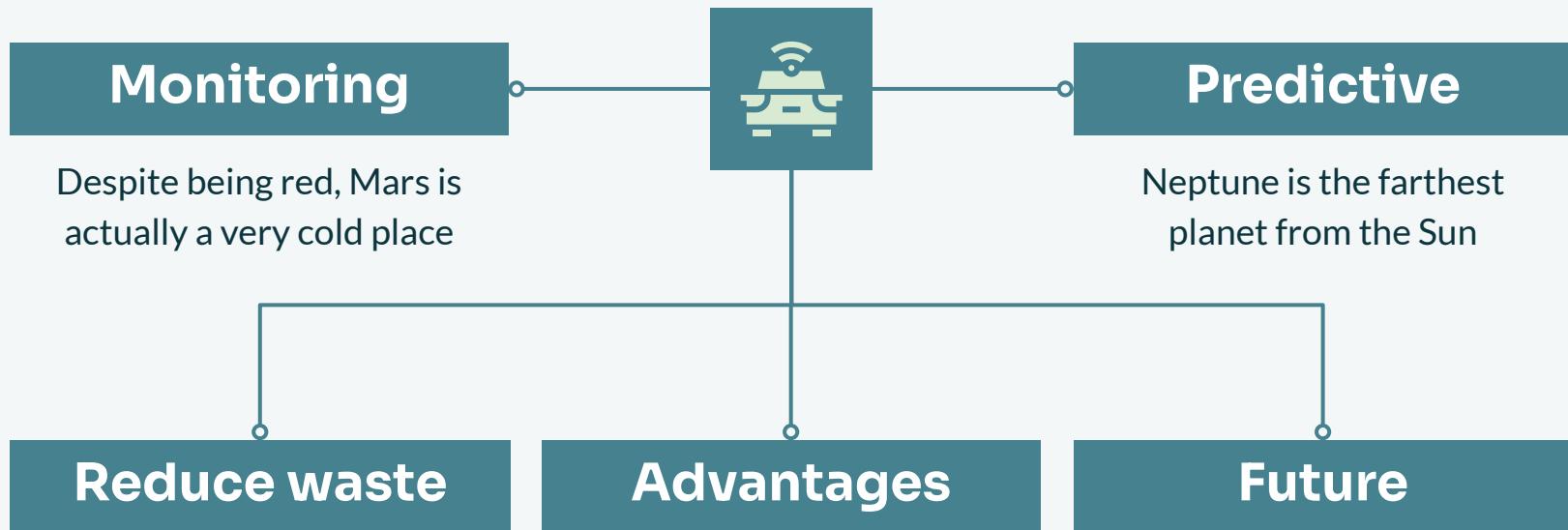
<b>What I know</b>	Mercury is the closest planet to the Sun Despite being red, Mars is a very cold planet
<b>What I want to know</b>	Venus is the second planet from the Sun Jupiter is the biggest planet of them all
<b>What I learned</b>	Saturn is composed of hydrogen and helium Neptune is the farthest planet from the Sun



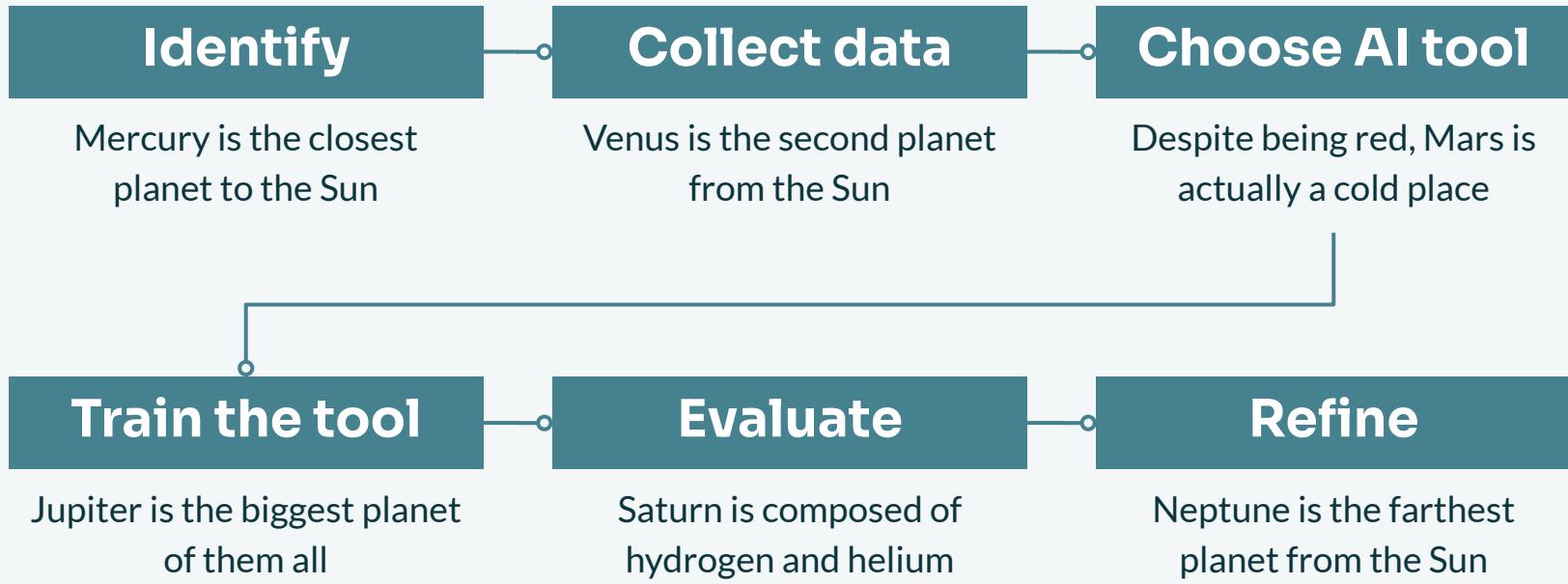
# Advanced threat detection



# AI and transportation



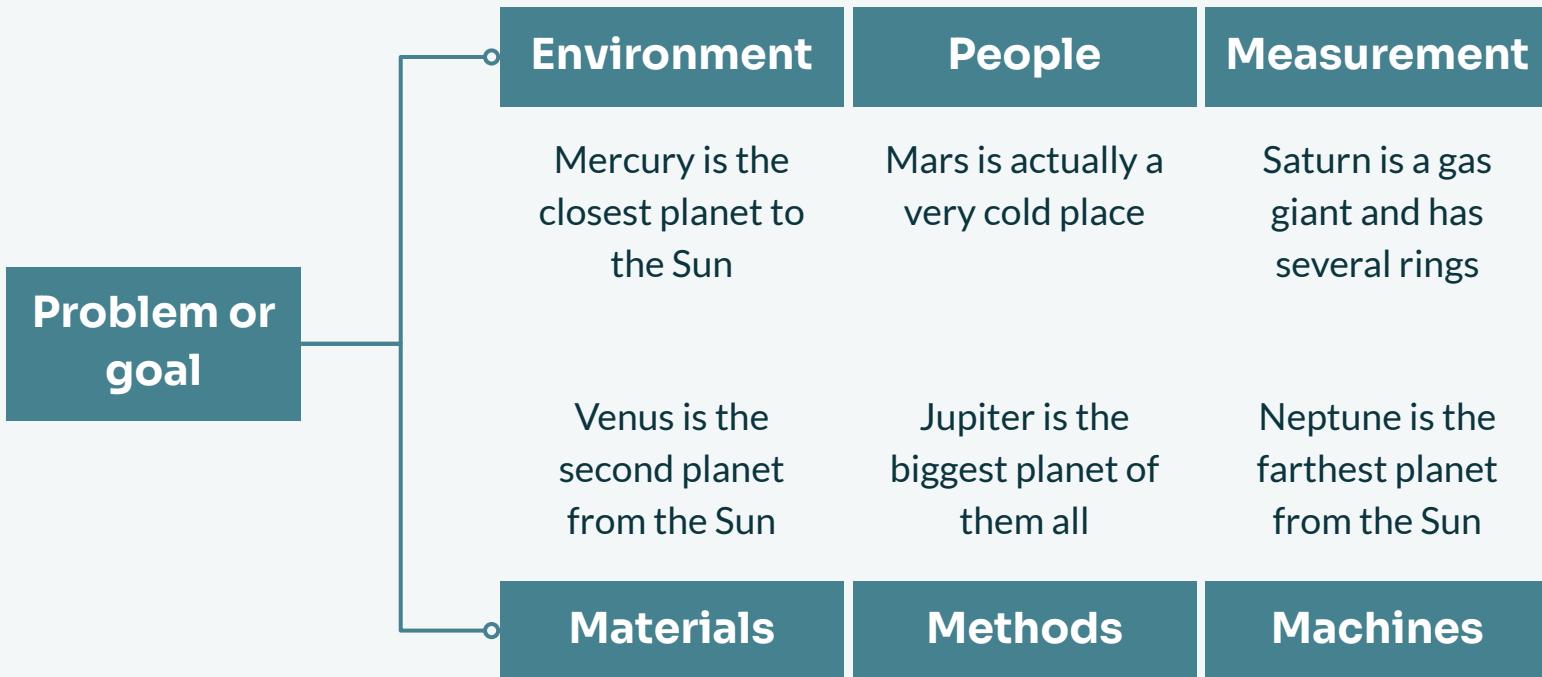
# Steps to apply AI in schools



# Classification of AI

Reactive machines	Limited memory	Theory of mind	Self-aware conscious
<ul style="list-style-type: none"><li>• Small</li><li>• Red</li><li>• Cold</li><li>• Rocky</li></ul>	<ul style="list-style-type: none"><li>• Small</li><li>• Hot</li><li>• Dry</li><li>• Volcanic</li></ul>	<ul style="list-style-type: none"><li>• Small</li><li>• Hot</li><li>• Rocky</li><li>• Cratered</li></ul>	<ul style="list-style-type: none"><li>• Large</li><li>• Cold</li><li>• Gassy</li><li>• Striped</li></ul>
Despite being red, Mars is actually a cold place	Venus is extremely hot, even more than Mercury	Mercury is the smallest planet of them all	Jupiter is the biggest planet of them all

# Cause and effect

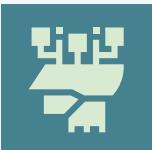


# Theory of mind



## Why is important the theory of mind?

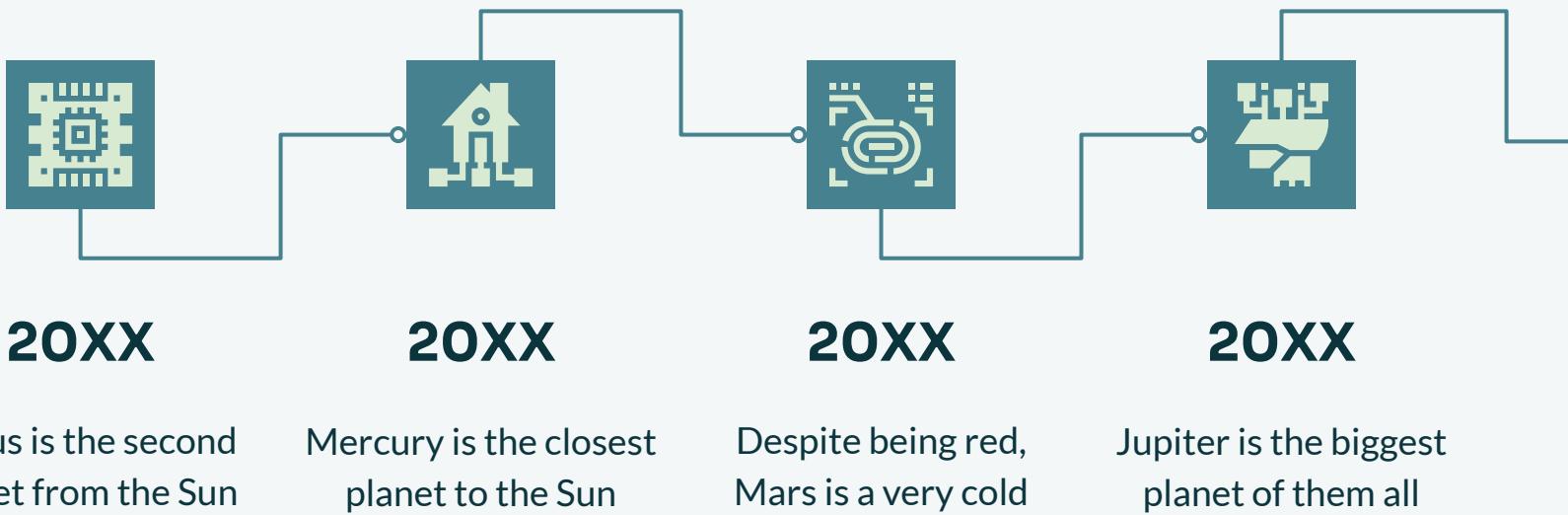
Is Mercury the closest planet to the Sun and the smallest one in the Solar System? Note that it's a bit larger than the Moon



## Understand the mind of humans

Venus has a beautiful name and is the second planet from the Sun. It's hot and has a poisonous atmosphere

# Evolution of AI



# Parts and whole

The whole object

Parts of the object

What happens if the parts are missing?

Mercury is the closest planet to the Sun and the smallest one in the entire Solar System. This planet's name has nothing to do with the liquid metal

Mercury

Mars

Saturn

Venus

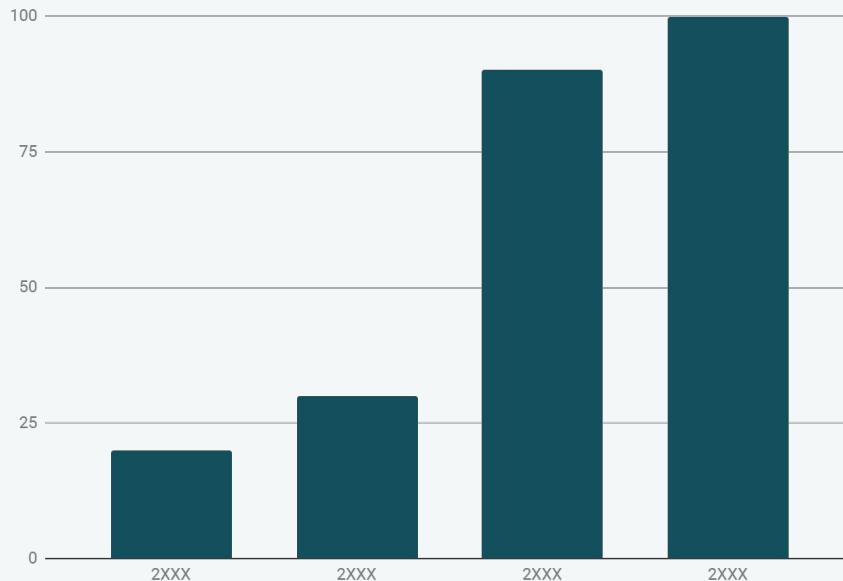
Jupiter

Venus has a beautiful name and is the second planet from the Sun

What's the function of the parts?

Saturn is a gas giant and has several rings. It's composed of hydrogen and helium

# Evolution of domestic AI



## Evolution

Mercury is the closest planet to the Sun and the smallest one in the entire Solar System. This planet's name has nothing to do with the liquid metal

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

# Where is AI being studied



## ● Universities

Venus is the second planet from the Sun

## ● Institutions

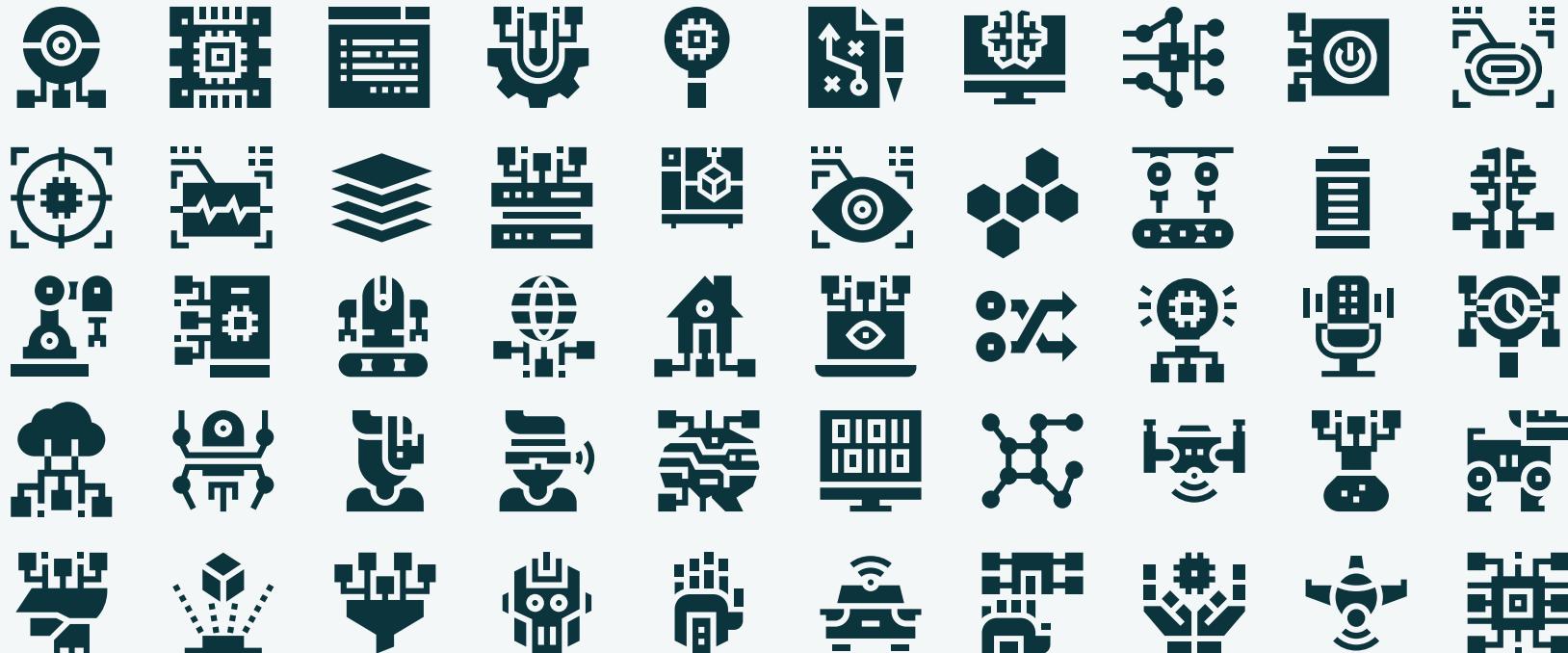
Mercury is the first planet from the Sun

# Mockups

You can replace the images on the screen with your own work. Just right-click on them and select “Replace image”



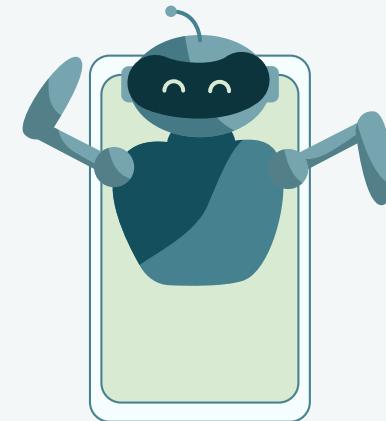
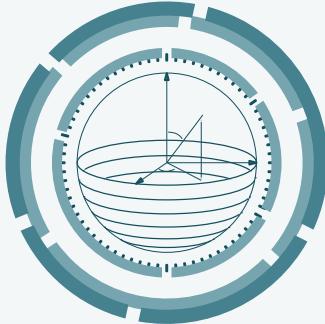
# Icon pack



# Alternative resources

Here's an assortment of alternative resources whose style fits the one of this template:

- [Gradient quantum illustration](#)
- [Landing page artificial intelligence template](#)
- [Template artificial intelligence landing page](#)



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# Fonts & colors used

This presentation has been made using the following fonts:

**Sora**

(<https://fonts.google.com/specimen/Sora>)

**Lato**

(<https://fonts.google.com/specimen/Lato>)

#0c343d

#f3f7f8

#134f5c

#45818e

#76a5af

#d9ead3

#88ada5

#f3f3f3

#ffffff

# Storyset

Create your Story with our illustrated concepts. Choose the style you like the most, edit its colors, pick the background and layers you want to show and bring them to life with the animator panel! It will boost your presentation. Check out [how it works](#).



Pana



Amico



Bro



Rafiki



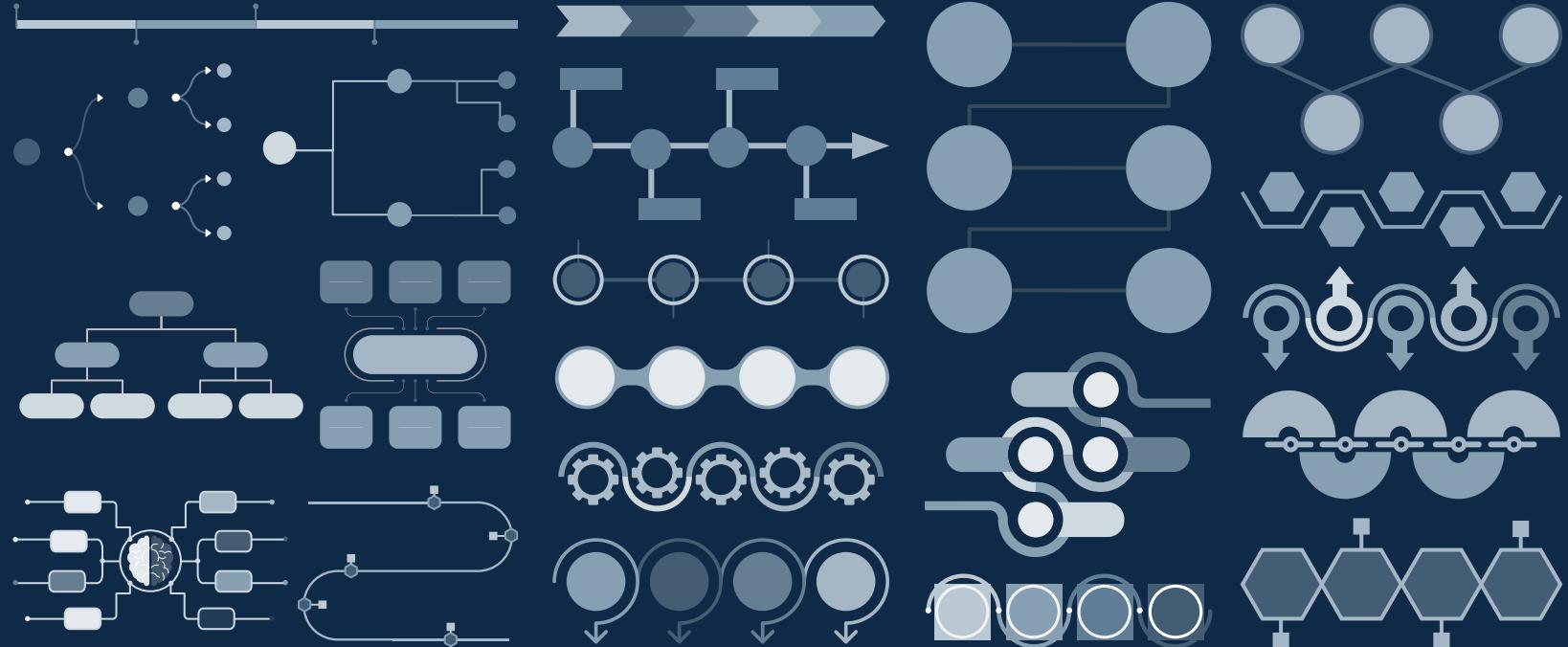
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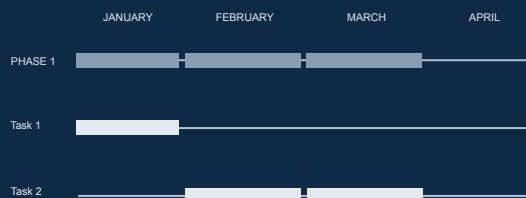
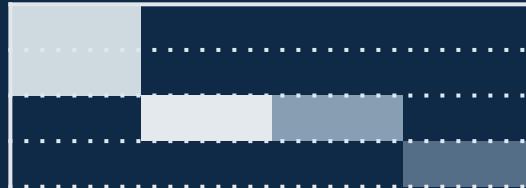
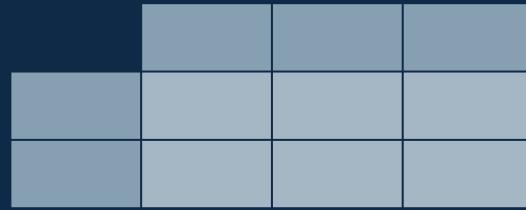
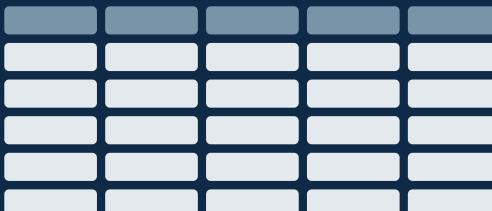
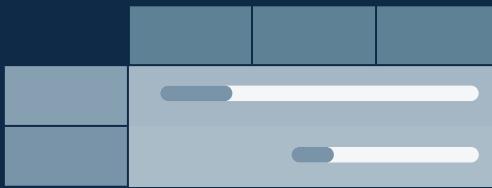
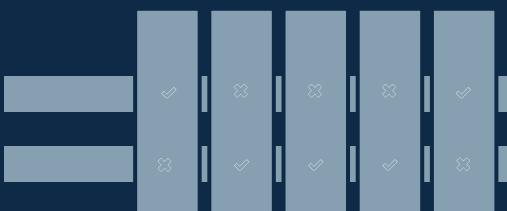
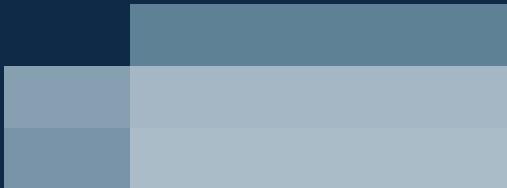
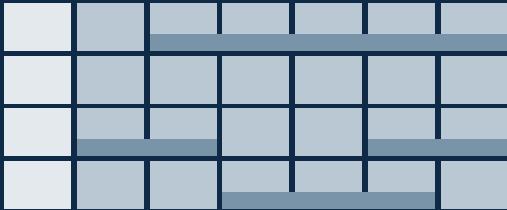
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You can easily **resize** these resources without losing quality. To **change the color**, just ungroup the resource and click on the object you want to change. Then, click on the paint bucket and select the color you want. Group the resource again when you're done. You can also look for more **infographics** on Slidesgo.

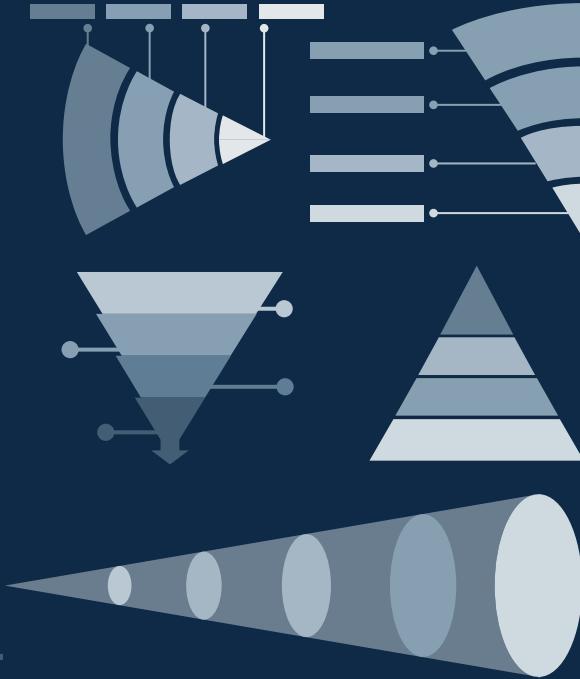
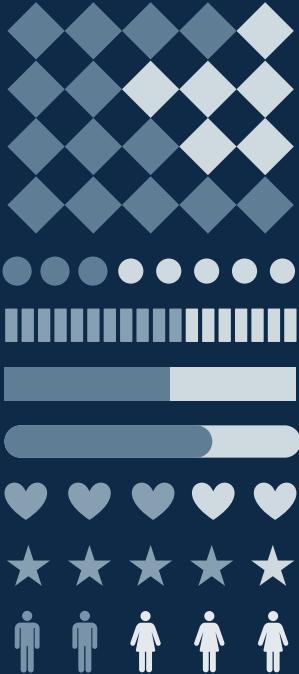
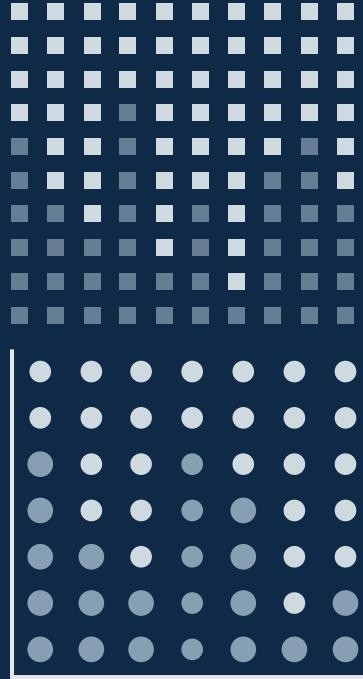












...and our sets of editable icons

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## Educational Icons



## Medical Icons



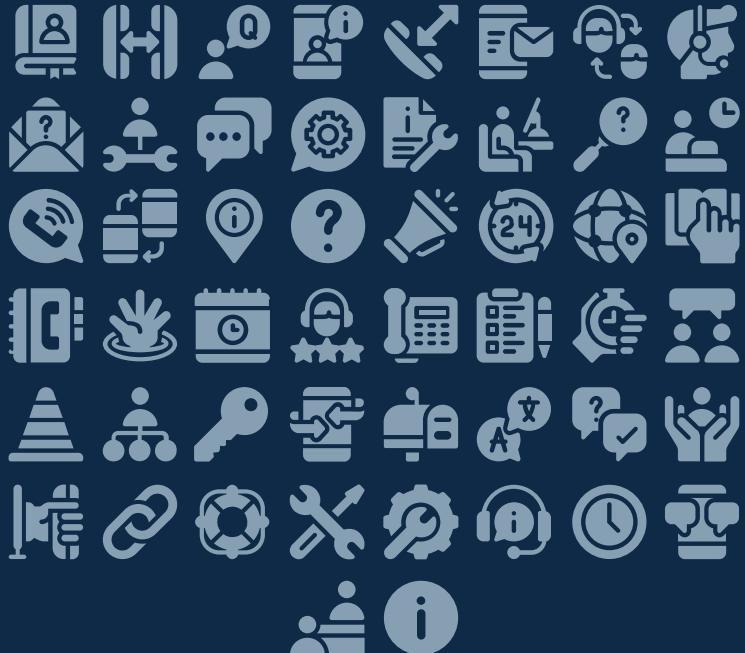
# Business Icons



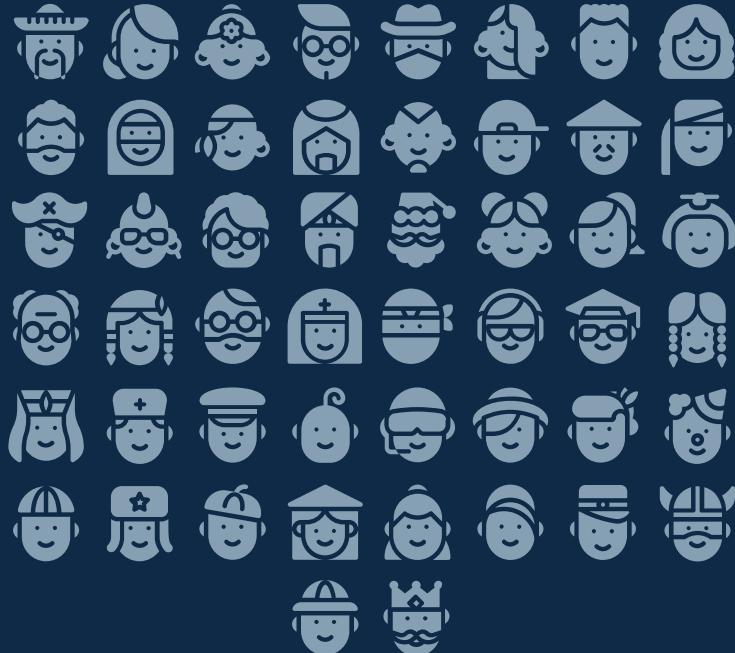
# Teamwork Icons



## Help & Support Icons



## Avatar Icons



## Creative Process Icons



## Performing Arts Icons



# Nature Icons



# SEO & Marketing Icons



