universidade de aveiro

deti universidade de aveiro
departamento de eletrónica, telecomunicações e informática

Garbage Classification

Authors:
Alexandre Cotorobai & André Oliveira

Affiliation: MEI, DETI, University of Aveiro

Class: CAA
Professor: Pétia Georgieva

Table of contents

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

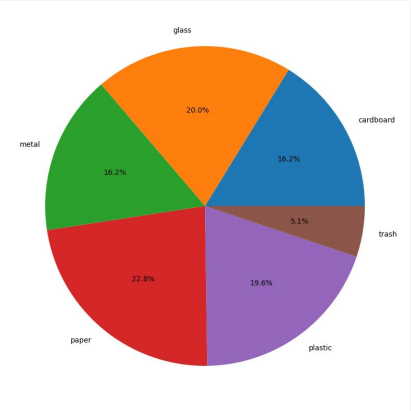
Data and preprocessing

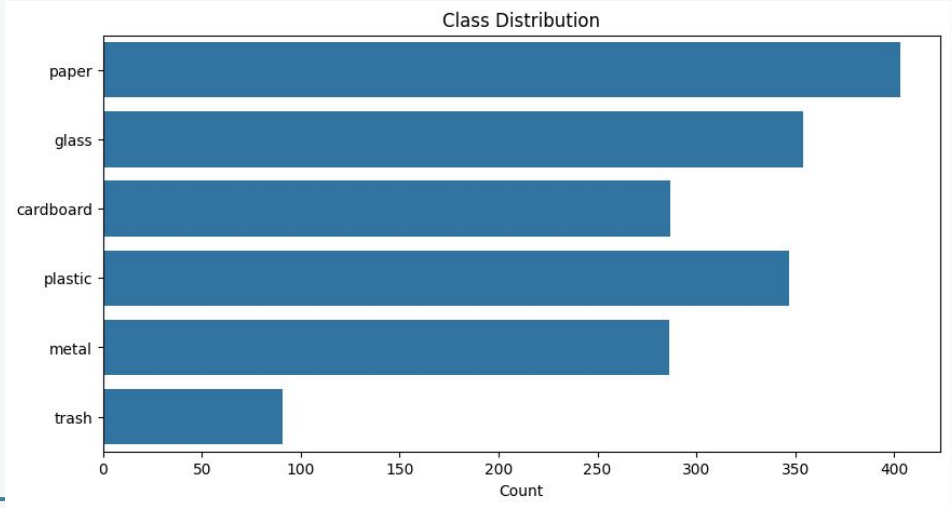
Dataset

Dataset:
2,467 images, 6 classes:

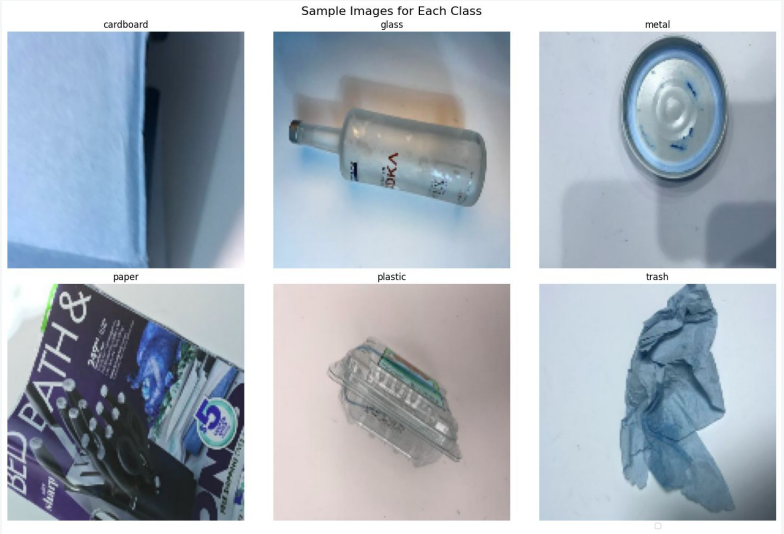
- Paper (584)
- Glass (491)
- Plastic (472)
- Metal (400)
- Cardboard (393)
- Trash (127)

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

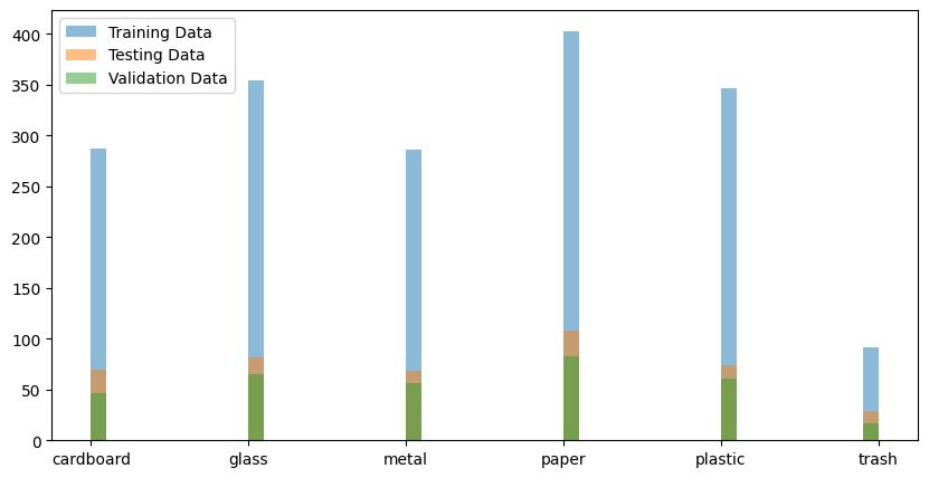
Model Training

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

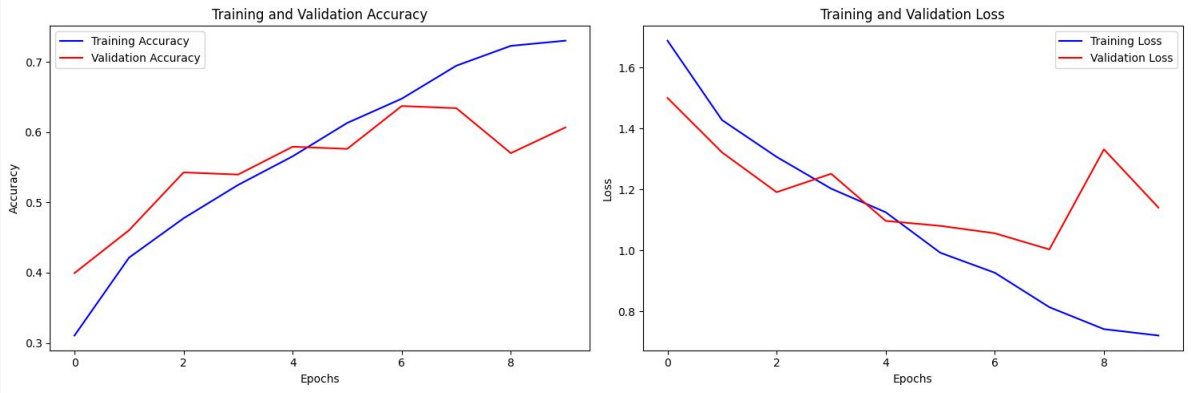
Performance comparison between models

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…

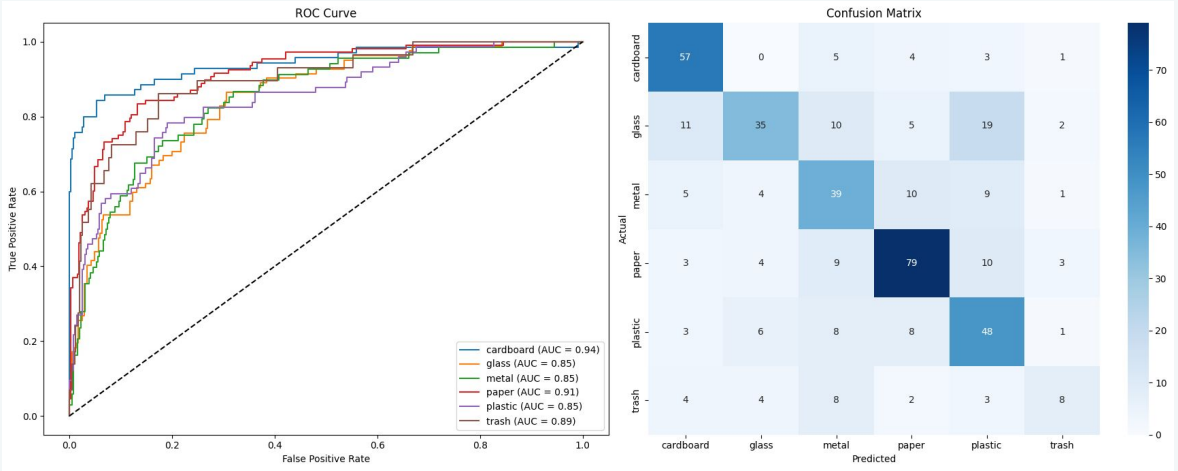
TABLE II
CNN ACCURACY RESULTS FOR OPTIMIZATION TECHNIQUES

Technique	Train Acc.	Val Acc.	Test Acc.	$\lvert Tr - Ts \rvert$
Adam	0.730	0.607	0.617	0.113
L2	0.834	0.588	0.622	0.212
L1	0.404	0.402	**0.422**	**0.018**
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 × 3 or 5 × 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: 1×10^{-2}, 1×10^{-3}, 1×10^{-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: 1×10^{-3}

CNN

TABLE II
CNN ACCURACY RESULTS FOR OPTIMIZATION TECHNIQUES

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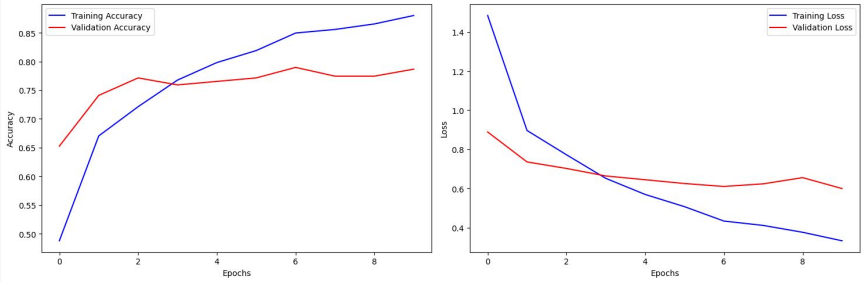
DenseNet

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	**0.824**	**0.048**
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

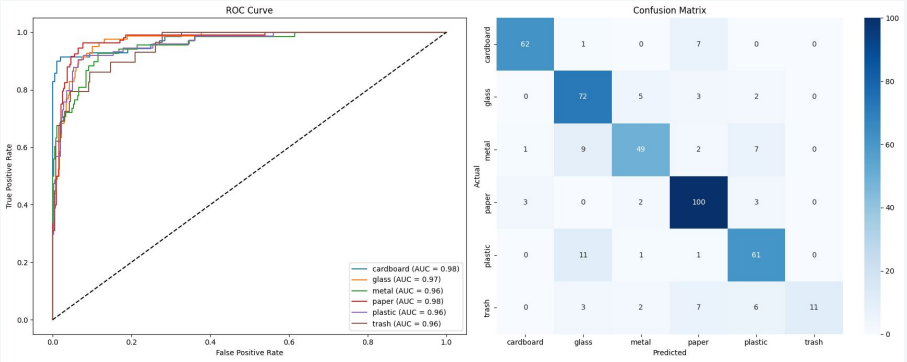
DenseNet

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:

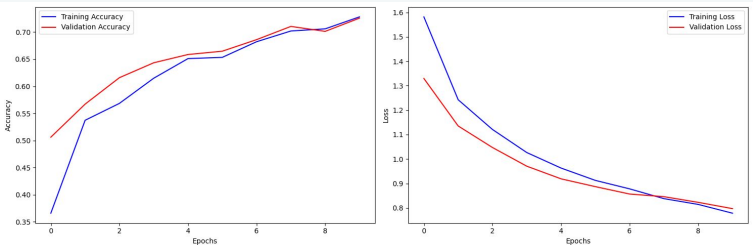
- Test Acc: 73%
- AUC: 0.91–0.97.

Advantages:

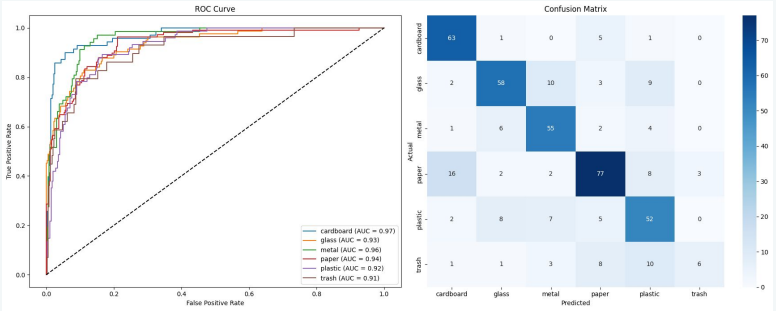
- Simpler architecture, competitive performance.

TABLE V
ACCURACY RESULTS FOR VGG16 WITH DIFFERENT OPTIMIZATION TECHNIQUES

Technique	Train Acc.	Val Acc.	Test Acc.	$\lvert Tr - Ts \rvert$
Adam	0.728	0.726	**0.722**	**0.006**
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



VGG16 with Adam Optimizer: Training and Validation Accuracy/Loss



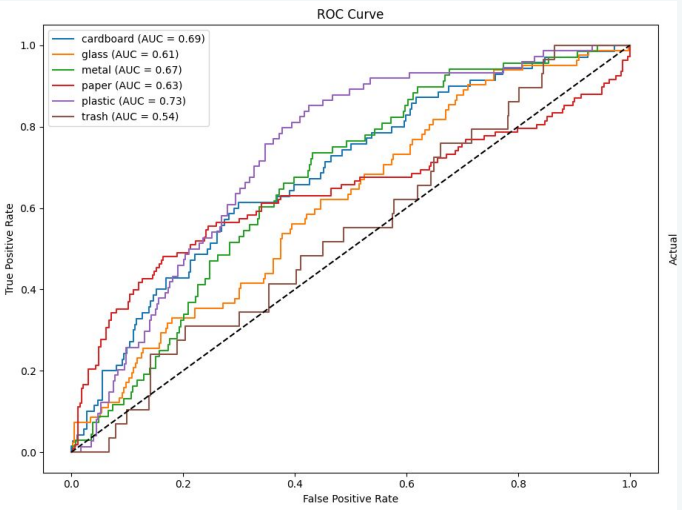
ROC curves and confusion matrix for VGG16 with Adam optimizer

ResNet50

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

TABLE IV
ACCURACY RESULTS FOR RESNET50 WITH DIFFERENT OPTIMIZATION TECHNIQUES

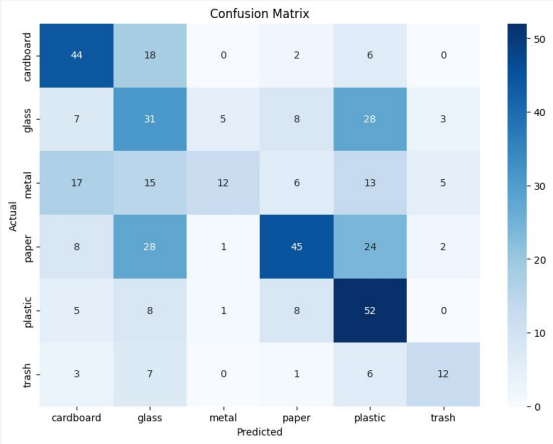
Technique	Train Acc.	Val Acc.	Test Acc.	$\|Tr - Ts\|$
Adam	0.241	0.299	0.318	0.077
L2	0.329	0.253	0.295	0.034
L1	0.272	0.293	**0.290**	**0.018**
Dropout	0.287	0.308	0.329	0.042
EarlyStop	0.434	0.427	0.404	0.030
DO + ES	0.267	0.280	0.302	0.035



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
Accuracy			0.45	431
Macro Avg	0.51	0.45	0.44	431
Weighted Avg	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 OVERFITTING WITH AND WITHOUT DATA AUGMENTATION

Technique	Test Accuracy		$\lvert Tr - Ts \rvert$	
	Original	Augmented	Original	Augmented
Adam	**0.824**	**0.789**	**0.048**	**0.002**
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

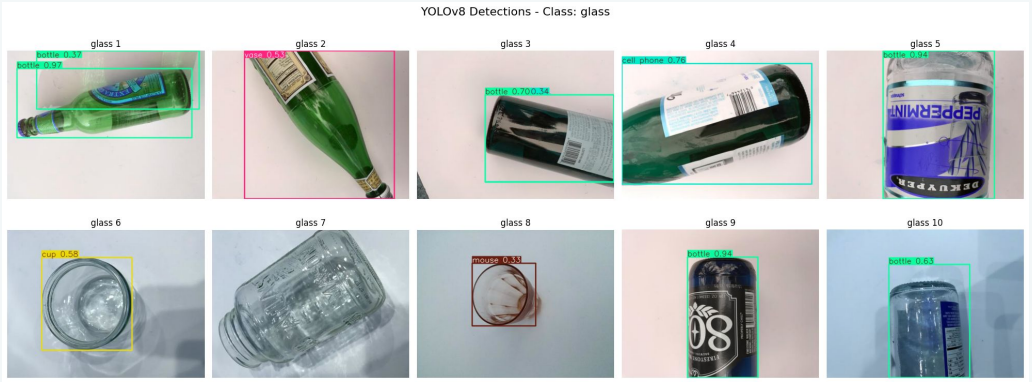
TABLE X
COMPARISON OF VGG16 TEST ACCURACY AND OVERFITTING WITH AN WITHOUT DATA AUGMENTATION

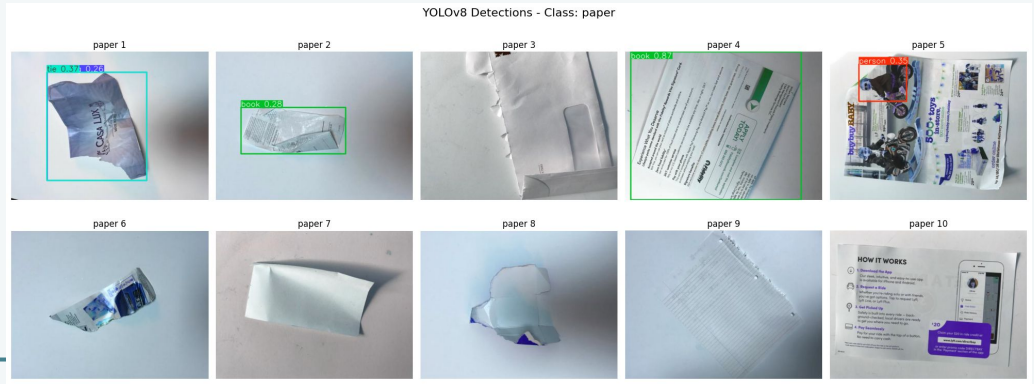
Technique	Test Accuracy		$\lvert Tr - Ts \rvert$	
	Original	Augmented	Original	Augmented
Adam	**0.722**	0.715	**0.006**	0.082
L2	0.763	**0.738**	0.097	**0.005**
L1	0.694	0.710	0.033	0.065
Dropout	0.763	0.742	0.085	0.006
EarlyStop	0.766	0.780	0.143	0.007
DO + ES	0.775	0.749	0.065	0.022

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)


YOLOv8 Detections - Class: glass
glass 1
glass 2
glass 3
glass 4
glass 5
glass 6
glass 7
glass 8
glass 9
glass 10


YOLOv8 Detections - Class: paper
paper 1
paper 2
paper 3
paper 4
paper 5
paper 6
paper 7
paper 8
paper 9
paper 10

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
andreaoliveira@ua.pt

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.

- asdasdasasdas, “Garbage Classification Dataset,” Kaggle, 2019. [Online]. Available: https://www.kaggle.com/datasets/asdasdasasdas/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

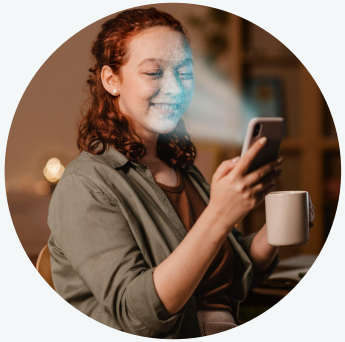
Government

Saturn is a gas giant and has several rings

Examples

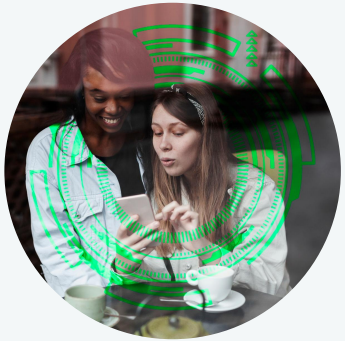
Business

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

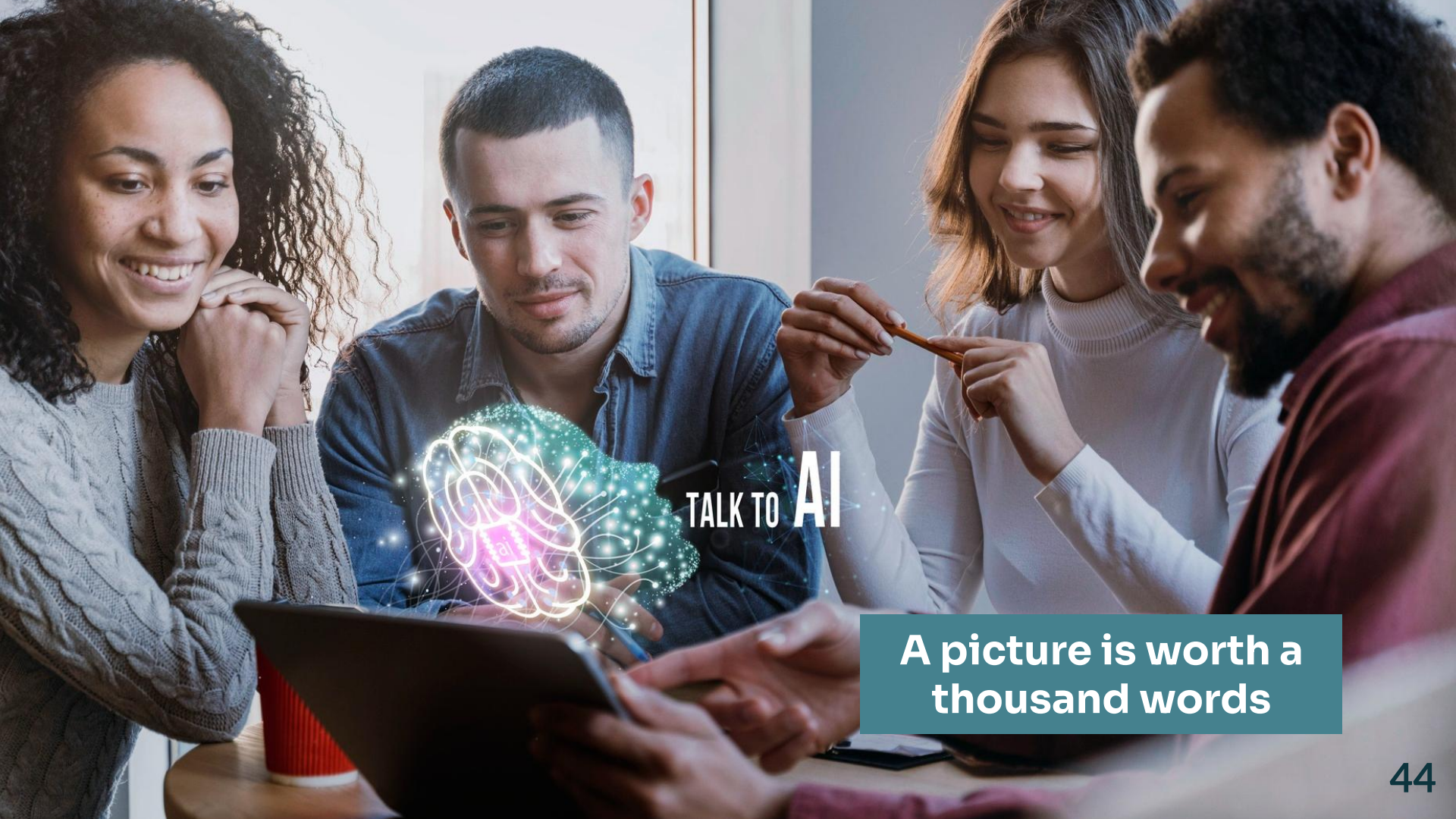
Jupiter is the biggest planet of them all

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

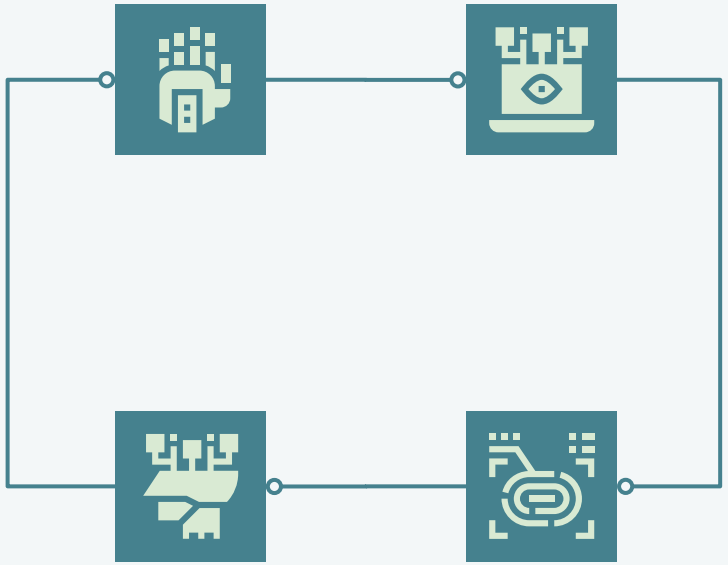
Big numbers catch your audience’s attention



A picture is worth a thousand words

Improve your cybersecurity for AI

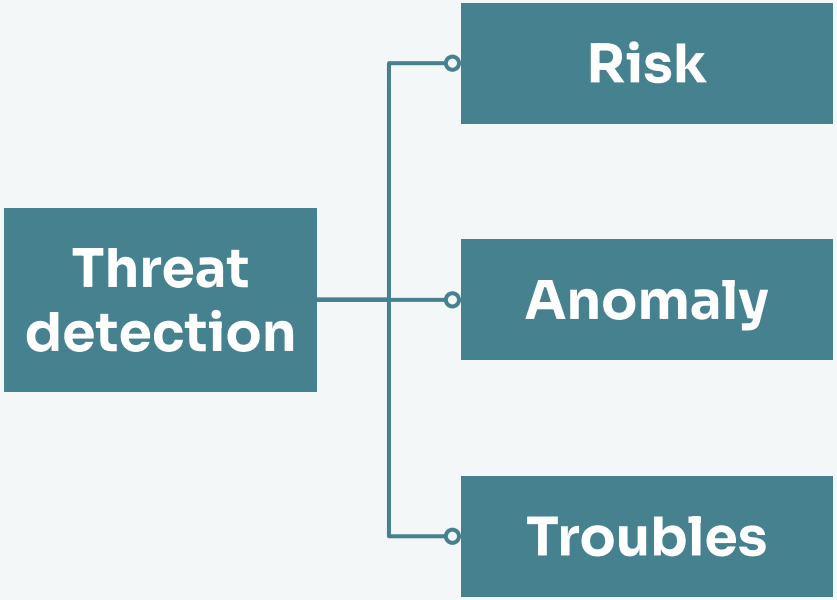
1. Mercury is the closest planet
2. Mercury is very small
3. Mercury has a thin atmosphere
4. Mercury takes 59 Earth days



KWL (brainstorming)

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

Advanced threat detection



Mercury is the closest planet to the Sun and the smallest one in the Solar System

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

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

AI and transportation

Monitoring

Despite being red, Mars is actually a very cold place

Predictive

Neptune is the farthest planet from the Sun

Reduce waste

Mercury is the closest planet to the Sun

Advantages

Saturn is a gas giant and has several rings

Future

Jupiter is the biggest planet of them all

Steps to apply AI in schools

Identify

Mercury is the closest planet to the Sun

Collect data

Venus is the second planet from the Sun

Choose AI tool

Despite being red, Mars is actually a cold place

Train the tool

Jupiter is the biggest planet of them all

Evaluate

Saturn is composed of hydrogen and helium

Refine

Neptune is the farthest planet from the Sun

Classification of AI

Reactive machines	Limited memory	Theory of mind	Self-aware conscious
• Small • Red • Cold • Rocky	• Small • Hot • Dry • Volcanic	• Small • Hot • Rocky • Cratered	• Large • Cold • Gassy • Striped
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

Problem or goal

Environment	People	Measurement
Mercury is the closest planet to the Sun	Mars is actually a very cold place	Saturn is a gas giant and has several rings
Venus is the second planet from the Sun	Jupiter is the biggest planet of them all	Neptune is the farthest planet from the Sun

Materials	Methods	Machines

Theory of mind

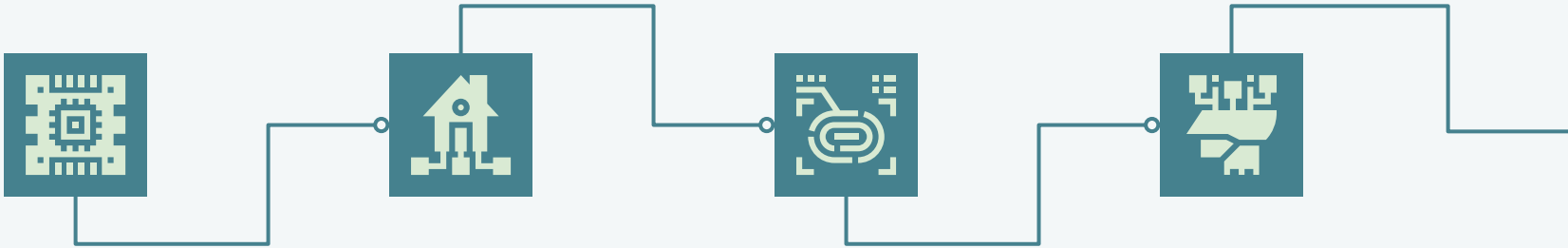
Why is important the theory of mind?

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



20XX

Venus is the second planet from the Sun

20XX

Mercury is the closest planet to the Sun

20XX

Despite being red, Mars is a very cold

20XX

Jupiter is the biggest planet of them all

Parts and whole

The whole object

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

Parts of the object

Mercury

Mars

Saturn

Venus

Jupiter

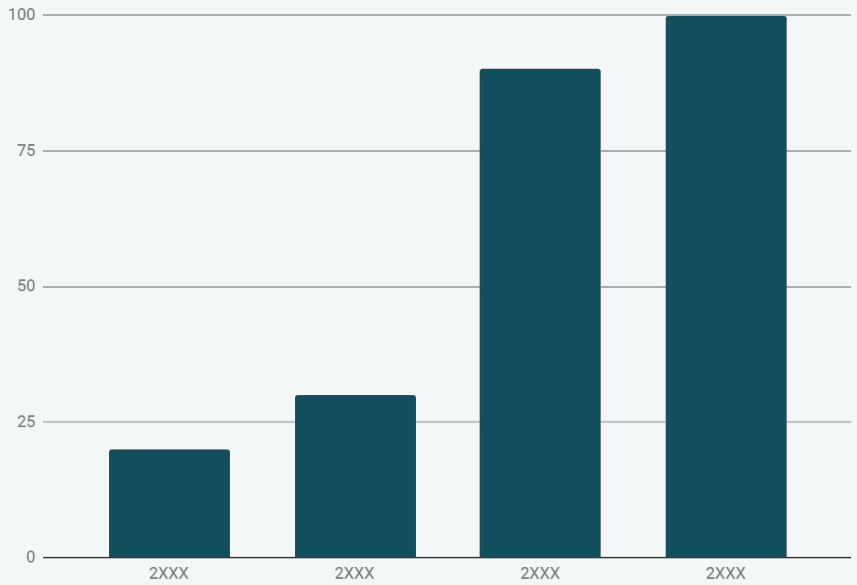
What happens if the parts are missing?

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

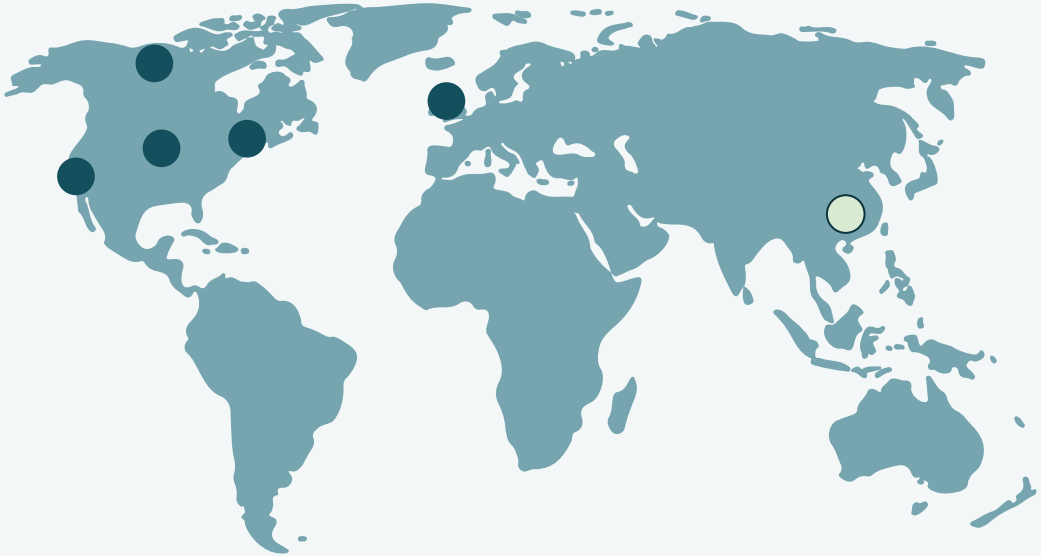


Evolution

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

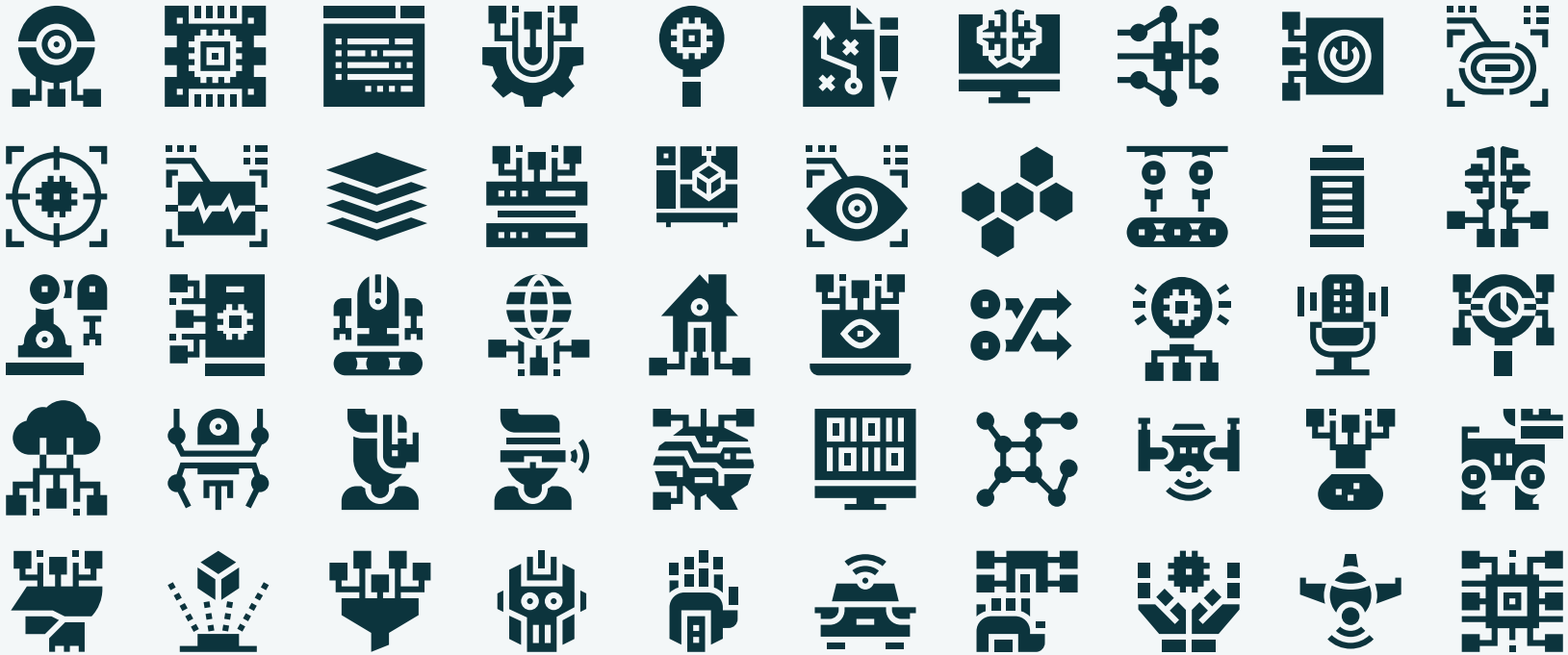
Institutions

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”

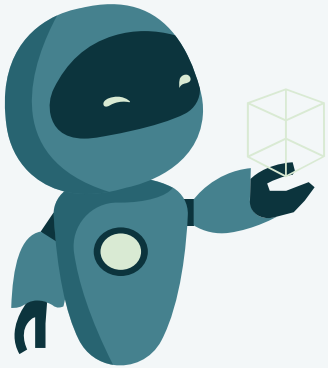
Icon pack

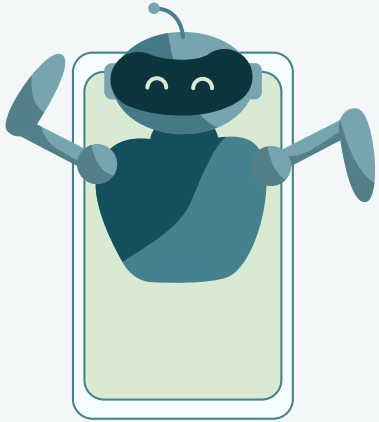


Alternative resources

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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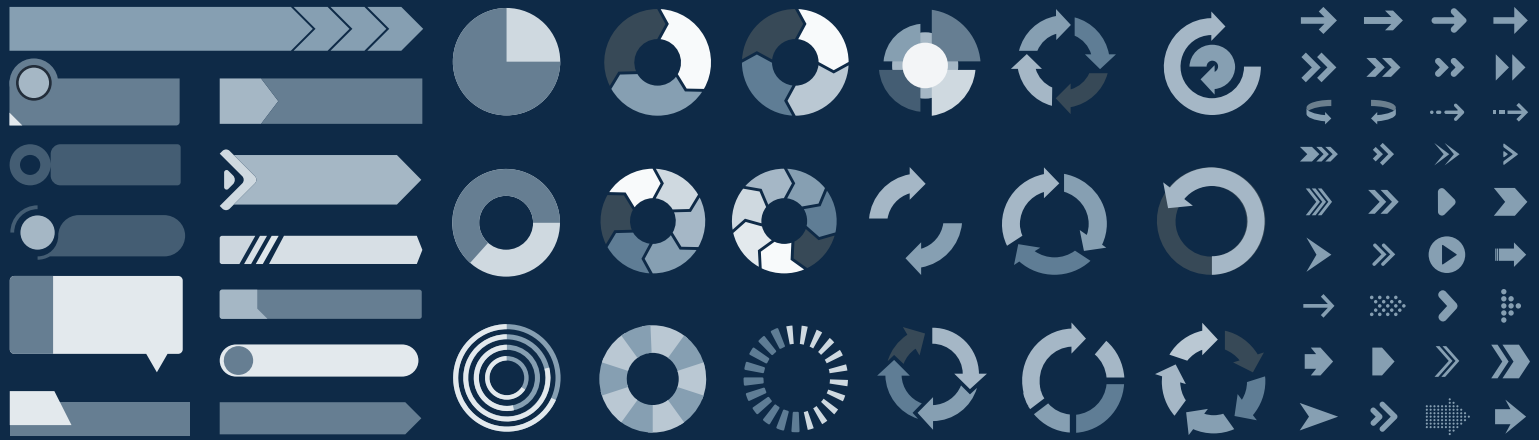

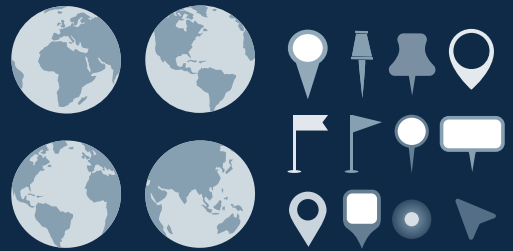

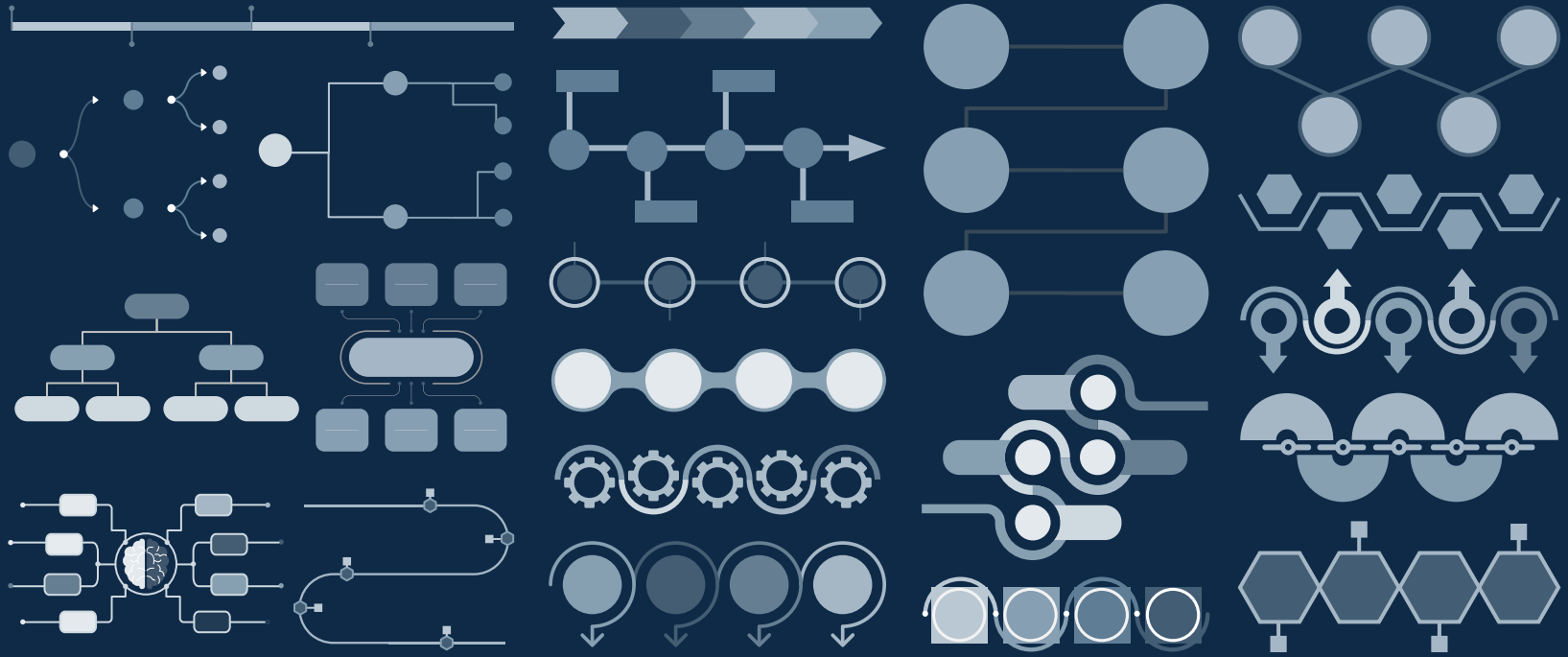

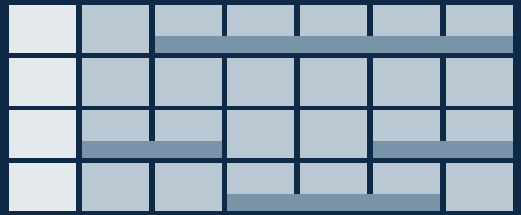

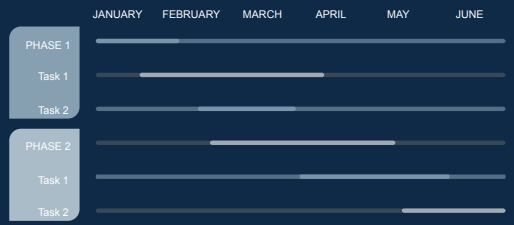
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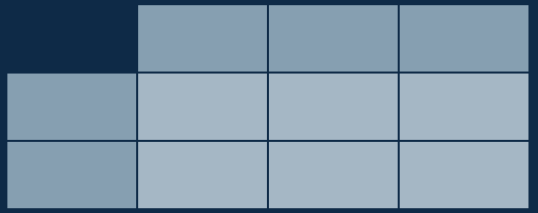

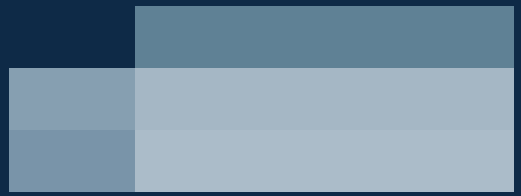

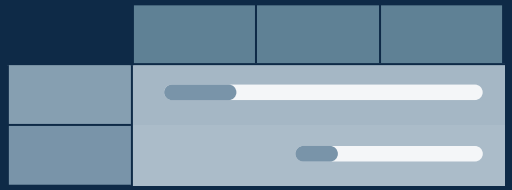

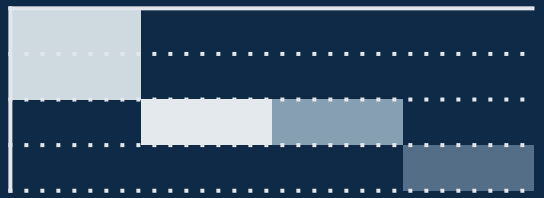

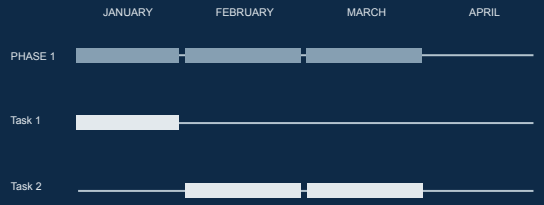
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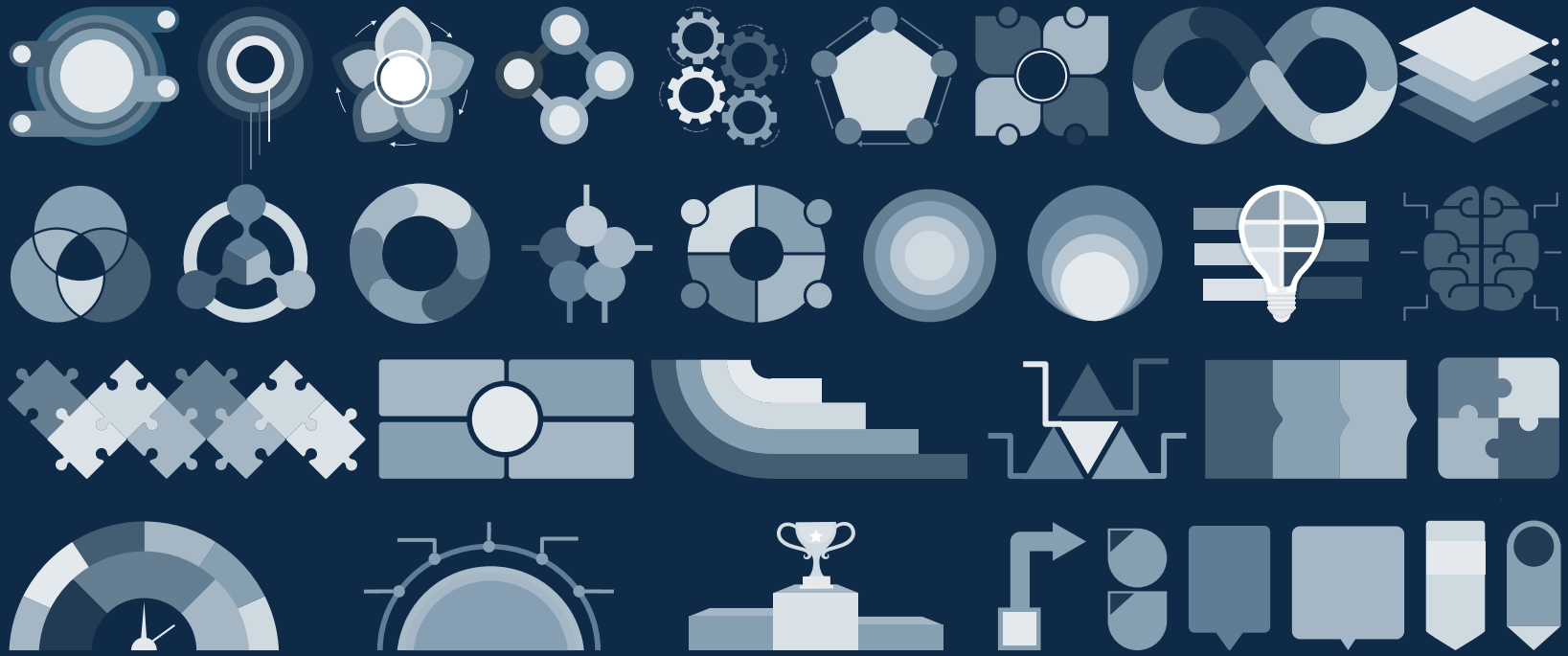

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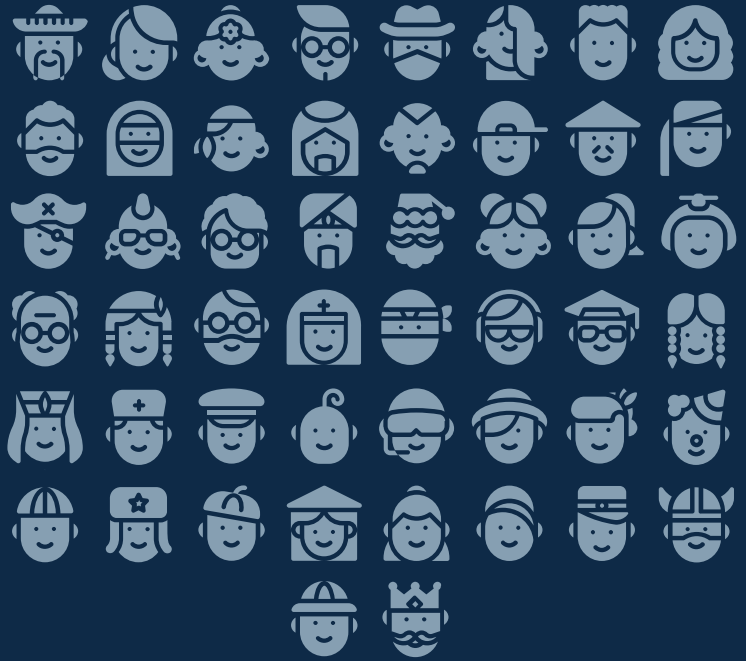

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