

# Mars Surface Terrain Classification from NASA Satellite Imagery

## 281 Final Project

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## Outline

### 01 Introduction

### 02 Data

### 03 Feature Extraction

- HOGs
- SIFT
- Edge Detection
- GLCM
- Wavelet
- Resnet 50
- Dimensionality Reduction

### 04 Results

- Classification Models
- Generalizability
- Efficiency

01

# Introduction

## Introduction

Classification of Mars' surface terrain provides direct insight into:

- Surface activity on Mars
- Mar's geological history

Also aids in:

- Resource identification and mission planning
- Enhances general scientific knowledge of Mars
- Aids in the future study of other planets in our solar system



02

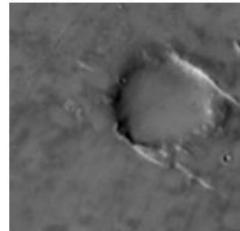
Data

## 2.1 - Dataset

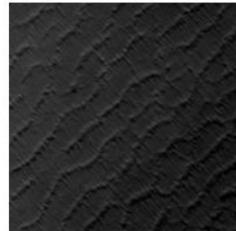
- NASA's HiRISE (High Resolution Imaging Science Experiment)
  - 1 of 6 instruments aboard NASA's Mars Reconnaissance Orbiter, launched in 2005.
- Data Augmentation:
  - 90-degree clockwise rotation
  - 180-degree clockwise rotation
  - 270-degree clockwise rotation
  - Horizontal flip
  - Vertical flip
  - Random brightness adjustment
- Challenges Identified:
  - Class imbalances
  - Duplicate images
  - Image artifacts

One Image of Each Class

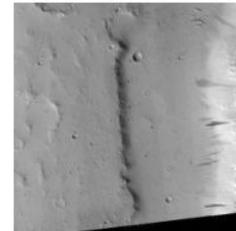
1. Crater



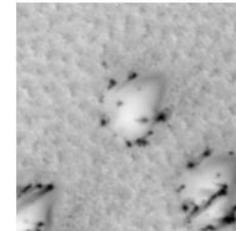
2. Dark Dune



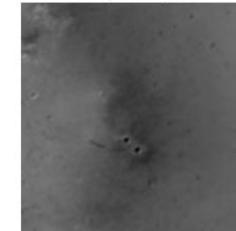
3. Slope Streak



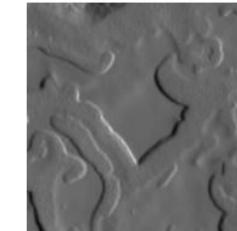
4. Bright Dune



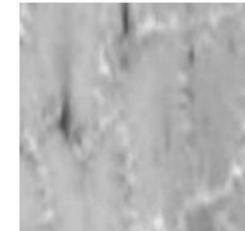
5. Impact Ejecta



6. Swiss Cheese

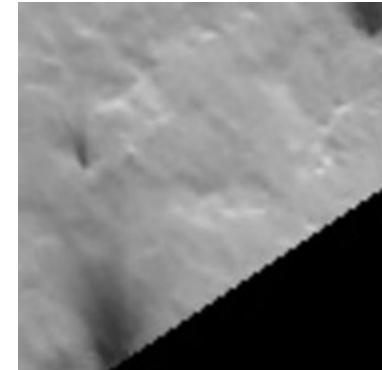
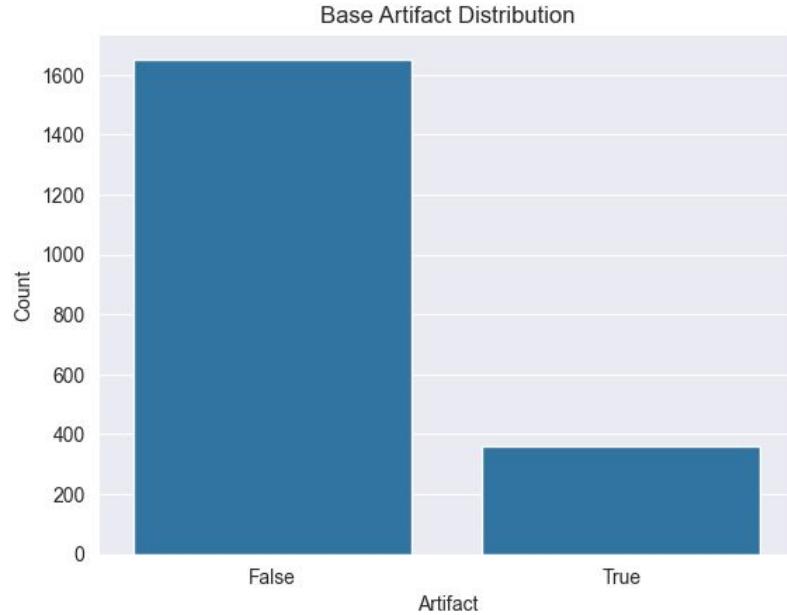


7. Spider



## 2.2 - Data Preprocessing

- Removed duplicate images
- Applied transformations to remove blacked-out areas
  - Re-generated 6 augmentations
- Rebalanced class distribution to Train/Val/Test sets
  - 60/20/20



### Final Dataset Counts:

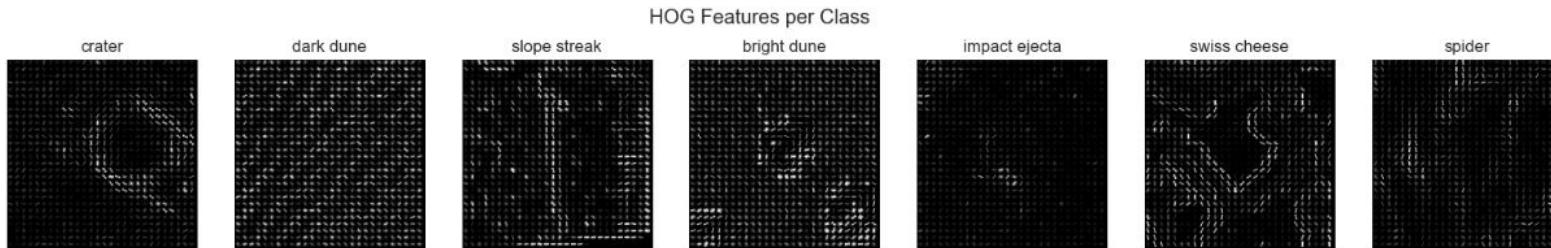
- Train: 8449 Images
- Validation: 2821 Images
- Test: 403 Images

03

## Feature Extraction

### 3.1 - HOG Feature Extraction

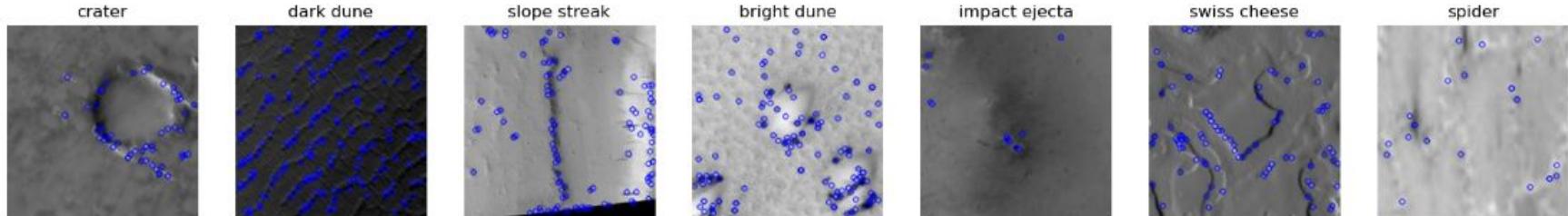
- Parameters:
  - Orientations: 8, pixels per cell: (8x8), cells per block: (2x2)
- Raw Feature Space:  $27 \times 27 \times 2 \times 2 \times 8$
- Binned for summary statistics
  - Mean, std, min, max
- Binned Feature Space: 720



### 3.2 - SIFT Feature Extraction

- Detects key points & descriptors of an image that are invariant to scale, rotation, and small distortions
- Converted to Bag of Visual Words (BOVW)
  - Similar descriptors are grouped together using k-means
  - Cluster centers represent vocabulary of an image
  - Computes frequencies of vocabulary per image

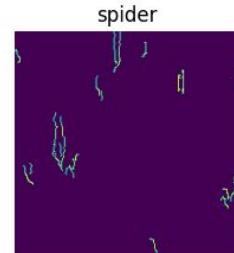
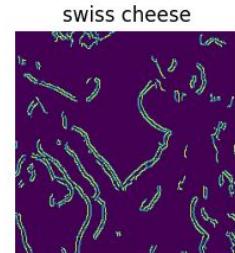
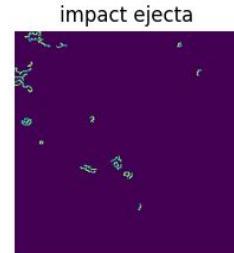
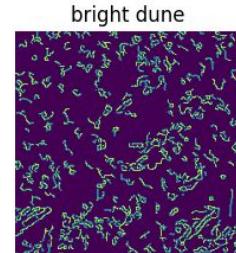
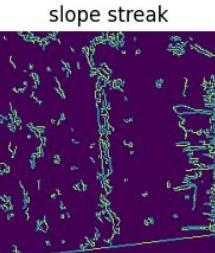
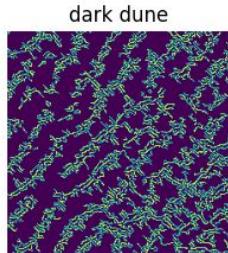
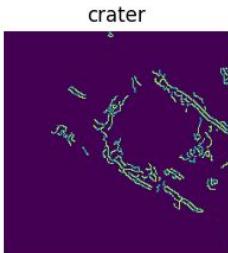
One SIFT Image For Each Class



### 3.3 - Edges Feature Extraction

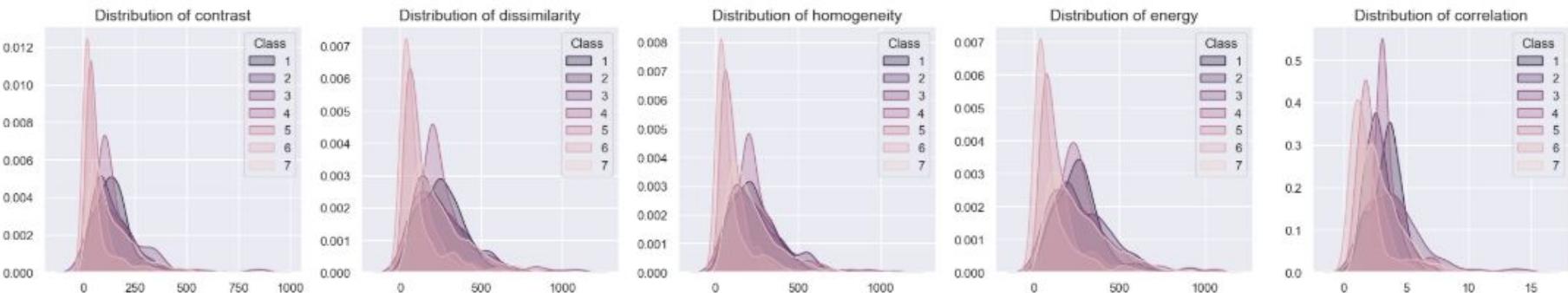
- Identifies edges by detecting areas with a rapid change in intensity using Gaussian filters and edge tracing
- Raw edge feature size: 227x227 of binary T/F
  - Large dimension, overfitting
- Found summary statistics of contours
  - (length, mean, standard deviation, number of contours)

One Canny Edge Detection Image For Each Class



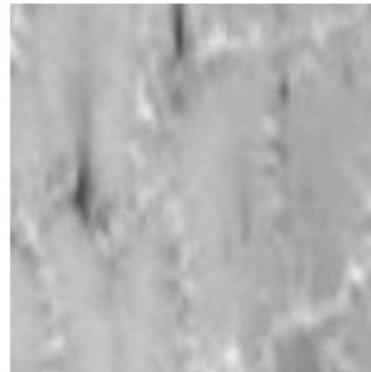
### 3.4 - Gray Level Co-occurrence Matrix (GLCM) Feature Extraction

- Analyzes spatial relationships between pixel intensities
- Useful to extract texture features of contrast, dissimilarity, homogeneity, energy, and correlation
- Params:
  - Distance = 3, angle = 90°

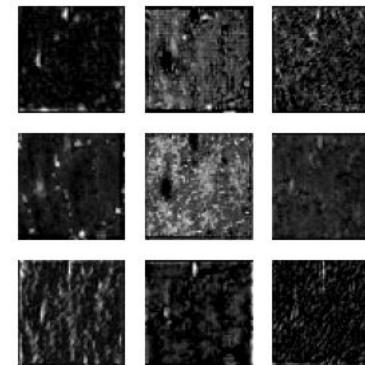


### 3.6 - Resnet Feature Extraction

- Used pretrained Resnet-50 to extract feature embeddings
  - 50 layer CNN architecture
  - Convolutional layers, identity block, convolutional block, fully connected layers
  - Solves vanishing gradient issue from previous deep-learning models



Resnet-50



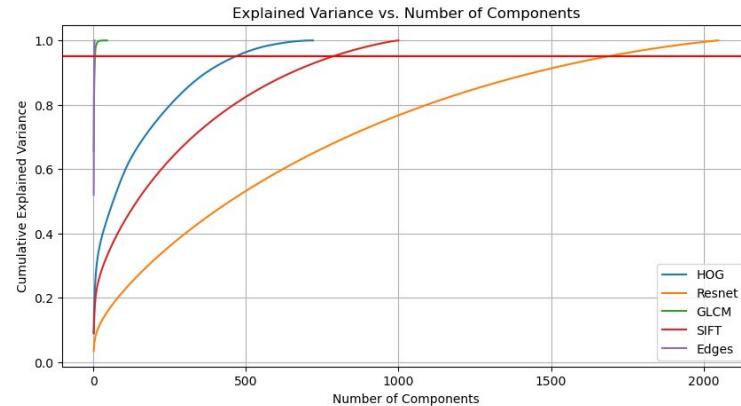
Spider Example

Feature Embeddings

## 3.7 - Dimensionality Reduction

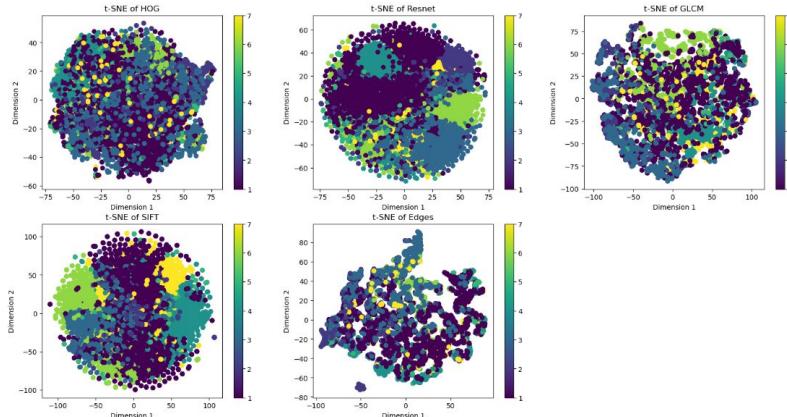
### PCA

- Reduce overfitting
- Increase computational efficiency



### t-SNE

- Visualize data on 2 dimensions
- Identify feature separation



### 3.8 Final Features

Feature	Original Dimension	New Dimension	Explained Variance	% Reduction
HOG	720	5	~0.2	99%
GLCM	45	15	~0.6	67%
ResNet-50	2048	100	~0.3	95%
SIFT (BOVW)	1000	30	~0.3	97%

Final Feature Vector: 150

# 04

## Classification Results

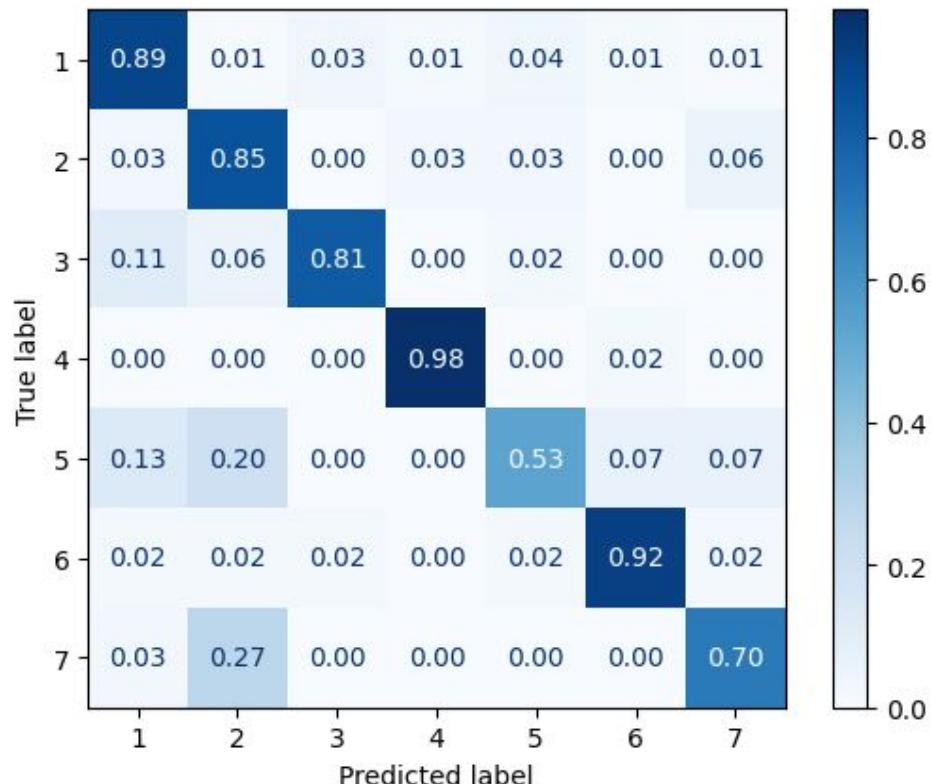
## 4.1 - Classification Results

Model	PCA	Parameter Tuned	Training Accuracy	Validation Accuracy	Test Accuracy
Majority Class	N	N	0.39	0.39	0.39
Logistic Regression	N	N	1.00	0.82	N/A
Logistic Regression	Y	Y	0.96	0.83	0.86
Hist Gradient	Y	Y	1.00	0.81	0.86
SVM	N	N	1.00	0.81	N/A
SVM	Y	Y	1.00	0.82	0.86
Voting Classifier (SVM, Logistic Regression, Histogram Boosting)	Y	Y	1.00	0.84	0.87

<sup>1</sup> All models were not run against test, this was to leave models as unbiased as possible.

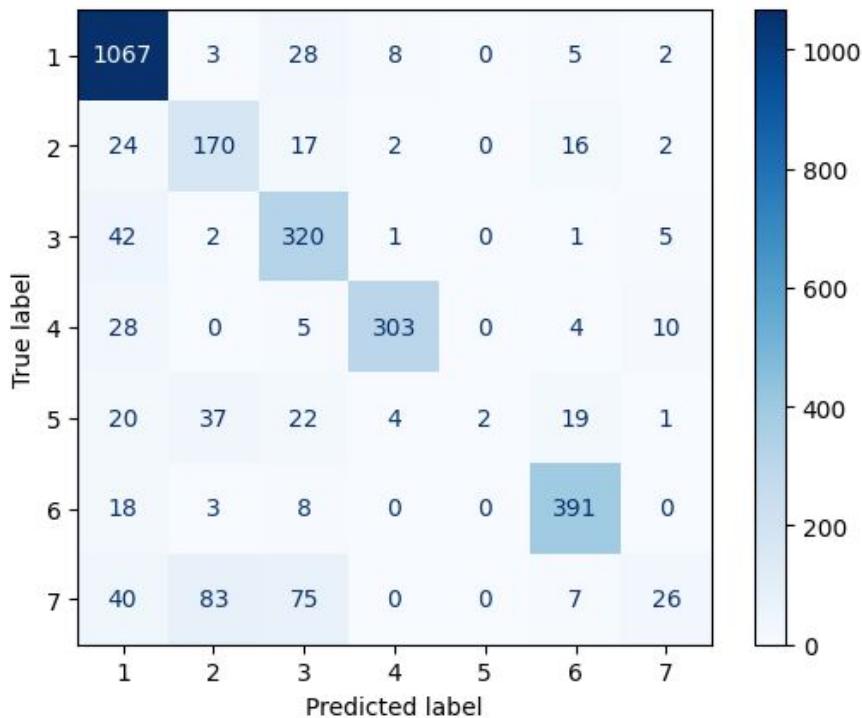
## 4.2 Generalizability

Class	Precision	Recall	Accuracy	Count
1	0.94	0.90	0.92	159
2	0.64	0.85	0.73	33
3	0.87	0.83	0.85	54
4	0.89	0.98	0.93	50
5	0.47	0.47	0.47	15
6	0.96	0.92	0.94	59
7	0.86	0.76	0.81	33

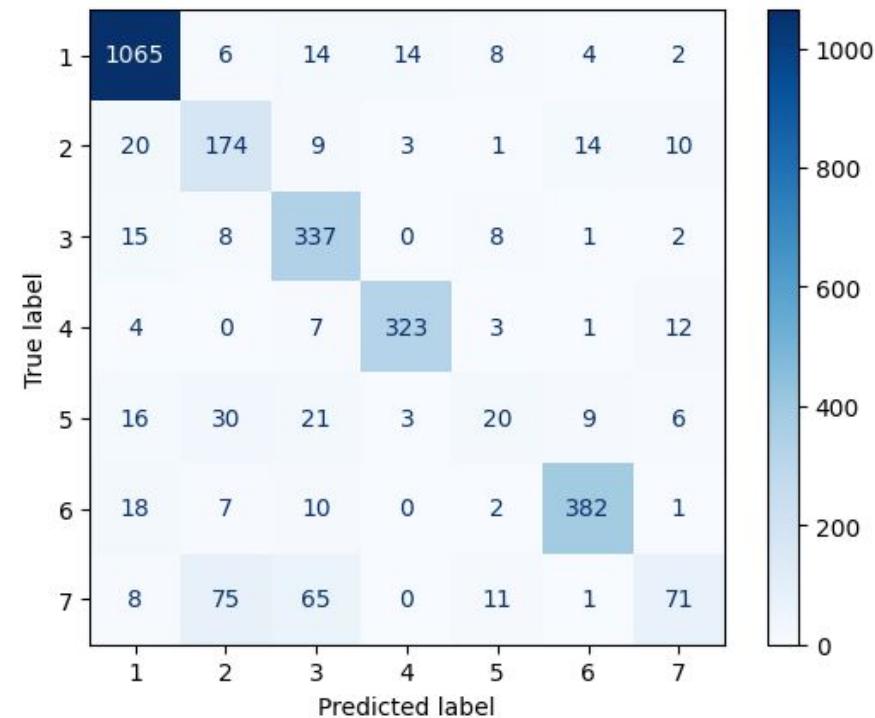


<sup>2</sup> These results are the from the voting classifier.

### Full SVM model on Validation



### Voting model on Validation



### 4.3 Accuracy vs Efficiency

Model	PCA	Parameter Tuned	Training Time	Inference Time	Test Accuracy
Majority Class	N	N	N/A	N/A	0.39
Logistic Regression	N	N	0.9s	.001s	N/A
Logistic Regression	Y	Y (~4.8m)	4.9s	.000s	0.86
Hist Gradient	Y	Y (~3.2m)	5.7s	.035s	0.86
SVM	N	N	149.3s (~2.5m)	.6s	N/A
SVM	Y	Y (~2.5m)	0.8s	.009s	0.86
Voting Classifier (SVM, Logistic Regression, Histogram Boosting)	Y	Y	14.8s	0.043s	0.87

<sup>3</sup> Inference time is based on a batch of 32.

# Questions?

### 4.3 Accuracy vs Efficiency

Model	PCA	Parameter Tuned	Training Time	Inference Time	Test Accuracy
Majority Class	N	N	N/A	N/A	0.39
Logistic Regression	N	N	0.9s	.001s	N/A
Logistic Regression	Y	Y (~4.8m)	4.9s	.000s	0.86
Hist Gradient	Y	Y (~3.2m)	5.7s	.035s	0.86
SVM	N	N	149.3s (~2.5m)	.6s	N/A
SVM	Y	Y (~2.5m)	0.8s	.009s	0.86
Voting Classifier (SVM, Logistic Regression, Histogram Boosting)	Y	Y	14.8s	0.043s	0.87

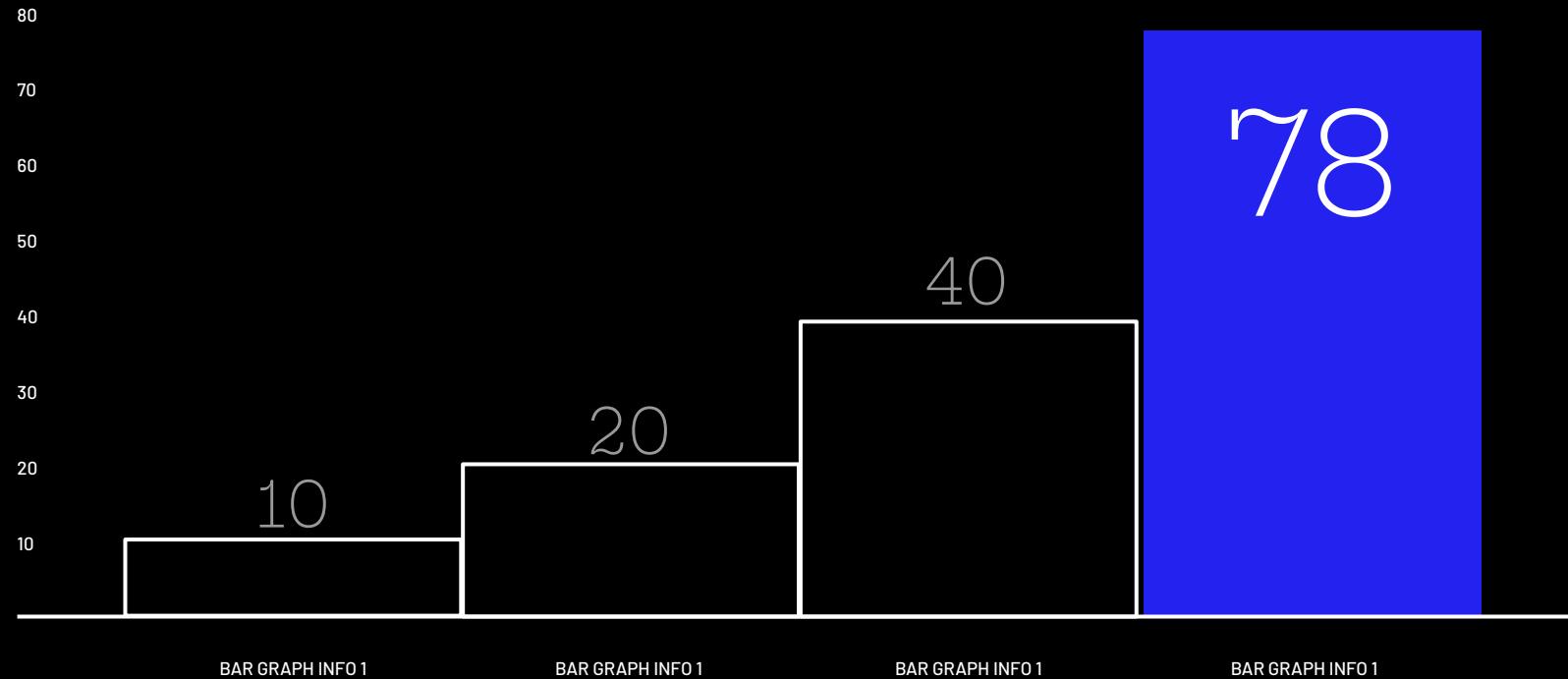
<sup>3</sup> Inference time is based on a batch of 32.

THANK YOU

SLIDE TEMPLATES BELOW

## BAR CHART

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## SWOT ANALYSIS

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### Strengths

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### Opportunities

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### Weaknesses

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### Threats

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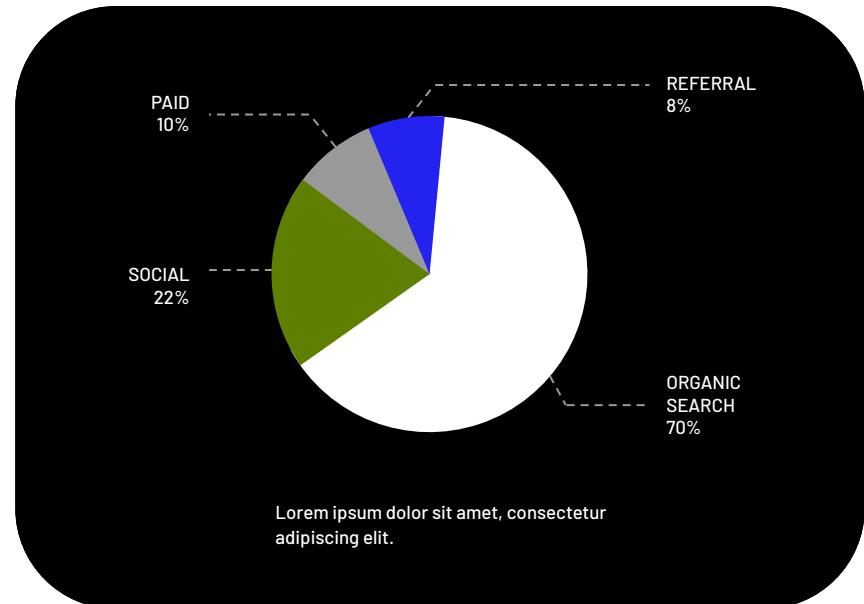
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# Team Leadership

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# Market Size

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03

Vision

# Vision

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QUOTE AUTHOR NAME





**LOREM IPSUM**

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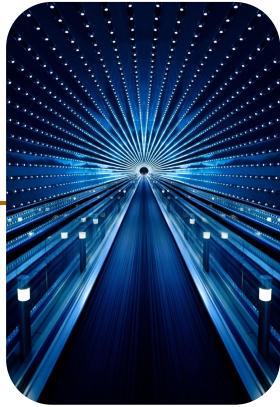
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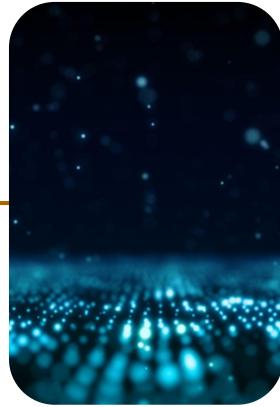
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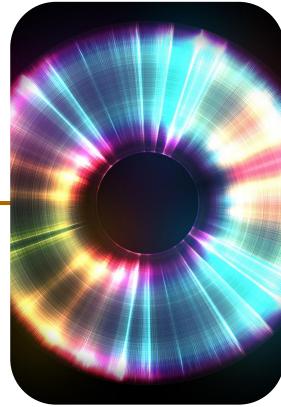
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**Step 3**

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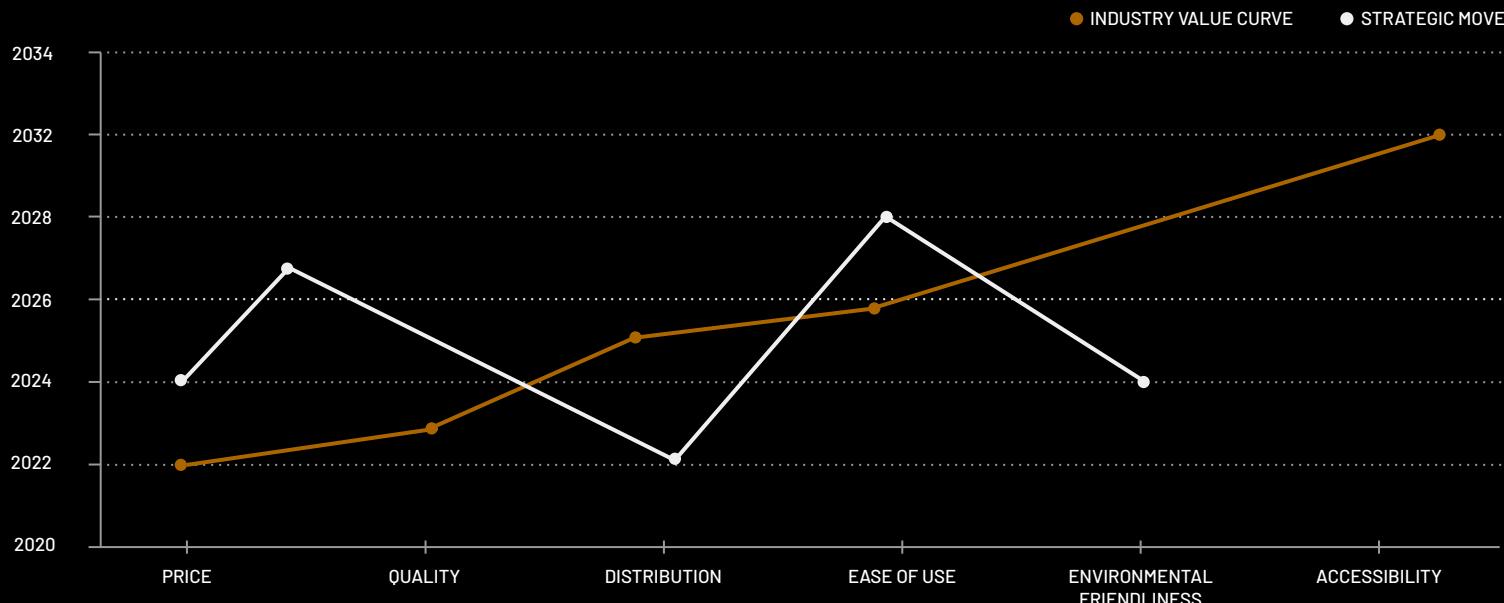
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**Step 5**

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## GOALS

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## Strategy Canvas

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# 04

## Action Plan

# Key Points Go Here

01



**Key Point Subhead**  
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02



**Key Point Subhead**  
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03



**Key Point Subhead**  
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**Step 1**

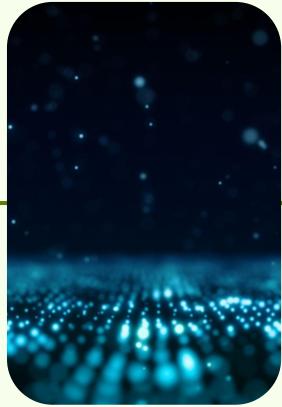
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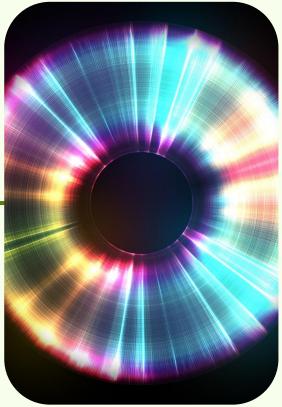
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**Step 5**

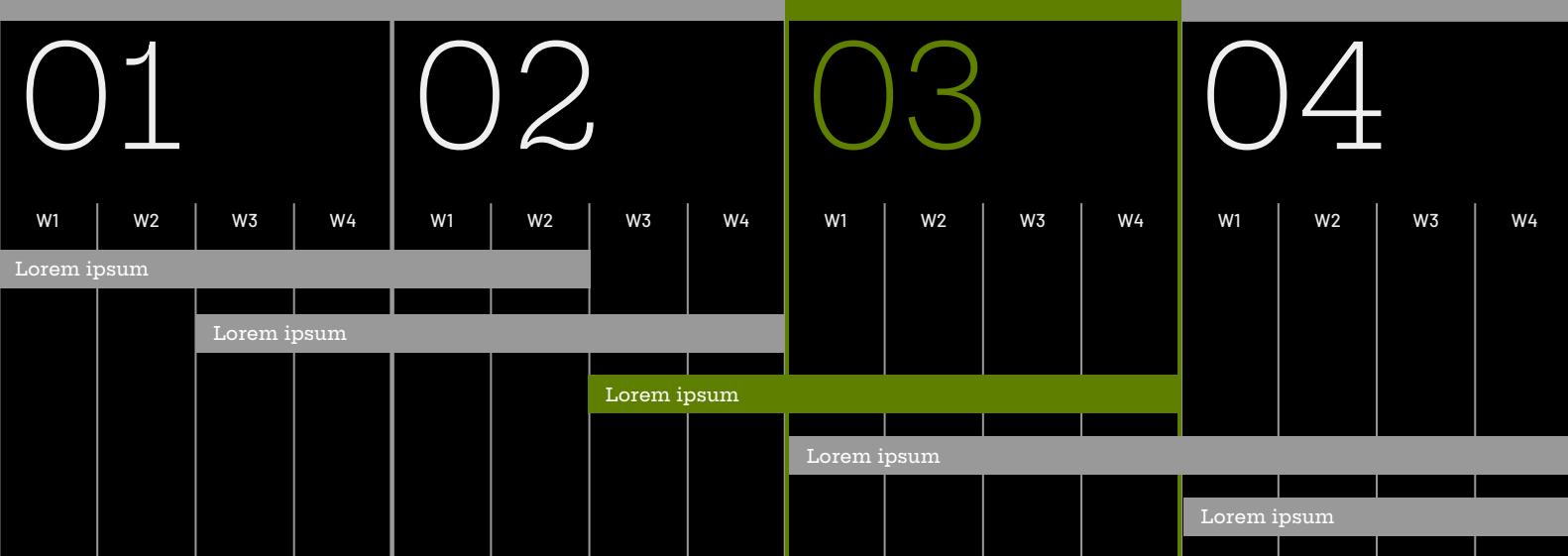
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## ACTION PLAN

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# Timeline

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## REVENUE

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