

Lecture 2:

Data Visualization

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Lecture Contents

Part 1: Visualization Fundamentals

Part 2: Mastering Basic Charts

Part 3: Advanced Visualization for ML

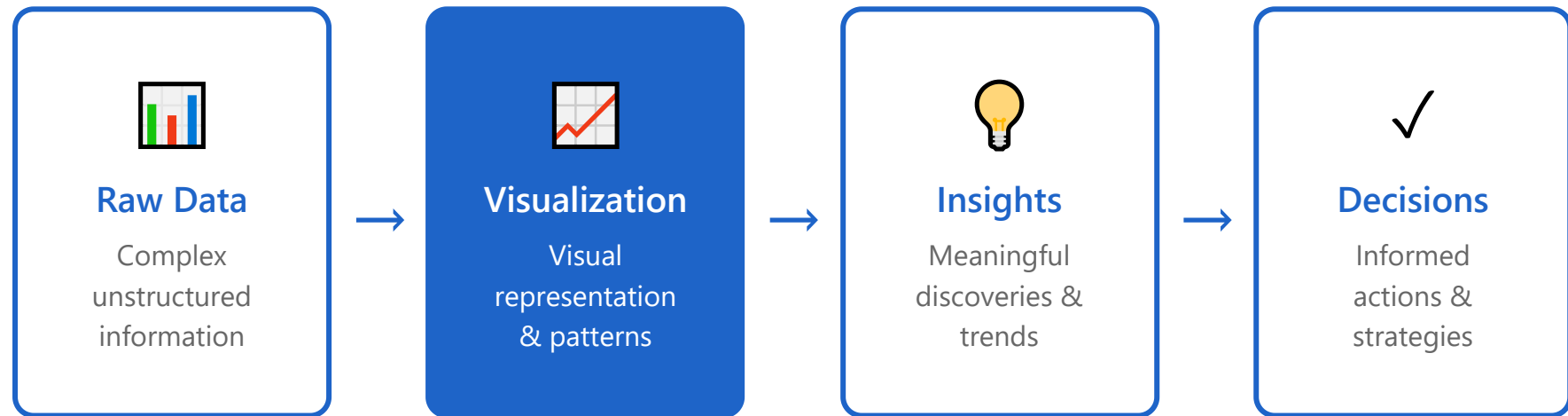
Part 1/3:

Visualization Fundamentals

1. Importance and Goals of Data Visualization
2. Visual Encoding Principles
3. Gestalt Principles and Perception
4. Color Theory and Color Blindness Accessibility
5. Typography and Layout
6. Information Density and Data-Ink Ratio
7. Grammar of Graphics
8. Good vs Bad Visualization Examples

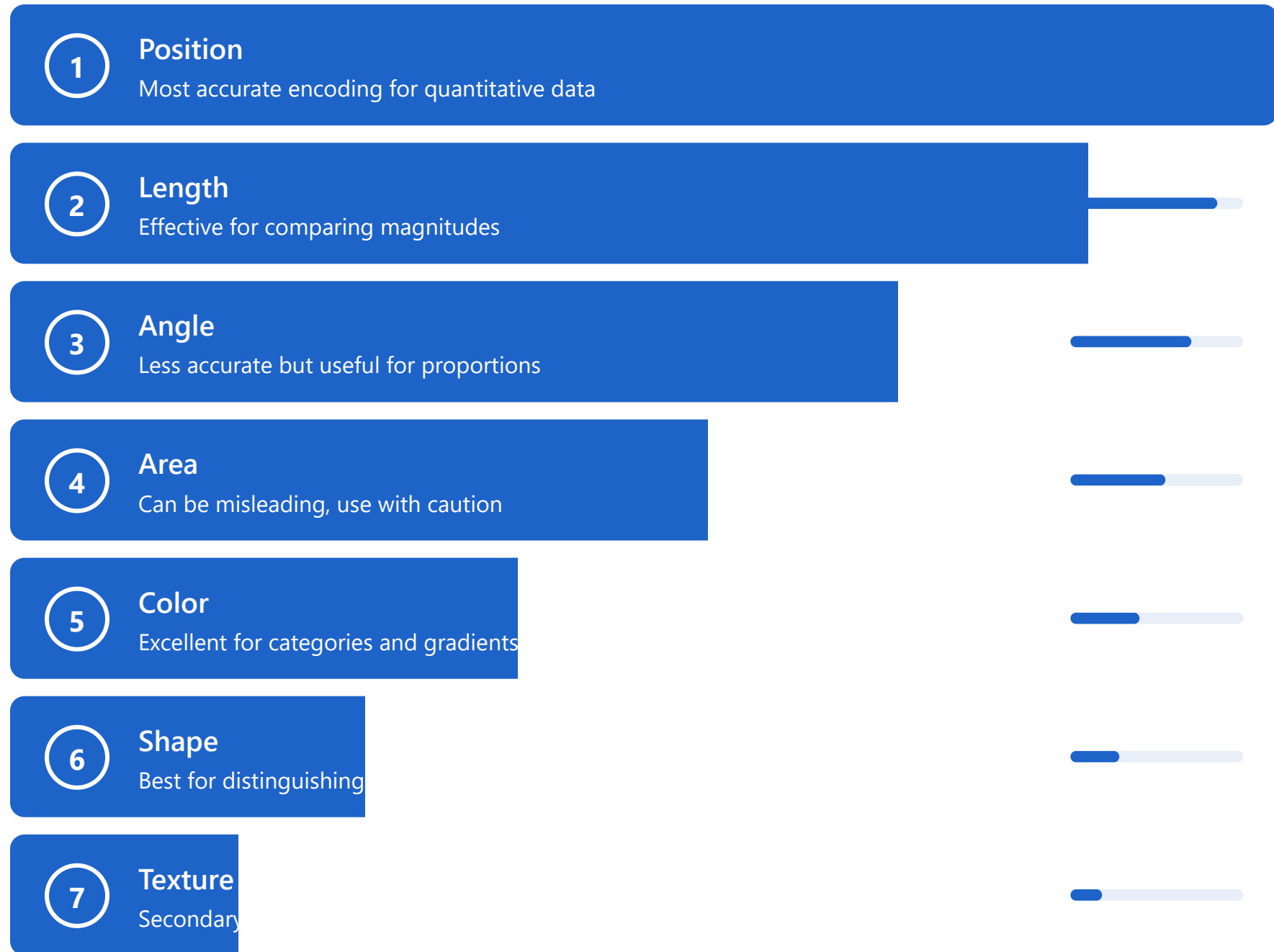
Data Visualization Process

Transform Data into Actionable Insights



Visual Encoding Hierarchy

Effectiveness Ranking from Most to Least Accurate



Gestalt Principles and Perception

Visual Organization Principles for Effective Data Visualization

Proximity



Objects close together
are grouped

Similarity



Similar elements
grouped together

Continuity



Eyes follow smooth
paths

Closure



Mind completes shapes

Figure-Ground



Objects vs background

Common Fate



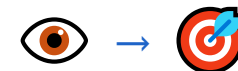
Moving together =
related

Symmetry



Balanced compositions

Application



Guide viewer attention

Color Theory and Accessibility

Choosing the Right Color Palette for Inclusive Visualization

S

Sequential

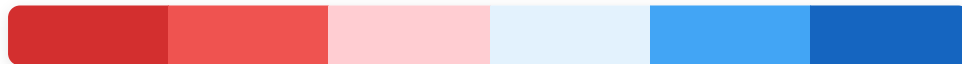
Single hue, varying lightness (temperatures)



D

Diverging

Two hues meeting at neutral (gains/losses)



C

Categorical

Distinct hues for different categories



~8%

of males have color vision deficiency



Accessibility Guidelines

- Avoid red-green combinations
- Use [ColorBrewer](#) or [Viridis](#) palettes
- Add [texture/patterns](#) as redundant encoding
- Test with [color blindness simulators](#)

✓ Color Contrast Examples

Good Contrast
WCAG AAA

Poor Contrast
Avoid

Blue-Orange
Safe

Red-Green
Unsafe

Typography and Layout Principles

Creating Clear and Professional Visualizations

Visual Hierarchy

TITLE (24PT)

Main Visualization Title

SUBTITLE (20PT)

Supporting Context

BODY (16PT)

Detailed information and annotations with proper spacing and clarity

Key Principles

- 1 Sans-serif for digital, serif for print
- 2 12-14pt minimum for readability
- 3 2-3 font families maximum
- 4 Consistent alignment is professional

Grid System & White Space

Chart

Legend

Metrics

✓ Best Practices

- ✓ White space improves clarity
- ✓ Grid systems ensure balance
- ✓ Annotations enhance content
- ✗ Avoid cluttering with text

Concrete Examples: Good Design vs Bad Design

✓ Clear Visual Hierarchy

✗ Unclear Visual Hierarchy

Main Title

Subtitle

Body text is smallest and organized for easy reading.

Size and weight express information priority

Main Title

Subtitle

Body text is smallest and organized for easy reading.

Mixed sizes make it hard to identify priority

✓ Proper Spacing

Element A

Element B

Element C

Adequate spacing makes each element clear

✗ Insufficient Spacing

Element A

Element B

Element C

Cramped spacing feels cluttered and hard to read

Data-Ink Ratio & Information Density

Maximize Data-Ink, Minimize Chartjunk (Tufte's Principle)

Key Principles to Remember

Remove chartjunk & decorations

Eliminate redundant labels

High density \neq cluttered

Iterate until nothing can be removed

Grammar of Graphics

A Systematic Framework for Building Visualizations

1

Data

Foundation: Raw dataset to visualize

2

Aesthetics

Map data to visual properties (x, y, color)

3

Geometries

Visual marks (points, lines, bars)

4

Statistics

Transform data (mean, count, regression)

5

Scales

Control mapping from data to aesthetics

6

Coordinates

Map to 2D plane (Cartesian, polar)

7

Facets

Framework

ggplot2

by Leland Wilkinson

Key Concepts



Build graphics incrementally



Separates data from visuals



Systematic & composable



Layer-based architecture

Split data into multiple subplots

Step-by-Step Implementation

Building Visualizations Layer by Layer



Practical Example: Car Fuel Efficiency Analysis

Using the mtcars dataset, we'll visualize the relationship between car weight (wt) and fuel efficiency (mpg). Watch how each layer progressively builds the visualization from an empty canvas to a complete, insightful graph.



Complete Visualization Achieved

By layering all 7 components, we've built a sophisticated multi-dimensional visualization that reveals:

Key Insights:

- Heavier cars have worse fuel efficiency (negative correlation)
- More cylinders → heavier cars → worse MPG (shown by red colors)
- Manual transmission cars are generally lighter and more efficient

This is the power of Grammar of Graphics: systematic, composable, and infinitely flexible!

Good vs Bad Visualization Examples

Common Pitfalls and Best Practices

1 Chart Type Selection

✗ Bad

3D pie charts distort proportions and values

vs

✓ Good

Simple 2D bar charts for clear comparisons

2 Axis Management

✗ Bad

Dual y-axes mislead by arbitrary scaling

vs

✓ Good

Normalized or separate charts for clarity

3 Y-Axis Baseline

✗ Bad

Truncated y-axis exaggerates differences

vs

✓ Good

Start at zero or clearly indicate breaks

4 Color Application

✗ Bad

Too many colors causing confusion

vs

✓ Good

Intentional color use highlighting key insights

Part 2/3:

Mastering Basic Charts

- 9. 1D Data - Histogram, KDE
- 10. 2D Relationships - Scatter Plot, Bubble Chart
- 11. Categorical Data - Bar Chart, Pie Chart
- 12. Distribution Comparison - Boxplot, Violin Plot
- 13. Time Series - Line Graph, Area Chart
- 14. Correlation - Heatmap, Correlation Matrix
- 15. Multidimensional - Parallel Coordinates, Radar Chart
- 16. Geographic Data - Choropleth, Bubble Map

1D Data: Histogram & KDE

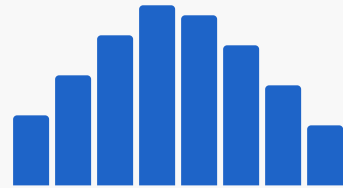
Understanding Distribution Through Binning and Smoothing

Few Bins



⚠ Loses detail

Optimal Bins



✓ Clear pattern

KDE Curve



✓ Smooth & continuous



Key Concepts

- Histogram: Binned frequency distribution
- KDE: Smooth density curve
- Bandwidth affects smoothness
- Identify: normal, skewed, bimodal
- Overlay multiple distributions



Bin Size Rules

Sturges' Rule: $\text{bins} \approx \log_2(n) + 1$

Freedman-Diaconis: Based on IQR & sample size

When to Use

- ✓ Exploring distribution
- ✓ Detecting outliers
- ✓ Understanding data spread
- ✓ Comparing distributions



How KDE (Kernel Density Estimation) Works

1

Place a kernel at each data

$$\hat{f}(x) = \frac{1}{nh} \sum_{i=1}^n K\left(\frac{x - x_i}{h}\right)$$

point

- A small bell curve (Gaussian) is centered at every observation

2

Sum all kernels

- Add up the contributions from all kernels at each position

3

Normalize the curve

- Scale so the total area under the curve equals 1

n = number of data points

h = bandwidth (smoothing parameter)

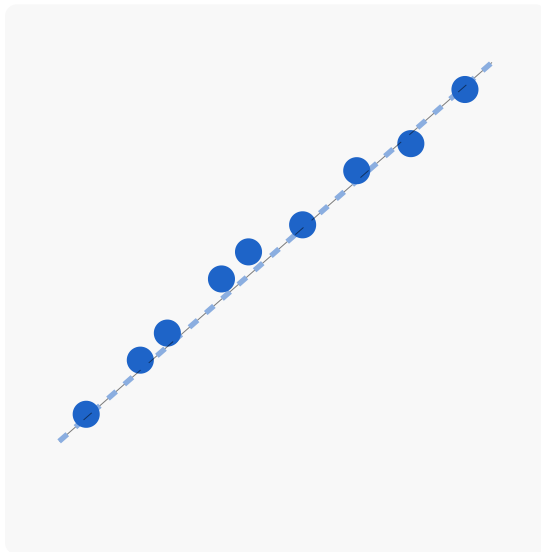
K = kernel function (usually Gaussian)

x_i = individual data points

2D Relationships: Scatter Plot & Bubble Chart

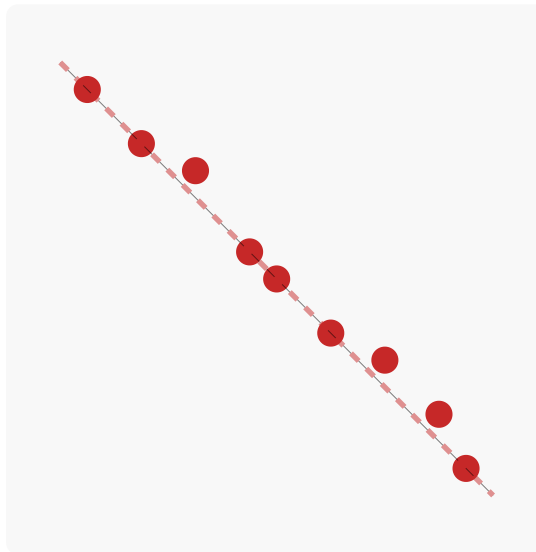
Exploring Relationships Between Continuous Variables

Positive Correlation



Strong Positive ($r \approx +0.9$)

Negative Correlation



Strong Negative ($r \approx -0.9$)

No Correlation

Non-linear Pattern

Key Features

- Reveals correlation & clusters
- Identifies outliers
- Shows non-linear patterns
- Add trend lines for clarity



Bubble Chart

Add 3rd dimension (size) + optional 4th (color)

💡 Best Practices

- ▶ Use alpha transparency
- ▶ Try hexbin for large data
- ▶ Annotate key points

When to Use

- ✓ Correlation analysis
- ✓ Trend detection
- ✓ Multivariate exploration

Categorical Data: Bar Chart & Pie Chart

Comparing Categories and Showing Proportions

Simple Bar Chart



Best for comparing categories

Grouped Bar Chart

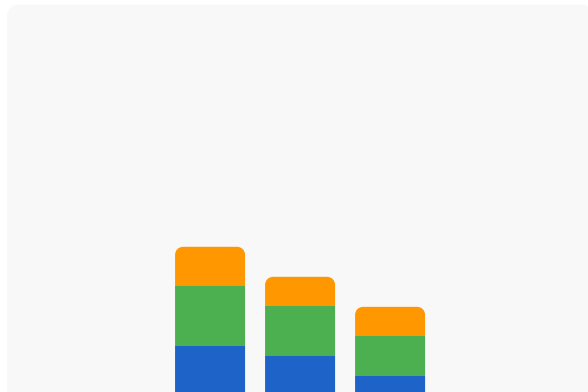


Compare subcategories

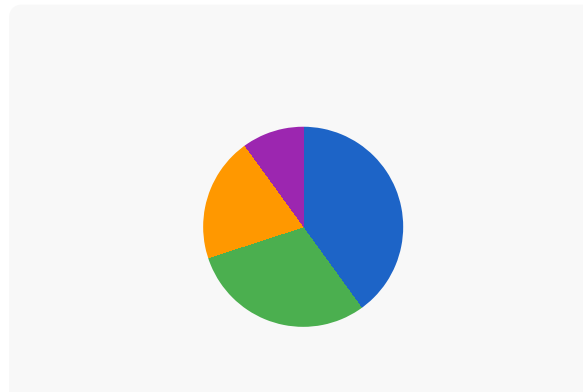
Guidelines

- Horizontal bars for long names
- Sort by value (descending)
- Stacked bars harder to compare
- Pie only for simple proportions

Stacked Bar Chart



Pie Chart



Perception Accuracy

Length (Bar) High ✓

Angle (Pie) Low ✗

When to Use



Show composition

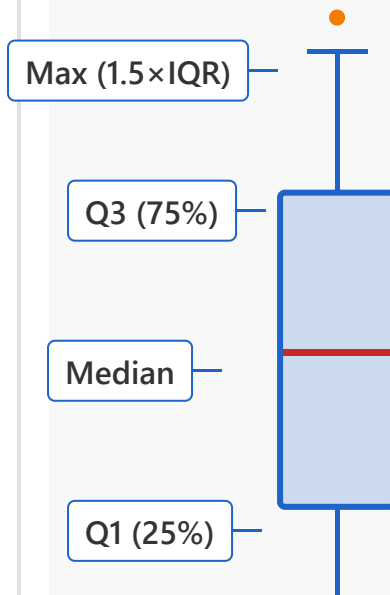
Use sparingly (<5 categories)

- ✓ Category comparison
- ✓ Ranking & ordering
- ✓ Simple proportions

Distribution Comparison: Boxplot & Violin Plot

Anatomy and Components of Distribution Visualizations

Boxplot Anatomy



Violin Plot Anatomy

Density Width

Median



Key Features

- Boxplot shows 5-number summary
- Violin reveals full distribution
- $IQR = Q3 - Q1$
- Width = density at each value

Whisker Formula

Upper: $Q3 + 1.5 \times IQR$

Lower: $Q1 - 1.5 \times IQR$

Comparison

Min ($1.5 \times \text{IQR}$)

Outliers

Distribution Shape

Boxplot: Summary stats

Violin: Full shape + KDE

When to Use

- ✓ Comparing groups
- ✓ Identifying outliers
- ✓ Seeing data spread
- ✓ Detecting multimodality

Time Series: Line Graph & Area Chart

Visualizing Trends and Changes Over Time

Single Line

Multiple Lines

Stacked Area



Features

Line Graph

- Sequential continuity
- Trend comparison

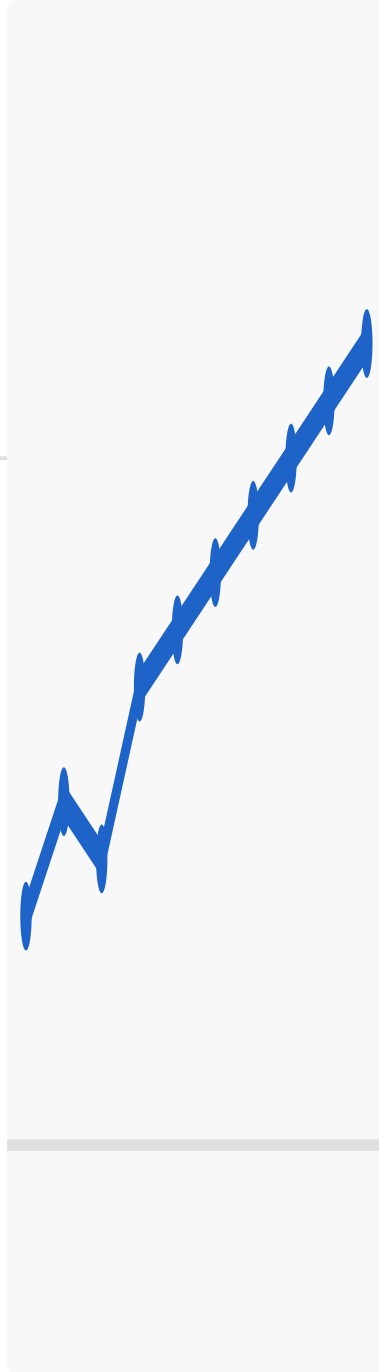
Area Chart

- Emphasizes magnitude
- Shows composition

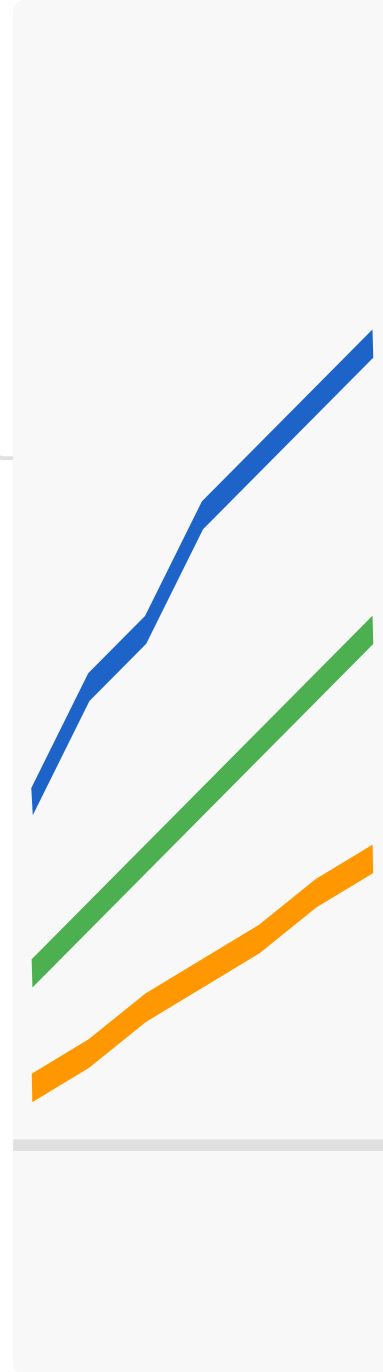


Best Practices

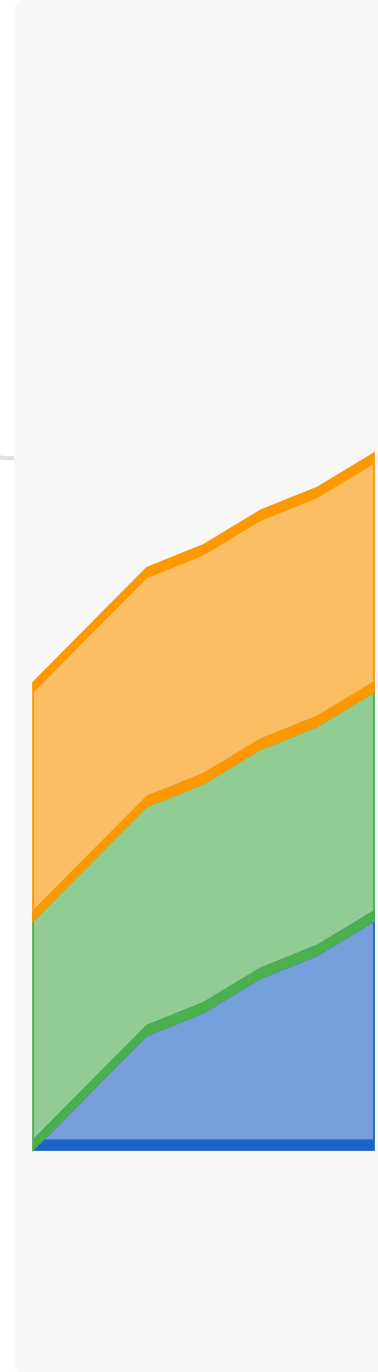
- Distinct colors for lines
- Add reference lines
- Appropriate granularity



Shows continuous trend over time



Compares multiple trends with distinct colors



Shows composition changes over time

▶ Avoid over/undersampling

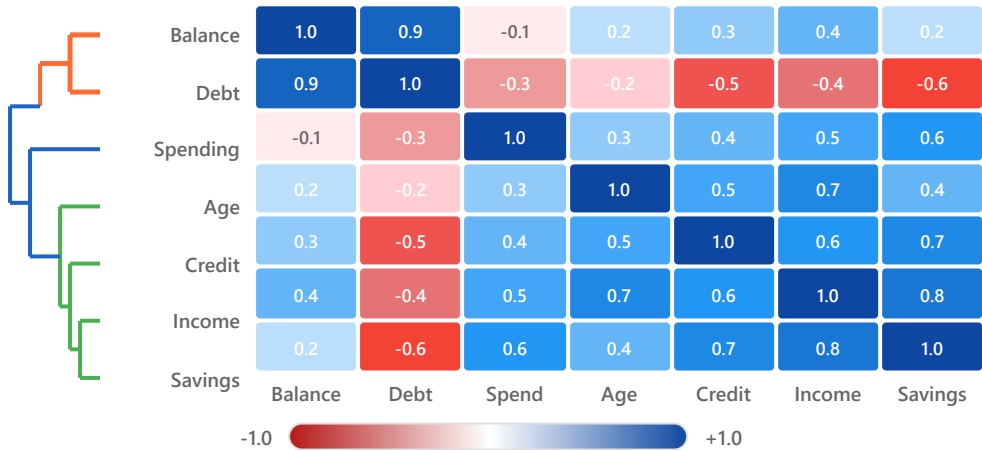
When to Use

- ✓ Trend analysis
- ✓ Forecasting
- ✓ Seasonal patterns
- ✓ Change over time

Correlation Analysis

Heatmap & Correlation Matrix

Correlation Heatmap with Dendrogram



Interpretation

- Positive: Variables move together
- Negative: Inverse relationship
- Zero: No linear relationship
- Dendrogram groups similar features

Correlation Matrix (Original Order)

	Age	Income	Credit	Balance	Spend	Savings	Debt
Age	1.00	0.70	0.50	0.20	0.30	0.40	-0.20
Income	0.70	1.00	0.60	0.40	0.50	0.80	-0.40
Credit	0.50	0.60	1.00	0.30	0.40	0.70	-0.50
Balance	0.20	0.40	0.30	1.00	-0.10	0.20	0.90
Spend	0.30	0.50	0.40	-0.10	1.00	0.60	-0.30
Savings	0.40	0.80	0.70	0.20	0.60	1.00	-0.60

Key Insights

- Balance-Debt:** 0.9 (very strong)
- Income-Savings:** 0.8 (strong)
- Age-Income:** 0.7 (strong)
- Financial health cluster visible

Best Practices

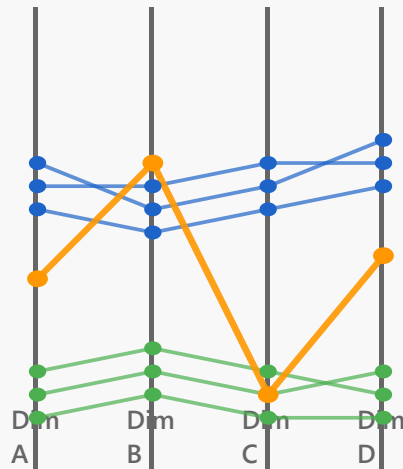
- Use diverging colormap
- Cluster similar variables
- Identify redundant features

✓ Look for multicollinearity

Multidimensional Visualization

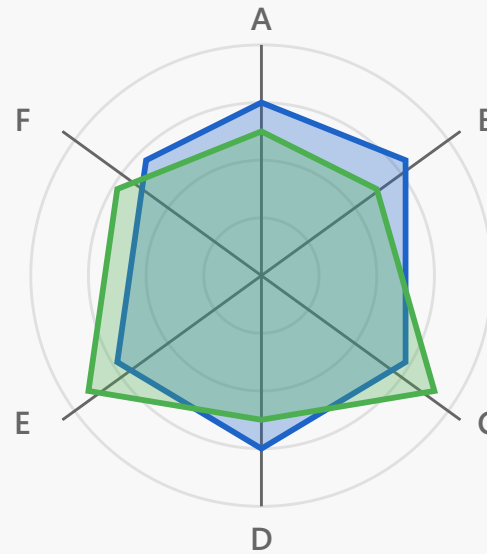
Parallel Coordinates & Radar Chart

Parallel Coordinates



Lines connect observations across dimensions

Radar Chart



Circular layout comparing entity profiles

Comparison

Parallel Coords

- Many dimensions
- Reveals clusters
- Color by class

Radar Chart

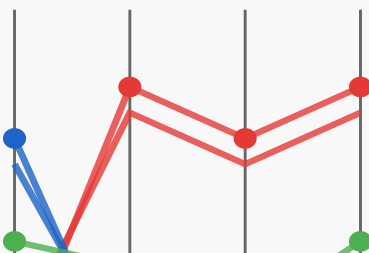
- 6-8 dimensions max
- Profile comparison
- Circular symmetry

Limitations

- Parallel: Axis order matters
- Radar: Limited dimensions
- Both: Can be cluttered

Real-World Examples

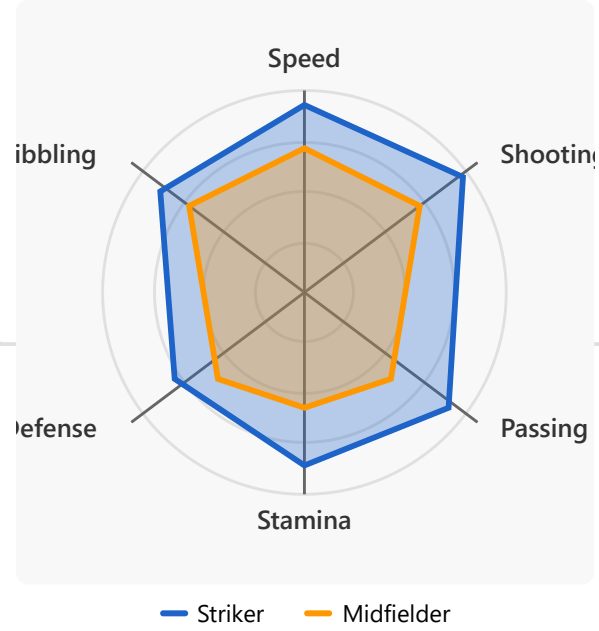
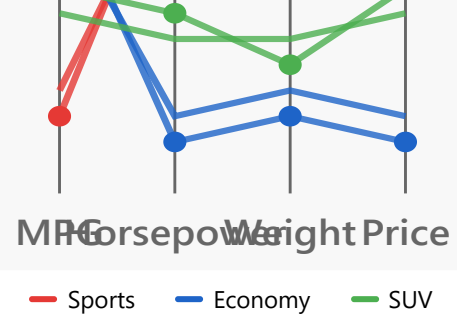
Car Comparison



Player Stats

When to Use

- ✓ High-dim exploration
- ✓ Pattern detection
- ✓ Profile comparison
- ✓ Player/product stats



Geographic Data Visualization

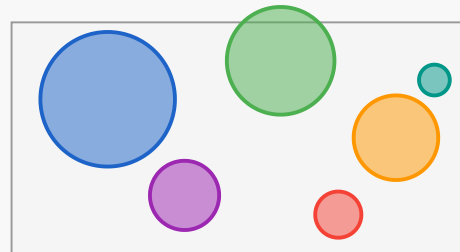
Choropleth Map & Bubble Map

Choropleth Map



Very High Medium Low

Bubble Map



Large Medium Small

Features

Choropleth

- Color-encode regions
- Sequential/diverging scales

Bubble Map

- Size at coordinates
- Combine size + color

Best Practices

- ▶ Normalize by population/area
- ▶ Consider projection distortion
- ▶ Add borders & labels
- ▶ Use appropriate color scale

When to Use

- ✓ Spatial patterns
- ✓ Regional comparison
- ✓ Location-based insights

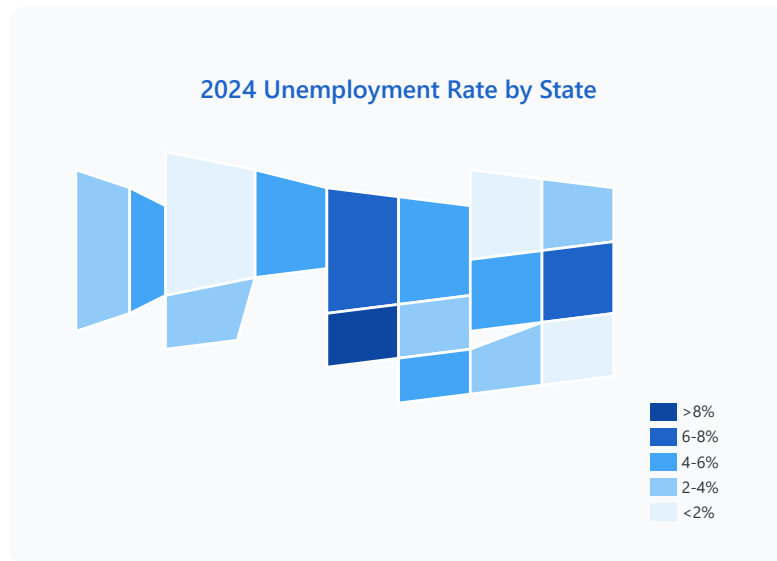
Color encodes regional statistics

Size encodes values at coordinates

✓ Demographics analysis

Real-World Examples

Choropleth: US Unemployment Rate



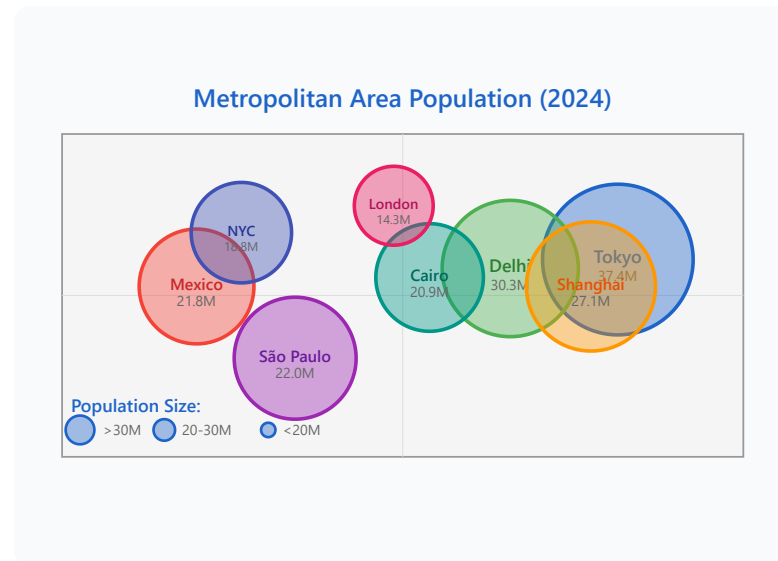
Use Case

This choropleth map visualizes unemployment rates across US states using color intensity. Darker blues indicate higher unemployment rates.

Key Insight: Regional patterns show economic disparities

Color Scale: Sequential (light to dark blue)

Bubble: Global City Populations



Use Case

This bubble map displays population sizes of major cities worldwide. Bubble size represents population, and colors distinguish different cities.

Key Insight: Asia dominates with largest urban centers

Encoding: Size = population, Position = geography

Advantage: Shows both location and magnitude

Data Type: Normalized percentages

Part 3/3:

Advanced Visualization for ML

- 17. Visualization Strategy for EDA
- 18. Feature Distribution and Outlier Detection
- 19. Visualizing Feature Interactions
- 20. Dimensionality Reduction Visualization (PCA, t-SNE, UMAP)
- 21. Model Performance Visualization - Learning Curves
- 22. Classification Model Evaluation - Confusion Matrix, ROC, PR
- 23. Regression Model Evaluation - Residuals, QQ Plot
- 24. Model Interpretation - SHAP, LIME, Attention
- 25. Dashboard Design and Storytelling

Visualization Strategy for EDA

Systematic Workflow for Exploratory Data Analysis

1

Data Loading

Import and understand data structure



2

Univariate Analysis

Distributions, missing values, outliers



3

Bivariate Relationships

Correlations, dependencies, patterns



Multivariate Patterns



Key Principles

- Systematic pipeline
- Automate repetitive plots
- Use small multiples (facets)
- Document insights iteratively



Best Practices

- ▶ Start simple, add complexity
- ▶ Maintain visualization journal

4

Interactions, clusters, dimensionality



- Compare across categories
- Iterate hypothesis
→ viz → insight



5

Insights & Hypotheses

Generate actionable insights



Balance

Breadth ↔ Depth

Many features ↔ Detail analysis

Feature Distribution & Outlier Detection

Assessing Normality and Identifying Anomalies

Histogram

Q-Q Plot

Box Plot

Key Insights

- Reveals skewness & modality
- Identifies outliers & quartiles
- Q-Q: diagonal = normal

Statistical Tests

Shapiro-Wilk

Anderson-Darling

Decision

Errors

Remove

ExtremeKeep/Investigate

Outlier Detection Methods

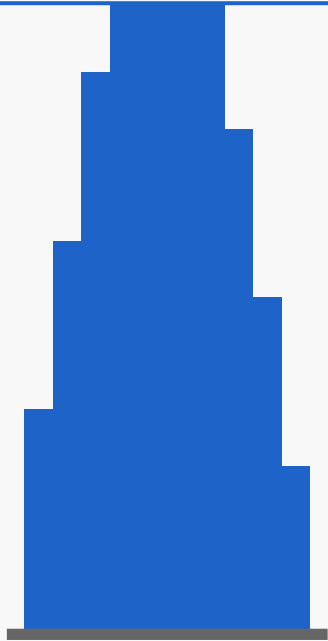
IQR Method

Z-Score

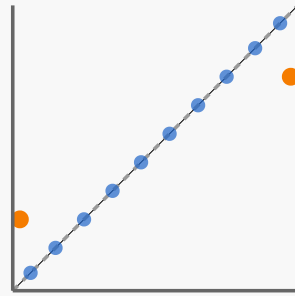
Isolation Forest

Transformations

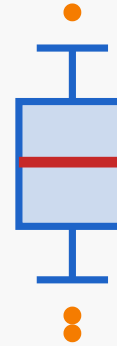
- ✓ Log transform
- ✓ Box-Cox
- ✓ Feature scaling



Shows distribution shape



Tests normality
assumption



Highlights outliers & IQR

Visualizing Feature Interactions

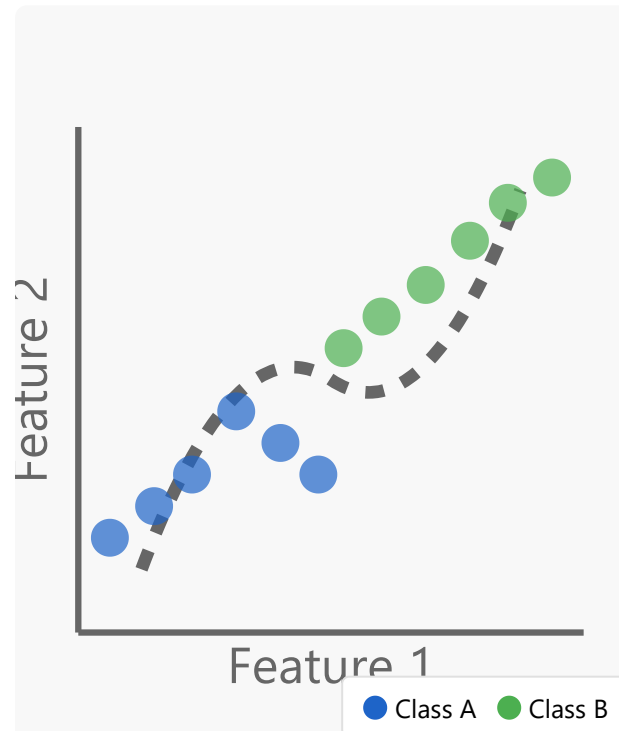
Understanding How Features Jointly Affect Target

Scatter Plot Matrix



All pairwise relationships

Interaction Plot



Non-linear decision boundary

Methods

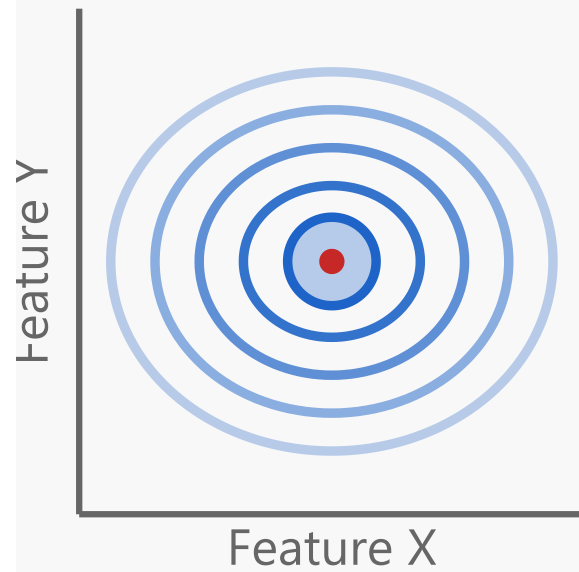
- Pairplot: All relationships
- Interaction: Joint effects
- Contour: Response surface
- Conditional: Fixed features

Key Insights

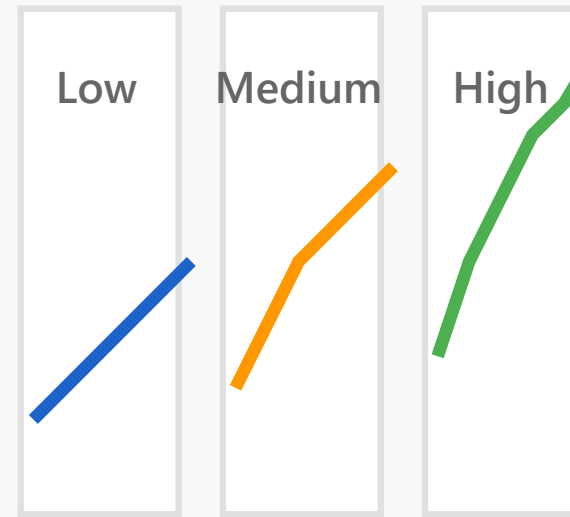
- ▶ Color-encode target variable
- ▶ Reveal discriminative patterns

Contour Plot

Conditional Plot



Response surface visualization



Fixed feature conditions

- ▶ Identify non-linear interactions
- ▶ Feature crosses for new space

✓ Best Practices

- ✓ Use stratification
- ✓ Separate by categories
- ✓ Explore feature crosses
- ✓ Catch what linear models miss

Dimensionality Reduction: PCA, t-SNE, UMAP

Projecting High-Dimensional Data to 2D

PCA

t-SNE

UMAP



Comparison



PCA

- Linear, interpretable
- Fast, deterministic



t-SNE

- Non-linear, local focus
- Perplexity: 5-50



UMAP

- Faster than t-SNE
- Local + global



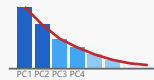
Cautions

- ▶ 2D projections lose info
- ▶ Can create false patterns
- ▶ Validate with multiple methods

✓ Best Practices

- ✓ Color by class labels
- ✓ Try continuous variables
- ✓ Combine with clustering
- ✓ Use scree plot for PCA

PCA Scree Plot: Explained Variance Ratio



Linear Projection

Non-linear

Balanced

Maximizes variance

Preserves local structure

Local + global structure

Model Performance: Learning Curves

Diagnosing Bias-Variance Tradeoff

Underfitting

Overfitting

Good Fit

Diagnosis

Underfitting

- Model too simple
- Add complexity/features

Overfitting

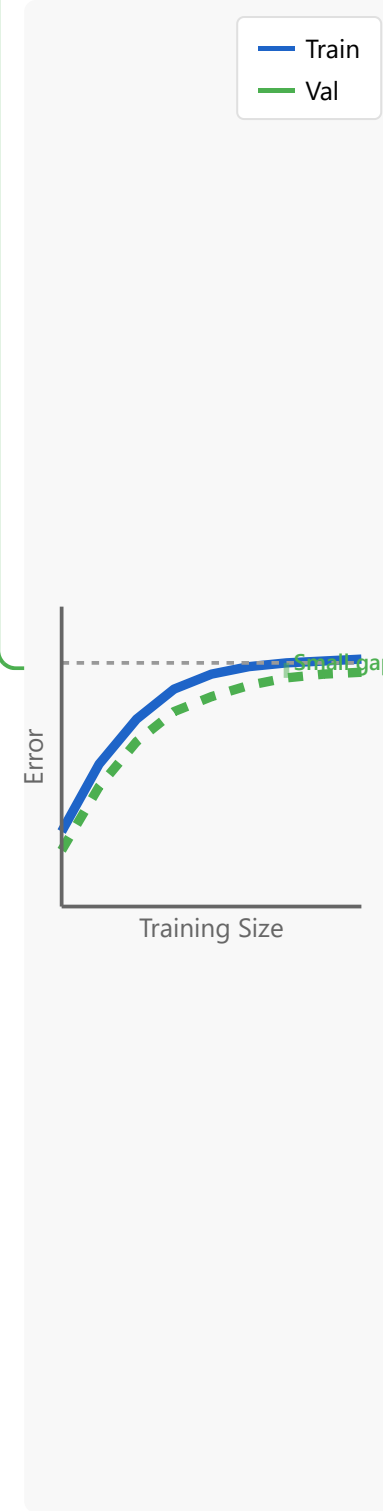
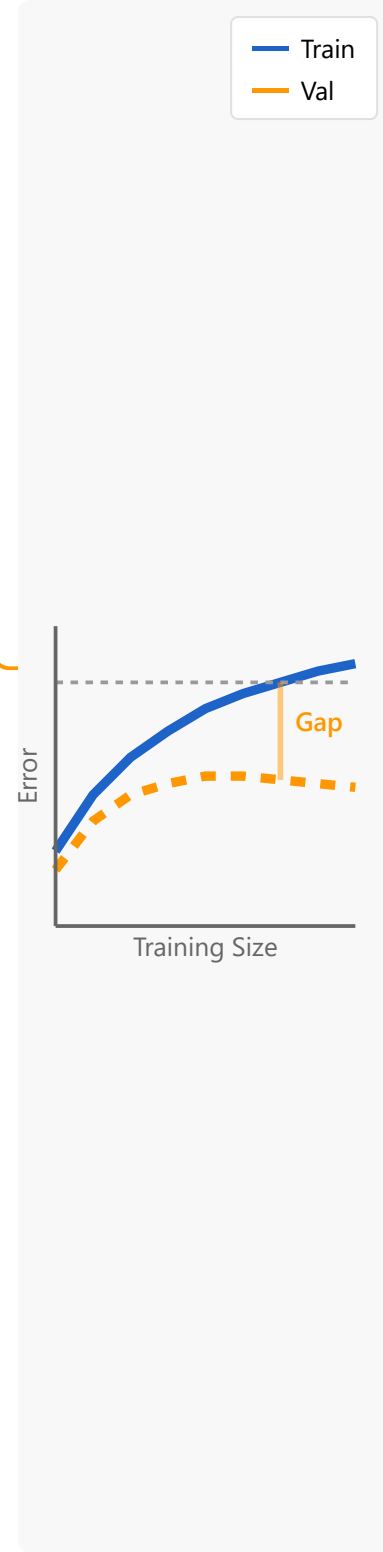
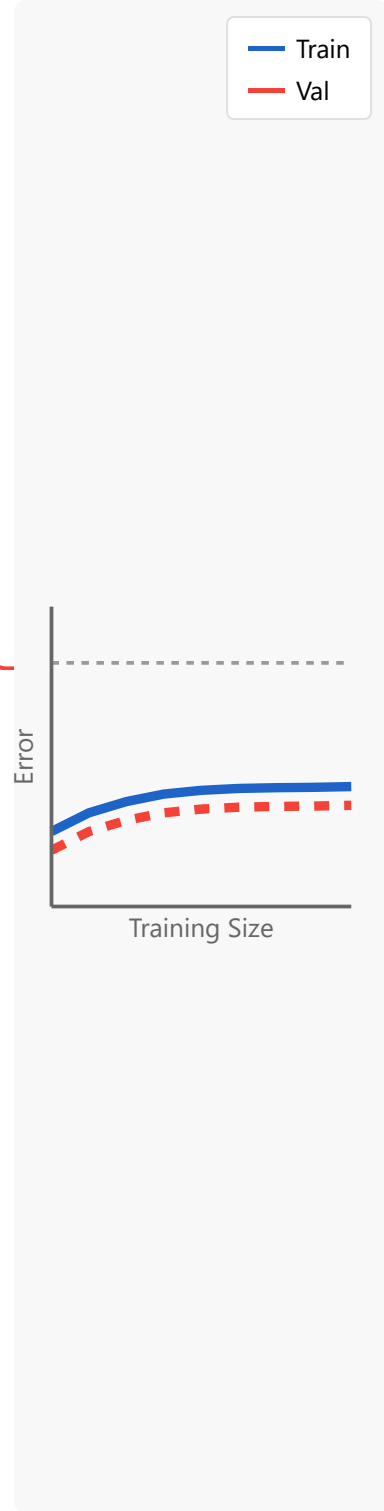
- More data helps
- Add regularization

Good Fit

- Balanced complexity
- Near optimal performance

What to Plot

- ▶ Loss curves



- ▶ Accuracy / F1
- ▶ Confidence intervals
- ▶ Convergence monitoring

- ✓ **Best Practices**
- ✓ Use cross-validation
 - ✓ Plot multiple metrics
 - ✓ Monitor early stopping
 - ✓ Compare train/val gap

High Bias

Both plateau at poor performance

High Variance

Large gap between curves

Well-Balanced

Curves converge near optimal

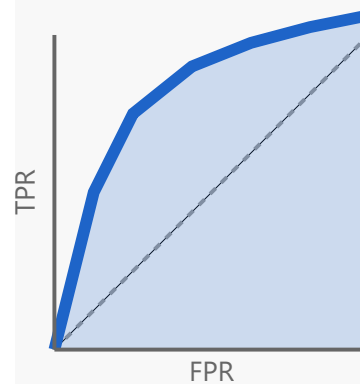
Classification Model Evaluation

Confusion Matrix, ROC, and Precision-Recall Curves

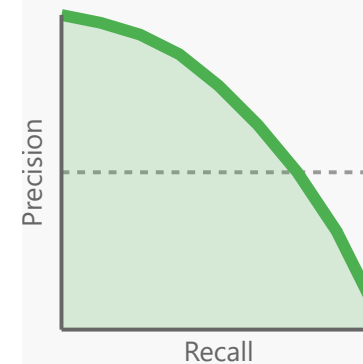
Confusion Matrix

Actual	85 TP	10 FP
	15 FN	90 TN

ROC Curve



PR Curve



Metrics

Confusion Matrix

- TP, FP, FN, TN
- Normalize by row/col

ROC Curve

- Balanced classes
- AUC summarizes

PR Curve

- Imbalanced data
- Focus on positive



When to Use

Predicted

Prediction outcomes grid

Accuracy: 87.5%

TPR vs FPR

AUC: 0.92

Precision vs Recall

AP: 0.88

- ▶ ROC: balanced classes
- ▶ PR: imbalanced datasets
- ▶ CM: detailed breakdown

✓ Best Practices

- ✓ Compare models
- ✓ Select threshold
- ✓ Balance P & R by cost
- ✓ Multi-class: one-vs-rest

Regression Evaluation: Residuals & Diagnostics

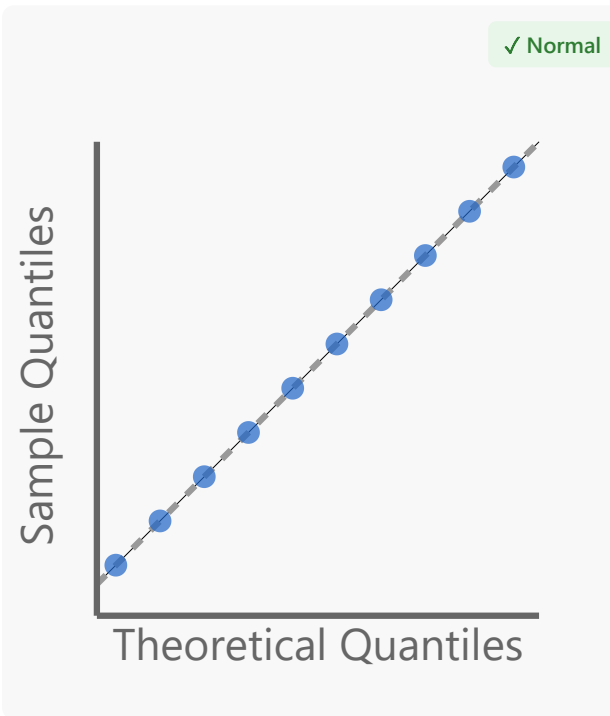
Checking Model Assumptions and Fit Quality

Residuals vs Fitted



Random scatter = good fit

Q-Q Plot (Residuals)



Points on line = normality

✓ Good Signs

Residuals

- Random scatter
- Zero mean

Q-Q Plot

- Points on diagonal

Scale-Location

- Horizontal band

Pred vs Actual

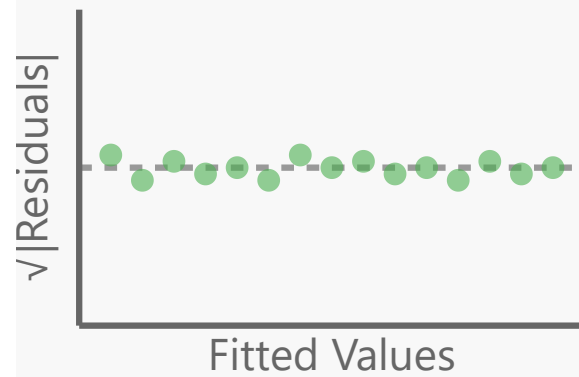
- Points near diagonal

Scale-Location

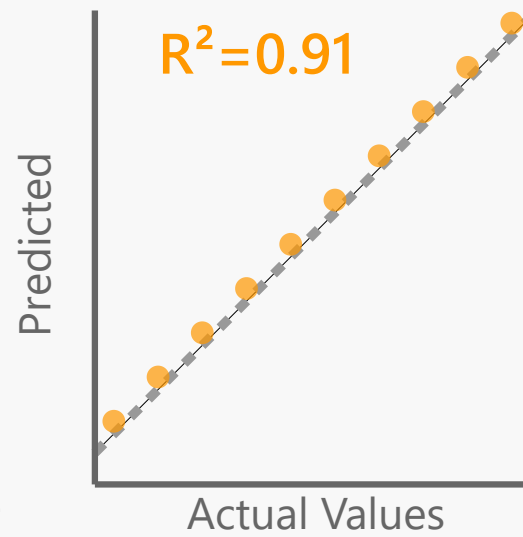
Predicted vs Actual

⚠ Warning Signs

- ▶ Patterns → model issues
- ▶ Funnel → heteroscedasticity



Constant variance



Close to diagonal = good

- ▶ Curved → non-linearity
- ▶ Q-Q deviates → non-normal

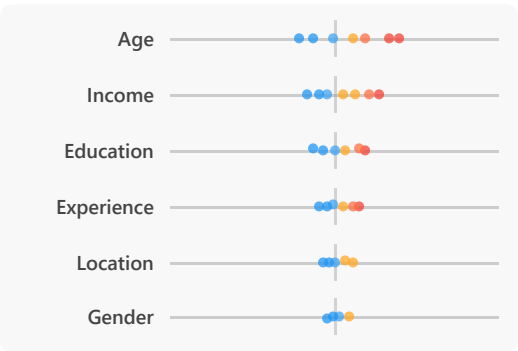
✓ Best Practices

- ✓ Check all 4 plots
- ✓ Look for patterns
- ✓ Identify influential points
- ✓ Transform if needed

Model Interpretation Methods

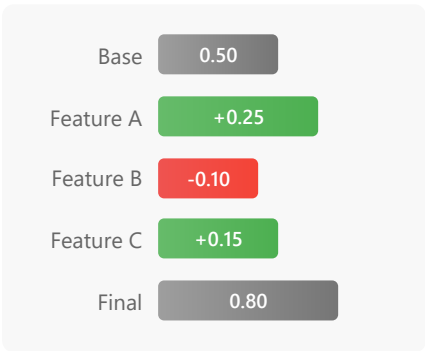
SHAP, LIME & Attention Mechanisms

SHAP Summary Plot



Feature importance ranking

SHAP Waterfall



Individual contribution

Methods

SHAP

- Game-theory based
- Global + local

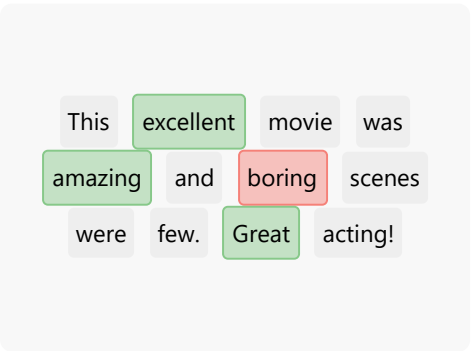
LIME

- Model-agnostic
- Local perturbation

Attention

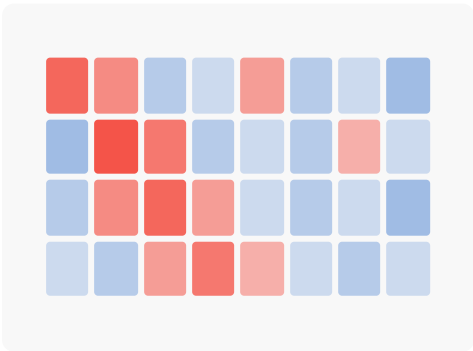
- Built-in mechanism
- Text/image focus

LIME Explanation



Local linear approximation

Attention Heatmap



Model focus visualization

Scope

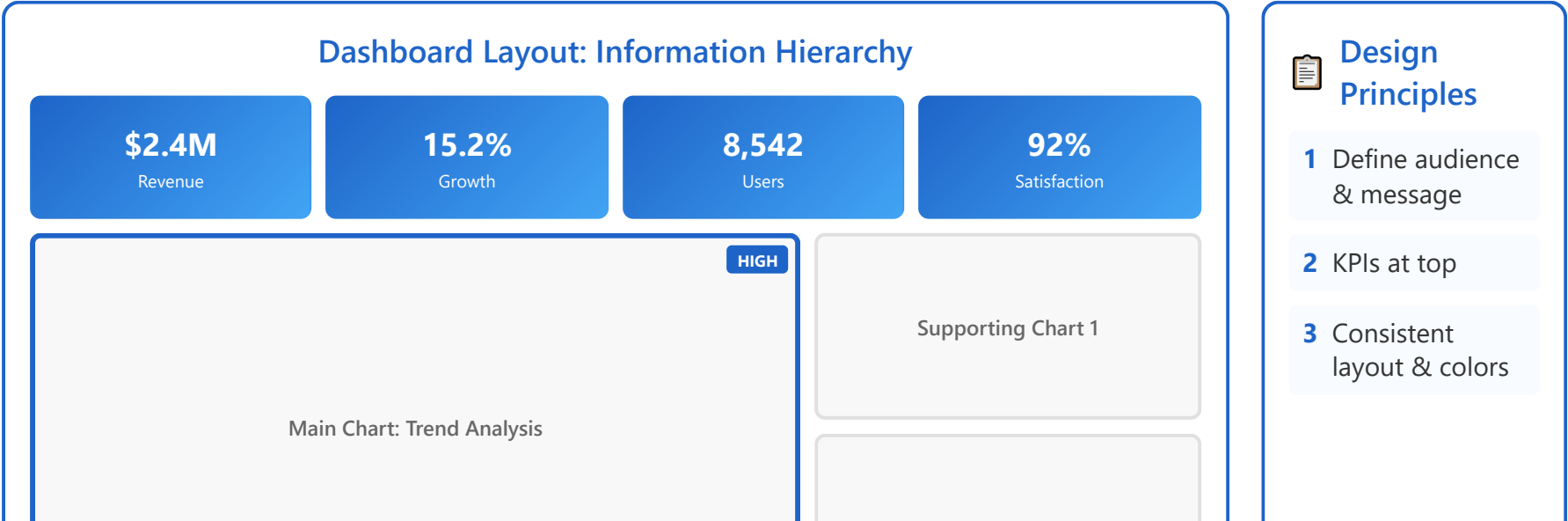
SHAP	Global/Local
LIME	Local only
Attention	Instance-level

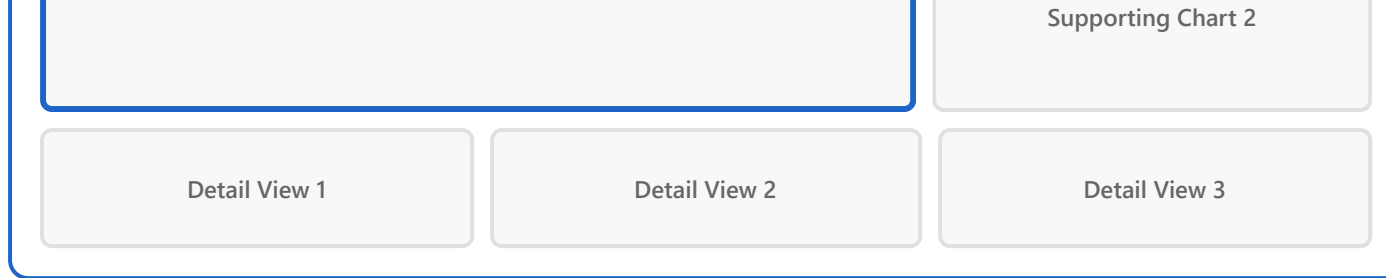
✓ Best Practices

- ✓ Use SHAP for importance
- ✓ LIME for quick insights
- ✓ Attention for NLP/vision
- ✓ Compare with PDP

Dashboard Design & Storytelling

Information Hierarchy and Narrative Structure





4 Progressive disclosure

Interactive Elements

- ▶ Filters
- ▶ Drill-downs
- ▶ Hover details
- ▶ Dynamic updates

✓ Best Practices

- ✓ Test with users
- ✓ Iterate based on feedback
- ✓ Measure engagement
- ✓ Keep it simple

Data Storytelling Structure



Thank you

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