Machine Learning-
Theory & Practice

Module 1: An Overview of Machine Learning

Lecture 3:

Theme: *Performance Issues*

Lecture Outline

Topic 1: Performance Perspectives

Topic 2: Sources & Types of Errors

Topic 3: Confusion Matrix

Topic 1: Performance Perspectives

Performance perspectives of stakeholders

End User

Exporter of mangoes

Low quality mangoes should not
be mis-classified as high quality mangoes

Stock Trader

The prediction should closely match the
real variations in stock values

Librarian

Online research papers on ML should
be segregated from research papers on COVID

Online recommendation system

Predictions should evolve as
customers' tastes change over time

ML System Developer

 Classification: Maximize ratio of True
Positives to False Positives

 Regression: Maximize match
between the *Variances* in actual stocks
data and predictions

 Clustering: Maximize cohesiveness of
books clustered together &
maximize distance between clusters

 Real Time system: Reinforcement learning
- maximize short term rewards and long term
rewards

System Architect's perspective

- Aim: Maximize overall system performance by reducing data acquisition time and training time

- Concern 1: How much data is required for acceptable performance?
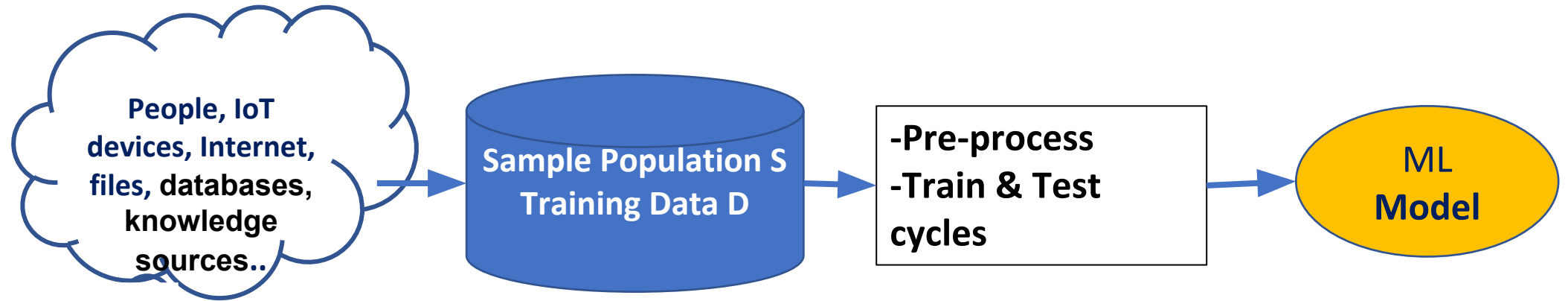
- Concern 2: Will training time be excessive?

  COMPUTATIONAL LEARNING THEORY

- Decisions: What sources should data be collected from? Should the system be parallelized / distributed?

Topic 2: Sources & Types of Errors

Sources of Errors

People, IoT devices, Internet, files, databases, knowledge sources..

Sample Population S Training Data D

-Pre-process
-Train & Test cycles

ML Model

1. NOISE
Environmental errors
Human Errors
Transmission Errors

DATA ERRORS
-Erroneous values
-Missing values
-Redundant Data
-Not desired form

2. TRAINING & TESTING ERRORS

Mean Squared Error

- **Consider one random data point (X$_i$,y$_i$) in sample space S**
  Prediction Error due to one piece of training data is

$$e_i = \widehat{y}_i - y_i$$

  Mean Prediction Error over S:

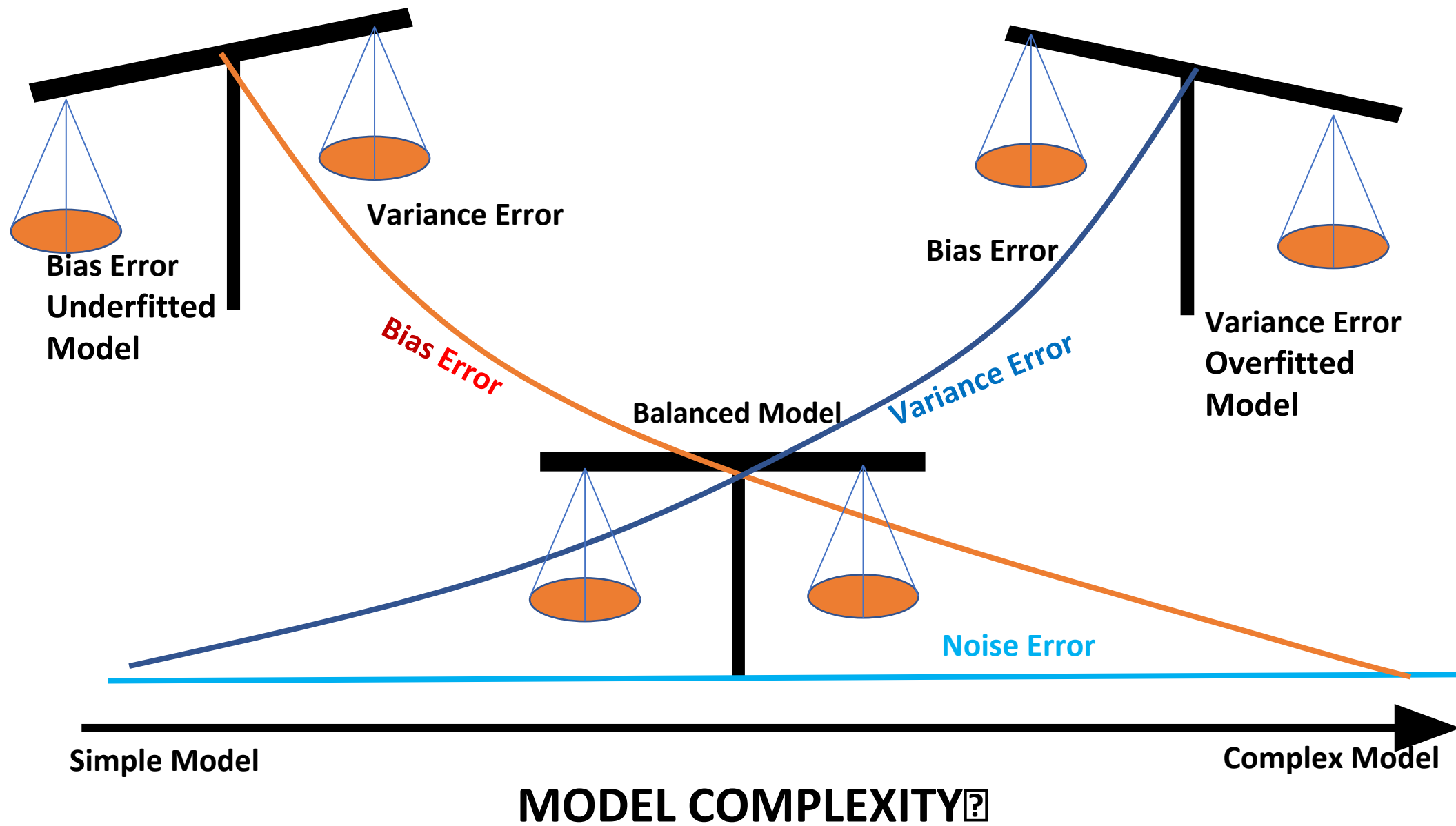$$\bar{e} = Exp_S[e] = \frac{1}{n}\sum_{i=1,n} e_i$$

  Mean Squared Error is:

$$\overline{e^2} = Exp_S[e^2] = \frac{1}{n}\sum_{i=1,n} e_i^2$$

Components of MSE - Variance and Bias Errors
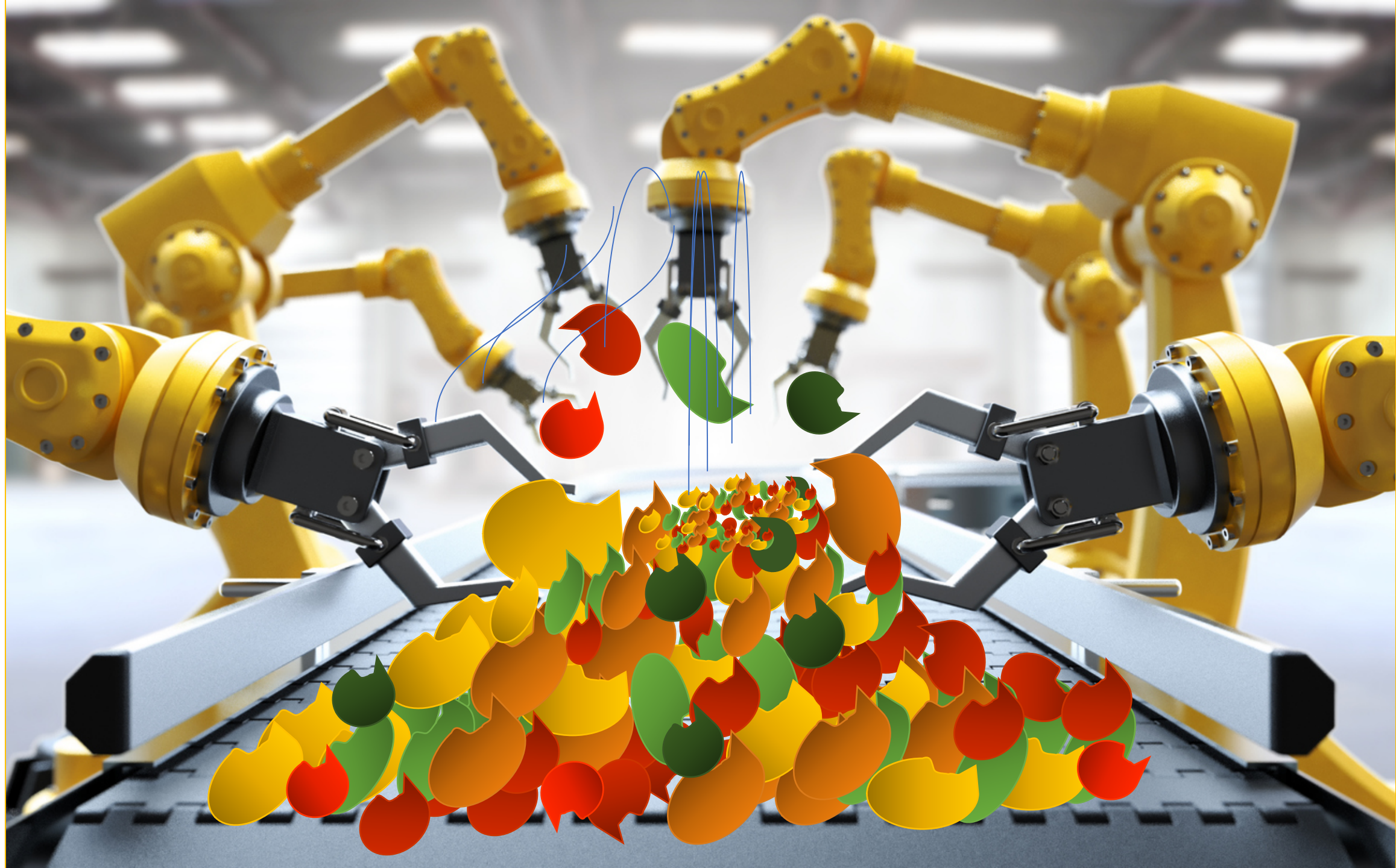
The Variance in Prediction Error is:

Mean Squared Error =
Variance in Error + Constant Bias Error + Noise

Bias Error
Underfitted
Model

Variance Error

Bias Error

Bias Error

Variance Error

Variance Error
Overfitted
Model

Balanced Model

Noise Error

Simple Model

Complex Model

MODEL COMPLEXITY

Topic 3: Confusion Matrix

Confusion Matrix

Ground Truths↓ Predictions→	Actual Alphanso	Actual Chausa	Actual Totapuri	Actual Dushehri
Predicted Alphanso	True Positive	False Positive	False Positive	False Positive
Predicted Chausa	False Negative	True Negative	True Negative	True Negative
Predicted Totapuri	False Negtiative	True Negative	True Negative	True Negative
Predicted Dusheri	False Negative	True Negative	True Negative	True Negative

Confusion Matrix

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Predicted Chausa	True Negative	False Negative	True Negative	True Negative
Predicted Totapuri	True Negative	False Negtiative	True Negative	True Negative
Predicted Dusheri	True Negative	False Negative	True Negative	True Negative

Confusion Matrix parameters

	Actual Class 1	Actual Class 2	
Predicted Class 1	**True Positive TP 20**	**False Positive FP 56**	76
Predicted Class 2	**False Negative FN 44**	**True Negative TN 78**	122
	64	134	

$$\text{TPR} = \frac{TP}{TP+FN} = \frac{20}{64}$$

$$\text{TNR} = \frac{TN}{FP+TN} = \frac{78}{134}$$

$$\text{FNR} = \frac{FN}{TP+FN} = \frac{44}{64}$$

$$\text{FPR} = \frac{FP}{FP+TN} = \frac{56}{134}$$

Performance Metric: Accuracy

	Actual True	Actual False
Predicted True	True Positive TP	**False Positive FP**
Predicted False	**False Negative FN**	True Negative TN

$$Accuracy = \frac{TP + TN}{TP + FP + FN + TN}$$
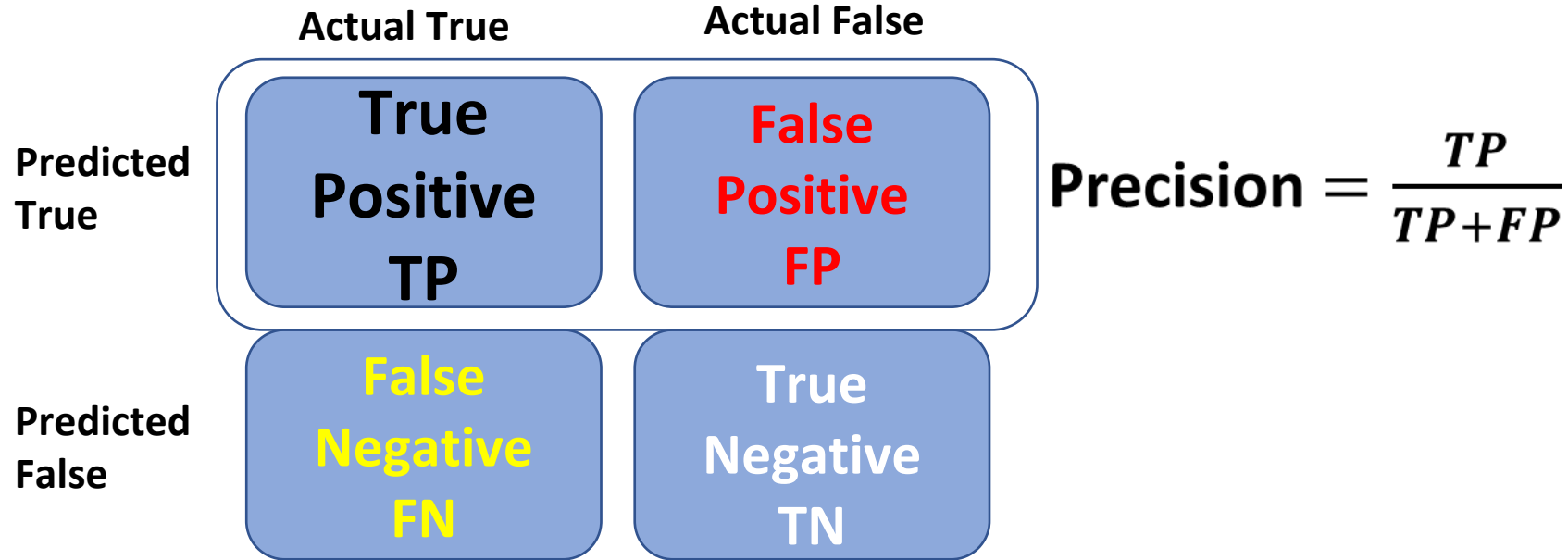
Indicates aggregate performance of the system

Recall

	Actual True	Actual False
Predicted True	**True** **Positive** **TP**	**False** **Positive** **FP**
Predicted False	**False** **Negative** **FN**	**True** **Negative** **TN**

$$Recall\ or\ Sensitivity\ or\ True\ Positive\ Rate\ or\ Hit\ Rate = \frac{TP}{TP + FN}$$

-Profit Motive in Business: No Alphanso should be missed

-Medical treatment: All COVID affected people should be identified during screening

Precision

Actual True   Actual False

Predicted True

| True Positive TP | False Positive FP |

Predicted False

| False Negative FN | True Negative TN |

$$\text{Precision} = \frac{TP}{TP+FP}$$

-Quality Objective in business: No Chousa should creep into a box of Alphansos to be exported.
-Medical: People not having cancer should not be falsely diagnosed.

Specificity

	Actual True	Actual False
Predicted True	**True Positive TP**	**False Positive FP**
Predicted False	**False Negative FN**	**True Negative TN**

$$Specificity\ or\ True\ Negative\ Rate = \frac{TN}{TN + FP} = 1 - \frac{FP}{TN + FP} = 1 - FPR$$

-Secondary Decision: How many non-Alphansoes can be sold in local market?

-How many people do not test COVID +ve?

Recall and Precision Tradeoff
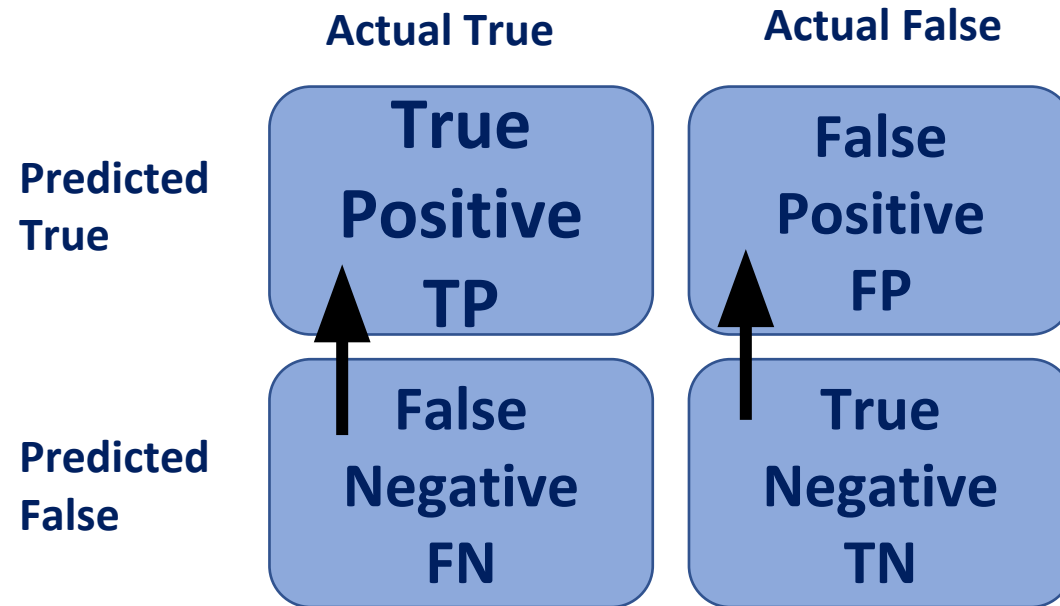
F1 Measure

- Harmonic Mean of Recall and Precision
- Gives a good overall balance between Recall and Precision

$$F1 = \frac{1}{\frac{1}{2}\left(\frac{1}{Recall} + \frac{1}{Precision}\right)} = 2 \times \frac{Recall \times Precision}{Recall + Precision}$$

$$F1 = \frac{TP}{TP + \frac{1}{2}(FN + FP)}$$

Multiclass Average Metrics

$$Microaveraged\ Recall = \frac{\sum_i TP}{\sum_i TP + \sum_i FN}$$

$$Microaveraged\ Precision = \frac{\sum_i TP}{\sum_i TP + \sum_i FP}$$

Macro-averaged Metrics

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$$Macroaveraged\ Recall\ MR = \frac{1}{N} \sum_i \frac{TP_i}{TP_i + FN_i}$$

$$Macroaveraged\ Precision\ MP = \frac{1}{N} \sum_i \frac{TP_i}{TP_i + FP_i}$$

$$Macroaveraged\ F1 = Harmonic\ Mean\ (MR, MP)$$

IMBALANCED CLASSES

Actual Classes

	A	B	C	
A	5	90	8	103
B	1	30	10	41
C	2	20	25	47
	8	140	43	

Predicted Classes

Class	TP	FP	FN	Recall	Precision
A	5	98	3	0.625	0.048
B	30	11	110	0.214	0.731
C	25	22	18	0.581	0.532
Totals	60	131	131		

Macroaveraged Recall = 0.473

Microaveraged Recall = 60/(60+131)= 0.314

Macroaveraged Precision = 0.437

Macroaveraged F1 = $2*(0.437^{-1} + 0.473^{-1})^{-1} = 0.454$

Recap: Performance and errors

 Performance can be understood from the perspectives of user, software developer and system architect

 The components of Mean Squared Error are Variance error and Bias error that occur during training, and random noise

  Bias-Variance Tradeoff: A simple model underfits and gives bias error. A complex model overfits and gives variance error. A balanced model gives the least overall Mean Square Error

Recap: Confusion matrix

 Accuracy: What proportion of all cases are correctly predicted

 Recall: What proportion of given class are predicted correctly (+ve)

 Precision: What proportion of +ve predictions of a given class actually belong to that class

 Specificity: What proportion of another class are predicted -ve

 There is a tradeoff between Recall and Precision. F1 measure is harmonic mean of Recall and Precision

Recap: Microaveraged and Macroaveraged metrics

 For any Micro measure, first add the TP, TN, FP and FN for all classes, and then calculate it. The contribution of any given class is in proportion to its relative population strength.

 Macroaveraged performance metrics are averaged over all classes, with equal priority to each class.

IF YOU WANT TO CREATE ENDURING PRODUCTS,

BE PREPARED FOR TRADE-OFFS….