St. Michael's

Inspired Care.
Inspiring Science. | LKS-CHART

A Gentle Introduction to Advanced Analytics

Josh Murray

December 3rd, 2018

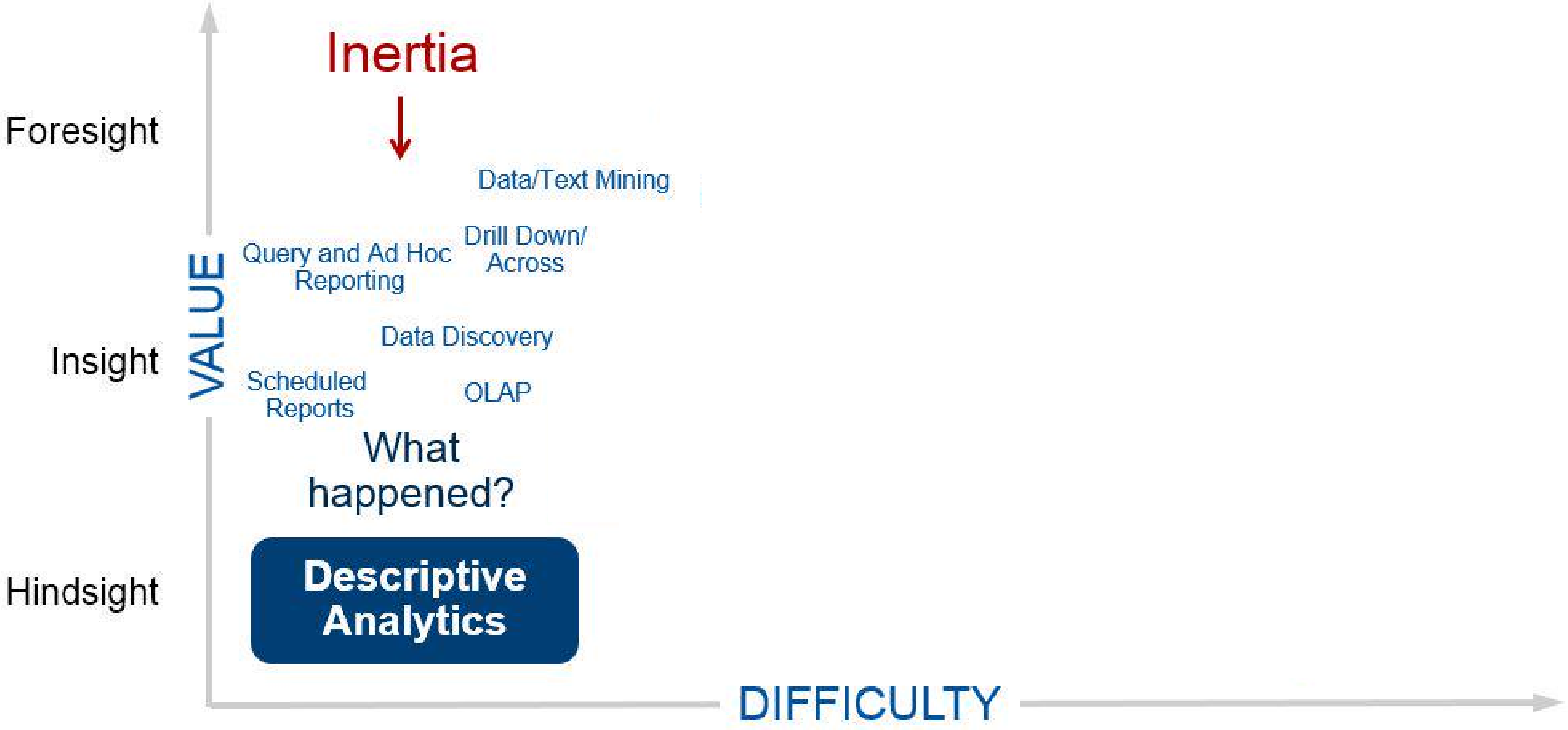
Overview

- The Analytics Continuum
- High level overview of Different analytical tools
  - From Descriptive to Prescriptive analysis
- Workflow for Advanced Analytics
  - CRISP DM
- What tools do we use

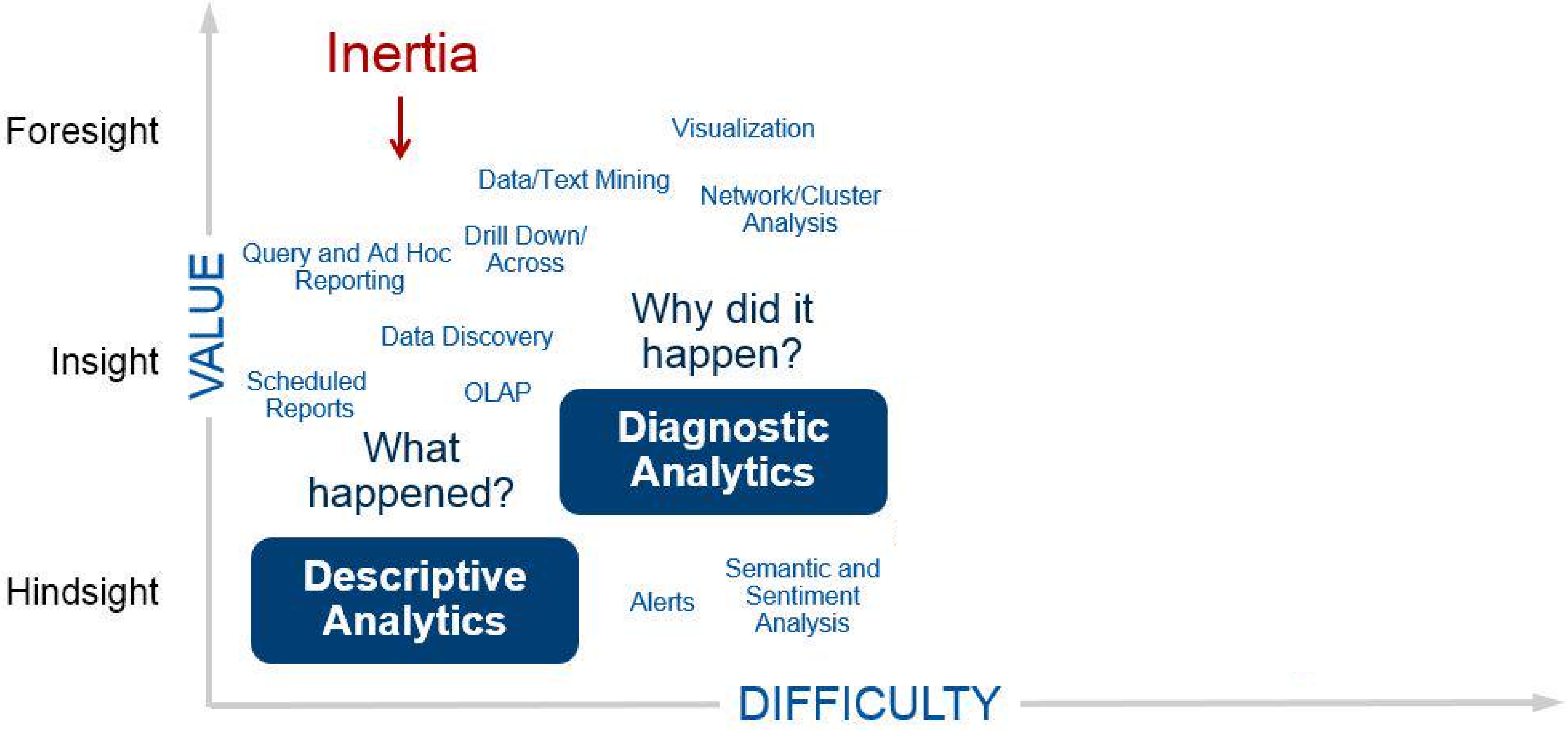
Let's dig in

```
class NeuralNetwork:
    def __init__(self, x, y):
        self.input      = x
        self.weights1   = np.random.rand(self.input.shape[1],4)
        self.weights2   = np.random.rand(4,1)
        self.y          = y
        self.output     = np.zeros(self.y.shape)
    def feedforward(self):
        self.layer1 = sigmoid(np.dot(self.input, self.weights1))
        self.output = sigmoid(np.dot(self.layer1, self.weights2))
    def backprop(self):
        # application of the chain rule to find derivative of the loss
  function with respect to weights2 and weights1
        d_weights2 = np.dot(self.layer1.T, (2*(self.y - self.output) *
  sigmoid_derivative(self.output)))
        d_weights1 = np.dot(self.input.T,  (np.dot(2*(self.y -
  self.output) * sigmoid_derivative(self.output), self.weights2.T) *
```

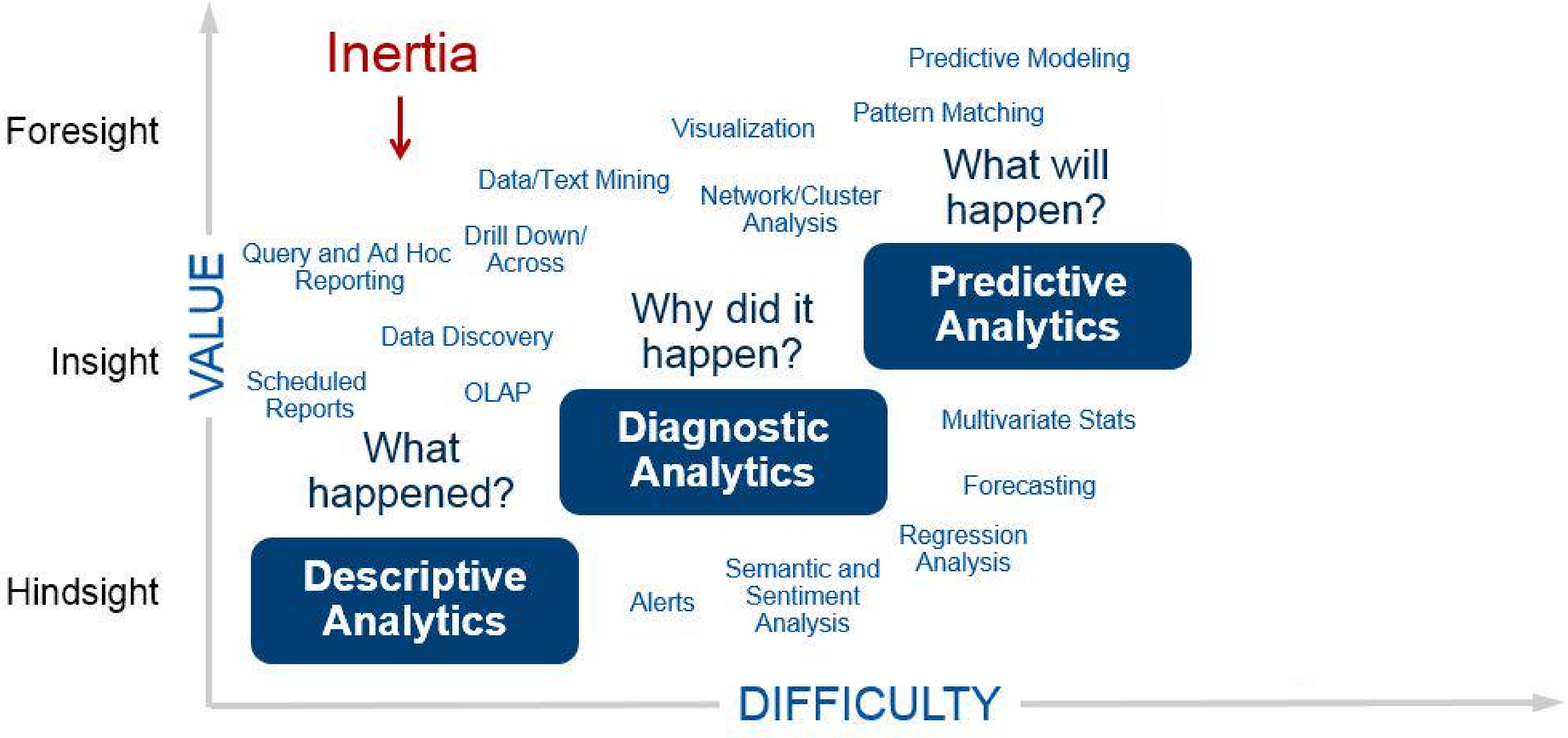
Gartner Analytic Continuum



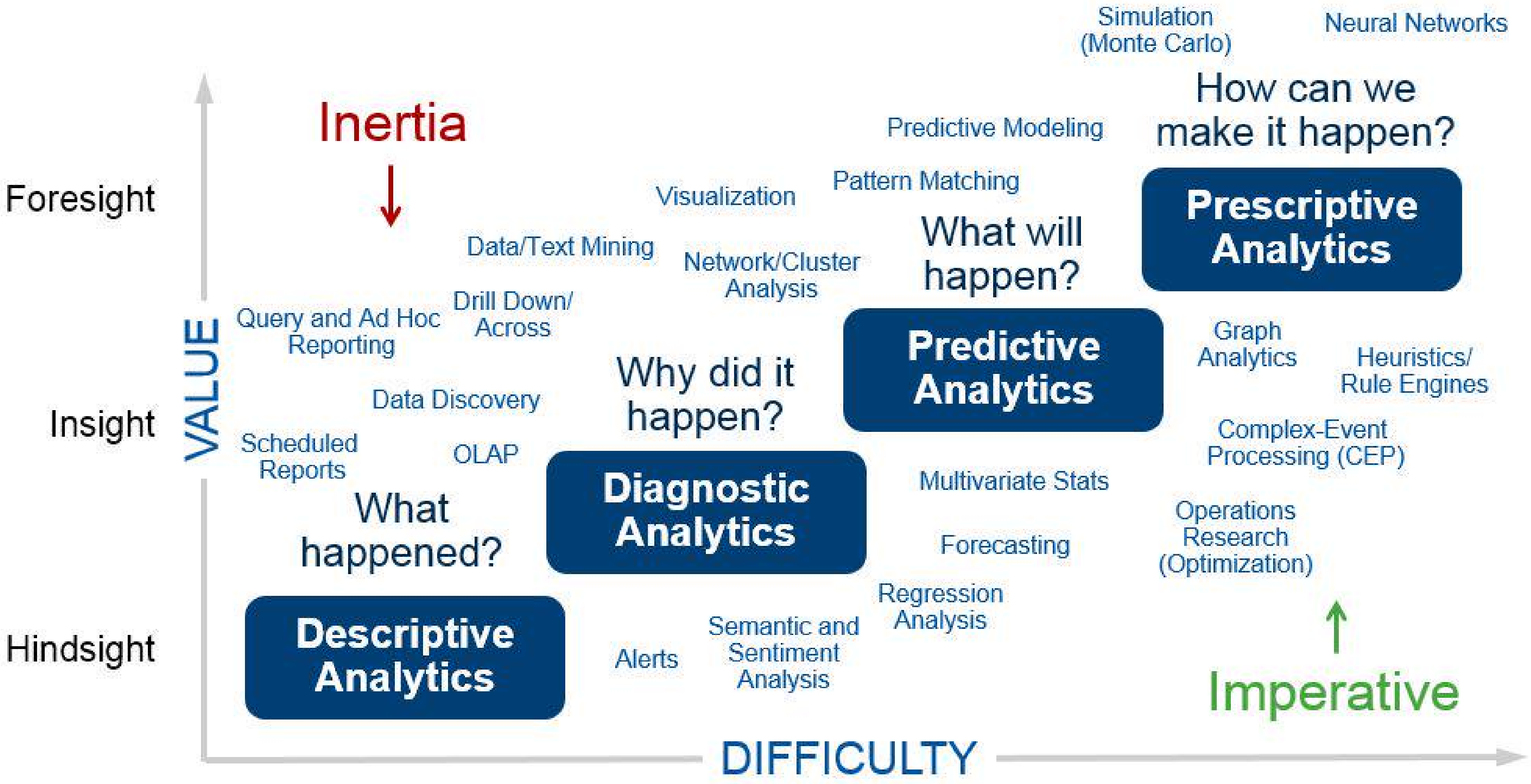
Gartner Analytic Continuum



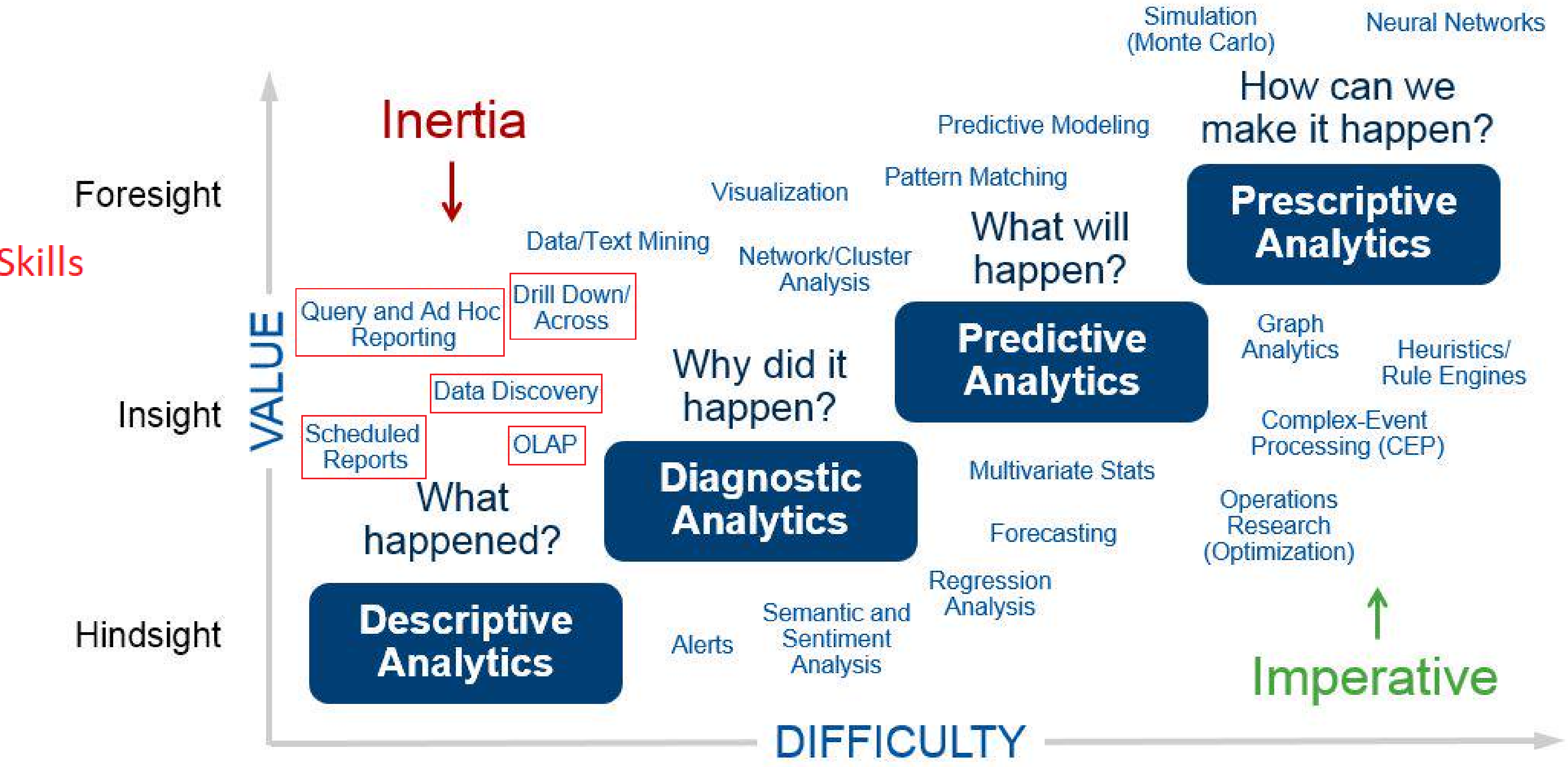
Gartner Analytic Continuum



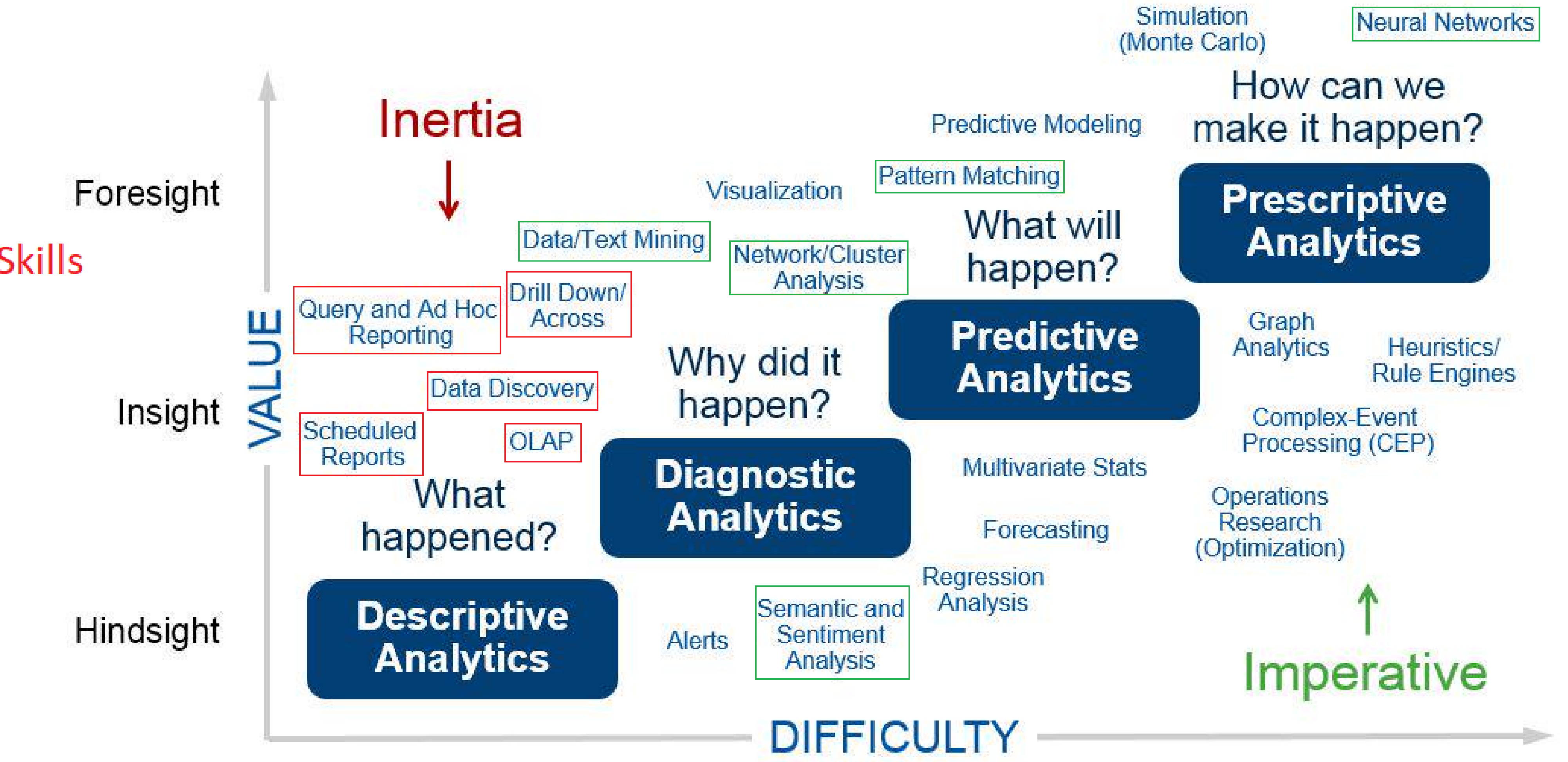
Gartner Analytic Continuum



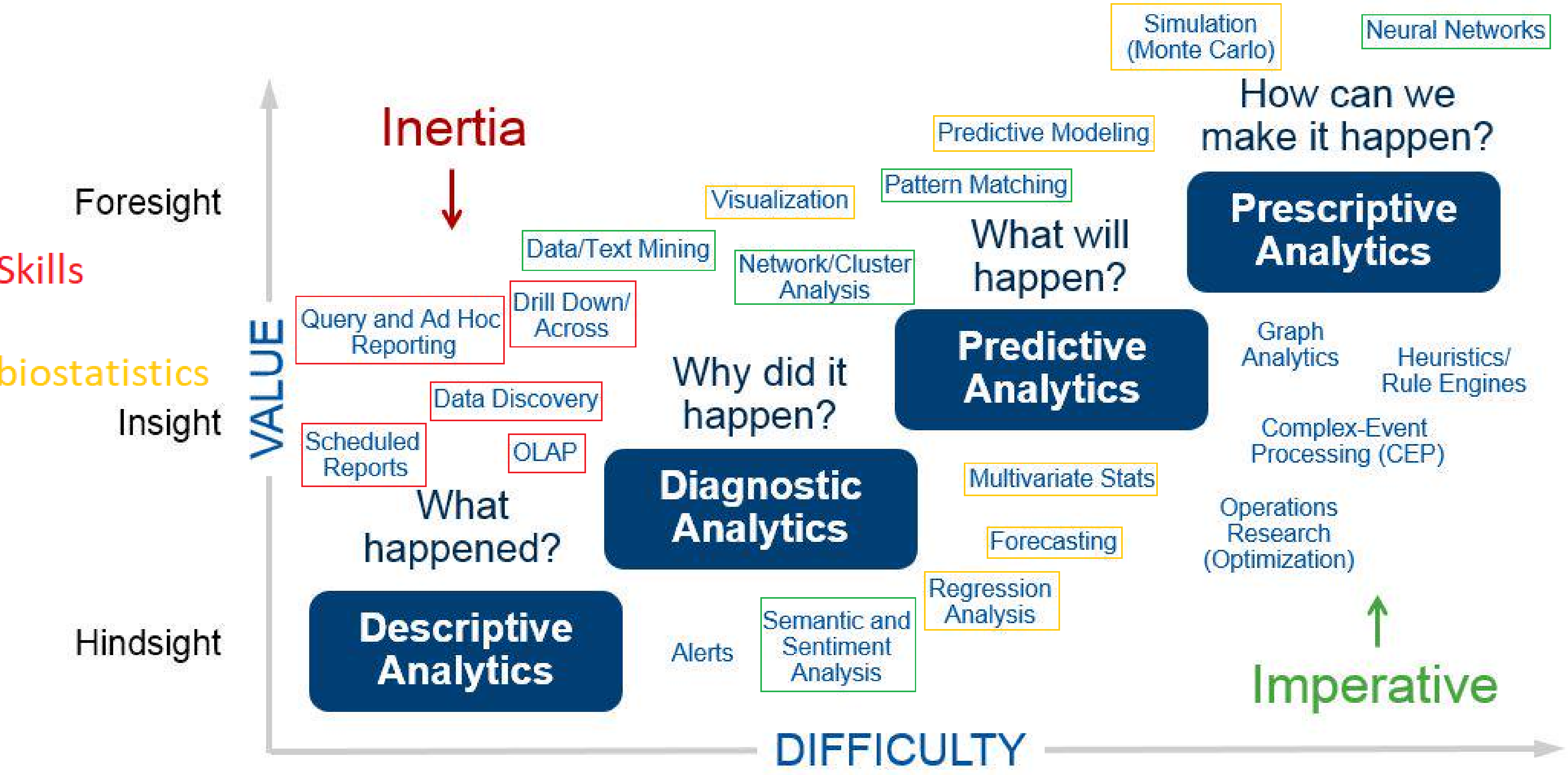
Gartner Analytic Continuum



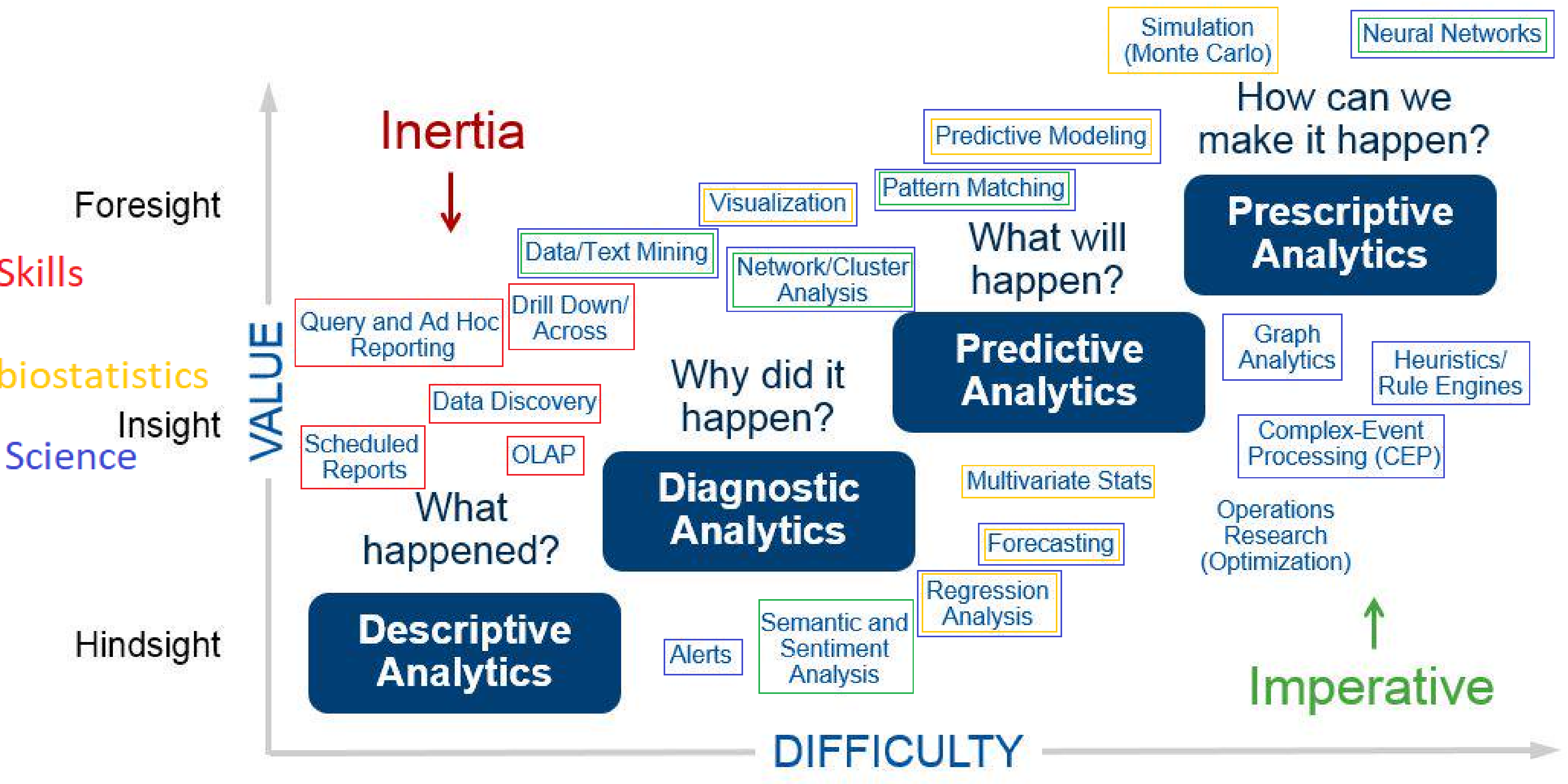
Gartner Analytic Continuum



Gartner Analytic Continuum



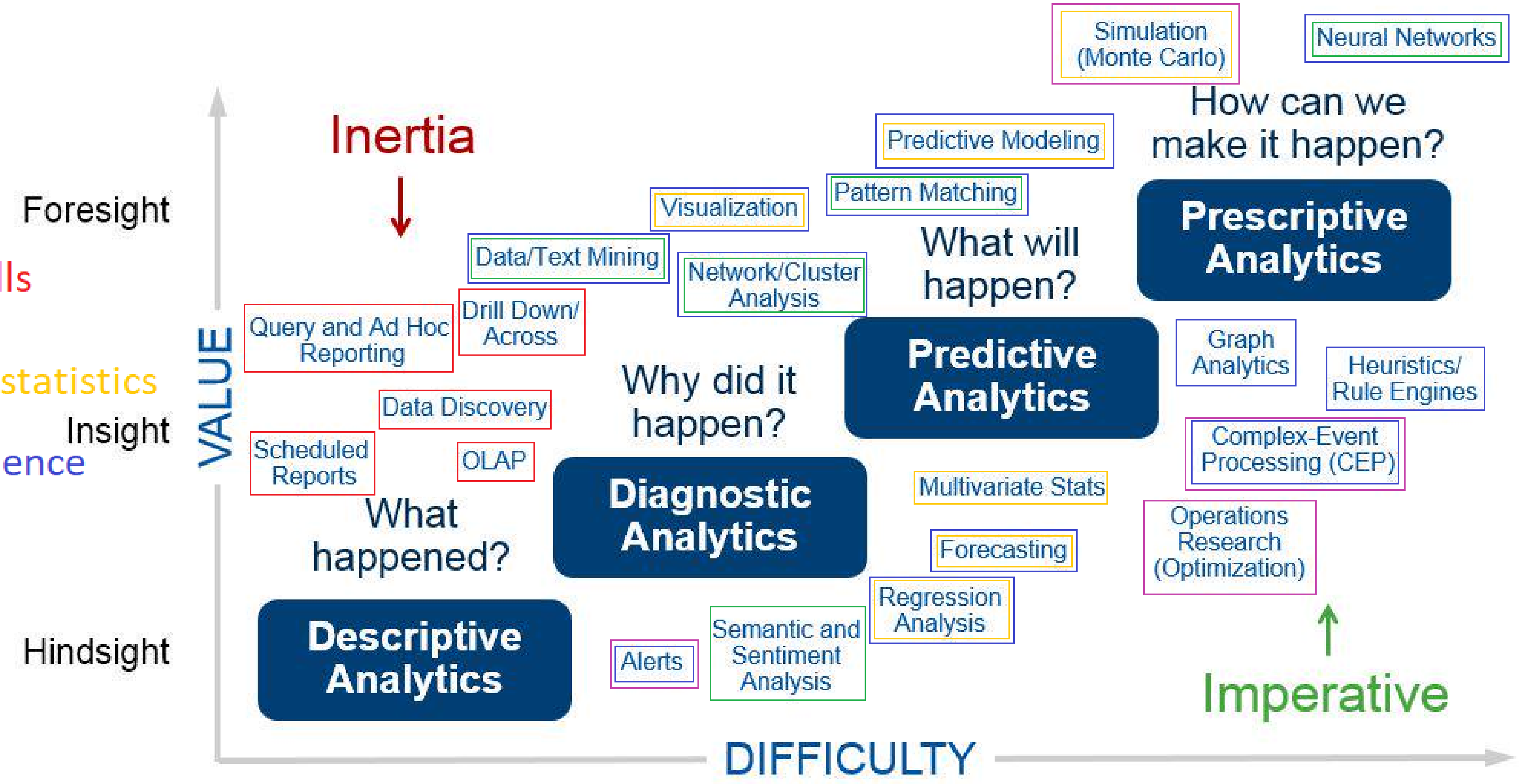
Gartner Analytic Continuum



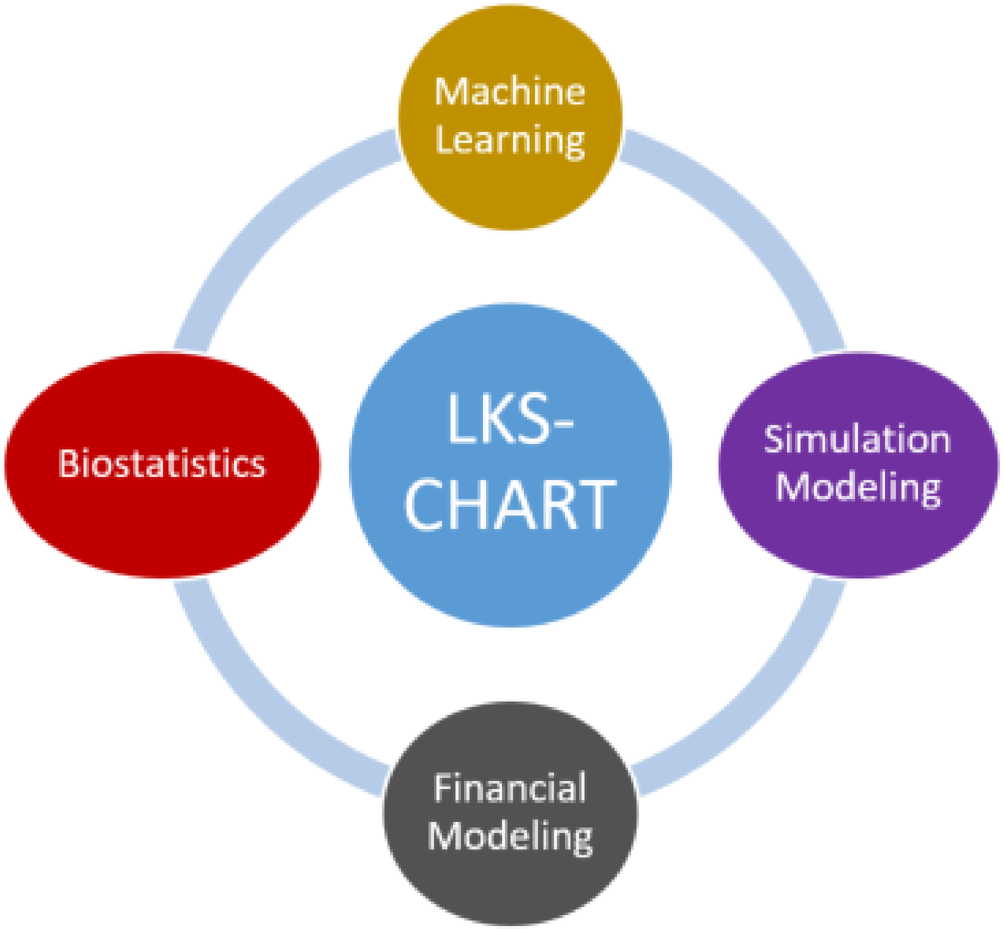
Ga

Gartner Analytic Continuum

Skills
biostatistics
Science
ng



The ideal data scientist



Machine Learning
Biostatistics
LKS-CHART
Simulation Modeling
Financial Modeling

David Dai
Jr. Data Scientist

Joshua Murray
Sr. Data Scientist

Neal Kaw
Sr. Data Scientist

Chloé Pou Prom
Sr. Data Scientist

Frank Rudzicz
Associate Scientist, Li Ka Shing Knowledge Institute

Marzyeh Ghassemi
Affiliate Scientist, LKS-CHART

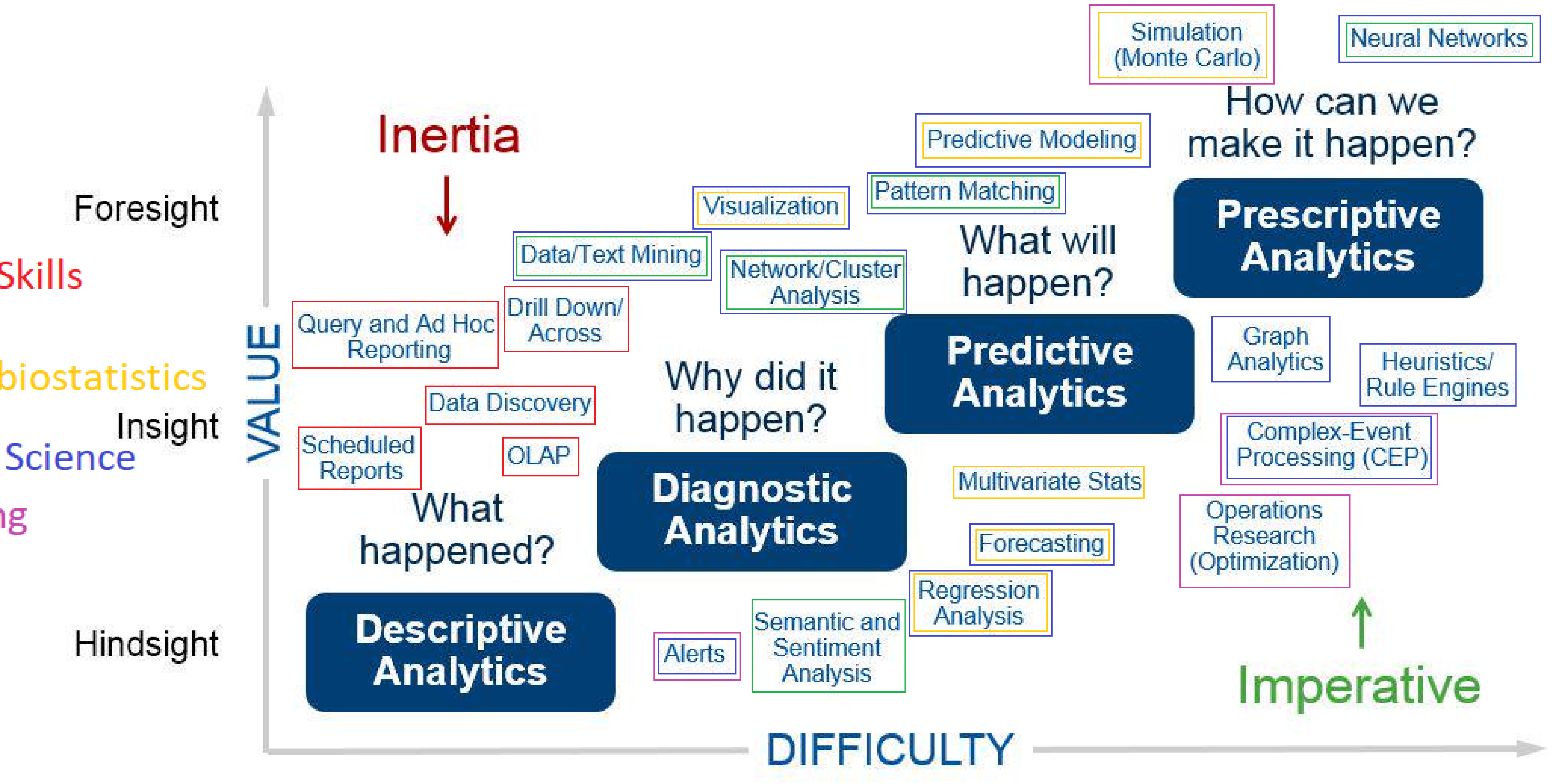
Michael Guerzhoy
Affiliate Scientist, LKS-CHART

Michaelia Young

Research Coordinator III

Brief tour of the analytics continuum

Gartner Analytic Continuum



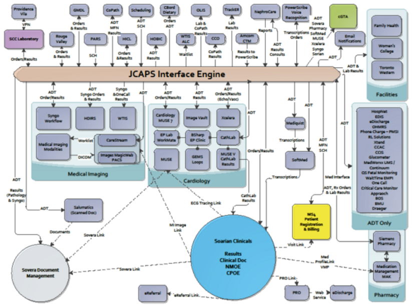
Data and Questions (Historical Paradigm)

Question

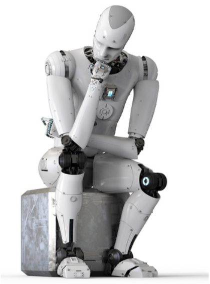
Data Collection

New Insights!!!

Data and Questions (Age of Cheap Data)



Existing Data Infrastructure

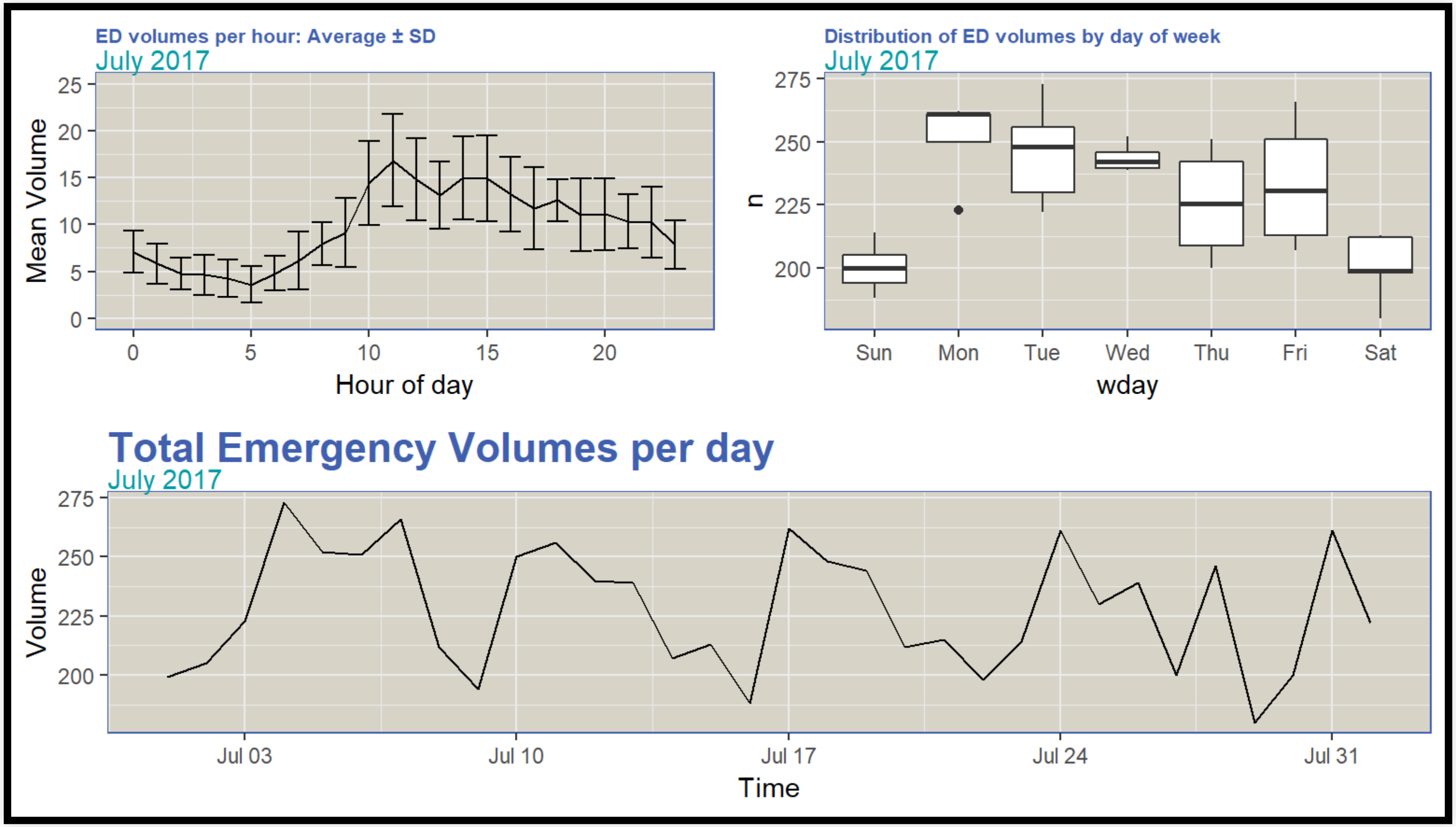


Questions

Insight!!!

What Are Descriptive Analyses?

- Descriptive analyses are the summarization of historical data.



Why are descriptive analyses useful?

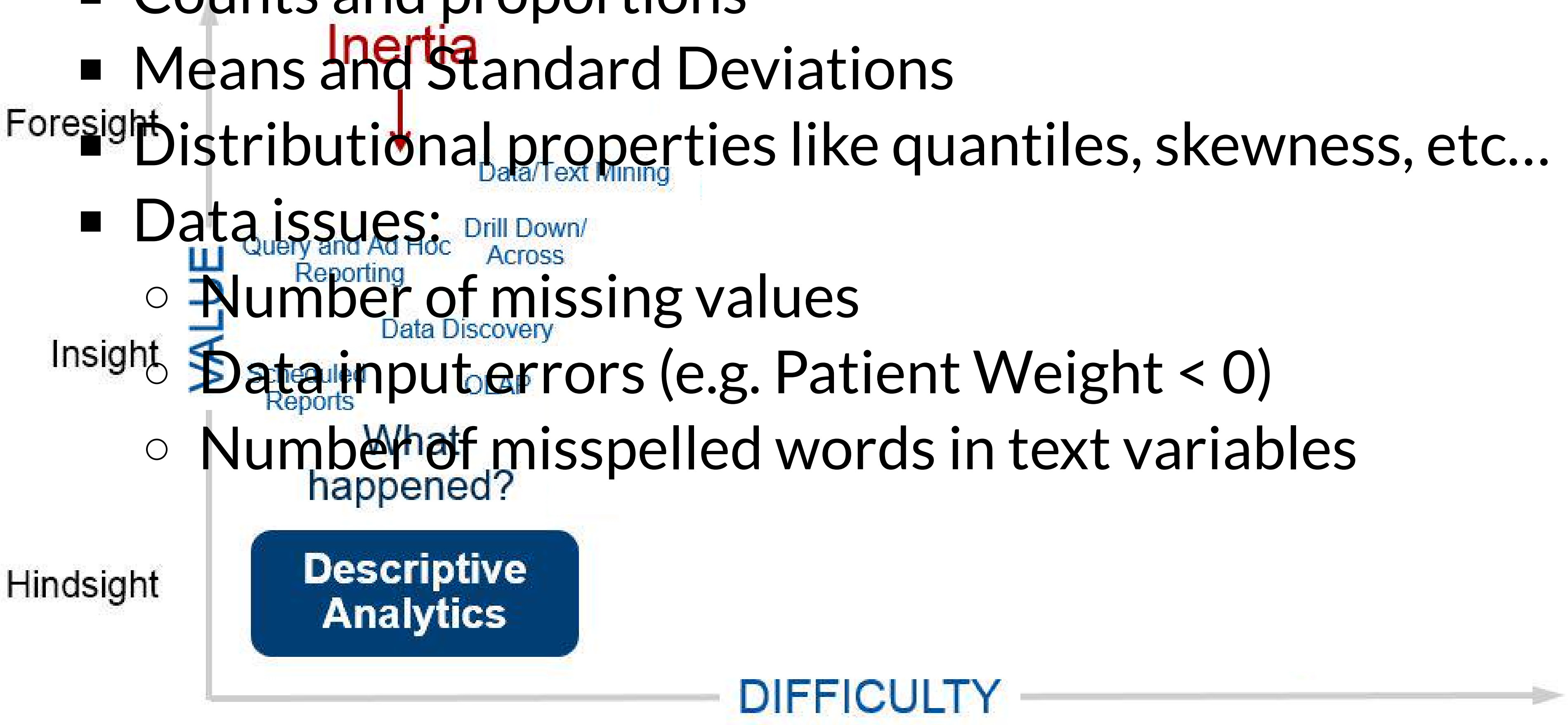
They help us:

1. Understand our data
2. Identify outliers and potential data issues
3. Identify baseline models (for prediction problems)
4. Answer historical data questions
   - What's the average LOS in the ED
   - On average, how many patients get transferred to the ICU per year
   - Have our Inpatient length of stays been increasing?
   - Which Physicians have the highest variance in outcomes?

Descriptive Analyses

- Summarizing data through:
  - Counts and proportions
  - Means and Standard Deviations
  - Distributional properties like quantiles, skewness, etc…
  - Data issues:
    - Number of missing values
    - Data input errors (e.g. Patient Weight < 0)
    - Number of misspelled words in text variables

Gartner Analytic Continuum



Diagnostic Analytics

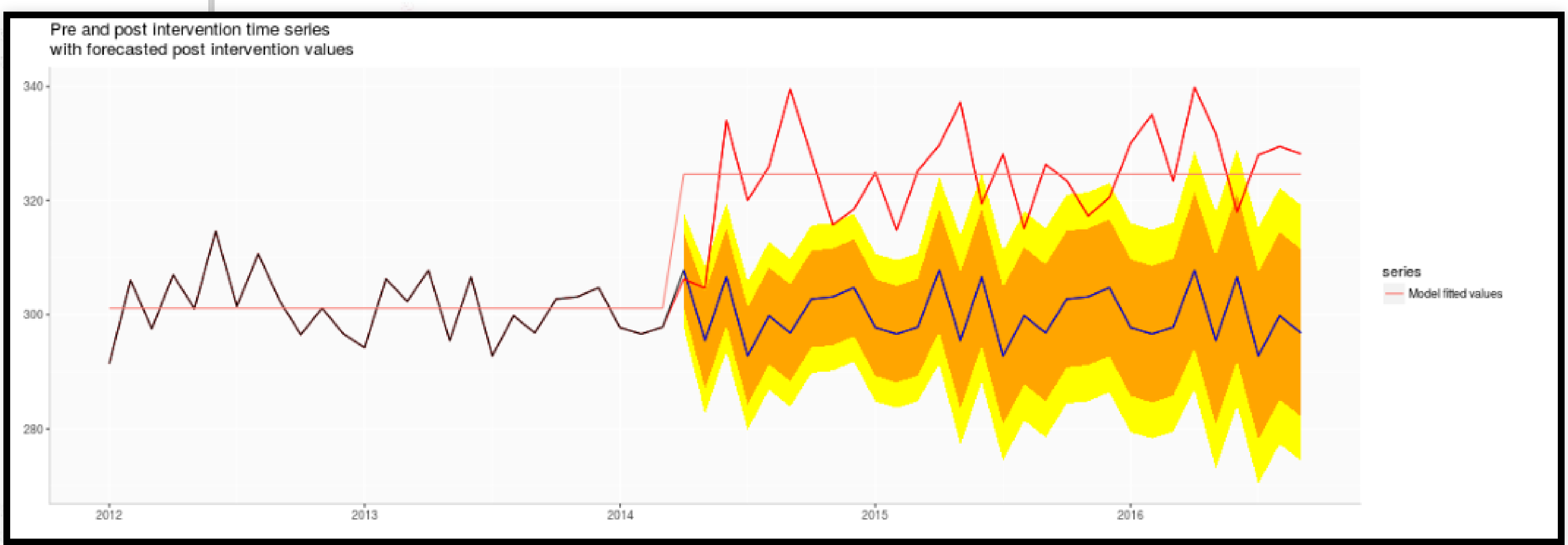
- Diagnostic analyses help us answer the question: “Why did it happen?”

Examples of Diagnostic Analytics?

Gartner Analytic Continuum

- Did our intervention in some clinic increase patient satisfaction

Inertia



Analytics

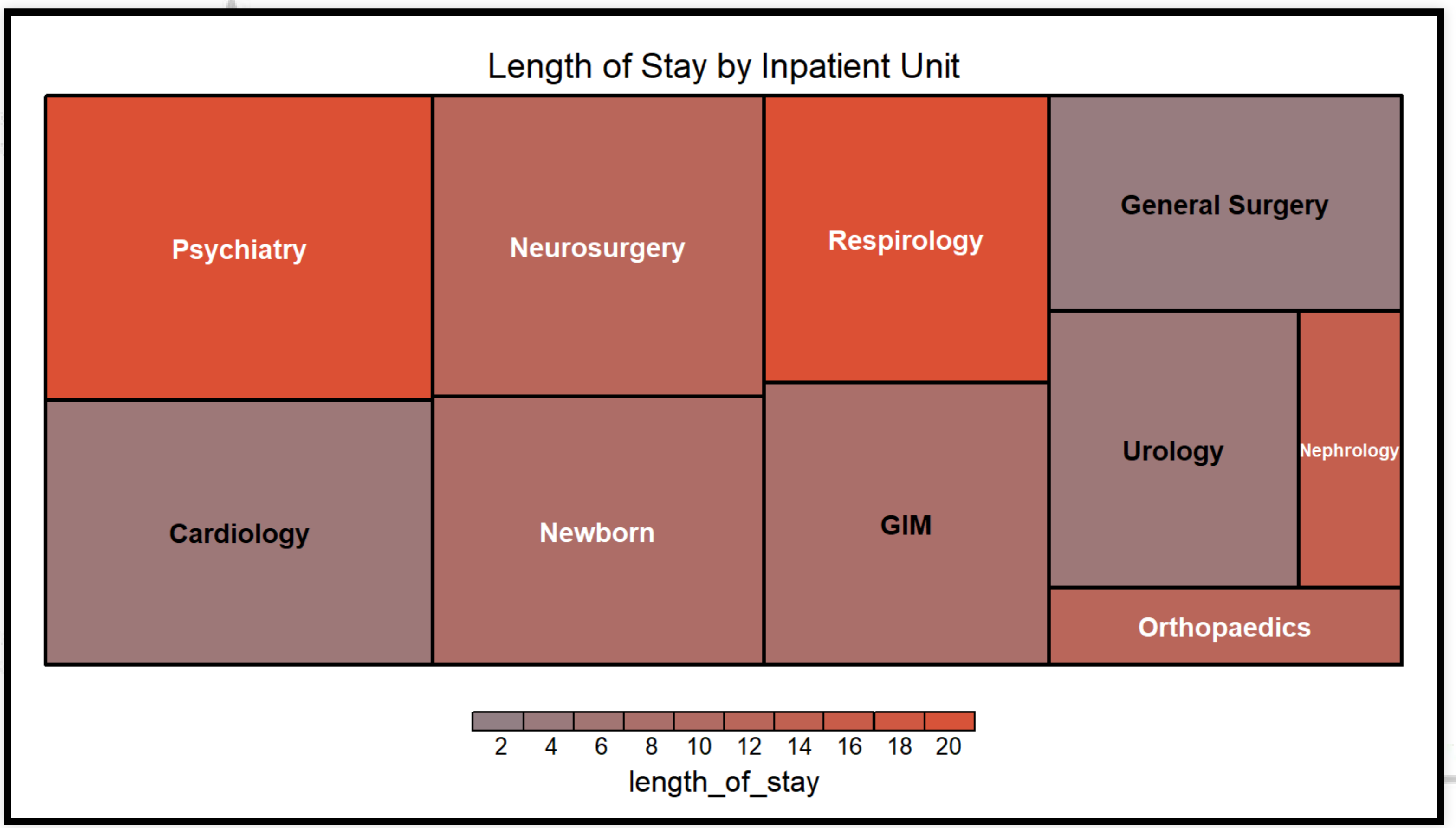
Analysis

DIFFICULTY

Gartner Analytic Continuum

Examples of Diagnostic Analytics?

- Which inpatient units are driving length of stay?

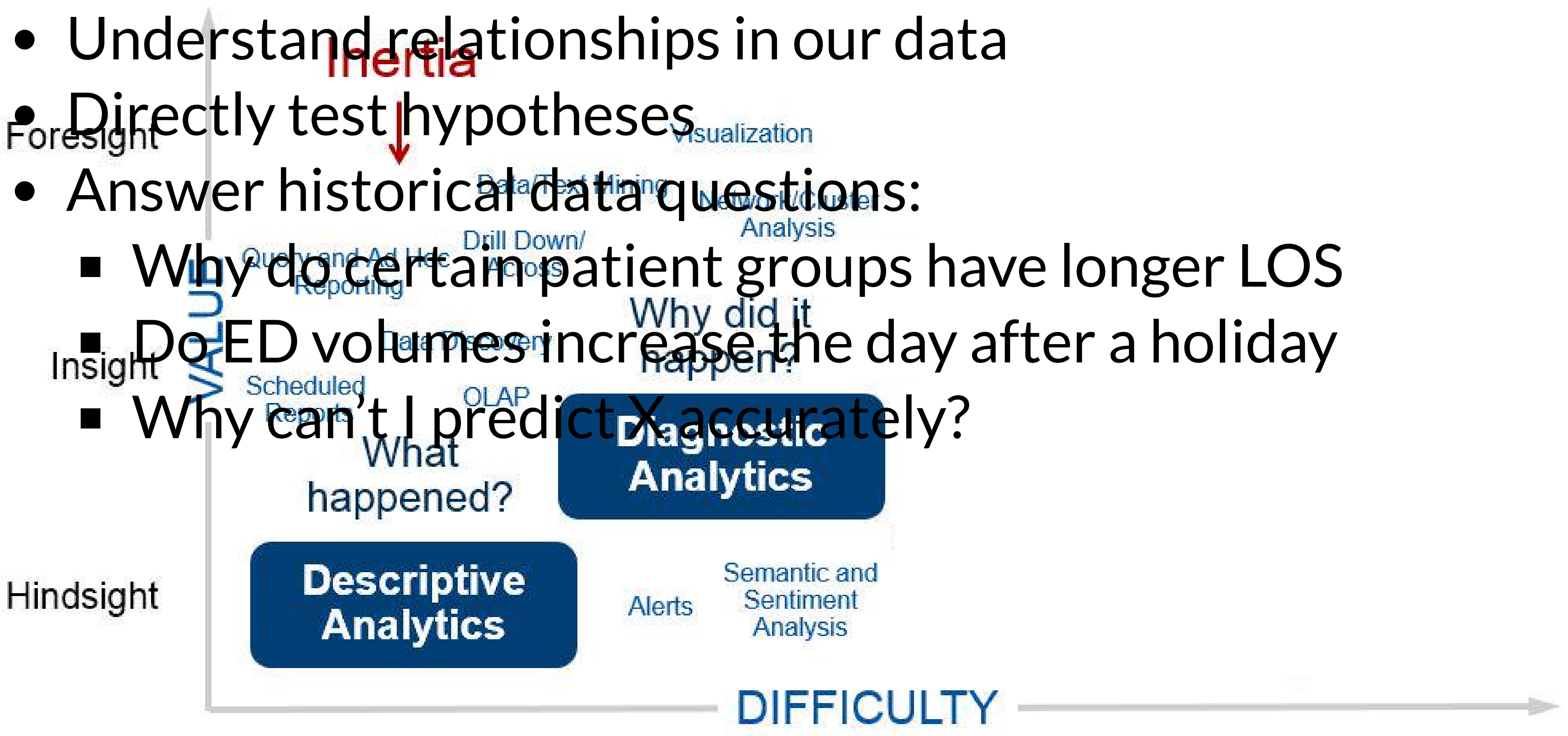


Gartner Analytic Continuum

Why are diagnostic analyses useful?

They help us:

- Understand relationships in our data
- Directly test hypotheses
- Answer historical data questions:
  - Why do certain patient groups have longer LOS
  - Do ED volumes increase the day after a holiday
  - Why can't I predict X accurately?

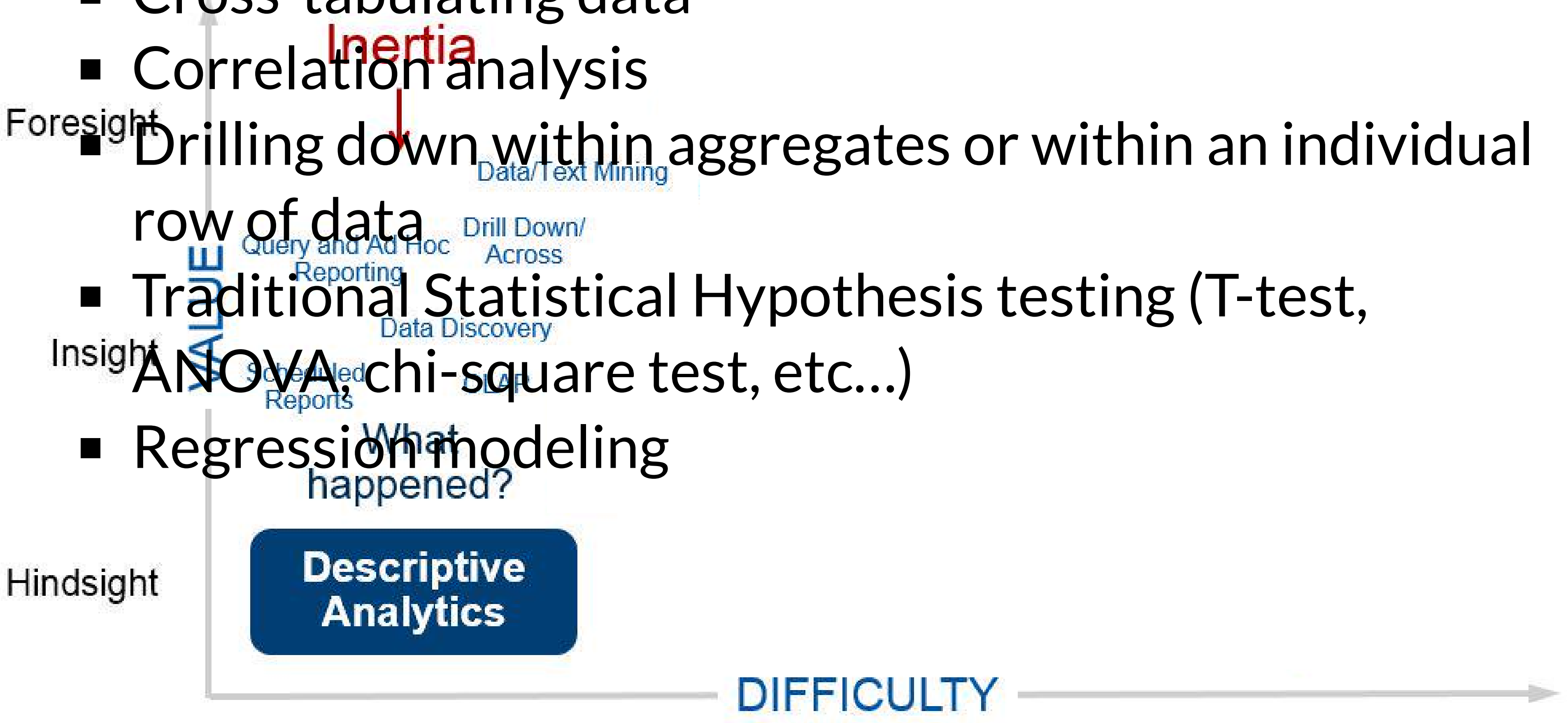


Gar

Forms of Diagnostic Analyses

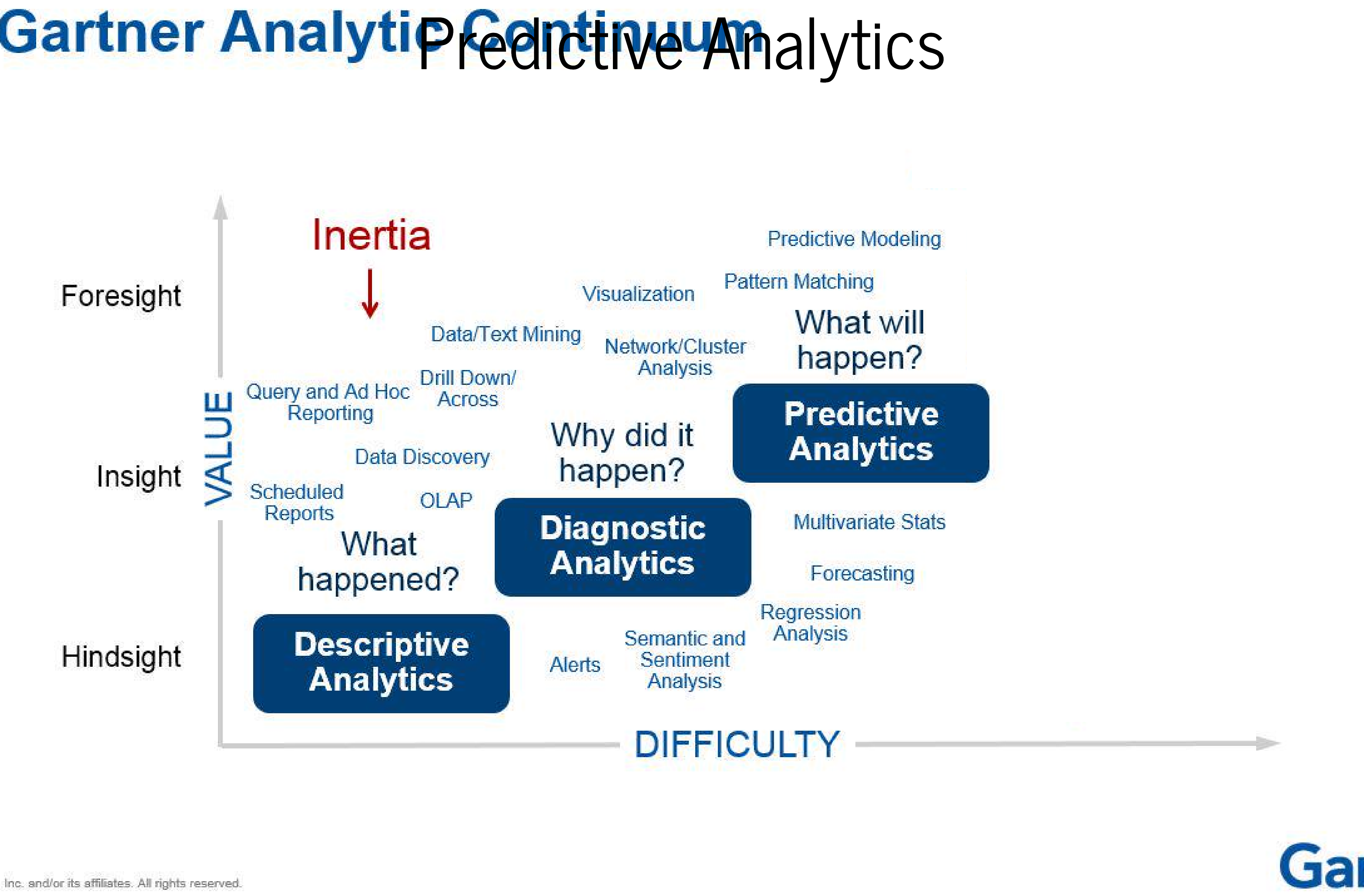
- Understanding relationships in the data through:
  - Cross-tabulating data
  - Correlation analysis
  - Drilling down within aggregates or within an individual row of data
  - Traditional Statistical Hypothesis testing (T-test, ANOVA, chi-square test, etc…)
  - Regression modeling

Gartner Analytic Continuum

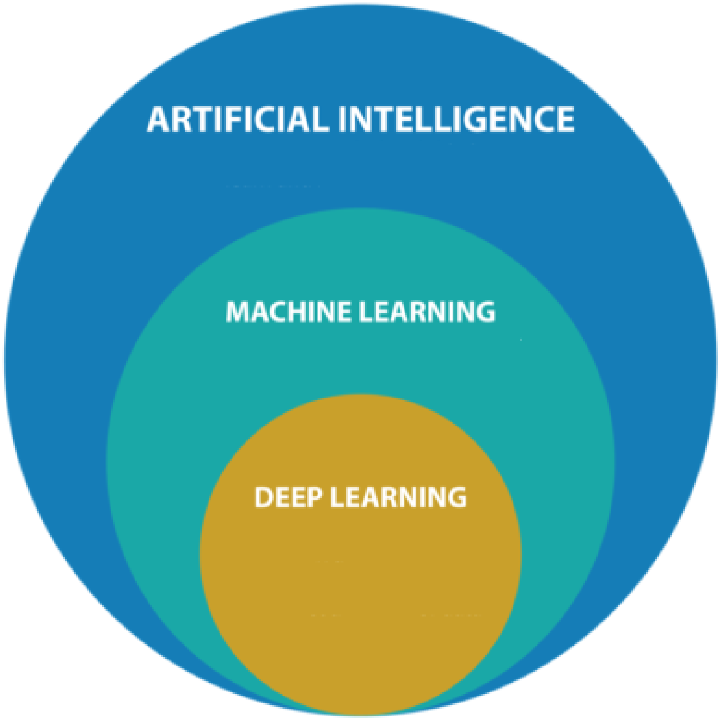


Ga

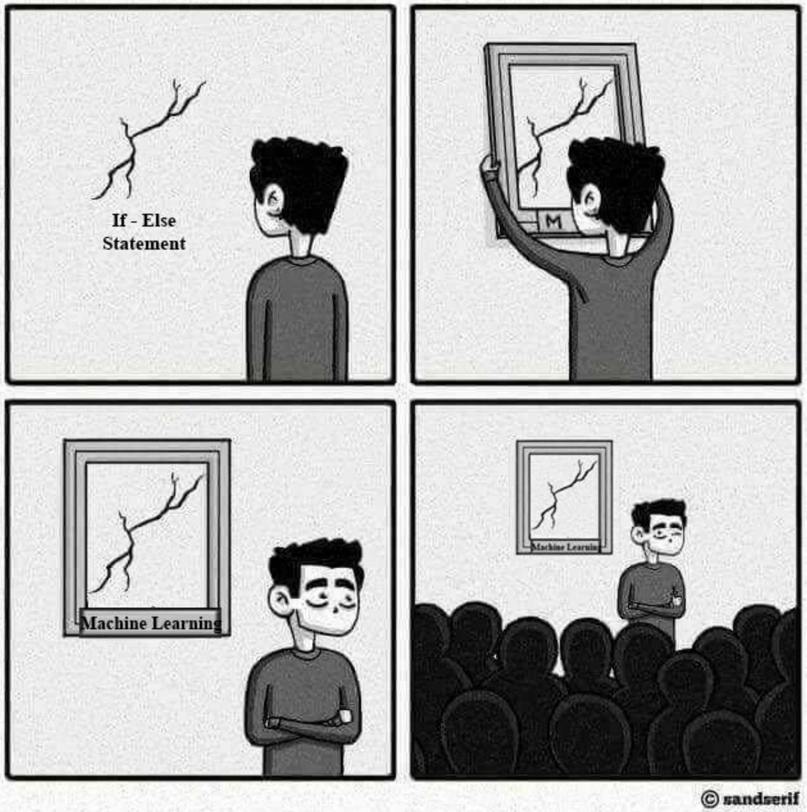
Predictive Analytics



AI/ML/Deep Learning



- Artificial Intelligence: Designing computer systems to perform tasks which are usually performed by humans
- Machine Learning: The study of algorithms that a computer can use to improve its performance on some task:
- Deep Learning: A machine learning algorithm inspired by the structure and function of the brain.


If - Else
Statement
M
Machine Learning
© sandserif

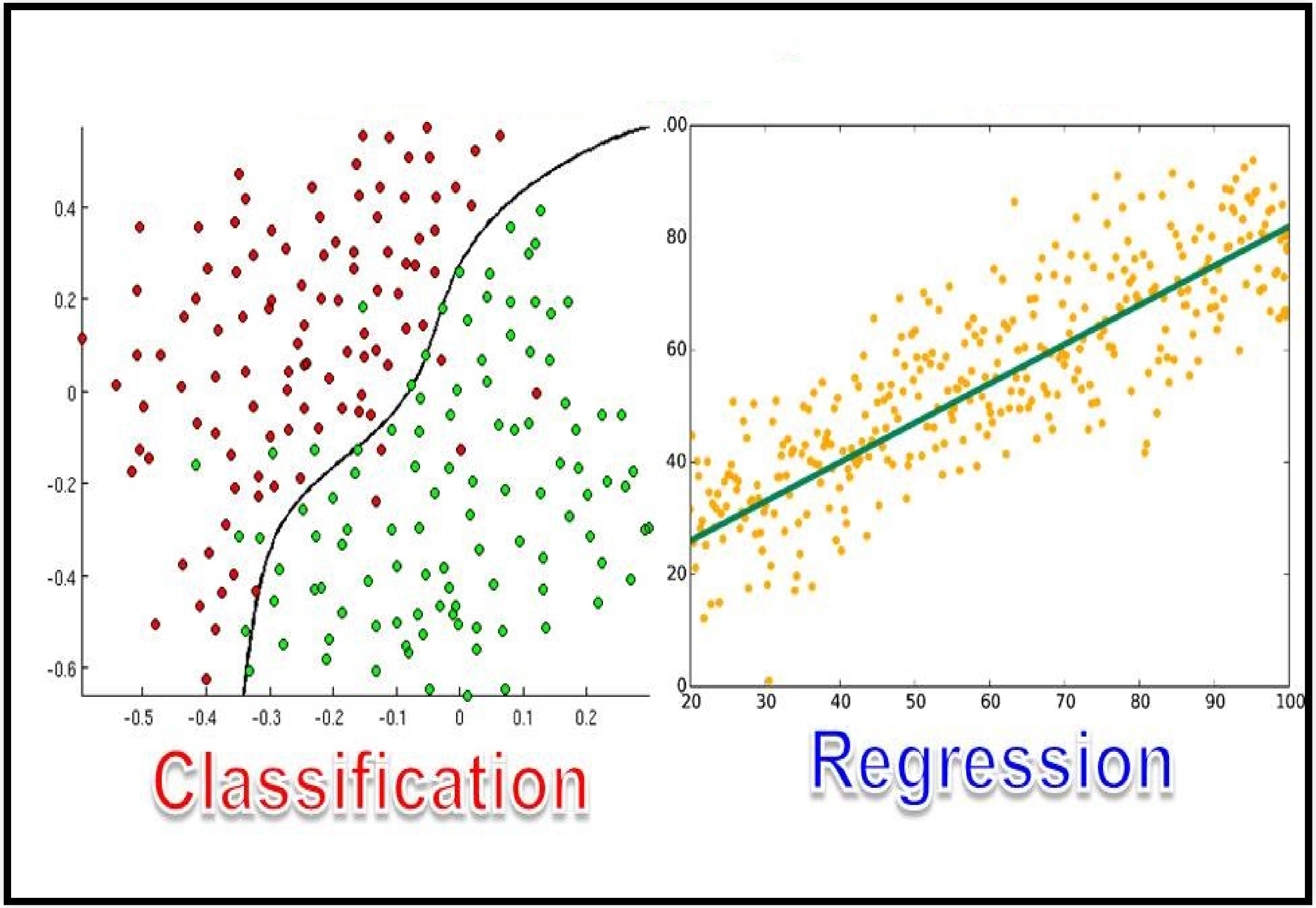
Machine Learning

Machine learning is the study of algorithms that a computer can use to improve its performance on some task:

- Identify which patients will need a transfer to the ICU in the next 24 hours
- Predict the number of inpatient admissions for the next 7 days
- What is the likelihood that a patient will not show up for an appointment
- Determine which radiology reports contain a bone with a fracture
- Determine a patient's diagnosis from admission/nursing notes
- Determine different treatment patterns among patients with the same disease/diagnosis
- Identify patient subgroups that have high hospital utilization

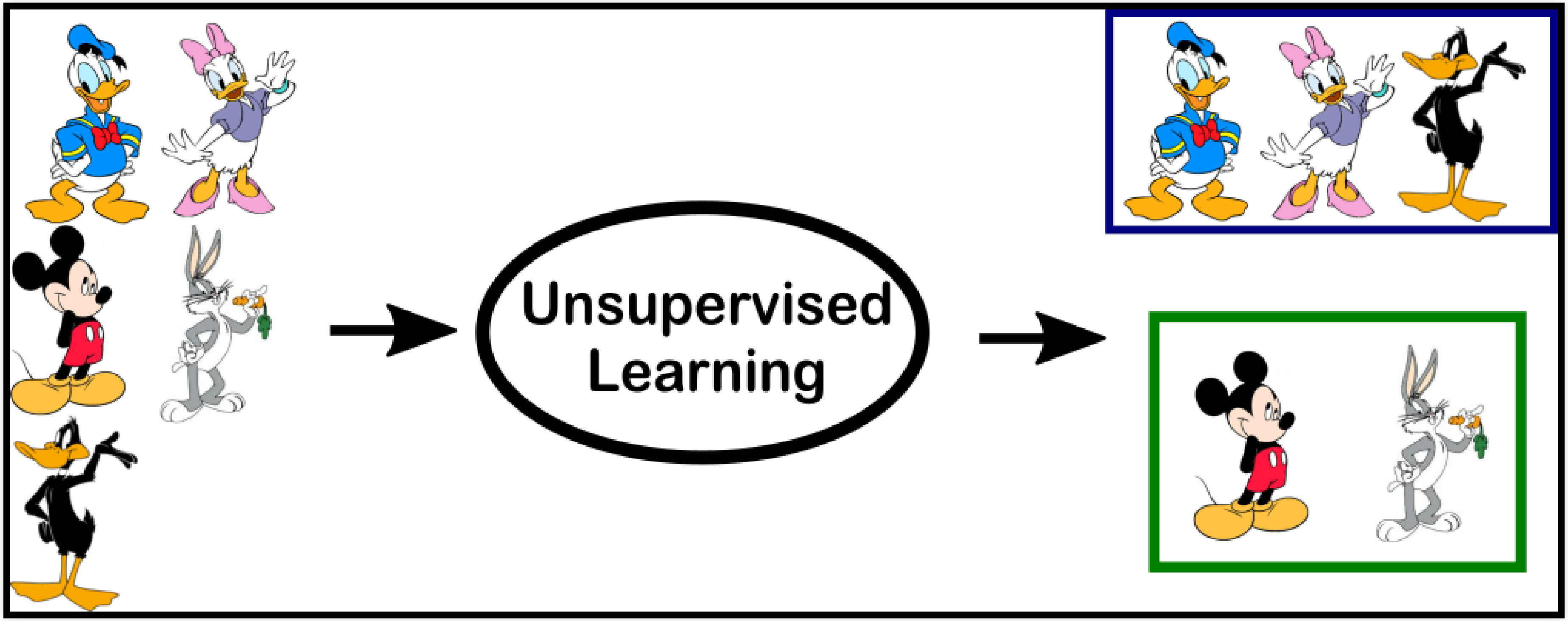
Machine Learning (Supervised Learning)

- **Surpervised learning**: The computer is provided with both the input data and the output data and design an algorithm to match the two as closely as possible. There are two types:
  - Regression: The output is a continuous variable. e.g. cost, length of stay, number of comorbidities etc…
  - Classification: The output is a categorical label e.g. icu transfer yes/no, readmission yes/no, patient diagnosis ICD10 codes


0.4
0.2
0
-0.2
-0.4
-0.6
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
Classification
.00
80
60
40
20
0
20
30
40
50
60
70
80
90
100
Regression

Machine Learning (Unsupervised Learning)

- **Unsupervised Learning**: The computer is provided with only input data (no labels) and attempts to find structure in the data. Often used to discover clusters in the data.



Classification, Regression, Unsupervized

- Identify which patients will need a transfer to the ICU in the next 24 hours
- Predict the number of inpatient admissions for the next 7 days
- What is the likelyhood that a patient will not show up for an appointment
- Determine which radiology reports contain a bone with a fracture
- Determine a patient's diagnosis from admission/nursing notes
- Determine different treatment patterns among patients with the same disease/diagnosis
- Identify patient subgroups that have high hospital utilization

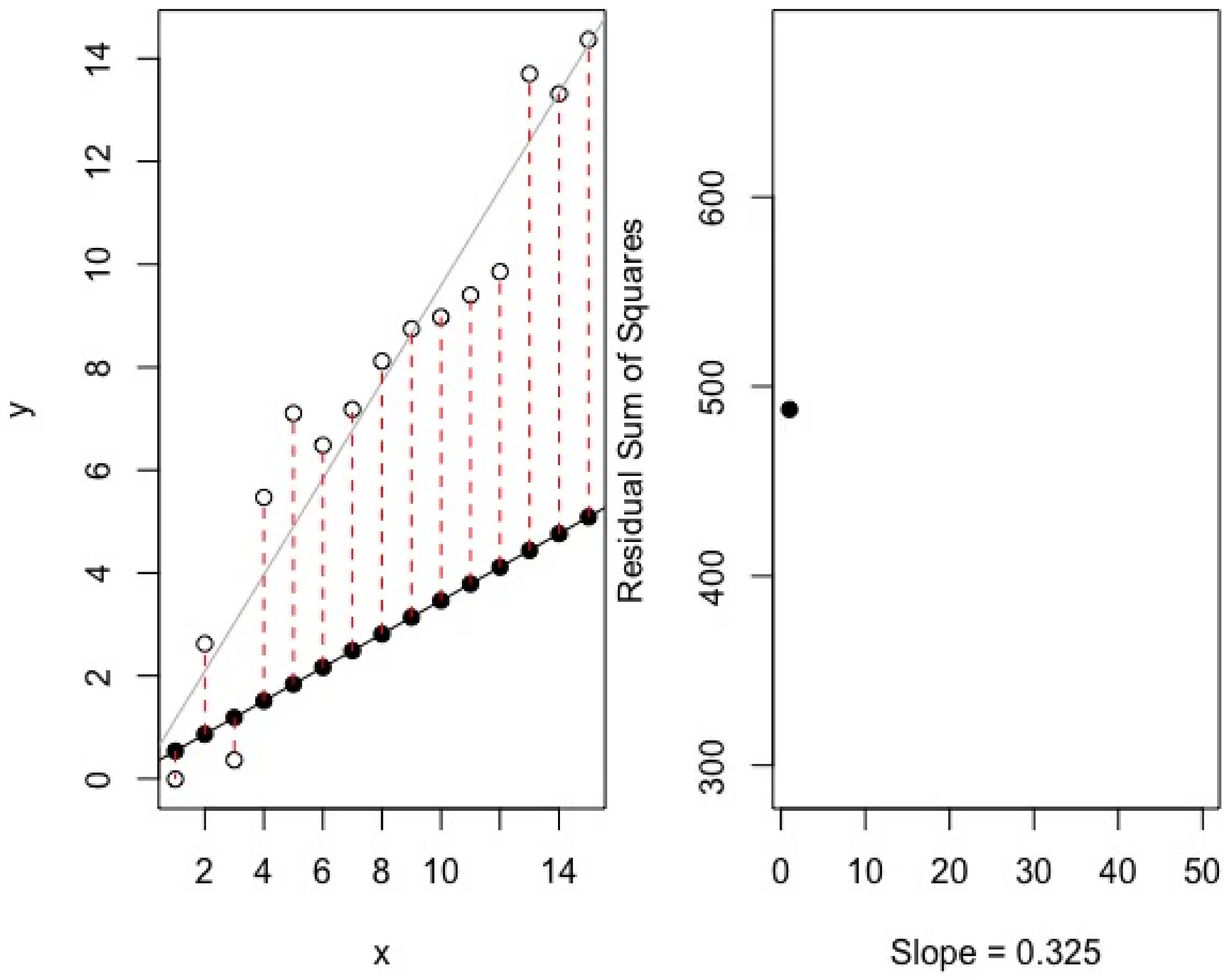
Machine Learning Process (supervised learning)

- Given some input data *X* and an outcome y
- Find a function f(X) that maps the values of X -> y
- Such that it minimizes some error e

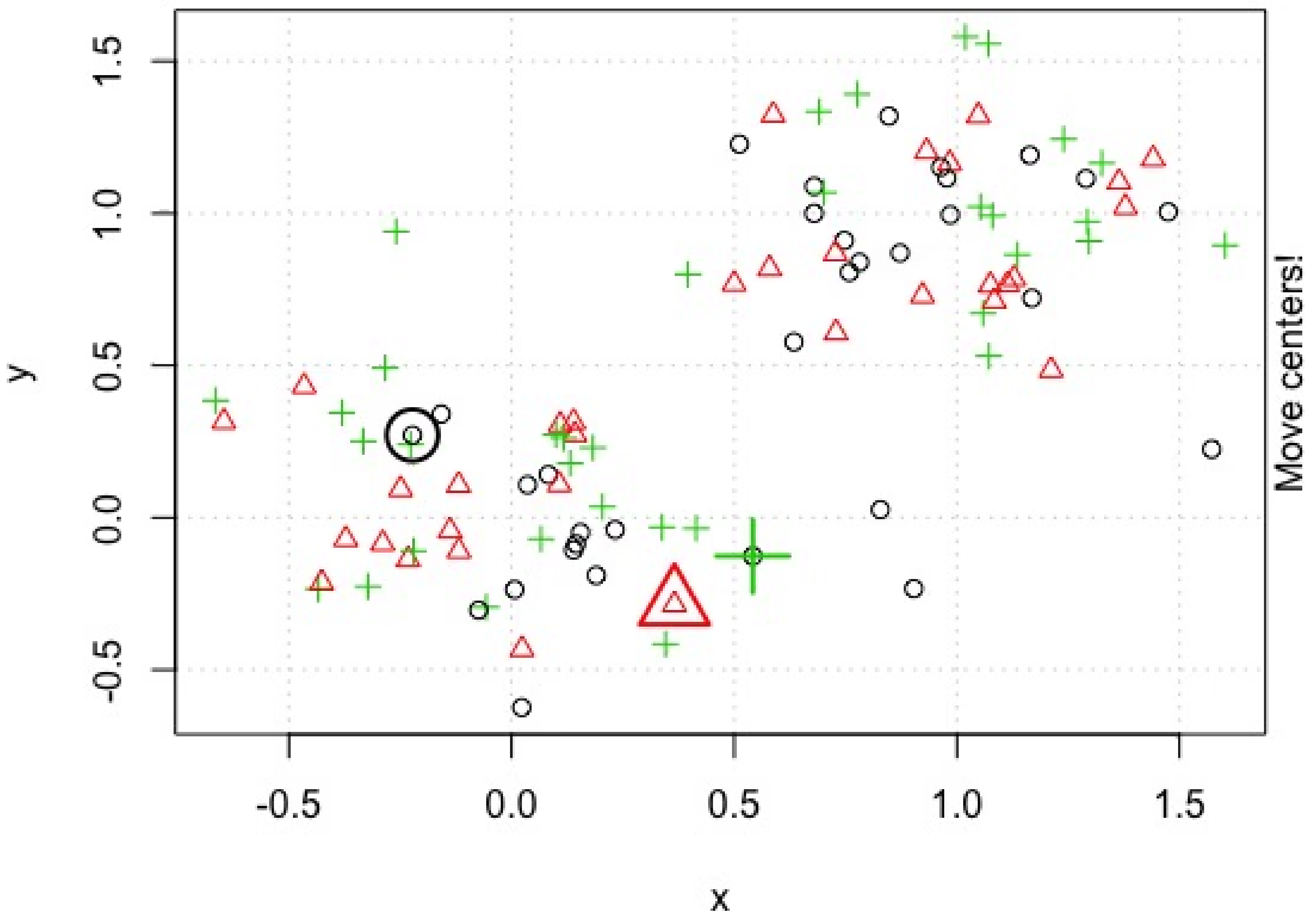
Inputs to Outputs

Examples of inputs and outputs into machine learning algorithms

- Inputs: Patient age, gender, admit diagnosis.
  - Outputs: Length of stay
- Inputs: The number of patients in the emergency department for each day in the last 365 days.
  - Outputs: Emergency department volume tomorrow
- Inputs: Patient admission note.
  - Outputs: ICD10 code of admit diagnosis
- Inputs: Radiology image of a bone.
  - Outputs: yes/no is there a fracture in the image

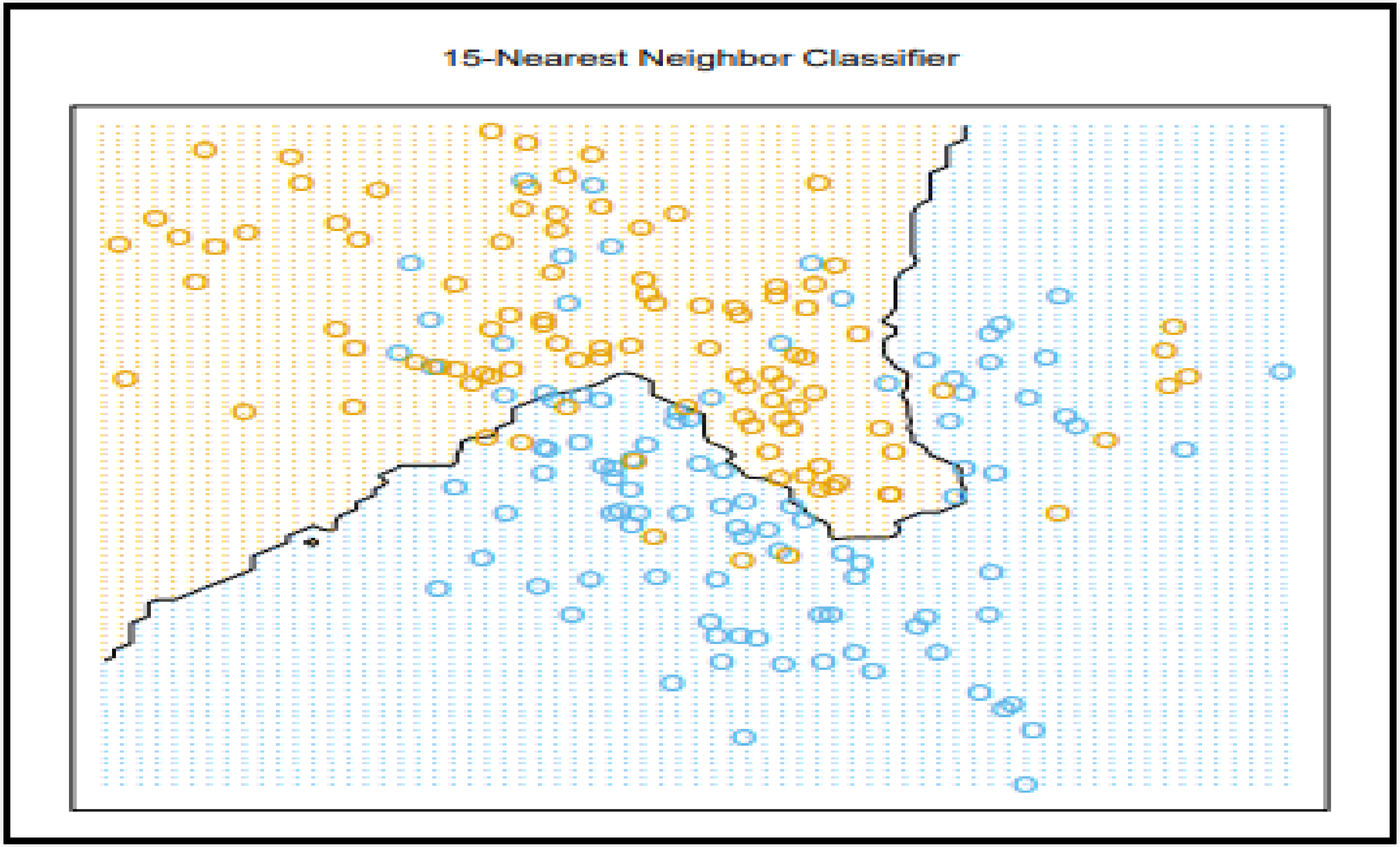


y
0
2
4
6
8
10
12
14
x
2
4
6
8
10
14
Residual Sum of Squares
300
400
500
600
0
10
20
30
40
50
Slope = 0.325

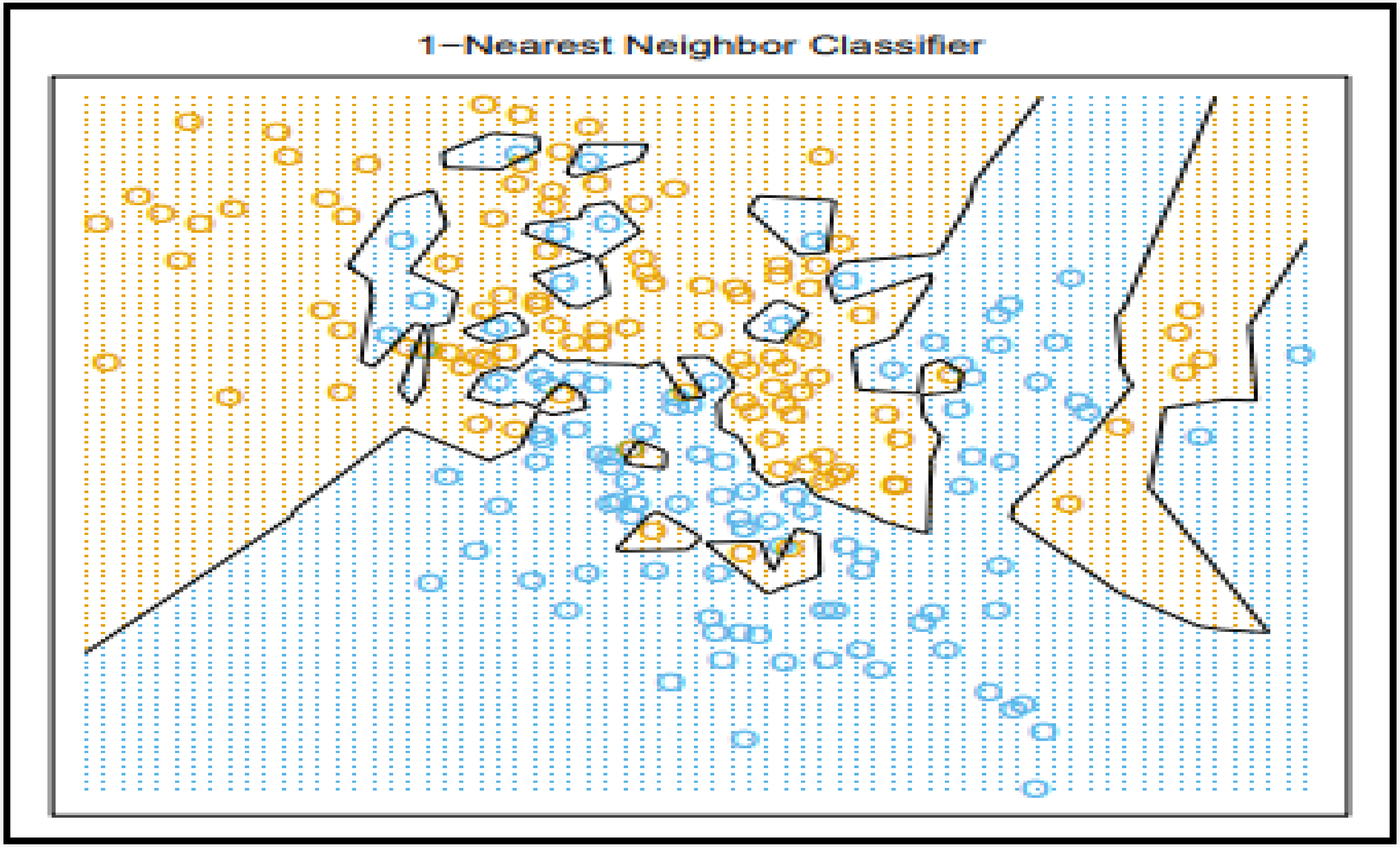


Move centers!
y
x
-0.5
0.0
0.5
1.0
1.5

Classification example

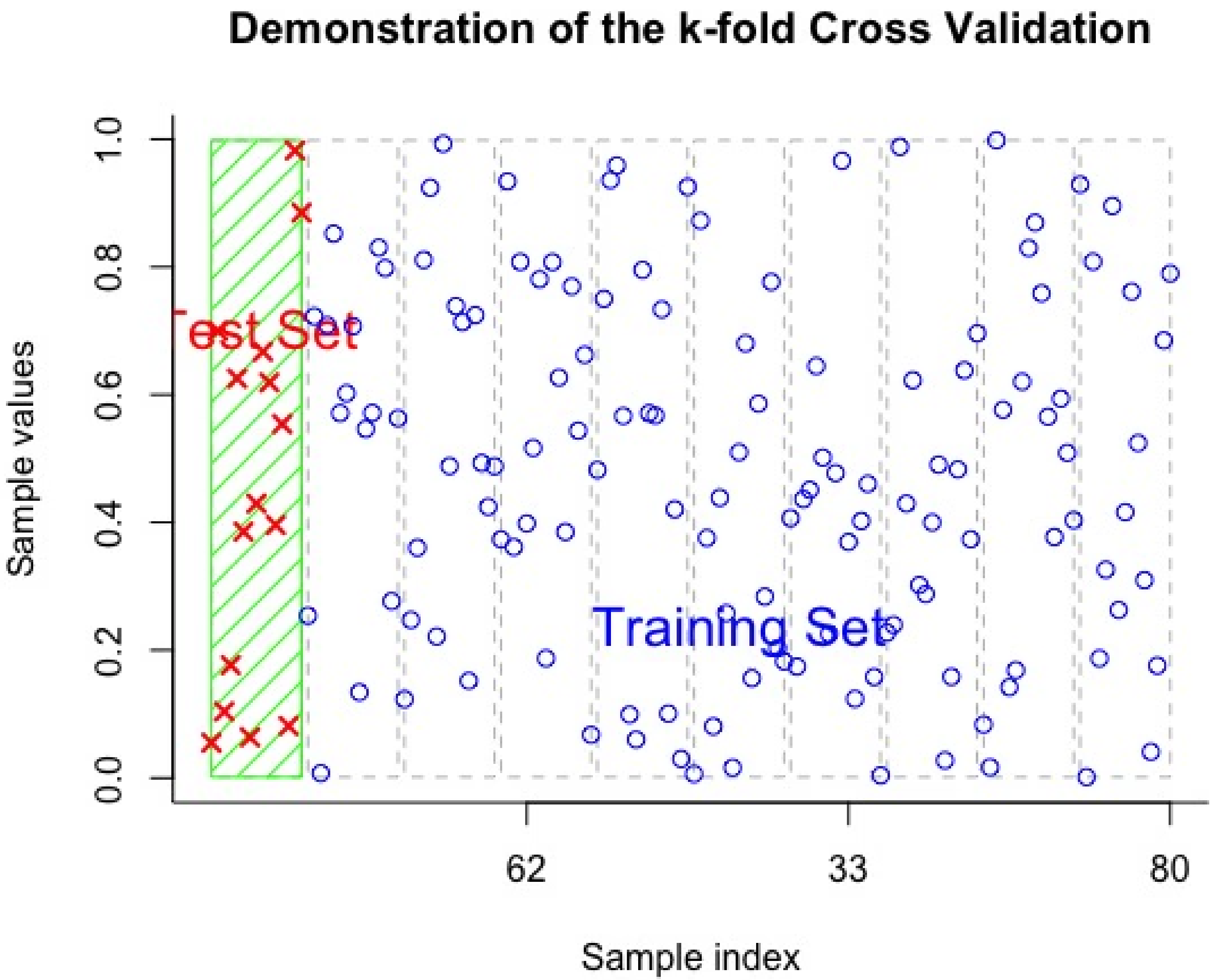


Overfitting



Machine learning performance

- Given our input and data (X, y), we split the data into:
  - (X_train, y_train), and (X_test, y_test)
- Our Machine learning problem is to find a model that is trained using:
  - (X_train, y_train) but generalizes to (X_test, y_test)



Demonstration of the k-fold Cross Validation
Test Set
Training Set
Sample values
Sample index
1.0
0.8
0.6
0.4
0.2
0.0
62
33
80

Common Regression Models

- Linear Regression
  - Generalized Linear Models
- Generalized Additive Models (non-linear regression)
- Support Vector Machines
- Decision Trees
- Random Forests
- Gradiant Boosting Machines

Common Classifiers

- Logistic Regression
  - Generalized Linear Models
- Naive Bayes
- Support Vector Machines
- Decision Trees
- Random Forests
- Gradiant Boosting Machines

Hyperparameters

Show 10 entries Search:

List of models with their hyperparameters

	model	type	tuning parameter
1	AdaBoost Classification Trees	Classification	nIter, method
2	AdaBoost.M1	Classification	mfinal, maxdepth, coeflearn
3	Adaptive Mixture Discriminant Analysis	Classification	model
4	Adaptive-Network-Based Fuzzy Inference System	Regression	num.labels, max.iter
5	Adjacent Categories Probability Model for Ordinal Data	Classification	parallel, link
6	Bagged AdaBoost	Classification	mfinal, maxdepth
7	Bagged CART	Classification, Regression	None

	model	Regression type	tuning parameter
8	Bagged FDA using gCV Pruning	Classification	degree
9	Bagged Flexible Discriminant Analysis	Classification	degree, nprune
10	Bagged Logic Regression	Classification, Regression	nleaves, ntrees

Showing 1 to 10 of 237 entries

Previous 1 2 3 4 5 … 24 Next

Outline of steps to creating a machine learning model

- Data Exploration
- Train, Test, Validation data split
- **Feature Engineering**
- Model Selection
- Hyperparameter Tuning
- Model Evaluation

Feature Engineering

age	diagnosis
65	chf
70	hypertension
24	hypertension
38	fracture
45	hypertension
90	cancer
19	hypertension
88	hypertension
72	hypertension

Hand Crafted Features

age	age70	diagnosis	hypertension
65	0	chf	0
70	1	hypertension	1
24	0	hypertension	1
38	0	fracture	0
45	0	hypertension	1
90	1	cancer	0
19	0	hypertension	1
88	1	hypertension	1
72	1	hypertension	1

Feature Engineering Text

“ Ms. Johnson is a 70 year old woman presenting with CHF. Her daughter and husband brought her in to the emergency room shortly after midnight last night. Ms. Johnson uses a cane to walk. She was recently diagnosed with alzheimer’s disease which required hospitalization recently. She is currently on the following medications…. ”

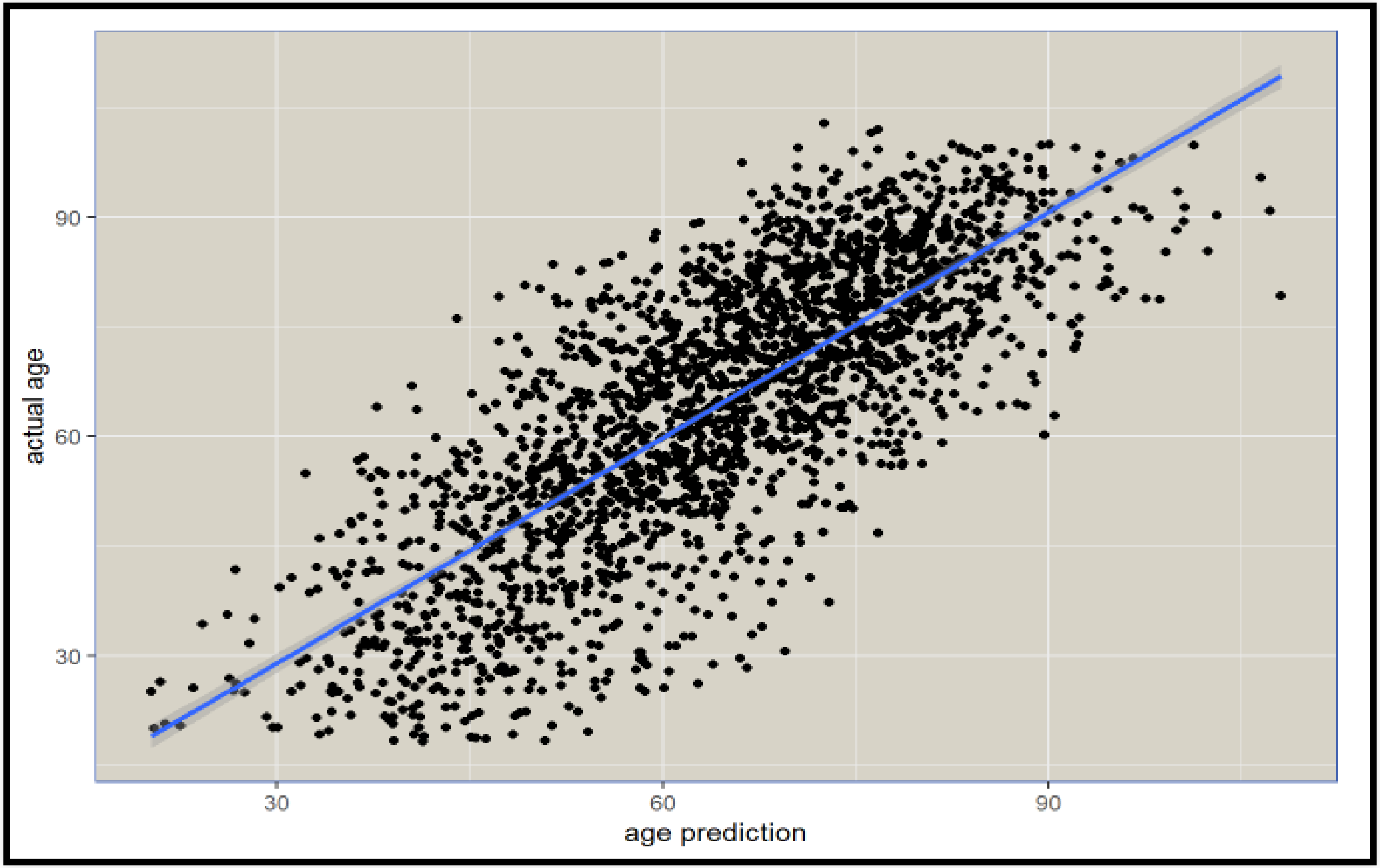
One hot encode words

alzheimer	uses_cane
1	0
0	0
0	0
1	1
0	0
0	0
1	1
0	1
1	0

Extracting topics

topic	term1	term2	term3	term4	term5	term6	term7	term8
11	risk	readmission	approximately	additional	supports	required	score	patients
12	atrial	fibrillation	afib	irregular	fib	apixaban	mg	anticoagulatio
13	cough	viral	symptoms	fever	days	sick	urti	throat
14	time	test	date	type	interpretation	summary	ecg	cardiology
15	pos	neg	describe	neck	head	musculoskeletal	cardiovascular	systems
16	chest	breath	dyspnea	shortness	sob	exertion	symptoms	worsening
17	pain	prn	chronic	hydromorphone	mg	tylenol	control	morphine
18	insulin	diabetes	sc	metformin	units	diabetic	type	dm
19	system	auscultation	sounds	cpoe	cardiovascular	distress	bilaterally	allergies
20	warfarin	inr	mg	daily	hold	elevated	dose	vitamin

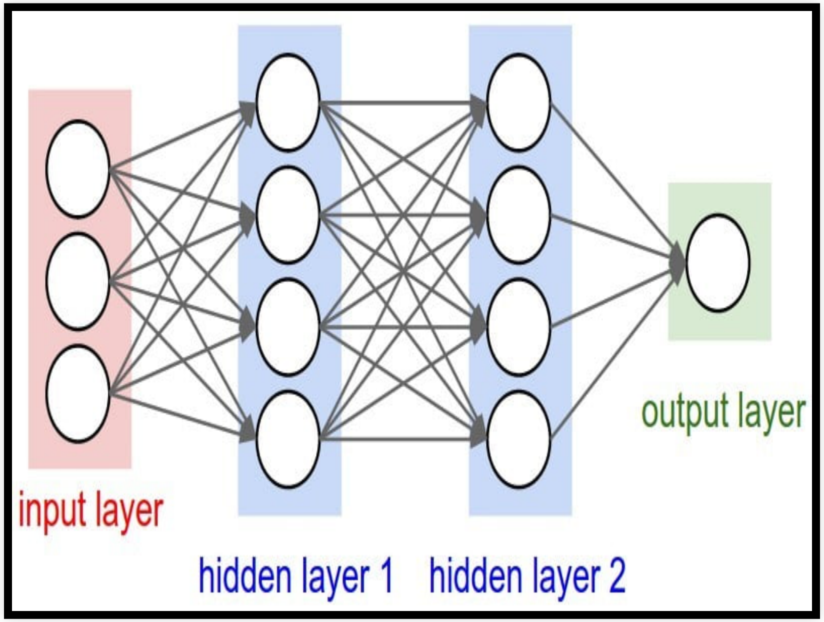
Predicting age with topics



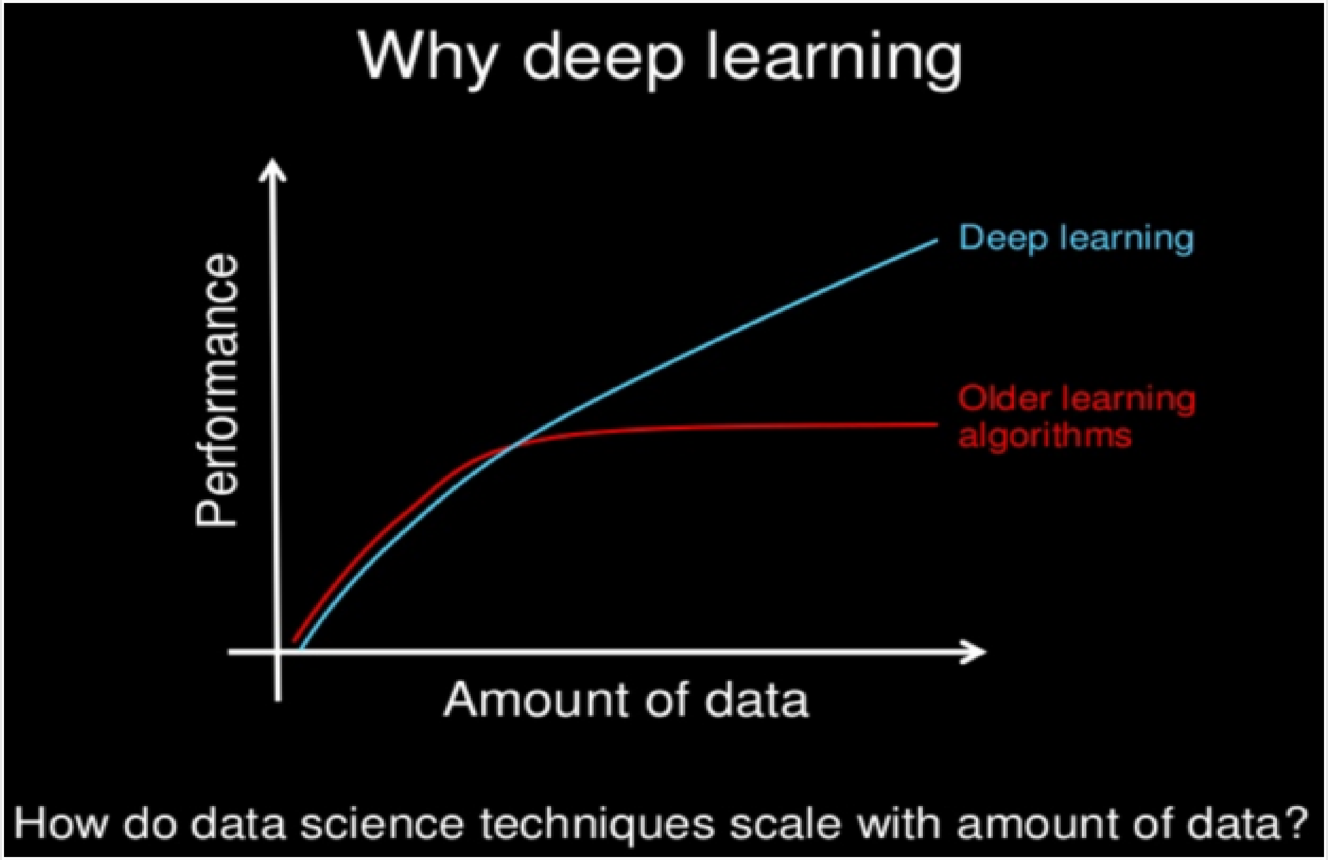
Neural Networks

Artificial Neural Networks are a set of frameworks inspired by the brain. They are primarily used for:

- Regression tasks
- Classification tasks
- Unsupervised tasks (finding data representations)



Why Deep Learning?



Why Deep Learning?
Slide by Andrew Ng,

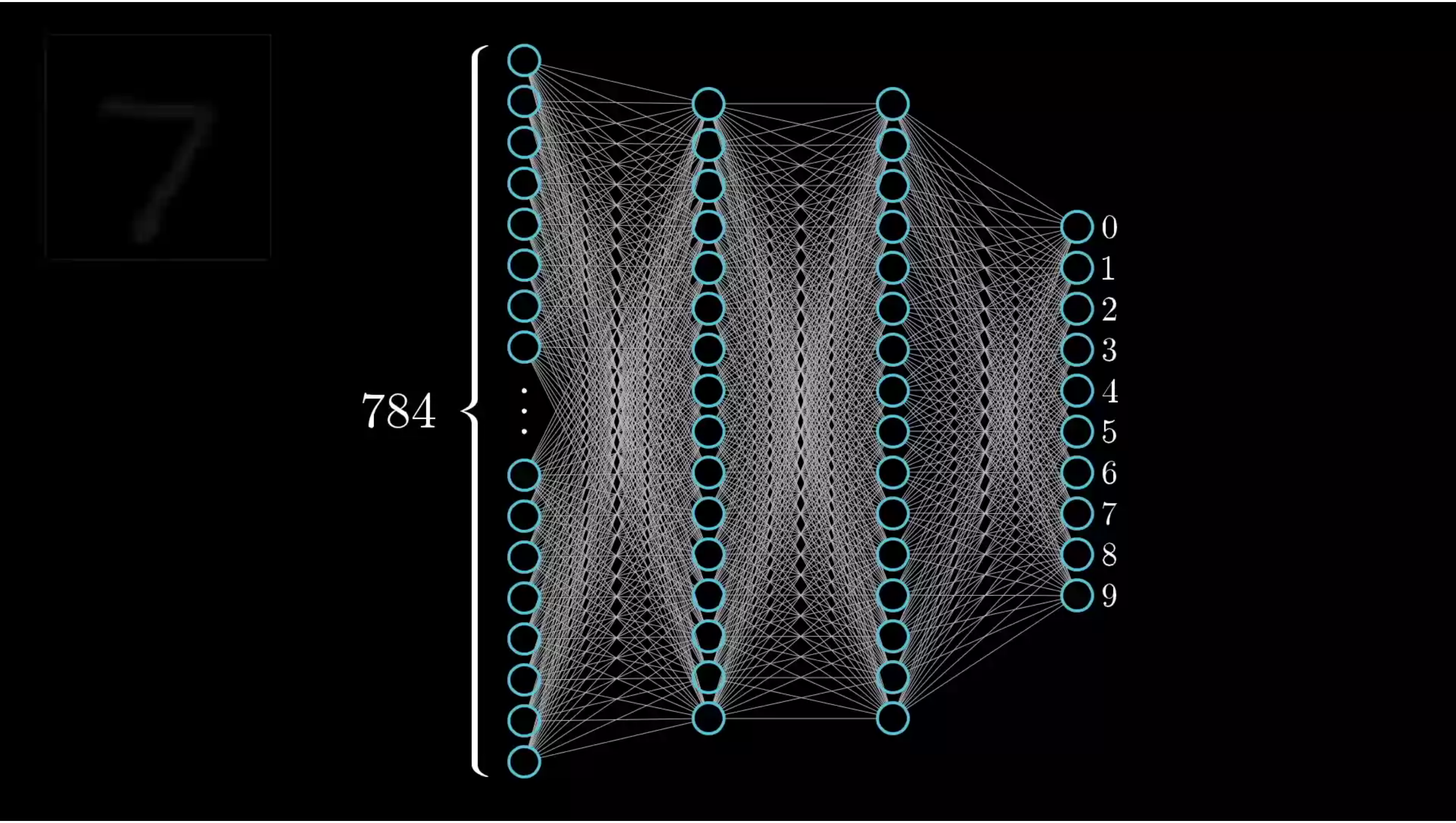
Why Deep Learning

- Unsure of relationships between variables
- Lots of data
- Certain there are lots of non-linear relationships in the data
- They outperform a lot of older models on image/video tasks

Deep Neural Networks

A neural network with more than one layer

- Feed Forward Networks
  - Regression and Forecasting
  - Classification, including images
- Convolutional Neural Networks (CNN or ConvNet)
  - Classifying images and video
  - Natural Language processing
  - Drug discovery
- Recurrent Neural Networks (RNNs)
  - Time series forecasting
  - Prediction in medical care pathways
  - Anomoly detection
  - machine translation


784
0
1
2
3
4
5
6
7
8
9

Prescriptive models

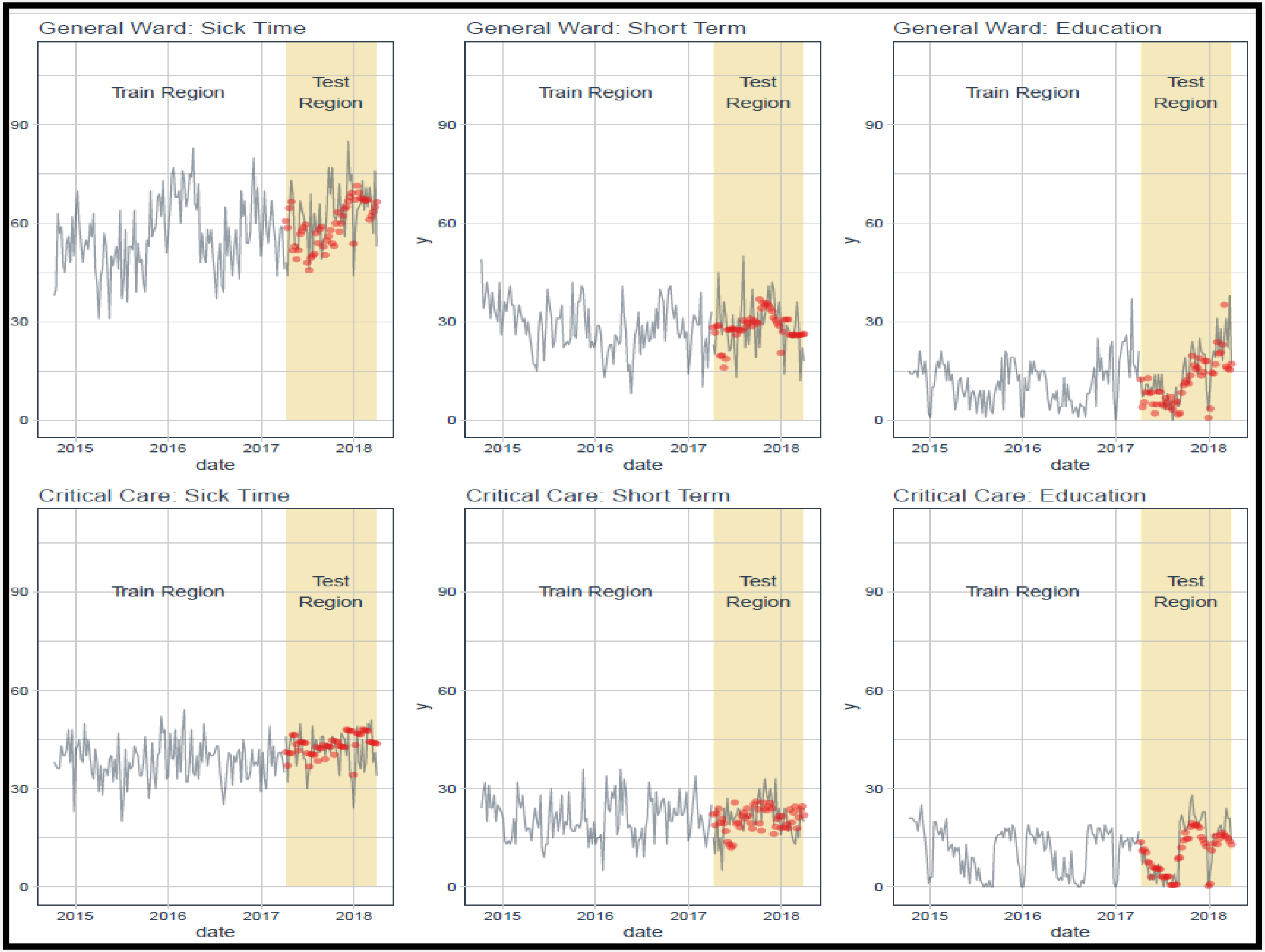
Models used to make decisions

- **Simulation modeling**
  - Build a mathematical model of the world and simulate that word under different scenatios (10k’s times)
  - e.g. What would adding an extra CT scanner do to wait times in the ED
- **optimization models**
  - Build a mathematical model of the world
  - Relate model parameters to some outcome, and generate some optimal solution
  - e.g. How many nurses on a nursing resource team?
- **Reinforcement Learning**
  - How an agent should make decisions to optimize some reward

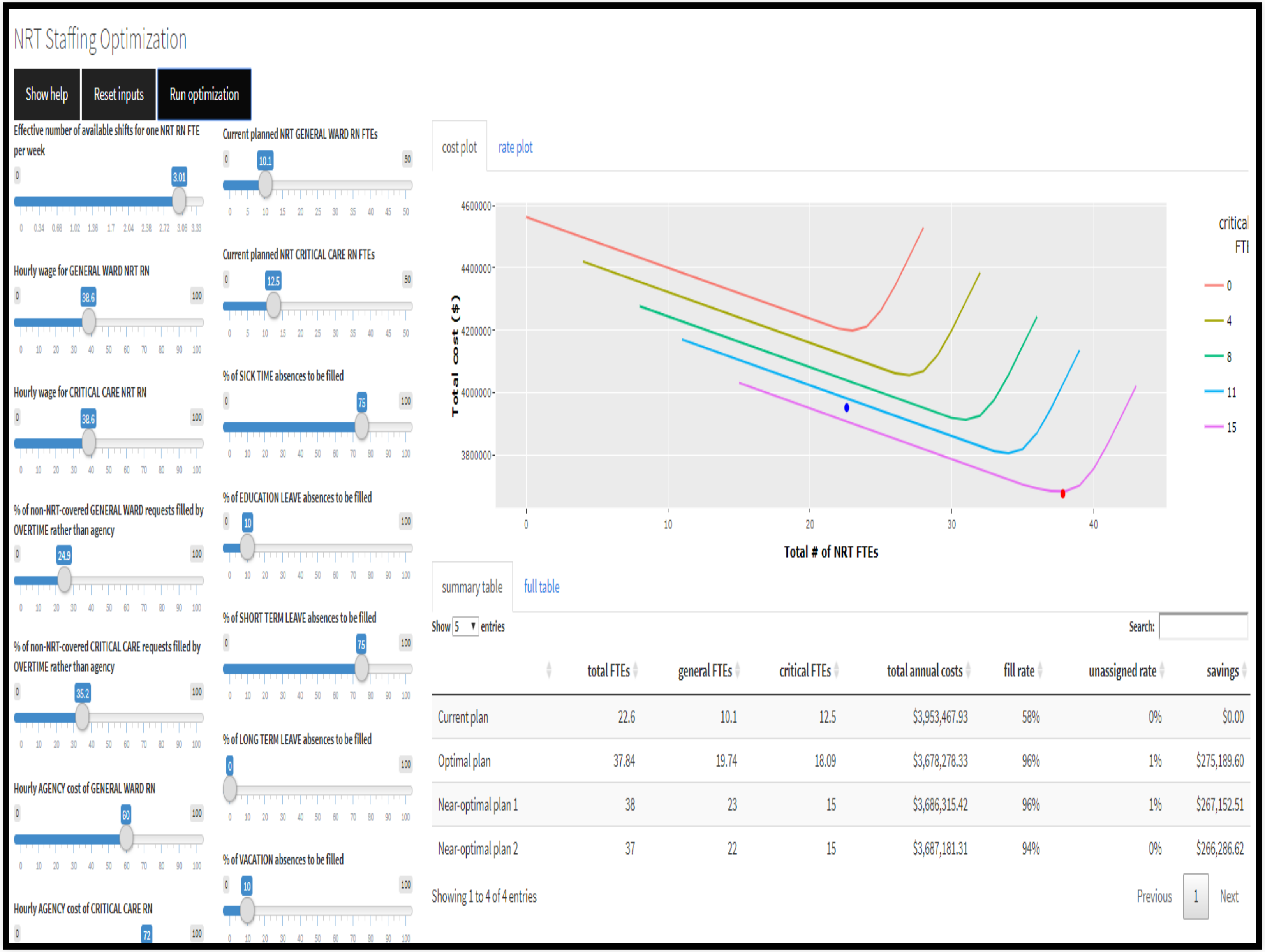
reward

- e.g. What care pathway to use?

Example NRT


General Ward: Sick Time
General Ward: Short Term
General Ward: Education
Critical Care: Sick Time
Critical Care: Short Term
Critical Care: Education
Train Region
Test Region
y
date
0
30
60
90
2015
2016
2017
2018

Example NRT GUI

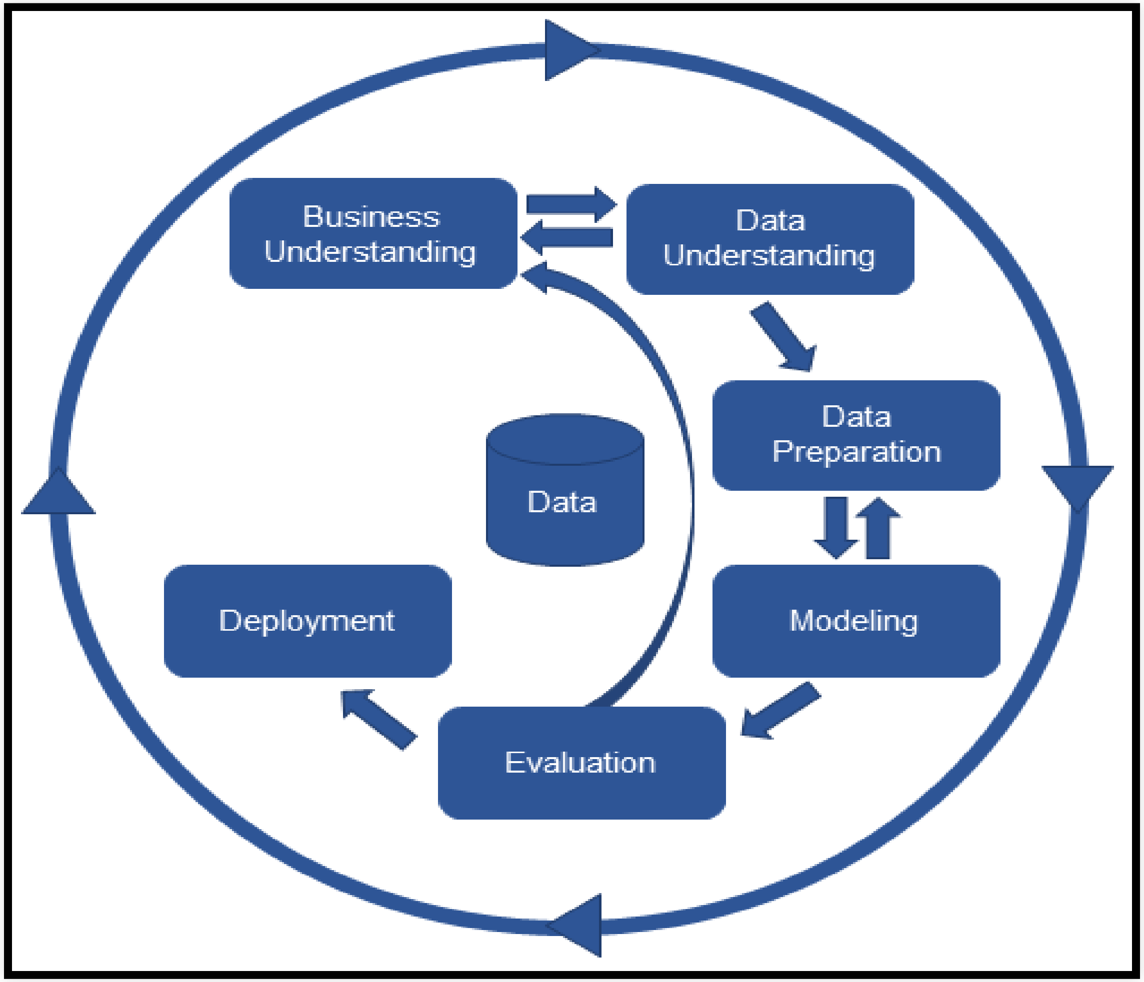


No Free Lunch

- No model is optimal for all problems

Workflow

- Cross Industry Standard for Process for Data Mining (CRISP DM)



Stage 1. Business Objectives

- Set primary business objective
  - e.g. Reduce number of patients dying unexpectedly in hospital
  - e.g. Reduce the number of patients readmitted within 90 days
- Project plan
  - Stages to be executed in the project + duration, resources required, inputs, outputs and dependencies
- Initial assessment of tools and techniques
  - At the end of your first phase you should undertake an initial assessment of tools and techniques

Stage 2. Data Collection

- Initial data collection report
  - List the data sources acquired together with their locations, methods used to acquire them and any problems encountered (record problems and resolutions)
- Explore Data:
  - Distribution of key variables
  - Relationships between pairs or small numbers of attributes
  - Simple statistical analyses
- Verify data quality
  - Outliers
  - Data input errors

Stage 3. Data Preparation

- Select Data
- Clean Data
  - Impute missing values
- Construct Required Data
  - transform variables
  - Create new variables
- Integrate Data
  - Merge data sources

Stage 4. Modeling

- Select Modeling Technique
  - Document modeling assumptions
- Set model Evaluation strategy

Model Evaluation

- Model Accuracy may not be the best way to evaluate a model

Evaluation (Classification)

- **Accuracy**: the proportion of the total number of predictions that were correct.
- **Positive Predictive Value**: the proportion of positive cases that were correctly identified.
- **Negative Predictive Value**: the proportion of negative cases that were correctly identified.
- **Sensitivity or Recall**: the proportion of actual positive cases which are correctly identified.
- **Specificity**: the proportion of actual negative cases which are correctly identified.

Evaluation Metrics

	Actual Outcome	
Prediction	No	Yes
No	True Negative	False negative
Yes	False Positive	True Positive

- Accuracy = (TP + TN)/(TP + TN + FP + FN)
- PPV = (TP)/(TP + FP)
- NPV = (TN)/(TN + FN)
- Sensitvity = (TP)/(TP + FN)
- Specificity = (TN)/(TN + FP)

Evaluation Metrics (Regression)

- Root Mean Squared Error (RMSE)
- R squared
- Adjusted R squared
- Mean Absolute Percent Error (MAPE)
- Mean Absolue Error (MAE)

Stage 5. Evaluation

- Assess the degree to which the model meets your business objectives, or test the model on test applications
- Approve the model(s) that meet business success criteria
- Review the process and set next steps

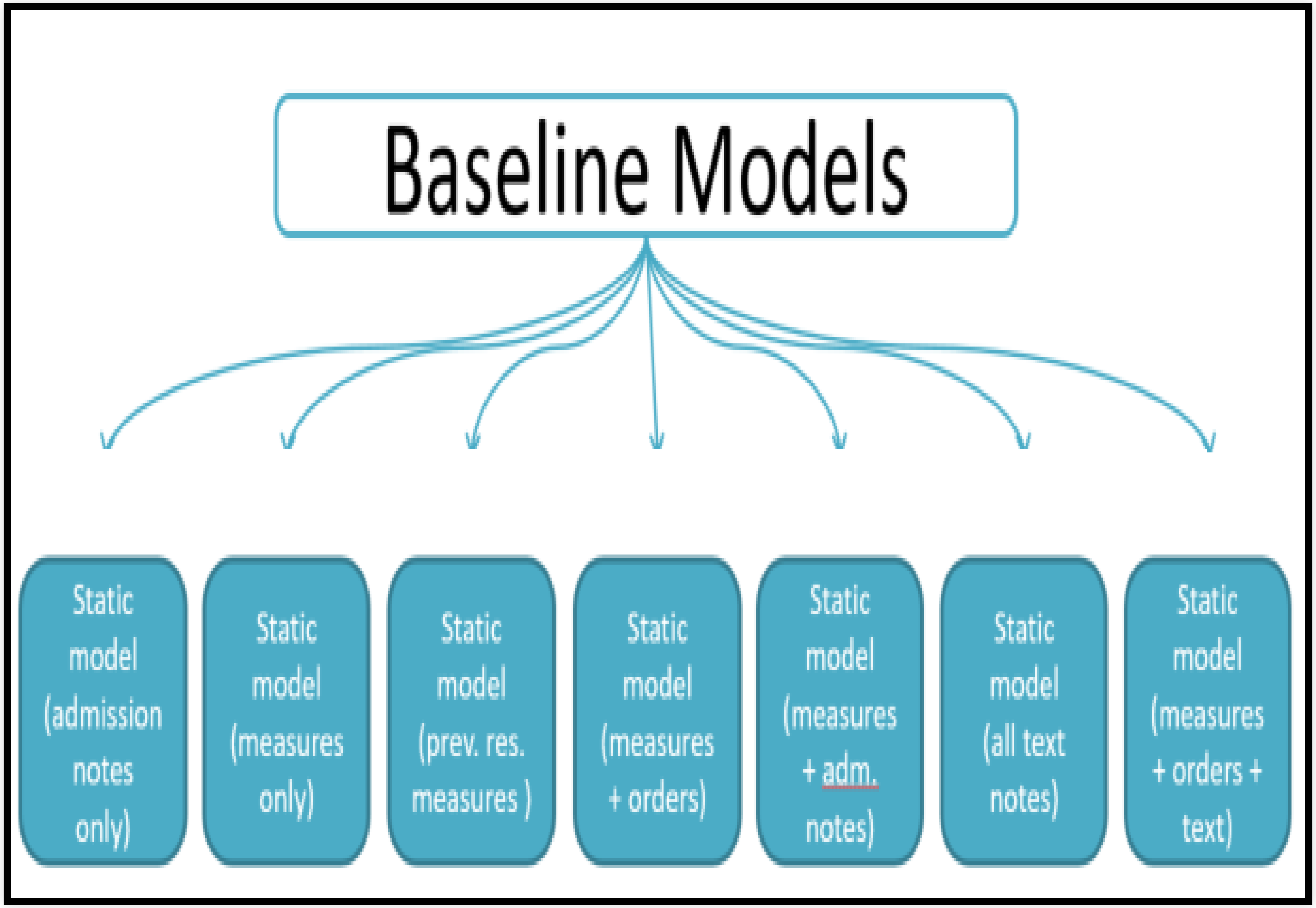
Stage 6. Deployment

- Plan Deployment
  - Summarize your deployment strategy including the necessary steps and how to perform them.
- Plan Monitoring and Maintenance

Example:

- Predict if a GIM patient will be transfered to the ICU using first 24 hours of data
- Collect Data:
  - Timestamps for patient outcomes
  - Vital Signs
  - Lab Results (~ 500)
  - Clinical Orders (~1000s)
  - Medication Orders (~1000s)
  - **Admission Notes**
  - **Nurse Notes**
  - **Radiology reports**

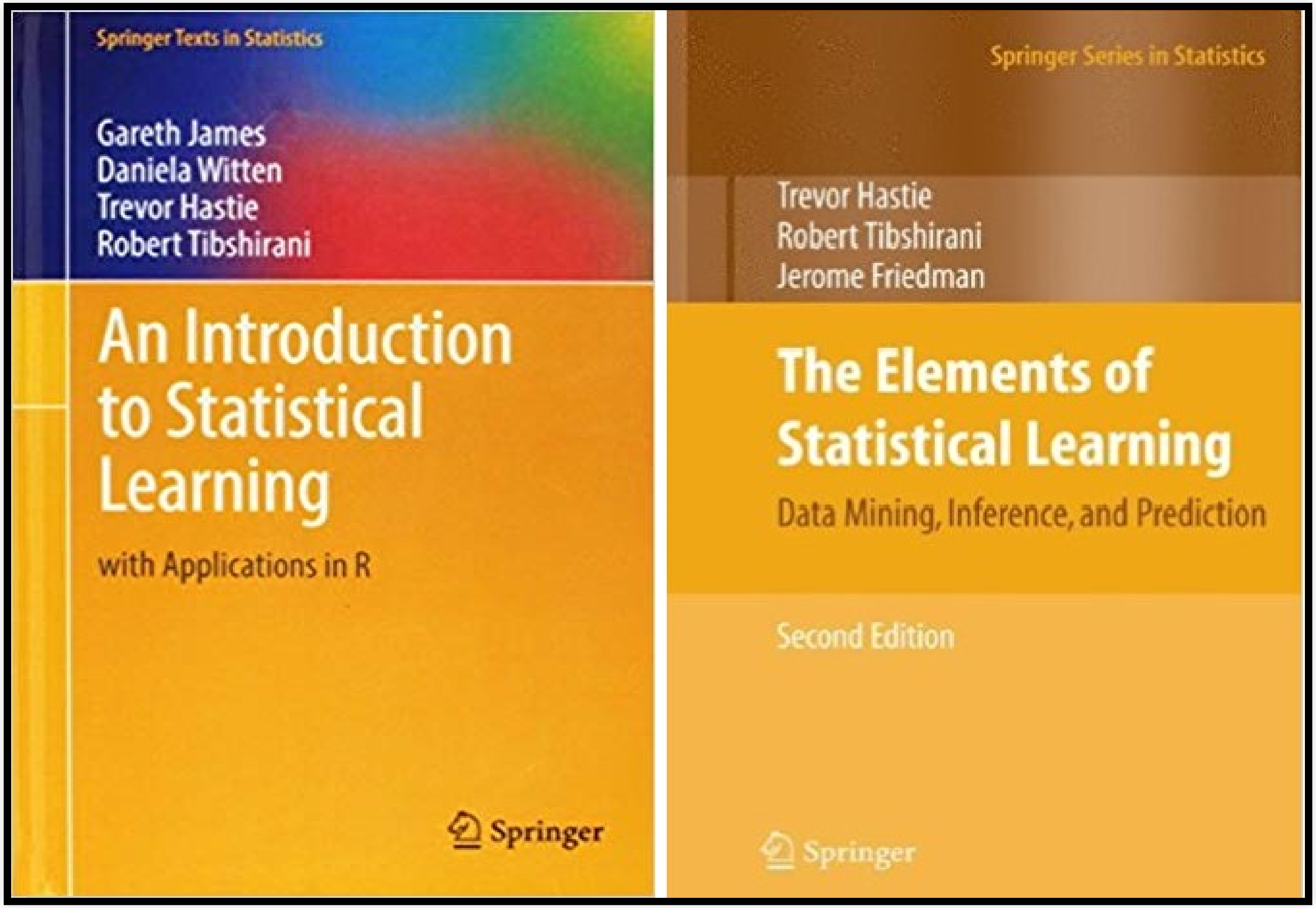
Example Models



Tools

- Data Prep/Analysis
  - SQL, R, Python, SAS, SPSS, Stata
- Data Visualization
  - ggplot, D3, matplotlib, javascript, html
- Deep Learning
  - Tensorflow, Keras, Pytorch, CNTK

References


Springer Texts in Statistics
Gareth James
Daniela Witten
Trevor Hastie
Robert Tibshirani
An Introduction to Statistical Learning
with Applications in R
Springer
Springer Series in Statistics
Trevor Hastie
Robert Tibshirani
Jerome Friedman
The Elements of Statistical Learning
Data Mining, Inference, and Prediction
Second Edition
Springer

Questions