



**Webinar**

# Reimagining the Science of Prediction



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Welcome, we will begin promptly at 11:00 AM ET.  
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# Reimagining the Science of Prediction

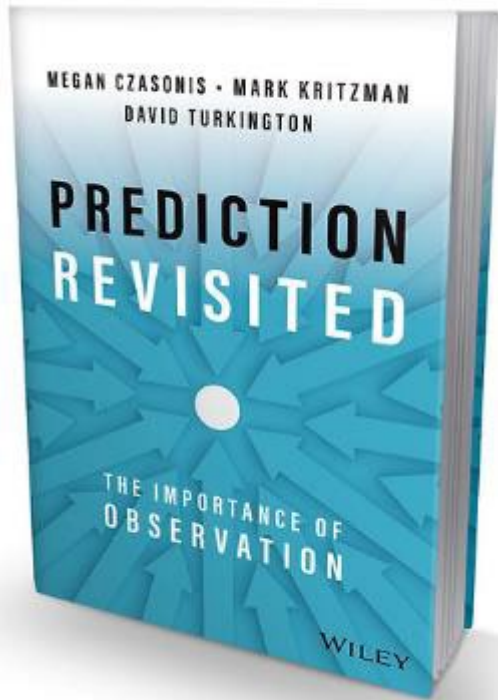
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# Related Resources

Book (2022: Wiley)



[predictionrevisited.com](https://predictionrevisited.com)

## PREDICTION REVISITED

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From Chapter 1:

We process experiences both naturally and statistically; however, the way we naturally process experiences often diverges from the methods that classical statistics prescribes. Our purpose in writing this book is to reconcile common statistical thinking to accord with our natural instincts.

...

The advantage of the natural process is that it is intuitive and sensible. The advantage of the statistical method is that by recording experiences as data we can analyze experiences more rigorously and efficiently than would be allowed by narratives. Our purpose is to reconcile classical statistics with our natural process in a way that secures the advantages of both approaches.

From Chapter 4: *Relevance Conceptually*

Relevance measures the importance of an observation to a prediction. It is equal to a sum of two parts: informativeness and similarity. Simply put, observations that are different from average but like present circumstances are more relevant than those that are not.

...

Filtering experience in this way is intuitive. Faced with a new situation, we automatically scour our memory for noteworthy experiences that bear some resemblance to the one we face. A pending snowstorm might recall past storms while stuck at home, plus some from six toes, and maybe even other types of severe weather events. A new illness might conjure images of people our age who recently struggled with a similar disease. A new product launch might spark comparison to a company's history and to related products from competitors. Relevance is a matter of degree: we might include less relevant experiences along with highly relevant ones, but we acknowledge the difference.

From Chapter 4: *Relevance Mathematically*

We are now able to augment our baseline predictor of the simple average of  $Y$  by applying unequal weights to the deviations of  $Y$  around its average. As before, we use the term, weight, loosely—it is a scalar multiple that can be positive, negative, or zero. In fact, the weight of each deviation is that observation's relevance.

$$\hat{y}_i = \bar{y} + \frac{1}{N-1} \sum_j r_{ij} ob_{ij}$$

Where:

$$ob_{ij} = (y_i - \bar{y})$$

Therefore:

$$\hat{y}_i = \bar{y} + \frac{1}{N-1} \sum_j r_{ij} (y_j - \bar{y})$$

Python code

pip install predictionrevisited

```
def relevance(x_1, x_2, x_bar=None, cov_inv=None, verbose):
    """
    RELEVANCE:
    Compute the relevance of one observation to another.

    Use the inverse covariance matrix and x_bar if provided, otherwise compute
    from X.

    Parameters
    -----
    x_1 : ndarray (1-by-N)
        Row vector of attributes for one observation.
    x_2 : ndarray (1-by-N)
        Row vector of attributes for a second observation.
    x_bar : ndarray (1-by-N)
        Row vector of average attribute values.
    cov_inv : ndarray (N-by-N), optional (default=None)
        Code executes faster when covariance inverse is already computed.
    X : ndarray (N-by-N), optional (default=None)
        Matrix of attributes in columns, for observations in rows. Required if
        cov_inv is not provided.

    Returns
    -----
    rel : ndarray (1-by-1)
        Relevance as a single number, formatted in a 2-dim array.
    rel_details: dict
        Contains sim_ij, info_1, info_2.
    """
    # similarity and informativeness will handle whichever inputs are given
    sim_ij = similarity(x_1, x_2, cov_inv=X)
    info_1 = informativeness(x_1, x_bar, cov_inv=X)
    info_2 = informativeness(x_2, x_bar, cov_inv=X)
    rel = sim_ij + 0.5 * (info_1 + info_2)

    # define a dictionary to store and pass detailed outputs
    rel_details = {
        'sim_ij': sim_ij,
        'info_1': info_1,
        'info_2': info_2
    }

    return rel, rel_details

def predict(x, x_1, x_2, thresh=0.5, verbose=True, plot_thresh=True,
           cov_inv=None, predict_binary_outcome=False):
    """
    PREDICT:
    Predicts an outcome based on a circumstance using partial sample regression.

    Parameters
    -----
    """

```

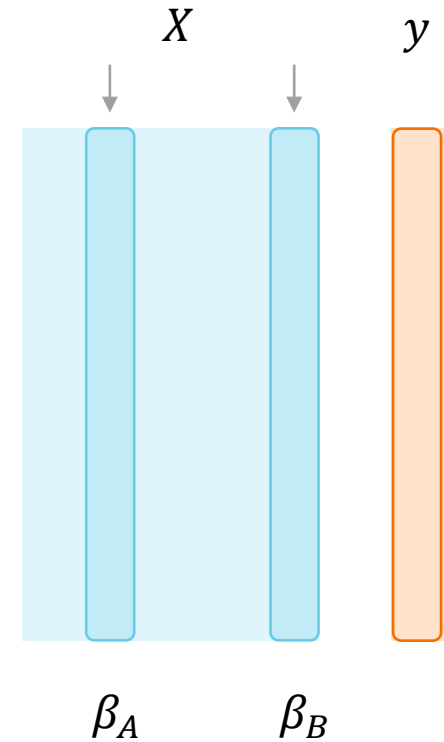
# Ava's approach

Ava is a quant analyst.

She runs a regression, analyzing betas and t-statistics.

Emphasizes variables.

Prediction = weighted average of today's variables.



$$\beta_A x_{t,A} + \beta_B x_{t,B} \rightarrow \hat{y}_t$$

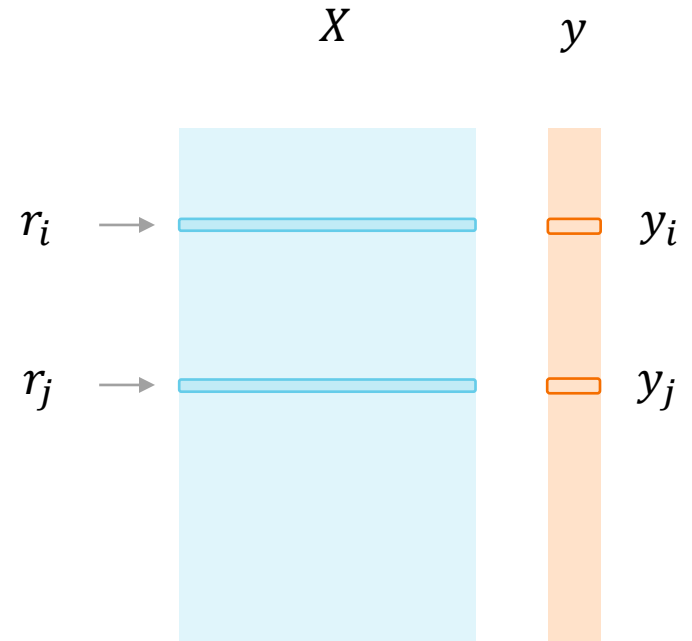
# Ben's approach

Ben is an economic historian.

He carefully picks two relevant episodes.

Emphasizes experiences.

Prediction = weighted average of prior outcomes.



$$r_i y_i + r_j y_j \rightarrow \hat{y}_t$$

# Prediction styles



## Classical Statistics

- Focus on the selection of variables
- Assemble as many observations as possible, regardless of similarity
- Treat unusual observations with skepticism



## Natural Process

- Focus on experiences
- Focus on those experiences that are similar to current circumstances
- Focus on unusual experiences because they are more memorable

# Looking ahead: Design principles for a prediction system

- Transparent
- Flexible
- Non-arbitrary

# Relevance-based prediction: Key tenets

- **Relevance** (of an observation)
- **Fit** (for an individual prediction task)
- **Situational learning** (for an individual prediction task)



# Relevance

We take a weighted average of what happened in the past to predict what will happen in the future.

$$\hat{y}_t = \sum_{i=1}^N w_{it} y_i$$

# Relevance

If we have no way to distinguish between prior experiences, then we weight them equally.

$$w_{it,equal} = \frac{1}{N}$$

In this case, our prediction is the simple average.

$$\hat{y}_t = \sum_{i=1}^N \frac{1}{N} y_i = \bar{y}$$

# Relevance

But what if we acknowledge that some observations are more relevant than others?

$$w_{it,linear} = \frac{1}{N} + \frac{1}{N-1} r(x_i, x_t)$$

Now, we tilt around the average by overweighting relevant experiences.

$$\hat{y}_t = \sum_{i=1}^N \left( \frac{1}{N} + \frac{1}{N-1} r(x_i, x_t) \right) y_i$$

$$\hat{y}_t = \bar{y} + \frac{1}{N-1} \sum_{i=1}^N r_{it} (y_i - \bar{y})$$

# The non-arbitrary starting point for statistical relevance

Information theory tells us that information equals surprise; it is inversely related to probability.

$$\textit{information} = -\log(p(x_i))$$

The Central Limit Theorem establishes the fundamental nature of the normal distribution.

The Mahalanobis distance measures an observation's informativeness; the amount of surprise accounting for typical dispersion and co-occurrence.

$$\textit{info}(x_i) = (x_i - x)\Omega^{-1}(x_i - x)'$$

$$\textit{info}(x_i) \propto -\log(p_{\textit{normal}}(x_i))$$

# Relevance = Similarity + Informativeness

All else equal, we want to overweight more informative observations. But we also want to overweight observations that are more similar to current circumstances.

$$\text{sim}(x_i, x_t) = -\frac{1}{2}(x_i - x_t)\Omega^{-1}(x_i - x_t)'$$

The relevance of an observation to current circumstances depends on the observation's informativeness, and its similarity to current circumstances.

$$r(x_i, x_t) = \text{sim}(x_i, x_t) + \frac{1}{2}(\text{info}(x_i) + \text{info}(x_t))$$

# Relevance = Similarity + Informativeness



# Linear regression equivalence

The relevance-weighted average outcome

=

Full sample regression model prediction

# Partial sample regression

Note that linear regression attaches as much importance to the least-relevant observation as it does to the most relevant observations; it just flips the sign of their effect on the prediction.

We can censor irrelevant observations to improve predictions.

$$w_{it,psr} = \frac{1}{N} + \frac{\lambda^2}{n-1} \left( \delta(r_{it}) r_{it} - \frac{n}{N} \bar{r}_{sub} \right)$$

Or, more simply, we only tilt based on the most relevant subset of experiences.

$$\hat{y}_t = \bar{y} + \frac{1}{n-1} \sum_{\substack{i \text{ where} \\ r > r^*}}^n r_{it} (y_i - \bar{y})$$



# Fit

Observation-based relevance weights allow us to compute the fit for a given prediction, before we have even made the prediction.

Fit measures the confidence we should have in a single prediction, and it varies.

$$fit_t = \rho(w_t, y)^2$$

Fit can be used to evaluate model choices on-demand for each prediction task.

- It inherently penalizes predictions formed from too small a subsample
- It inherently penalizes predictions that use too many noisy attributes
- Its extension, agreement, inherently penalizes predictions dominated by outliers

# R-squared equivalence

The information-weighted average fit across prediction tasks

=

Linear regression model R-squared

## Example: Global temperatures

We observe the latitude, time of year, and average monthly temperature for four major cities, which we will use to inform predictions for other cities.

	Attributes		Outcomes
	Latitude	January = 0 July = 1	Temperature (Celsius)
London	51.3	0	1.1
Tokyo	35.8	0	6.3
Rio de Janeiro	-22.8	0	27.9
Buenos Aires	-34.8	0	24.8
London	51.3	1	18.2
Tokyo	35.8	1	28.0
Rio de Janeiro	-22.8	1	21.1
Buenos Aires	-34.8	1	10.0

Notes: Latitude is approximate. Source: State Street Global Markets. Temperature data from Terrestrial Air Temperature, 1900-2017 Gridded Monthly Time Series v5.01, Kenji Matsuura and Cort J. Willmott.

# Example: Global temperatures

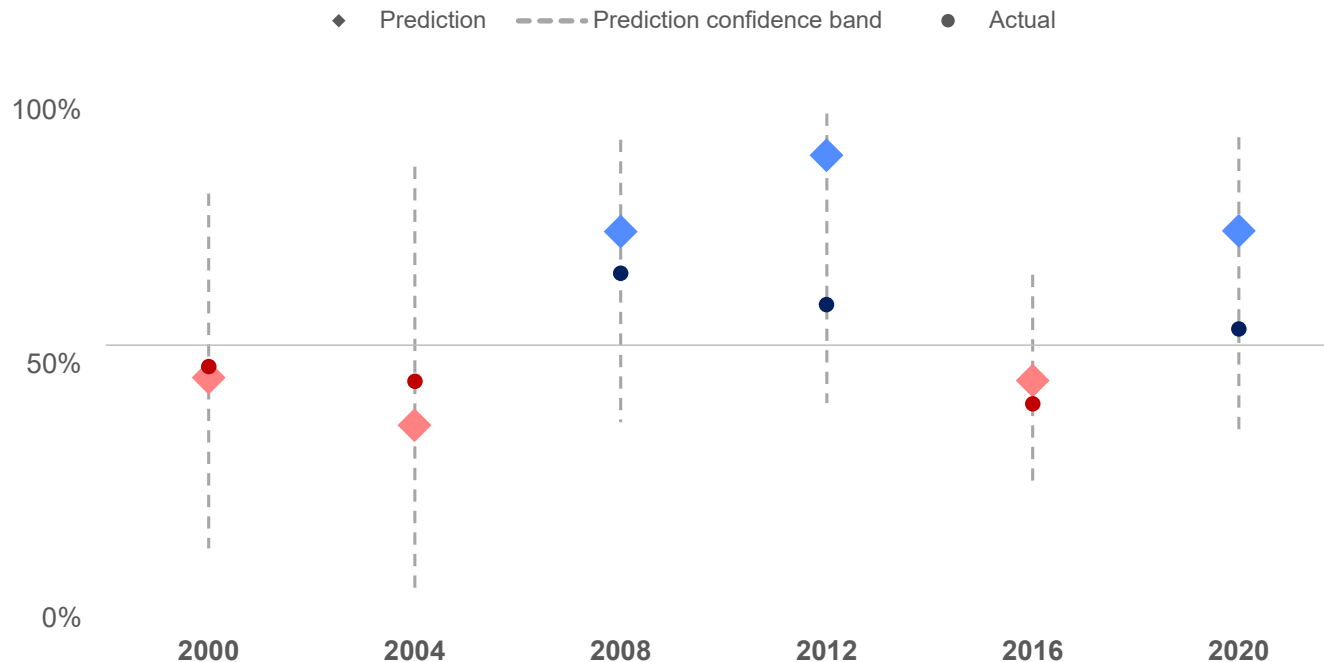
We predict the temperature in **New York** and **Sydney**, based on latitude and time of year.

	Attributes		Predictions		Outcomes
	Latitude	January = 0 July = 1	Full Sample Regression	Partial Sample Regression	Actual Temperature
New York	40.8	0	11.6	4.1	0.1
Sydney	-33.8	0	19.3	26.8	23.4
New York	40.8	1	15.9	22.4	25.9
Sydney	-33.8	1	23.6	14.9	12.5

Notes: Latitude is approximate. Partial Sample Regression uses the top 25 percent most relevant observations. Source: State Street Global Markets. Temperature data from Terrestrial Air Temperature, 1900-2017 Gridded Monthly Time Series v5.01, Kenji Matsuura and Cort J. Willmott.

# Example: Presidential elections

We predict the US presidential elections of **2000**, **2004**, **2008**, **2012**, **2016**, and **2020**, based on economic, political, and geopolitical circumstances.

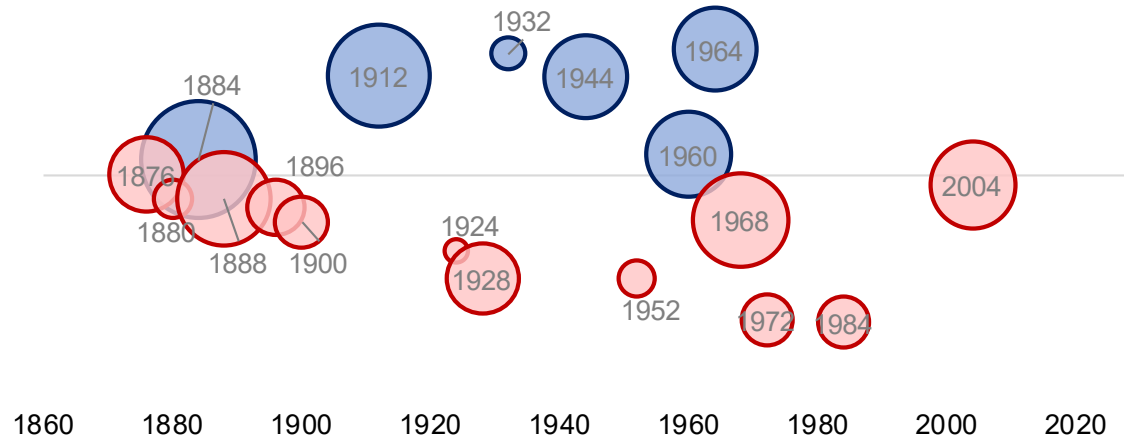


Source: Czasonis, M., M. Kritzman, and D. Turkington. "The Past as Prologue: How to Predict Presidential Elections." MIT Sloan School Working Paper, 6166-20. Confidence intervals represent one standard deviation.

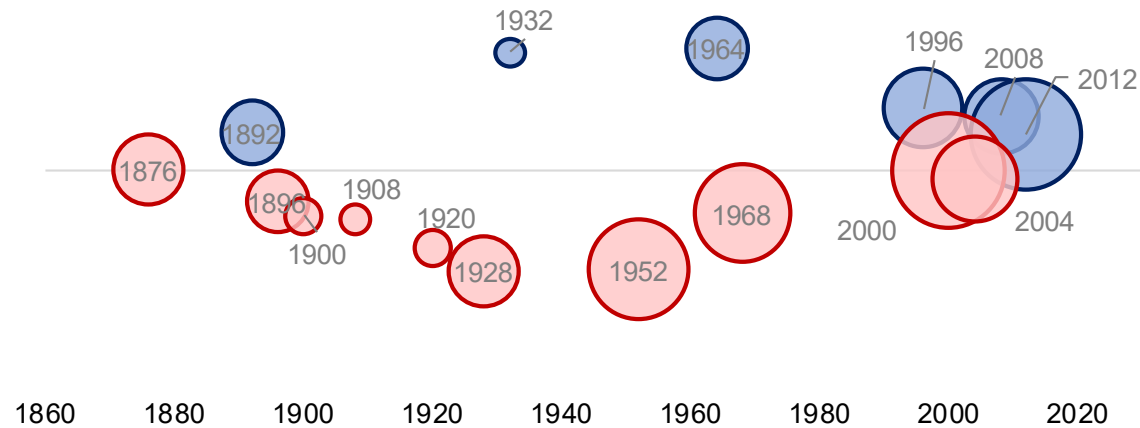
# Example: Presidential elections

Statistically relevant prior elections and their outcomes

2008



2016



Source: Czasonis, M., M. Kritzman, and D. Turkington. "The Past as Prologue: How to Predict Presidential Elections." MIT Sloan School Working Paper, 6166-20. Confidence intervals represent one standard deviation.

# Summary

- Prediction is all about determining relevance.
- Relevance = informativeness + similarity.
- The Mahalanobis distance measures relevance precisely.
- The relevance-weighted average outcome = full sample regression.
- We focus on a subset of relevant experience to improve prediction quality.
- We can scale bets according to each prediction's fit.

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