Sales Prediction with Time Series Modeling
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Predicting Sales
Sales forecasting is critical for retailers
• optimal stocking of products
• website stability under peak traffic
• planning, customer support, and marketing
Anomalies like Black Friday are especially difficult to capture with models
Example data from online sales of tech products:

Conventional Time Series Models
Autoregression (AR)
\[ r_t = c + \epsilon_t + \sum_{i=1}^{p} \phi_{t-i} r_{t-i} \]
Moving Average (MA)
\[ r_t = \mu + \epsilon_t + \sum_{i=1}^{q} \theta_{t-i} \epsilon_{t-i} \]
Autoregressive Integrated Moving Average (ARIMA)
\[ d_t = c + \epsilon_t + \sum_{i=1}^{p} \phi_{t-i} d_{t-i} + \sum_{i=1}^{q} \theta_{t-i} \epsilon_{t-i} \]

Feed-Forward Neural Networks
Nonlinearity induced by hidden layer
\[ y_j = b_j + \sum_{i=1}^{n} w_{ij} x_i \]
Parameters \( b_j \) and \( w_{ij} \) learned from data

Forecast Results
ARIMA
• Order (5,2,0) chosen by minimizing Akaike information, which is a regularized maximum likelihood estimate
• Fourier terms used to introduce multiple-seasonality
• Predictions are too smooth to capture sales spikes

Neural Net
• 10 autoregression lags and 14 hidden layers, chosen by minimizing generalization error
• Averaged prediction of 100 nets initialized with random seeds
• Qualitatively captures sales spikes with lower MSE than ARIMA, but low daily accuracy

ARIMA + Regression
• Regression with indicator vectors for special days like Black Friday and Christmas greatly improves ARIMA
• Captures sales spikes while retaining daily accuracy
• Lower MSE than the neural net

Model Fitting
Hidden Node Count and Autoregression Order
• Erratic behavior can be observed when the number of hidden nodes is low
• Autoregression order made little difference beyond 5 or so
• Both chosen to minimize test MSE, but nearby values could also have been reasonable

Learning Curve
• Curve is non-monotonic since data is not i.i.d. and set size affects prediction interval
• Neural nets require more data to achieve the same forecast accuracy, but can exceed ARIMA with large data sets