



Time Series Analysis and Forecasting

Chapter 8: Modern Extensions

Seminar



Seminar Outline

- 1 Quiz: ARFIMA and Long Memory
- 2 Quiz: Machine Learning for Time Series
- 3 Quiz: LSTM Networks
- 4 True/False Questions
- 5 Practice Problems
- 6 Summary

Quiz 1: Hurst Exponent

Question

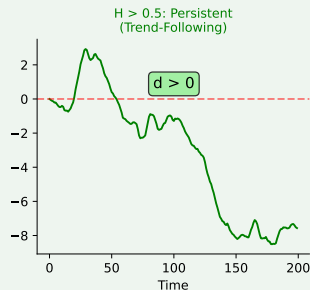
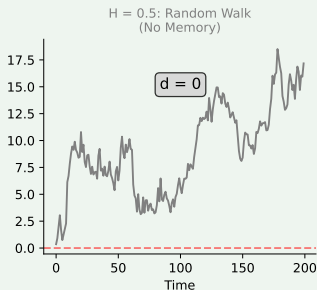
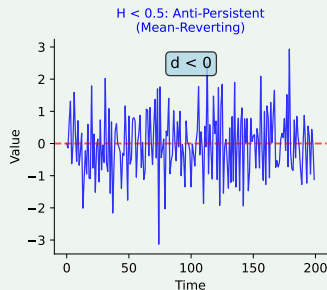
A time series has Hurst exponent $H = 0.8$. What does this indicate?

- ☐ A) The series is a pure random walk
- ☒ B) The series has long memory and is persistent (trend-following)
- ☐ C) The series is anti-persistent (mean-reverting)
- ☐ D) The series is stationary $I(0)$

Answer on next slide...

Quiz 1: Answer

Answer: B – Long memory and persistence



Hurst Exponent Interpretation:

- $H = 0.5$: Random walk (no memory)
- $0.5 < H < 1$: **Persistence** – trends continue
- $0 < H < 0.5$: **Anti-persistence** – mean reversion

Quiz 2: Fractional Differencing Parameter

Question

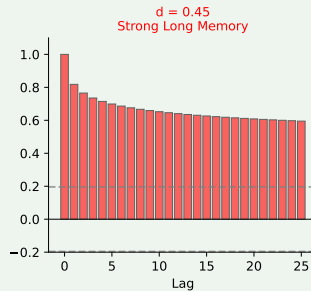
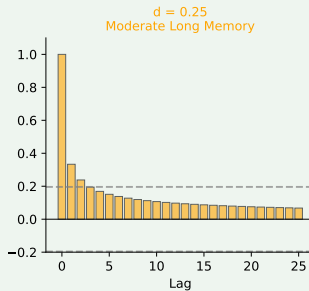
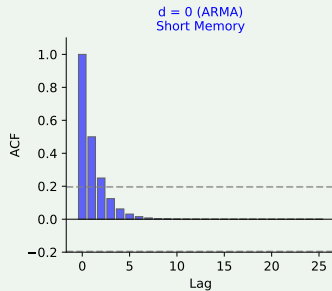
In the ARFIMA(p, d, q) model, the parameter d can take values:

- ☐ A) Only integer values (0, 1, 2, ...)
- ☐ B) Only $d = 0$ or $d = 1$
- ☐ C) Any real value, including fractional
- ☐ D) Only negative values

Answer on next slide...

Quiz 2: Answer

Answer: C – Any real value



Interpretation of d values:

- $d = 0$: Stationary (ARMA)
- $0 < d < 0.5$: Long memory, stationary
- $0.5 \leq d < 1$: Long memory, non-stationary
- $d = 1$: Unit root (classic ARIMA)

Relation to Hurst: $d = H - 0.5$

Quiz 3: Long Memory in Financial Series

Question

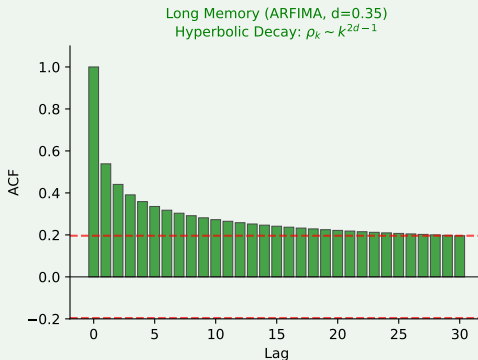
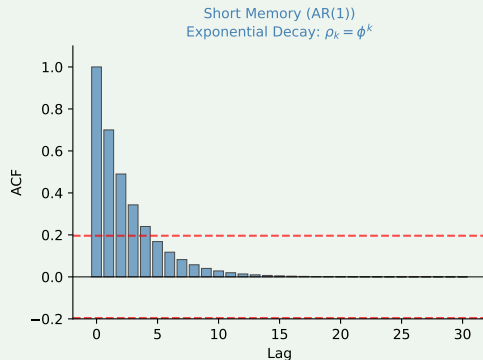
In which financial series is long memory most commonly documented?

- ☐ A) Stock prices
- ☐ B) Daily returns
- ☐ C) Volatility (squared returns)
- ☐ D) Trading volume

Answer on next slide...

Quiz 3: Answer

Answer: C – Volatility



Stylized facts in finance:

- **Returns:** Approximately memoryless ($H \approx 0.5$)
- **Volatility:** Pronounced long memory ($H \approx 0.7 - 0.9$)

Why? Volatility clustering – turbulent periods follow turbulent periods. This is the basis for FIGARCH and HAR-RV models.

Quiz 4: Feature Engineering

Question

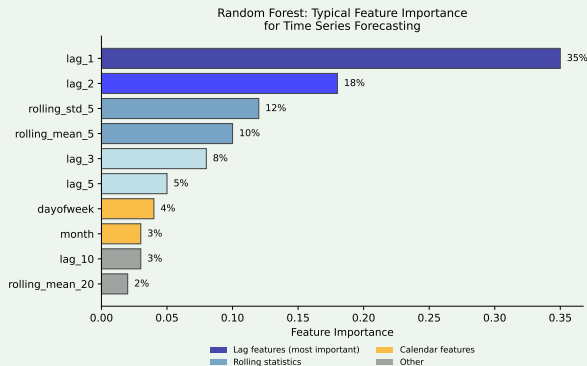
To apply Random Forest to time series, we must create:

- ☐ A) Dummy variables for each observation
- ☐ B) Lag features and rolling statistics
- ☐ C) Fourier transforms of the series
- ☐ D) Only the first difference of the series

Answer on next slide...

Quiz 4: Answer

Answer: B – Lag features and rolling statistics



Feature Engineering for Time Series:

- **Lag features:** $y_{t-1}, y_{t-2}, \dots, y_{t-k}$
- **Rolling statistics:** moving average, moving std, min/max
- **Calendar features:** day of week, month, etc.

Quiz 5: Time Series Cross-Validation

Question

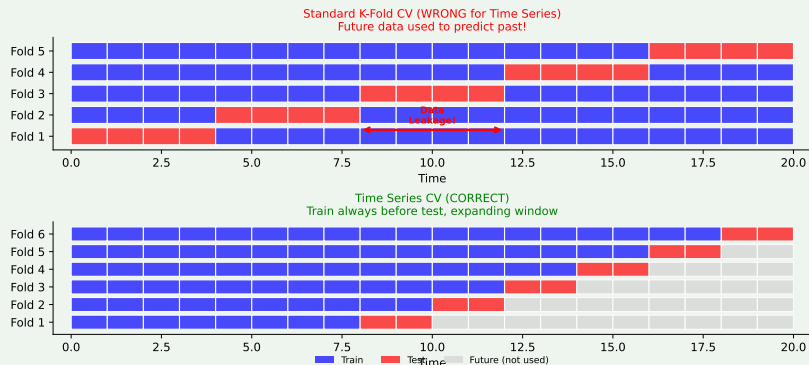
Why can't we use standard k-fold cross-validation for time series?

- ☐ A) It's too slow for long series
- ☐ B) It violates temporal order and causes data leakage
- ☐ C) It only works for classification
- ☐ D) It requires too much data

Answer on next slide...

Quiz 5: Answer

Answer: B – Violates temporal order



Problem with standard k-fold:

- Shuffles observations randomly
- Trains on future data, tests on past
- Data leakage \Rightarrow overestimated performance

Quiz 6: Feature Importance in Random Forest

Question

Feature importance in Random Forest for time series helps us:

- ☐ A) Eliminate all low-importance variables
- ☐ B) Identify which lags and features are most predictive
- ☐ C) Determine Granger causality
- ☐ D) Calculate confidence intervals

Answer on next slide...

Quiz 6: Answer

Answer: B – Identifies predictive features

Uses of feature importance:

- Understanding temporal structure
- Selecting optimal number of lags
- Identifying relevant factors

Caution:

- Importance does NOT imply causality
- Correlated variables may share importance
- Use for interpretation, not causal inference

Quiz 7: LSTM Advantage

Question

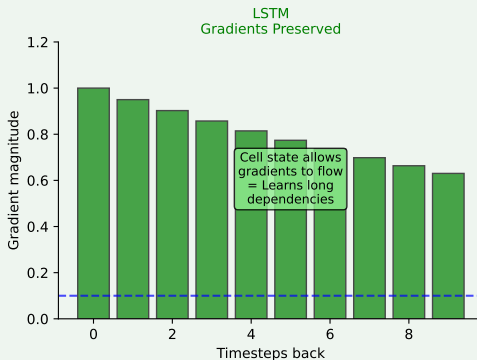
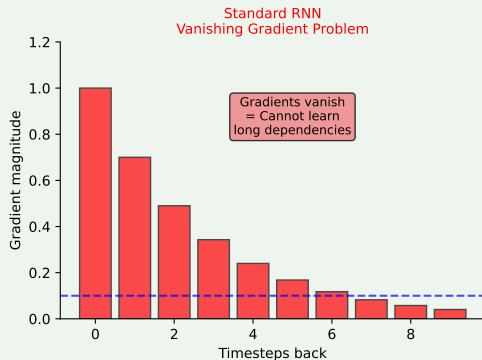
What is the main advantage of LSTM over simple RNNs?

- ☐ A) It's faster to train
- ☐ B) It solves the vanishing/exploding gradient problem
- ☐ C) It requires less data
- ☐ D) It's easier to interpret

Answer on next slide...

Quiz 7: Answer

Answer: B – Solves the gradient problem



Simple RNN Problem: Gradients decay exponentially with sequence length.

LSTM Solution:

- **Cell state:** Highway for information flow
- **Forget gate:** Decides what to forget
- **Input gate:** Decides what to remember

Quiz 8: Data Preparation for LSTM

Question

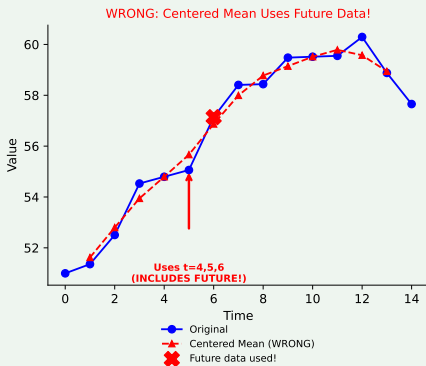
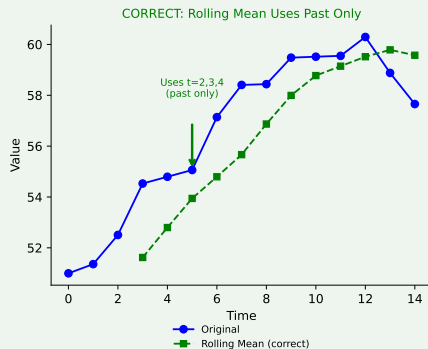
Before training an LSTM, data should be:

- ☐ A) Log-transformed
- ☐ B) Normalized/scaled to $[0,1]$ or $[-1,1]$
- ☐ C) Differenced twice
- ☐ D) Converted to integers

Answer on next slide...

Quiz 8: Answer

Answer: B – Normalized/scaled



Why normalization?

- Activation functions (sigmoid, tanh) work in limited ranges
- Faster convergence
- Numerical stability

Quiz 9: LSTM Hyperparameters

Question

Which is NOT a typical LSTM hyperparameter?

- ☐ A) Number of units (neurons) per layer
- ☐ B) Input sequence length
- ☐ C) Learning rate
- ☐ D) Differencing parameter d

Answer on next slide...

Quiz 9: Answer

Answer: D – The d parameter

d is specific to ARFIMA models, not LSTM!

LSTM Hyperparameters:

- **Architecture:** number of layers, units/layer
- **Sequence:** lookback length
- **Training:** learning rate, batch size, epochs
- **Regularization:** dropout, early stopping

Tuning: Grid search or Bayesian optimization with time series CV

Quiz 10: Model Selection

Question

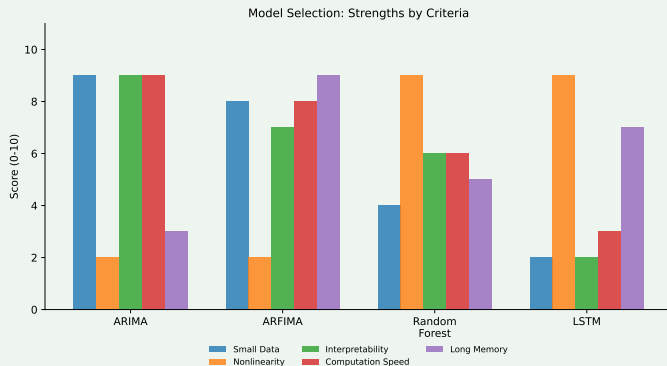
When comparing ARFIMA, Random Forest, and LSTM for forecasting:

- ☐ A) LSTM always wins because it's deep learning
- ☐ B) ARFIMA is always best for financial data
- ☐ C) The best model depends on data characteristics and problem requirements
- ☐ D) Random Forest can't be used for time series

Answer on next slide...

Quiz 10: Answer

Answer: C – Depends on data and requirements



Model Selection Guidelines:

- **ARFIMA:** Long memory, interpretability needed
- **Random Forest:** Nonlinear relations, feature importance
- **LSTM:** Long sequences, complex patterns, sufficient data

True/False Questions

Determine if each statement is True or False:

- ❶ The Hurst exponent $H = 0.5$ indicates long memory.
- ❷ ARFIMA reduces to ARIMA when d is an integer.
- ❸ Standard k-fold CV is appropriate for time series data.
- ❹ LSTM can capture long-range dependencies better than simple RNNs.
- ❺ Feature importance in Random Forest proves causality.
- ❻ Normalizing data is optional when training neural networks.

Answers on next slide...

True/False: Solutions

- ❶ The Hurst exponent $H = 0.5$ indicates long memory.

$H = 0.5$ means random walk (no memory). Long memory: $H > 0.5$.

FALSE

- ❷ ARFIMA reduces to ARIMA when d is an integer.

With $d = 0$ or $d = 1$, ARFIMA becomes standard ARMA or ARIMA.

TRUE

- ❸ Standard k-fold CV is appropriate for time series data.

Use time series split to maintain temporal order and avoid data leakage.

FALSE

- ❹ LSTM can capture long-range dependencies better than simple RNNs.

Cell state and gates allow gradients to flow without vanishing.

TRUE

- ❺ Feature importance in Random Forest proves causality.

Shows predictive power, not causal relationship.

FALSE

- ❻ Normalizing data is optional when training neural networks.

Critical for convergence and stability with activation functions.

FALSE

Problem 1: Hurst Exponent Estimation

Exercise

Given daily Bitcoin returns, estimate the Hurst exponent using the R/S method and interpret the result.

Solution Steps:

- 1 Calculate mean over subintervals of different lengths n
- 2 For each n : calculate $\text{Range}(R)$ and $\text{Std}(S)$
- 3 The ratio R/S grows as n^H
- 4 Fit regression: $\log(R/S) = H \cdot \log(n) + c$

Python code: `nolds.hurst_rs(returns)`

Problem 1: Solution and Interpretation

Typical Bitcoin Results

- Returns: $H \approx 0.45 - 0.55$ (approximately random walk)
- Volatility (—returns—): $H \approx 0.75 - 0.85$ (long memory!)

Interpretation:

- Returns are hard to predict (EMH approximately valid)
- Volatility is predictable over long horizons
- Implications for risk management and VaR

Application: FIGARCH models may outperform standard GARCH

Problem 2: Random Forest for Forecasting

Exercise

Build a Random Forest model for 1-day ahead Bitcoin price forecasting. Evaluate using TimeSeriesSplit.

Pipeline:

- ❶ **Feature engineering:**
 - Lags: $y_{t-1}, y_{t-2}, \dots, y_{t-7}$
 - Rolling mean/std: 7, 14, 30 days
- ❷ **Train/Test split:** TimeSeriesSplit(n_splits=5)
- ❸ **Model:** RandomForestRegressor(n_estimators=100)
- ❹ **Evaluation:** RMSE, MAE, Direction Accuracy

Problem 2: Code and Results

Python Code

```
from sklearn.ensemble import RandomForestRegressor
from sklearn.model_selection import TimeSeriesSplit

tscv = TimeSeriesSplit(n_splits=5)
rf = RandomForestRegressor(n_estimators=100)

for train_idx, test_idx in tscv.split(X):
    rf.fit(X[train_idx], y[train_idx])
    pred = rf.predict(X[test_idx])
```

Typical results:

- Direction accuracy: 52-55% (slightly above random)
- Feature importance: lag-1 and rolling_std dominate

Problem 3: LSTM for Time Series

Exercise

Implement a simple LSTM model for Bitcoin forecasting. Compare with Random Forest.

Simple LSTM Architecture:

- ① Input: 30-day sequences
- ② LSTM layer: 50 units
- ③ Dense output: 1 neuron (forecast)
- ④ Loss: MSE, Optimizer: Adam

Important steps:

- MinMaxScaler normalization
- Reshape to [samples, timesteps, features]
- Early stopping to prevent overfitting

Problem 3: LSTM Code

Keras/TensorFlow Code

```
from tensorflow.keras.models import Sequential
from tensorflow.keras.layers import LSTM, Dense

model = Sequential([
    LSTM(50, input_shape=(30, 1)),
    Dense(1)
])

model.compile(optimizer='adam', loss='mse')
model.fit(X_train, y_train, epochs=50,
        validation_split=0.1, verbose=0)
```

Typical RF vs LSTM comparison:

- RMSE similar (LSTM slightly better on smooth data)
- RF: faster, more interpretable
- LSTM: captures complex patterns better

Summary: When to Use Each Method

ARFIMA

- Series with long memory (volatility, hydrology)
- When $0 < d < 0.5$ is theoretically justified
- Statistical interpretability is important

Random Forest

- Nonlinear relationships between features
- Feature importance for understanding
- Structured data, not too long series

LSTM

- Long sequences with complex dependencies
- Sufficient data for deep learning
- Patterns difficult to capture with classical methods

ARFIMA and Long Memory

- Fractional differencing: $(1 - L)^d y_t = \varepsilon_t$
- Hurst exponent: $d = H - 0.5$
- ACF for long memory: $\rho(k) \sim k^{2d-1}$ (slow decay)

Machine Learning

- Lag feature: $X_t = [y_{t-1}, y_{t-2}, \dots, y_{t-k}]$
- RMSE: $\sqrt{\frac{1}{n} \sum (y_i - \hat{y}_i)^2}$
- Direction Accuracy: $\frac{1}{n} \sum \mathbf{1}[\text{sign}(\Delta y) = \text{sign}(\Delta \hat{y})]$

LSTM

- Forget gate: $f_t = \sigma(W_f \cdot [h_{t-1}, x_t] + b_f)$
- Cell update: $C_t = f_t * C_{t-1} + i_t * \tilde{C}_t$

Thank You!

Questions?

`danpele@ase.ro`