Vector Alpha:
An Institutional-Grade Multi-Asset Portfolio Backtesting and Risk Attribution Framework

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Abstract

Vector Alpha is an institutional-grade, multi-asset portfolio backtesting and risk attribution framework designed for systematic strategy evaluation under realistic execution constraints. The system emphasizes strict separation of concerns across data ingestion, execution modeling, portfolio accounting, and risk analysis to eliminate common sources of bias such as look-ahead leakage and misaligned returns. Weekly rebalancing with daily weight drift, explicit transaction cost modeling, and lagged-weight portfolio accounting are employed to replicate real-world portfolio dynamics. Using a long-only equity universe spanning the 2020–2025 period, Vector Alpha demonstrates how portfolio drawdowns and volatility can be decomposed at the asset level. Empirical results show that the 2022 drawdown was driven primarily by correlation concentration, with a small subset of growth-oriented equities dominating both return drag and risk contribution. Vector Alpha is fully deterministic, auditable, and intended as a research and evaluation platform rather than a trading system.

1 Introduction

Backtesting frameworks form the foundation of quantitative investment research. However, many academic and student-level implementations rely on simplifying assumptions that materially diverge from institutional practice, including frictionless execution, single-period evaluation, and incomplete risk analysis. Such assumptions often produce misleading conclusions about strategy robustness.

Vector Alpha is designed to address these shortcomings by prioritizing execution realism, accounting correctness, and explanatory risk attribution. Rather than proposing a novel alpha-generating strategy, the framework focuses on answering a more fundamental question: *why does a portfolio behave the way it does across market regimes?*

The core design principles of Vector Alpha are:

- Strict separation of data, execution, accounting, and analysis layers
- Elimination of look-ahead bias via lagged-weight portfolio returns
- Explicit modeling of turnover and transaction costs

- Risk-centric evaluation using drawdowns and rolling statistics

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2 System Architecture

Vector Alpha follows a modular, layered architecture in which each component serves a single, well-defined purpose. This structure ensures auditability, reproducibility, and robustness against silent implementation errors.

2.1 Data Layer

Raw OHLCV market data is ingested on a per-asset basis and stored in immutable CSV format. Processed data, consisting of aligned adjusted prices and returns, is persisted separately in columnar form. All downstream computations operate exclusively on processed data to guarantee determinism.

2.2 Feature Layer

The feature engine computes historical, cross-sectional features using only information available prior to each observation. All rolling features are explicitly shifted to prevent information leakage.

2.3 Strategy Layer

Strategies interact with the system only through rebalance-date weight generation. They are intentionally stateless and have no access to execution, portfolio accounting, or performance metrics.

2.4 Execution Layer

Execution logic converts target portfolio weights into realized daily weights by accounting for transaction costs and natural weight drift between rebalances. Turnover is computed explicitly, and transaction costs are applied only on rebalance dates.

2.5 Portfolio Accounting

Portfolio returns are computed using lagged weights and contemporaneous asset returns. Equity evolution is tracked explicitly, ensuring that trading decisions and accounting outcomes remain logically separated.

2.6 Risk and Attribution Layer

Risk metrics and attribution analyses are computed as post-processing steps. Both return and volatility are decomposed at the asset level to explain portfolio behavior rather than simply reporting aggregate performance.

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3 Methodology

3.1 Asset Universe and Data

The empirical evaluation uses a long-only universe of liquid U.S. equities spanning January 2020 to December 2025, comprising 1505 aligned trading days.

3.2 Rebalancing and Execution

Portfolios are rebalanced weekly using the final trading day of each week, resulting in 313 rebalance events. Between rebalances, portfolio weights drift according to asset returns and are renormalized daily.

Transaction costs are modeled linearly as a function of turnover:

$$\text{Cost}_t = c \sum_i \left| w_{i,t}^{\text{target}} - w_{i,t^-} \right|$$

where c denotes a constant per-unit cost parameter.

3.3 Portfolio Returns

Daily portfolio returns are computed as:

$$R_t^p = \sum_i w_{i,t-1} \cdot r_{i,t}$$

ensuring that portfolio performance reflects only information available prior to period t.

3.4 Risk Metrics

Risk is evaluated using annualized volatility, drawdown, and rolling Sharpe ratios. Rolling-window analysis is employed to capture regime-dependent instability and temporal variation in risk-adjusted performance.

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4 Return and Risk Attribution

4.1 Return Attribution

Asset-level return contributions are computed as:

$$C_{i,t} = w_{i,t-1} \cdot r_{i,t}$$

By construction, the sum of asset contributions equals the total portfolio return at each time step.

4.2 Risk Attribution

Volatility attribution is performed using a covariance-based decomposition. Let Σ denote the asset return covariance matrix and w the vector of average portfolio weights. Portfolio volatility is given by:

$$\sigma_p = \sqrt{w^\top \Sigma w}$$

Marginal and total risk contributions are derived to ensure additivity and interpretability.

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5 Empirical Results

5.1 Baseline Behavior

An equal-weight baseline strategy exhibits performance consistent with broad equity market behavior, including significant drawdowns during periods of market stress.

5.2 2022 Drawdown Analysis

The maximum drawdown of approximately 45% occurs during the 2022 market regime. Attribution analysis indicates that NVDA and TSLA dominate both volatility contribution and return drag during this period, reflecting heightened correlation among growth-oriented equities. META contributes materially to losses with elevated risk, while ORCL provides partial diversification benefits.

5.3 Interpretation

These findings demonstrate that diversification by asset count does not necessarily imply diversification by risk, particularly during correlation regimes driven by macroeconomic stress.

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6 Limitations

Vector Alpha intentionally omits several extensions:

- Factor-based risk attribution
- Dynamic universe selection
- Intraday execution modeling
- Nonlinear transaction cost models
- Leverage and short-selling

These omissions preserve interpretability and auditability and reflect deliberate design choices rather than implementation gaps.

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7 Conclusion

Vector Alpha demonstrates the construction of a robust, institutional-grade portfolio backtesting and risk attribution framework. By emphasizing execution realism, accounting correctness, and explanatory attribution, the system provides meaningful insights into portfolio behavior across market regimes. The results underscore the importance of correlation concentration and risk-aware evaluation when assessing systematic strategies.

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References

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