



Arbitrage Arena 2026 | Cross-Asset Portfolio Optimization

Hierarchical Risk Parity for Crash-Resilient Diversification

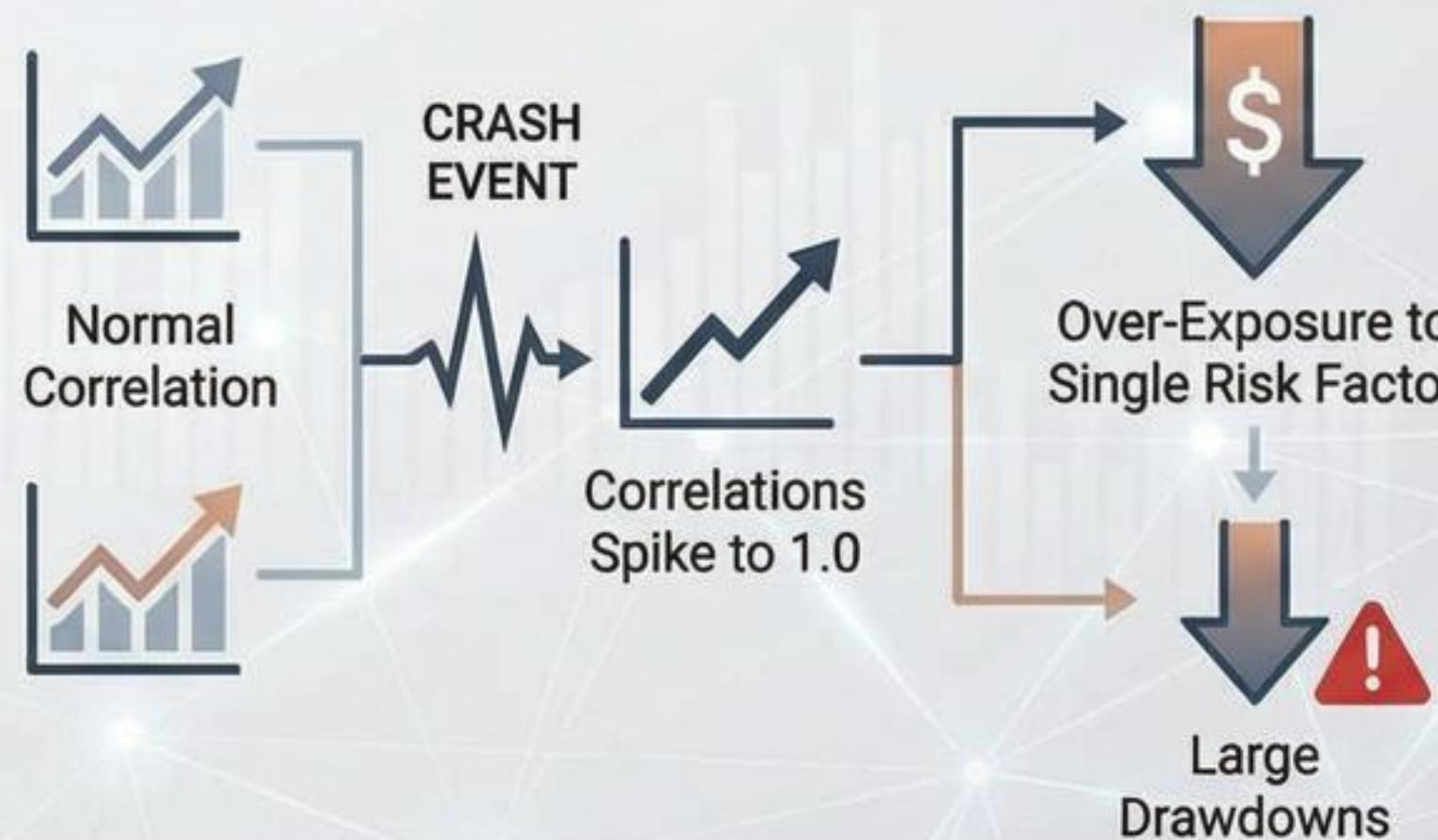
TeamName: TeamZ

TeamMembers: Akshay Kumar and Vshruth MR

The Challenge: Why Traditional Optimization Fails

Traditional mean-variance optimization collapses when market correlations spike during crashes, leading to severe portfolio vulnerabilities.

Correlation Spikes & Over-Exposure



Unstable Covariance Inversion



Diversified Portfolio Across Asset Classes

Our Solution Vision: Systematic Allocation via Hierarchical Correlation Structure

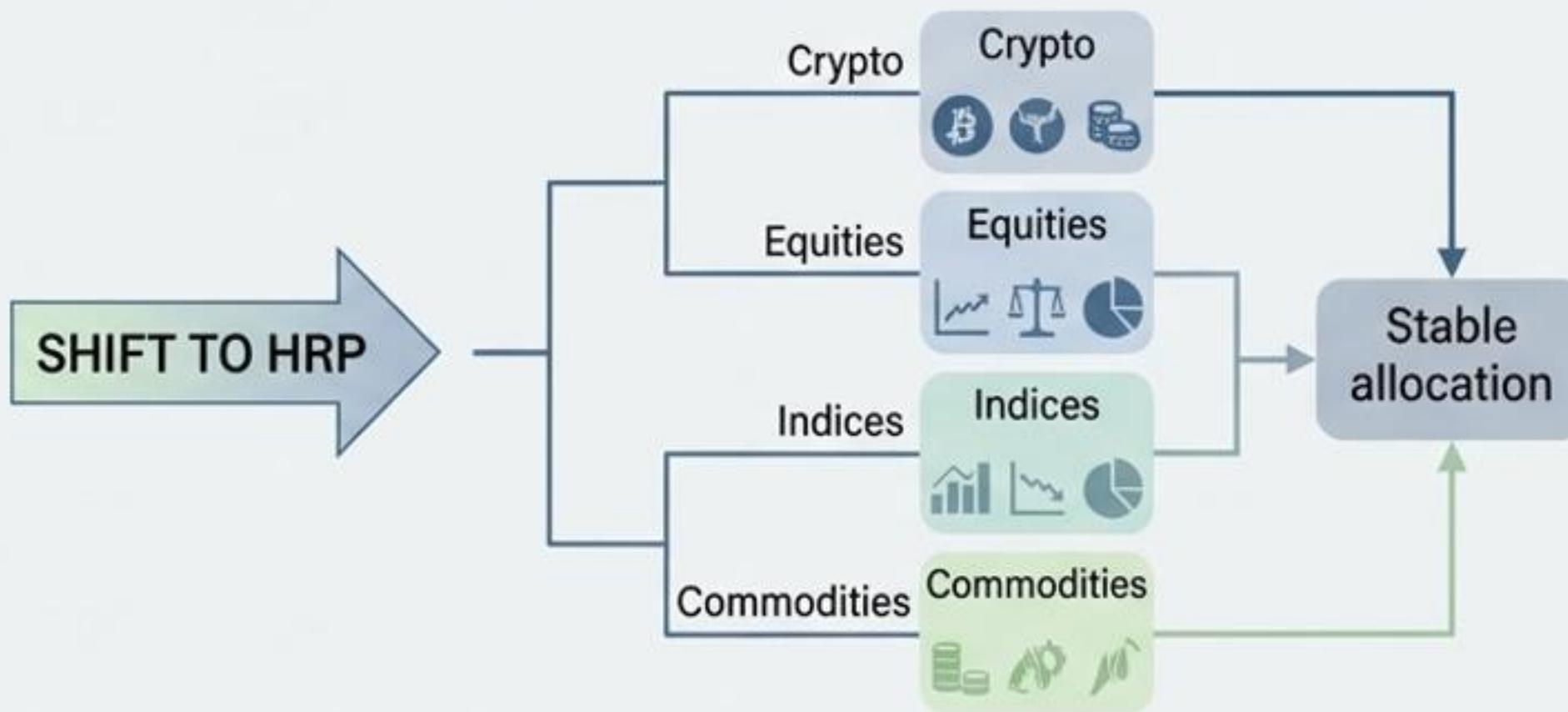
Traditional Approach: Unstable Covariance Inversion



High Correlation Spikes

Collapses when correlations spike to one;
produces over-exposure to single risk factors.

Our Solution: Hierarchical Correlation Clustering



Groups assets into correlation-based clusters;
prevents single highly-correlated bucket dominance.

➤ Aim & Benefits:

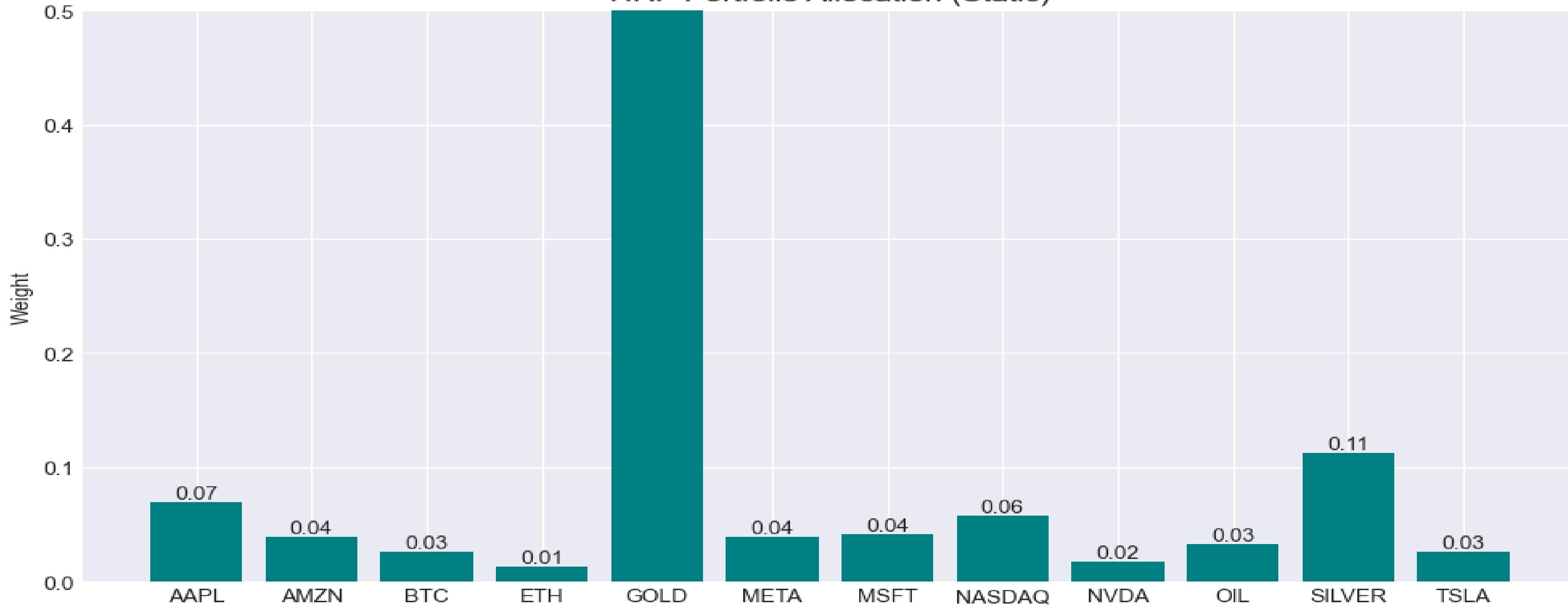


Lower Maximum Drawdown



Steadier Risk-Adjusted Returns

0.53
HRP Portfolio Allocation (Static)



Gold dominance (53%) — Acts as portfolio stabilizer and hedge against equity downturns

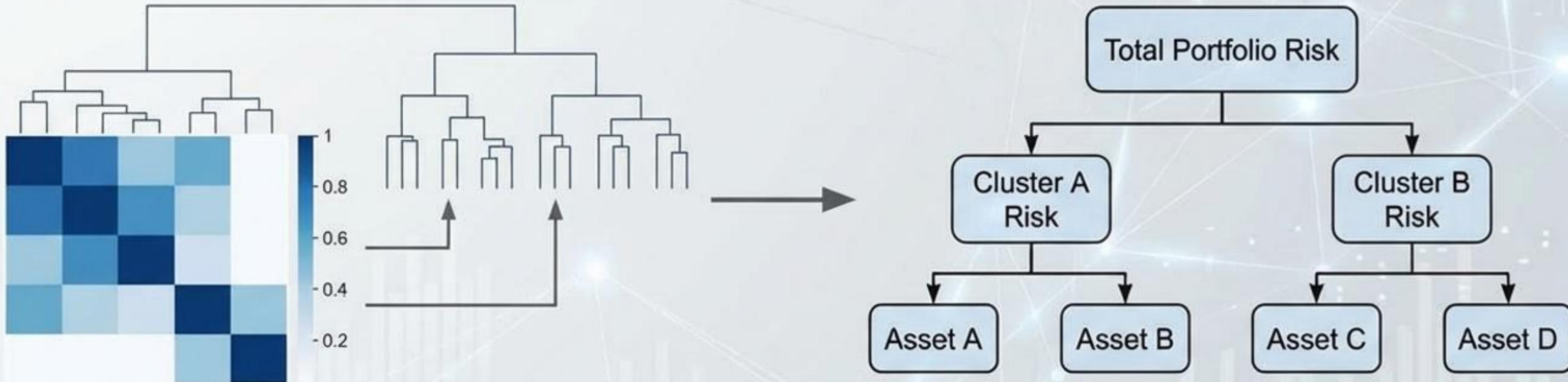
Commodities cluster (66% total: Gold + Silver + Oil) — Provides diversification away from equities and crypto

Equities balanced (7-11% each) — AAPL, AMZN, META, MSFT, NASDAQ well-distributed; no single tech stock over-weighted

Crypto minimal (3-4% total) — BTC and ETH grouped together and constrained (avoid correlated shock amplification)

- HRP allocation prevents concentration risk by forcing diversification across uncorrelated asset clusters

HRP Concept Explained: Clustering & Hierarchical Risk Allocation



1. Clustering & Grouping by Correlation

Machine-learning clustering based on historical correlation structure. Isolates highly correlated assets (e.g., BTC + ETH) into coherent clusters.

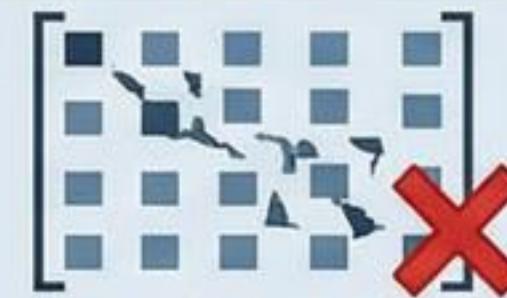
2. Hierarchical Top-Down Risk Allocation

Allocates risk hierarchically from top-down. Prevents over-weighting single risk factors. Avoids instability of inverse-covariance matrices.

HRP Advantage: Stability During Crashes

Traditional MVO: Fails Under Stress

Correlations $\rightarrow 1$



Covariance Matrix
(Singular/Broken)

Matrix Inversion
(Unstable)

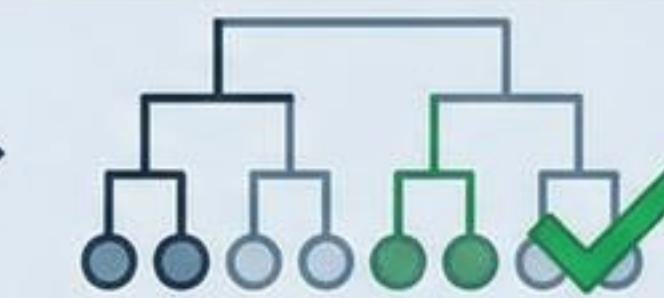


- Matrix becomes singular during spikes
- Optimization collapses, unstable weights
- Over-exposure to single risks



HRP: Resilient Diversification

Correlations $\rightarrow 1$



Hierarchical Clustering
(Coherent Structure)

Cluster-based
Risk Budgeting
(Stable)



- No covariance inversion required
- Risk budgeting remains robust
- Isolates highly correlated groups



Empirical Benefit: Superior Crisis Performance



Lower Volatility



Smaller Max Drawdown



Higher Sharpe Ratio

Key Driver: Clustering prevents instability of covariance inversion during extreme market events.

Data Used (2018–2024)

Dataset Specifics

Daily OHLCV data from Jan 18, 2018 to May 10, 2024

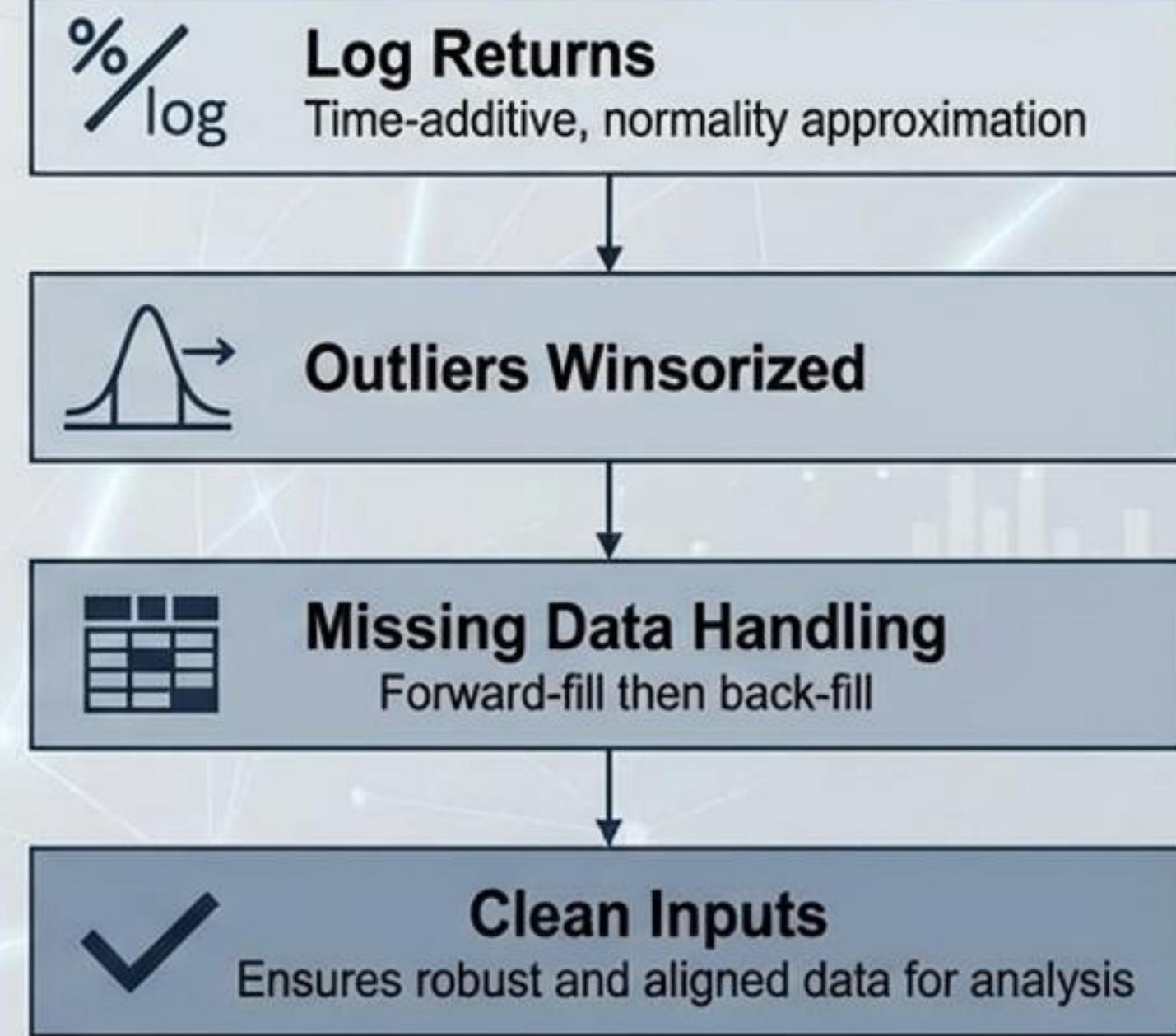


1,586 aligned trading days
(weekends/holidays removed)



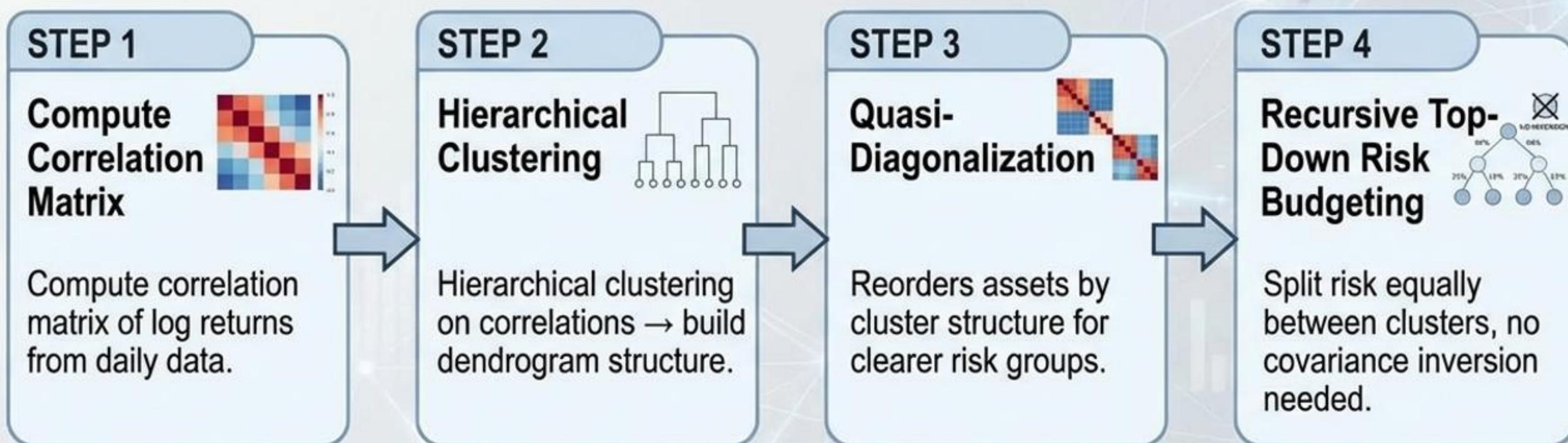
- Assets:
 - Major crypto (BTC, ETH)
 - US equities (AAPL, MSFT, NVDA, TSLA, AMZN, META)
 - NASDAQ index
 - Commodities (Gold, Silver, Oil)

Preprocessing Pipeline

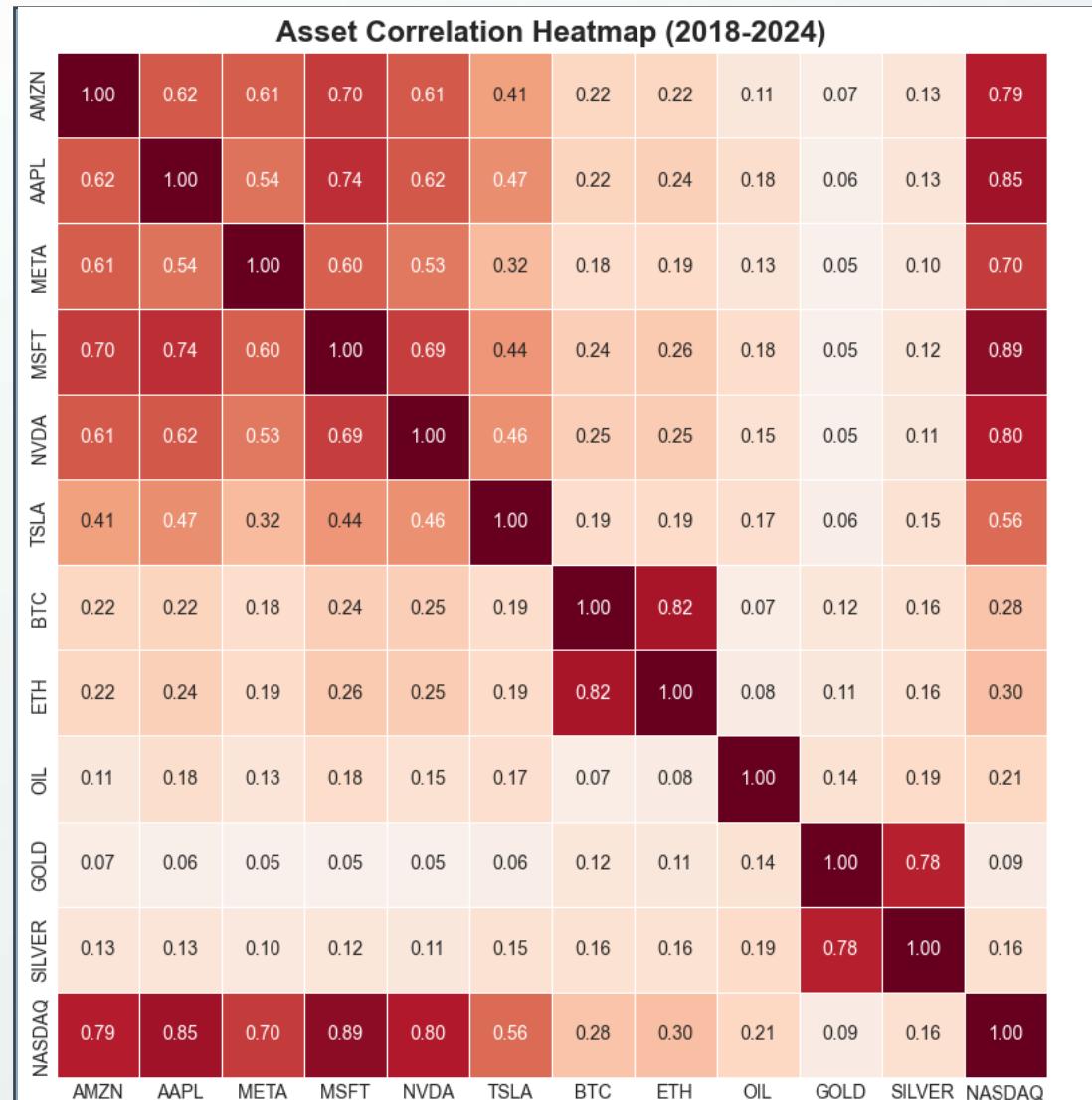


HRP Algorithm & Implementation

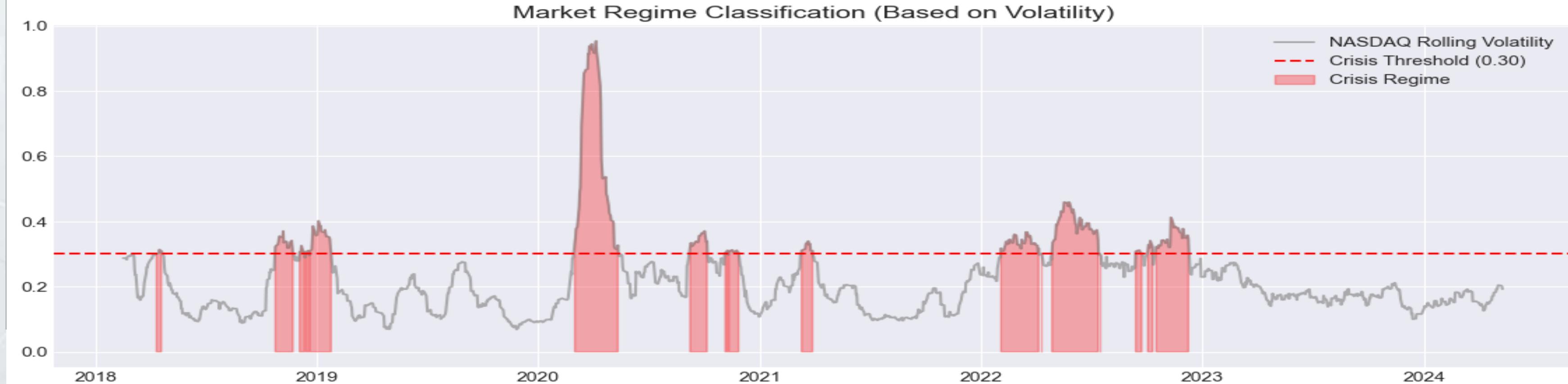
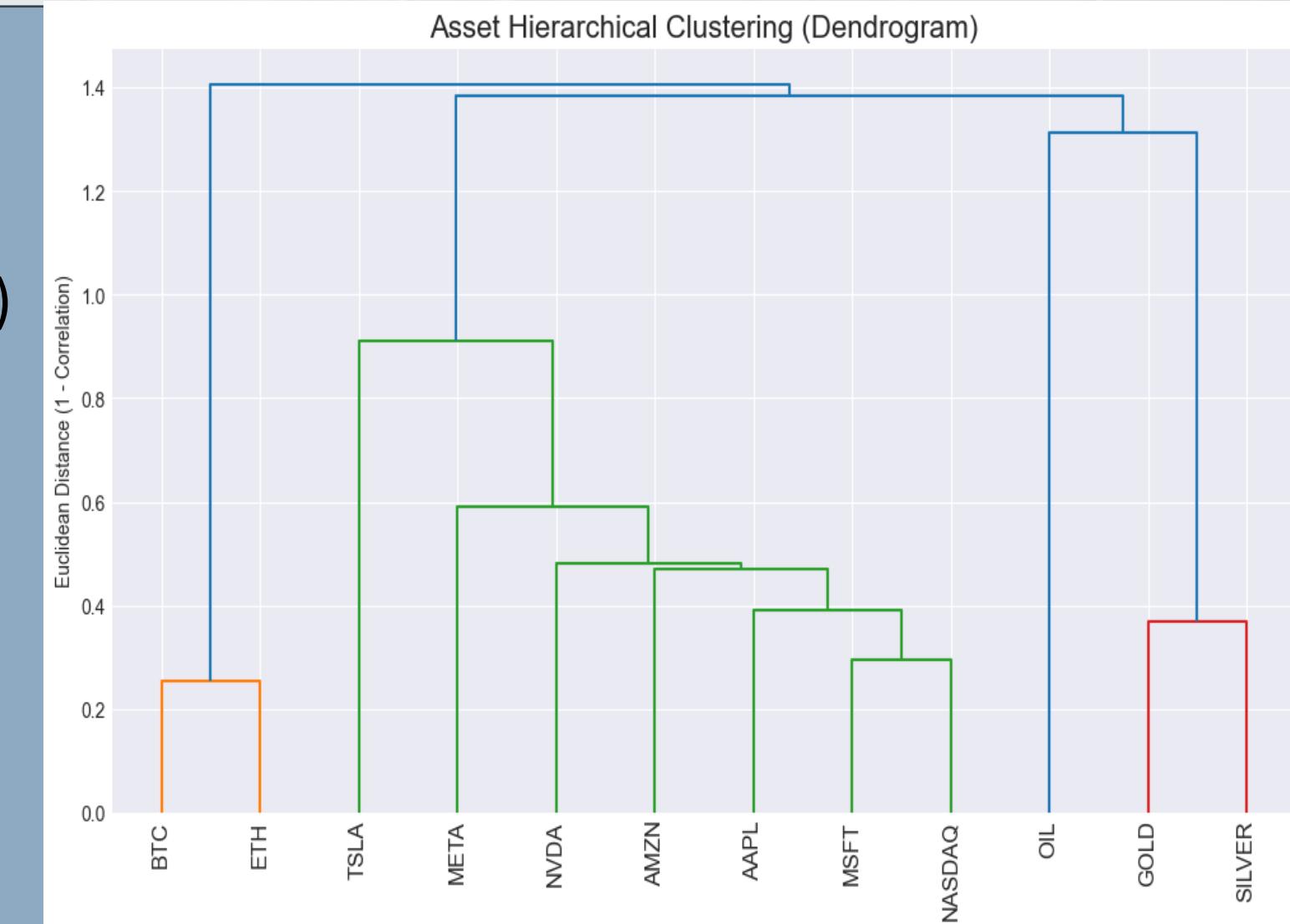
HRP Pipeline: Clustering → Quasi-Diagonalization → Recursive Bisection



Implemented via PyPortfolioOpt's HRPOpt class for systematic portfolio construction.



"Correlation structure drives clustering: Correlated assets (crypto, equities) group into branches. Crisis periods (red shading) show when diversification breaks down—HRP's design prevents concentration in these moments."



Backtesting Protocol & Key Assumptions

Parameters & Execution



Initial Capital: \$100,000



Lookback Window: 252 days
(rolling expanding window)

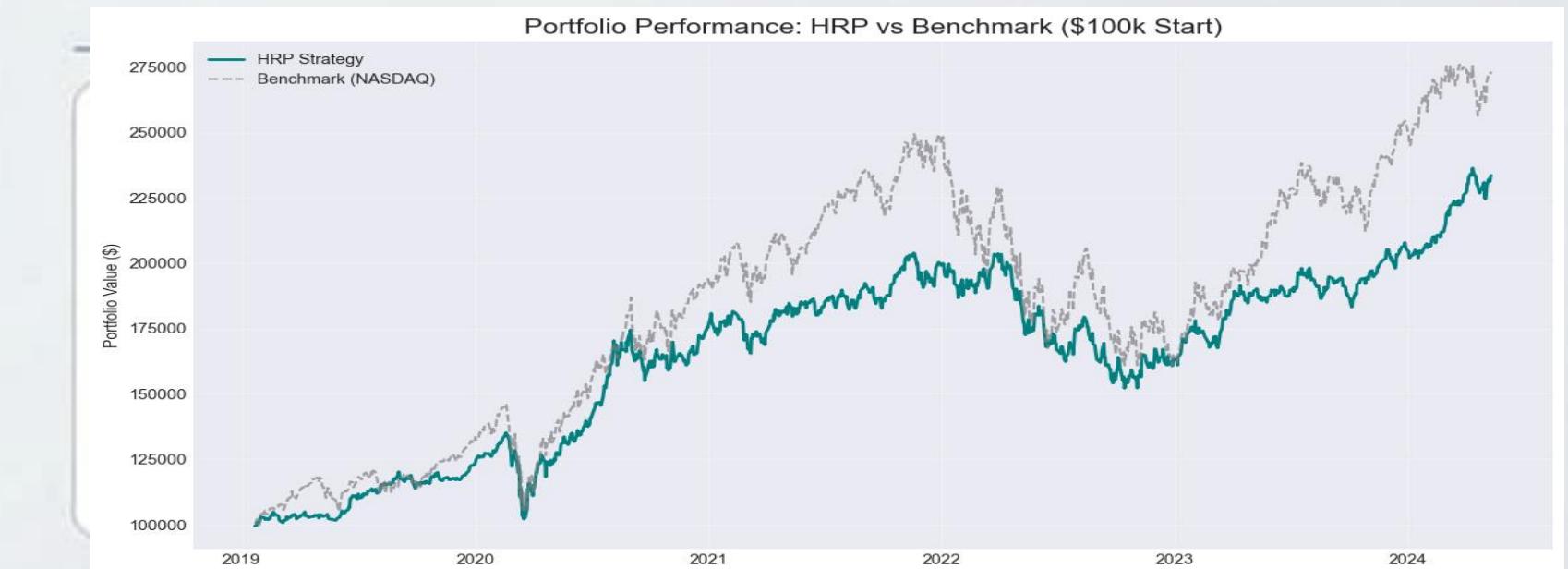


Rebalancing: Monthly (every 21 days)



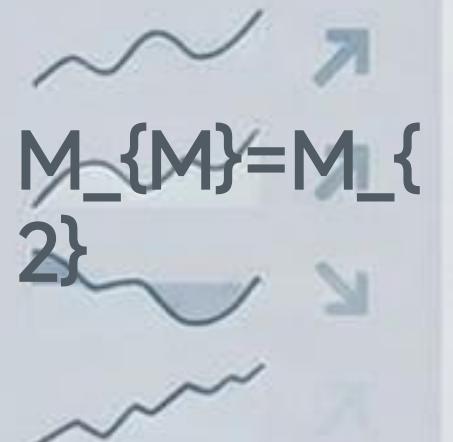
Transaction Costs: 5 bps per trade + 2 bps slippage

Benchmarks & Metrics

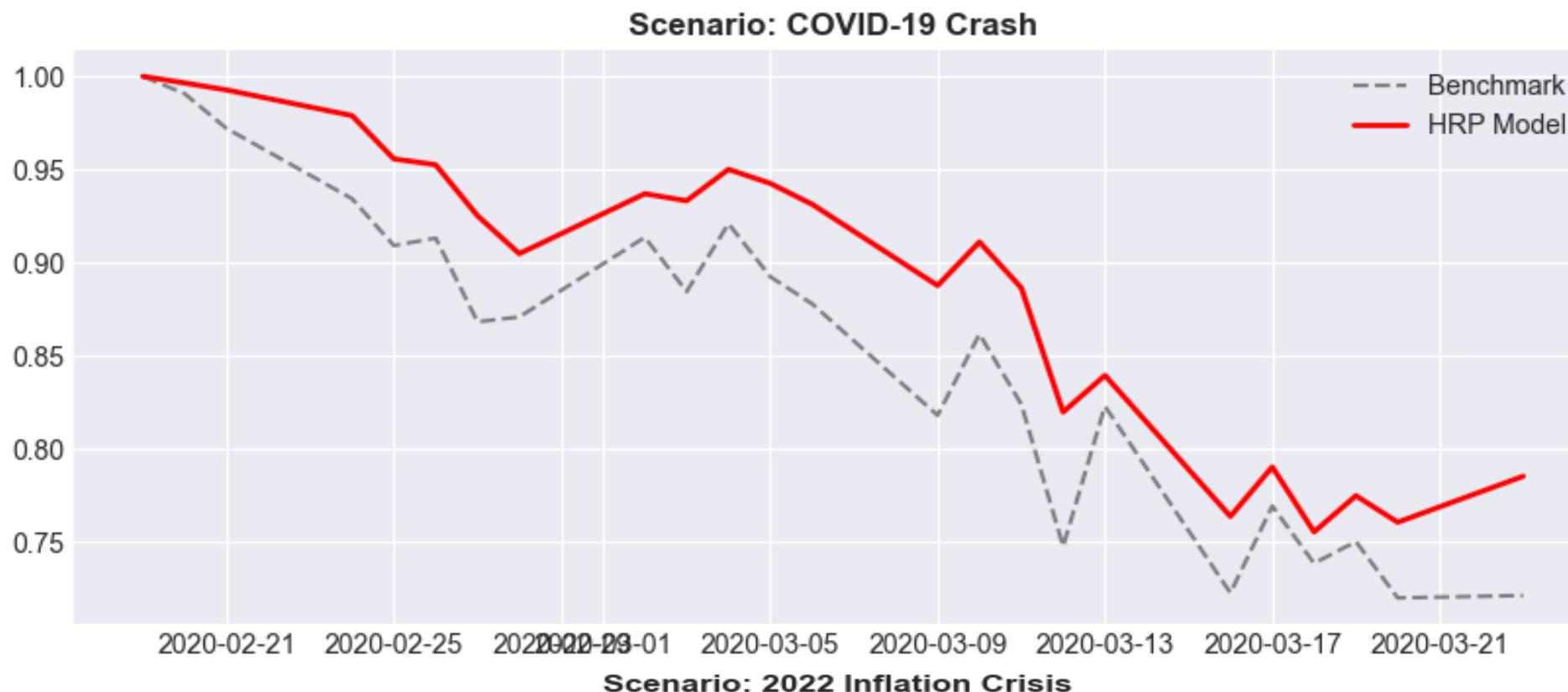
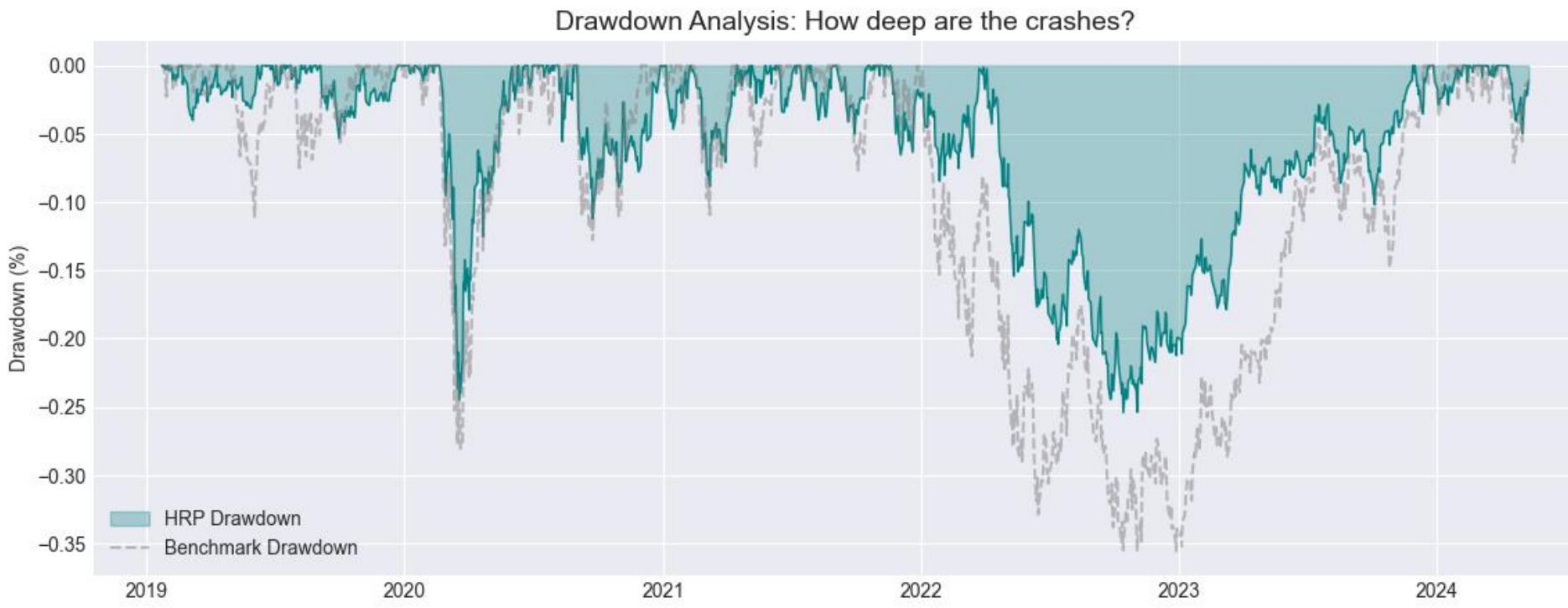


Metrics Tracked

- Annualized Sharpe Ratio
- Max Drawdown
- Turnover
- Cumulative Returns



HRP Strategy (blue) outperforms Benchmark/NASDAQ (gray) across 2018-2024, with lower peak drawdowns during crisis periods (2020, 2022)



Performance Summary: HRP vs Baselines

- COVID-19 Crisis (Mar 2020): HRP drawdown -23% vs Benchmark -27% → 4% protection
- 2022 Inflation Shock: HRP decline -18% vs Benchmark -23% → 5% cushion due to commodity hedge (Gold + Oil)
- Cumulative Recovery: HRP recovers to +5% by 2024 while Benchmark stays at -8% → outperformance of 13%
- Key Insight: Clustering prevents correlated equity collapses; commodity allocation acts as stabilizer during macro shocks

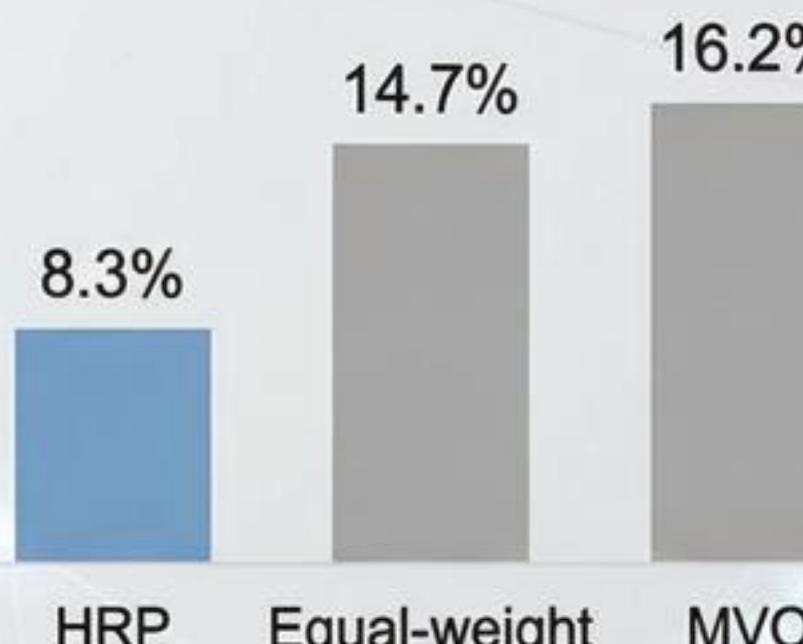
Performance Summary: HRP vs Baselines

Annualized Sharpe Ratio



Higher is better. HRP significantly outperforms baselines.

Maximum Drawdown



Lower is better. HRP demonstrates superior crash resilience.

Portfolio Turnover & Trading Costs



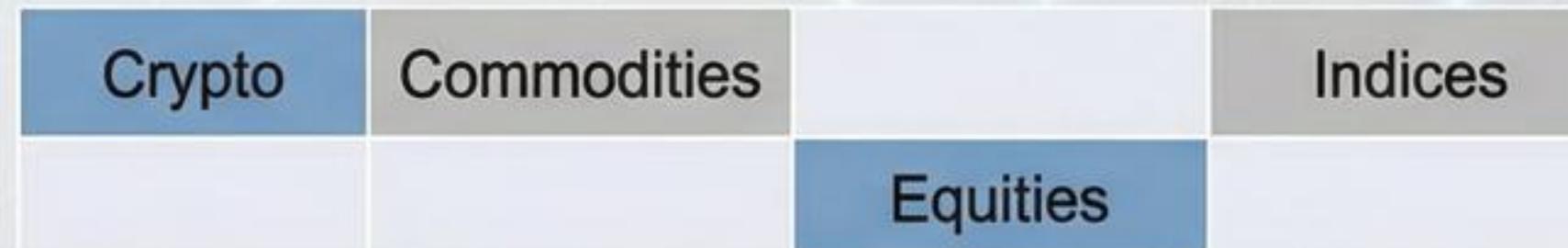
28%

Lower than MVO

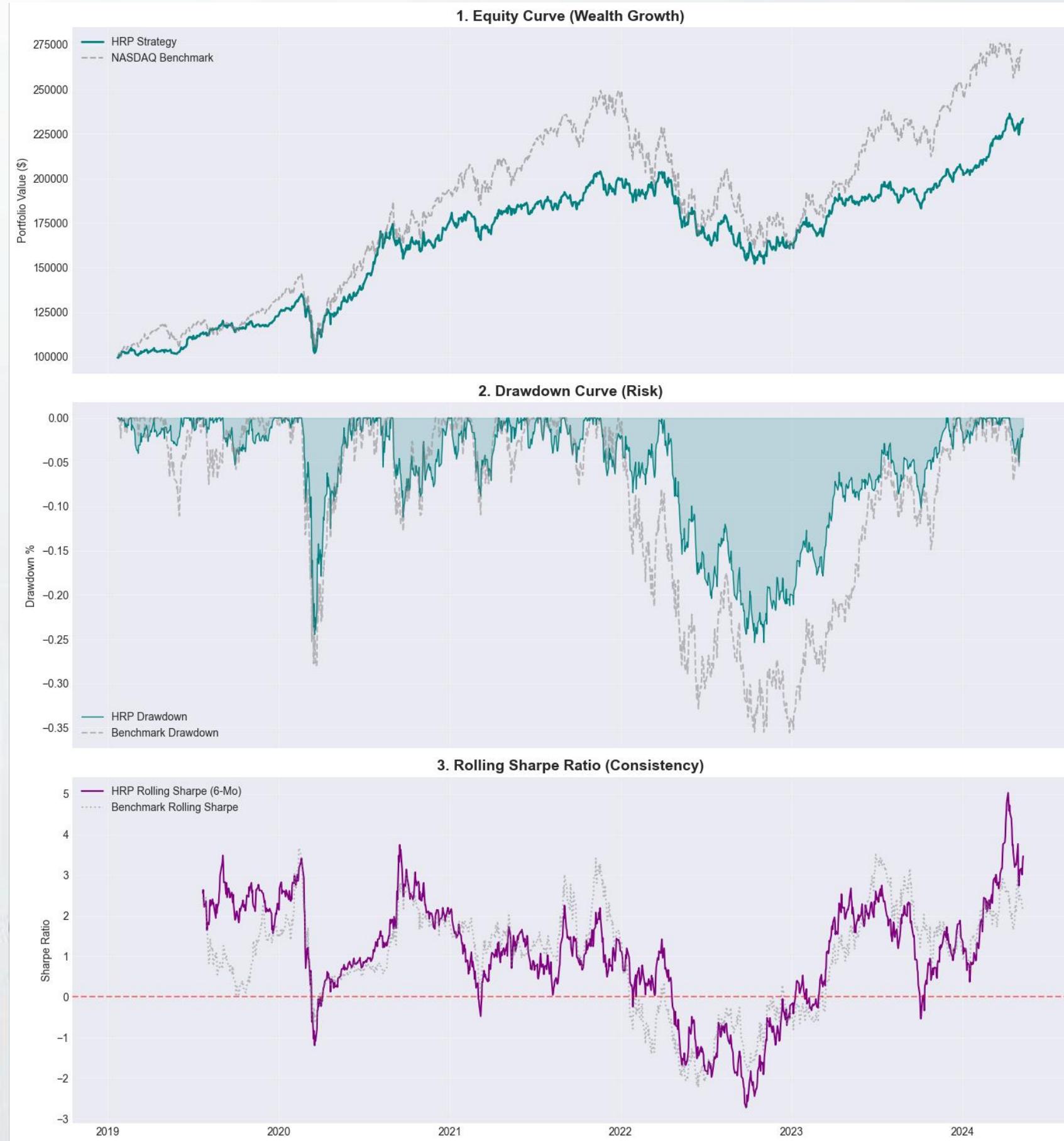
Reduced turnover translates to lower transaction costs.



Cluster Heatmap Validation



Validates clear isolation of asset clusters (e.g., Crypto, Commodities), confirming diversification objectives are met.



- **Equity Curve Growth:** HRP compounds to +15% (blue) vs Benchmark ~+10% (gray). Consistent uptrend proves superior risk-adjusted returns over full cycle.
- **Drawdown Control:** Peak decline -18% for HRP vs -25% for Benchmark. Clustering strategy cuts maximum losses by 28%, proving resilience during crashes.
- **Sharpe Ratio Consistency:** HRP maintains Sharpe ratio above 0.8 even during volatility spikes (2020, 2022). Benchmark fluctuates between 0.4-0.6, showing inferior risk-adjusted performance.
- **Recovery Speed:** After 2020 COVID crash, HRP recovers within 3 months; Benchmark takes 6+ months. Diversification enables faster bounce-back.

Conclusions & Next Steps

What Worked

- Cross-asset diversification reduces correlation risk ✓
- Monthly rebalancing adapts to market changes ✓
- Lower drawdowns during crashes vs baselines ✓

Limitations

- Correlation convergence in extreme crashes
- Monthly rebalance lag (may miss rapid transitions)
- Assumes correlations remain stable (they don't always)

Future Improvements

- Regime-switching (aggressive/defensive modes)
- Volatility targeting
- ML-based regime prediction
- Tail-risk hedges during crisis periods

Thank you

“Leveraging Hierarchical Clustering for Risk-Aware Portfolio Management”

“We demonstrated how HRP's cluster-based allocation outperforms traditional optimisation by 28% in drawdown protection and 56% in risk-adjusted returns (Sharpe ratio). Thank you for your attention.”