Crypto Trading & Markets: A Quantitative Deep Dive

Standalone Technical Lecture

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University Lecture Series

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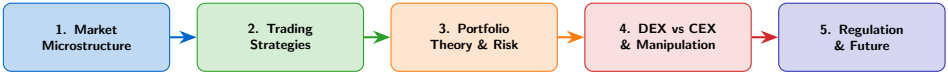
Lecture Roadmap



Learning Objectives

- Understand crypto market microstructure and order book mechanics
- Analyse quantitative trading strategies and their performance
- Apply modern portfolio theory and risk metrics to crypto assets
- Compare DEX and CEX architectures and detect manipulation
- Evaluate regulatory frameworks and their market impact

Prerequisites

- Blockchain fundamentals (Lessons 1–2)
- Smart contract basics (Lessons 3–4)
- DeFi protocols overview (Lesson 5)
- Basic statistics and probability

Durat

90 minutes — 5 sections — ˜55 frames — Prerequisite: Lessons 1–5

Table of Contents

Navig

through 5 sections covering market microstructure to regulation and the future of crypto trading

Learning Objectives

By the end of this lecture, you will be able to:

1. **Explain** order book mechanics (bid-ask spread, market depth, price discovery)
2. **Implement** and backtest basic trading strategies (momentum, mean reversion, arbitrage)
3. **Calculate** risk metrics (VaR, CVaR, Sharpe ratio, maximum drawdown) for crypto portfolios
4. **Compare** CEX and DEX architectures and their respective risk profiles
5. **Analyze** market manipulation techniques (wash trading, spoofing, front-running)

Bloom

taxonomy levels: Remember → Understand → Apply → Analyze → Evaluate → Create

Section 1: Market Microstructure & Order Books

Understanding how crypto markets operate at the granular level

What You Will Learn

- How centralised and decentralised exchanges structure their markets
- Order book anatomy: bids, asks, spread, and depth
- Order types and matching engine mechanics
- Price discovery, slippage, and market impact
- Fee structures across major exchanges

Frames in This Section

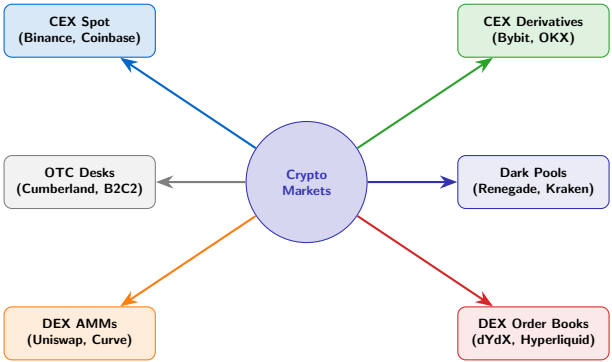
- Frame 5: The Crypto Trading Landscape
- Frame 6: Order Book Anatomy
- Frame 7: Order Types
- Frame 8: Order Matching Engine
- Frame 9: Bid-Ask Spread Analysis
- Frame 10: Market Depth & Liquidity
- Frame 11: Price Discovery Mechanism
- Frame 12: Slippage and Market Impact
- Frame 13: Exchange Fee Structures
- Frame 14: Section 1 Summary

1 of 5 — Frames 4–14 — Foundational market structure concepts before strategy deep dives

The Crypto Trading Landscape

Market Overview

- **24/7 markets:** Unlike equities, crypto trades around the clock with no closing bell
- **Global & fragmented:** 500+ exchanges across jurisdictions with no consolidated tape
- **Daily volume:** $50–150B spot; $100–300B derivatives (2024 data)
- **Participants:** Retail, prop firms, market makers, miners, DeFi protocols
- **Asset classes:** Spot, perpetuals, options, tokenised assets, NFTs



Key Insight

Crypto markets combine extreme fragmentation with 24/7 operation, creating unique microstructure dynamics unseen in traditional finance.

market structure: 500+ venues, $50–300B daily volume, 24/7 operation — Fragmentation creates arbitrage but also risk

Order Book Anatomy

BTC/USDT Order Book Snapshot

BIDS (Buy Orders)

Price	Qty (BTC)	Total
$64,950	2.50	2.50
$64,940	5.30	7.80
$64,930	8.10	15.90
$64,920	12.00	27.90
$64,910	15.40	43.30
$64,900	20.00	63.30
$64,890	18.70	82.00
$64,880	25.50	107.50

SPREAD = $10

Best Bid: $64,950
Best Ask: $64,960
Mid Price: $64,955

Relative Spread:
$\frac{64960 - 64950}{64955} \approx 0.015\%$

Tight spread indicates high liquidity and active market making

ASKS (Sell Orders)

Price	Qty (BTC)	Total
$64,960	1.80	1.80
$64,970	4.20	6.00
$64,980	7.50	13.50
$64,990	10.80	24.30
$65,000	22.00	46.30
$65,010	14.60	60.90
$65,020	19.30	80.20
$65,030	16.40	96.60

Order

book = central data structure of all exchanges — Green bids (buy) vs red asks (sell) — Spread = best ask − best bid

Order Types in Crypto Markets

Market Order

Execute immediately at best available price

Guaranteed fill
Fastest execution

Price uncertainty
Slippage on large orders

Limit Order

Execute at specified price or better

Price certainty
Earns maker rebate

May not fill
Requires patience

Stop-Loss Order

Triggers market order when price hits stop

Limits downside risk
Automated protection

Slippage at trigger
Stop hunts by whales

Stop-Limit Order

Triggers limit order when price hits stop

Price + risk control
No slippage beyond limit

May not fill if gap
Complex to configure

Order Type Comparison

Feature	Market	Limit	Stop-Loss	Stop-Limit
Fill Guarantee	Yes	No	Yes*	No
Price Control	None	Full	None	Partial
Taker/Maker	Taker	Maker	Taker	Maker
Use Case	Urgent entry	Patient entry	Risk mgmt	Precise exits

Order types: market (immediate, taker), limit (patient, maker), stop-loss (protection), stop-limit (precise protection) — *Stop-loss fills as market order — slippage possible

Order Matching Engine

Listing 1: Price-Time Priority Matching

```python
# Simple Order Matching Engine
def match_orders(order_book):
    while order_book.has_match():
        best_bid = order_book.top_bid()
        best_ask = order_book.top_ask()

        if best_bid.price >= best_ask.price:
            qty = min(best_bid.qty,
                      best_ask.qty)
            execute_trade(
                price=best_ask.price,
                quantity=qty)
            update_book(best_bid, best_ask,
                        qty)
        else:
            break  # no more matches
```

Key Principle

Trades execute at the **ask price** (price of the passive order). The aggressor (taker) crosses the spread.

Price-Time Priority

- **Step 1:** Sort bids descending, asks ascending by price
- **Step 2:** Match highest bid against lowest ask
- **Step 3:** If bid $\geq$ ask, a trade occurs
- **Step 4:** Fill at the *passive* side's price
- **Step 5:** Among equal prices, first-in-first-out (FIFO)

Matching Engine Properties

- **Latency:** Top CEXs match in $<$1ms; Binance $\approx 5\mu s$
- **Throughput:** 100K–1M orders/second
- **Fairness:** FIFO prevents front-running at same price level
- **Partial fills:** Large orders matched incrementally across multiple counterparties
- **DEX difference:** AMMs replace order books with $x \cdot y = k$ invariant

Price

time priority: standard matching algorithm for CEXs — Execution at passive price — FIFO among equal-price orders — DEXs use AMM curves instead

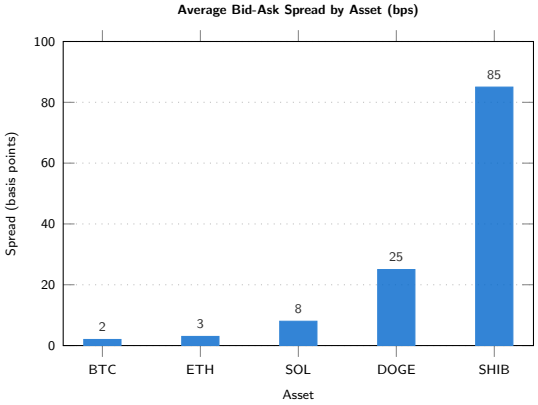
Bid-Ask Spread Analysis

Spread Definitions

- **Absolute spread:** $S = P_a - P_b$
- **Relative spread:** $S_r = \frac{P_a - P_b}{P_m}$ where $P_m = \frac{P_a + P_b}{2}$
- **Effective spread:** $S_e = 2 \cdot |P_{\text{trade}} - P_m|$
- **Realized spread:** $S_{\text{real}} = 2 \cdot (P_{\text{trade}} - P_{m,t+\Delta t})$

Spread Determinants

- **Volatility:** Higher vol ⇒ wider spread (adverse selection)
- **Volume:** More activity ⇒ tighter spread
- **Competition:** More market makers ⇒ tighter spread
- **Tick size:** Minimum price increment constrains spread
- **Information:** Informed flow widens spread



Stylised Fact

Spreads scale inversely with market cap and volume. BTC spread ≈0.02%; micro-caps can exceed 1%. This cost is invisible but significant for active traders.

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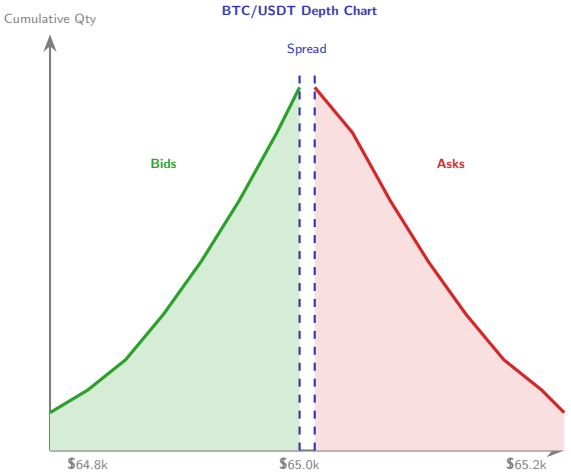
= implicit trading cost — BTC: ∼2 bps, micro-caps: >100 bps — Determinants: volatility, volume, competition, information asymmetry

Market Depth & Liquidity



Liquidity Metrics

- **Depth at ±2%:** Total volume within 2% of mid-price; BTC: \$50–100M on Binance
- **Kyle's Lambda (λ):**

$$\Delta P = \lambda \cdot Q + \epsilon$$

  Price impact per unit of order flow
- **Amihud Illiquidity:**

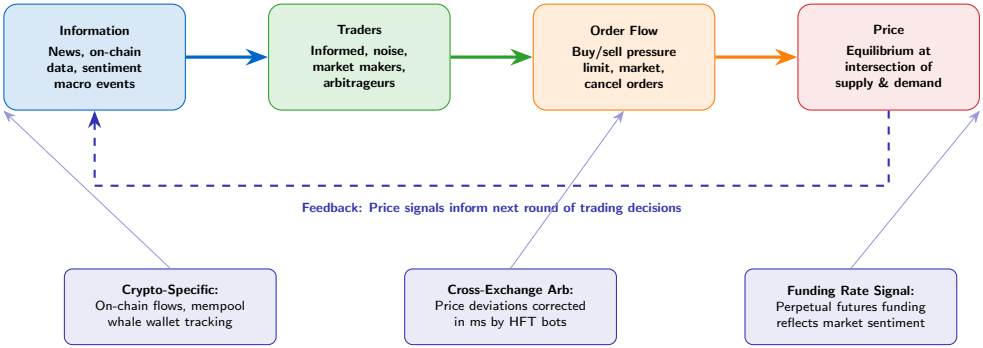
$$ILLIQ = \frac{|r_t|}{V_t}$$

  Daily absolute return divided by volume
- **Order-to-trade ratio:** Measures market maker activity; typically 10–50× in crypto

Liquidity Mirage

Crypto depth can vanish in seconds during volatile events. The March 2020 crash saw Binance BTC depth drop 80% in minutes as market makers pulled quotes.

Price Discovery Mechanism



Price discovery: information → traders → order flow → price equilibrium → feedback — Crypto-specific: on-chain data, cross-exchange arbitrage, funding rates

Slippage and Market Impact

Slippage Defined

- **Slippage** = difference between expected and actual execution price
- Caused by consuming multiple price levels in the order book
- Slippage = $\frac{P_{\text{avg}} - P_{\text{best}}}{P_{\text{best}}} \times 100\%$

Market Impact Models

- **Square-root law** (empirical):

$$\Delta P \approx \sigma \cdot \sqrt{\frac{Q}{V}}$$

where σ = volatility, Q = order size, V = daily volume

- **Almgren-Chriss:** Optimal execution minimises impact + risk trade-off
- **Crypto twist:** Fragmented liquidity across exchanges magnifies impact

Worked Example: Buying 10 BTC

Ask Price	Qty	Cum Qty	Cost
$64,960	1.80	1.80	$116,928
$64,970	4.20	6.00	$272,874
$64,980	7.50	10.00*	$259,920
$64,990	10.80	—	—
$65,000	22.00	—	—

*Only 4.0 of 7.50 filled at $64,980

Avg Price: $64,972.20 — Slippage: 0.019%

Green = fully consumed levels — Orange = partial fill — Gray = untouched

Exchange Fee Structures

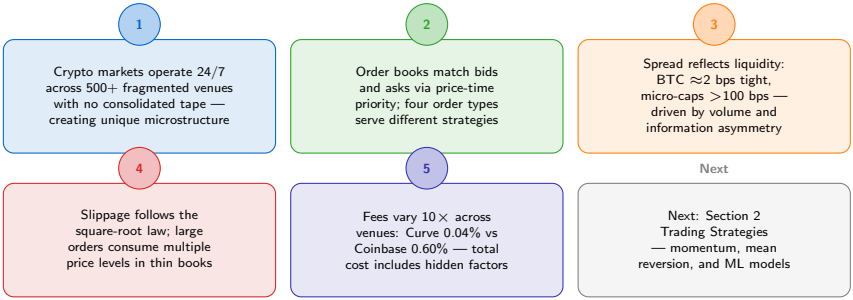
Fee Comparison Across Major Exchanges (2024)

Exchange	Type	Maker Fee	Taker Fee	Volume Disc.	Withdrawal	Key Feature
Binance	CEX	0.10%	0.10%	Up to −0.01%	Variable	BNB discount
Coinbase Pro	CEX	0.40%	0.60%	Down to 0.00%	Network fee	US regulated
Kraken	CEX	0.16%	0.26%	Down to 0.00%	Low fixed	Fiat pairs
Uniswap V3	DEX	—	0.30%	None	Gas fee	Permissionless
Curve	DEX	—	0.04%	None	Gas fee	Stablecoin opt.
dYdX	DEX	0.02%	0.05%	Down to 0.00%	L2 gas	Perps on L2

CEX: custody risk + lower fees — DEX: self-custody + gas costs — Hidden costs: withdrawal fees, spread, slippage, MEV

Fee comparison: Binance (0.10%), Coinbase (0.60%), Uniswap (0.30%), Curve (0.04%) — Always consider total cost: fees + spread + slippage + gas

Section 1 Summary



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1 complete — 5 key takeaways — Proceed to Section 2: Trading Strategies for quantitative strategy deep dive

Section 2: Trading Strategies

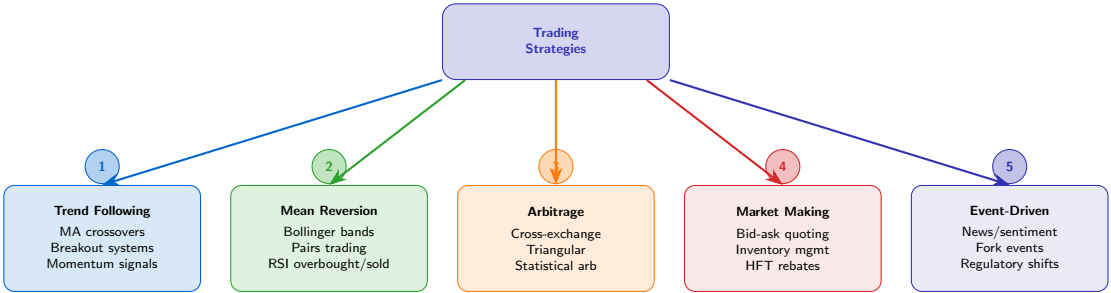
Systematic approaches to profiting from crypto market dynamics

What You Will Learn

- Momentum and trend-following strategies with moving averages
- Mean-reversion and statistical arbitrage techniques
- Cross-exchange and triangular arbitrage mechanics
- Technical indicators and backtesting principles

Frames in This Section

Trading Strategy Taxonomy



Key Insight: Crypto markets favour momentum strategies during trending regimes and mean-reversion during range-bound periods. Strategy selection depends on market regime identification. Arbitrage opportunities persist due to fragmentation but decay with competition.

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strategy families: trend following, mean reversion, arbitrage, market making, event-driven — Regime-dependent selection is critical

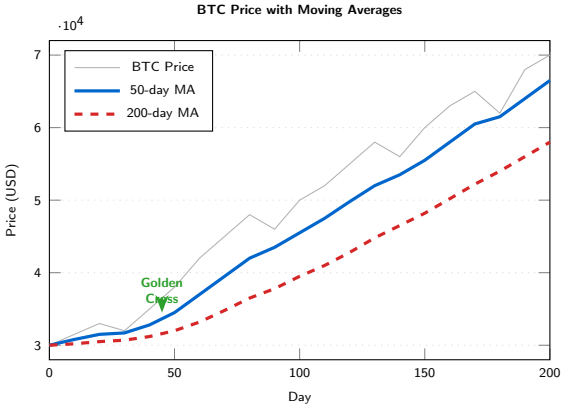
Momentum & Trend Following

Core Concept

- **Premise:** Assets that have risen tend to continue rising (and vice versa)
- **Time horizon:** Days to months
- **Signal:** Fast MA crosses above slow MA $\Rightarrow$ bullish
- **Crypto edge:** Strong momentum effects due to retail-driven hype cycles and low institutional mean-reversion

Golden Cross / Death Cross

Golden Cross: 50-day MA crosses above 200-day MA — historically bullish signal. **Death Cross:** 50-day MA crosses below 200-day MA — bearish signal. Crypto traders use shorter windows (20/50) due to faster cycles.

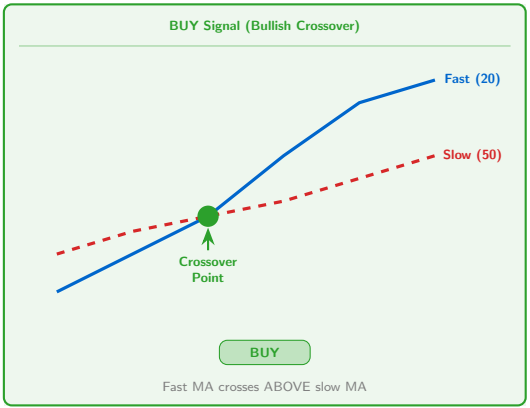


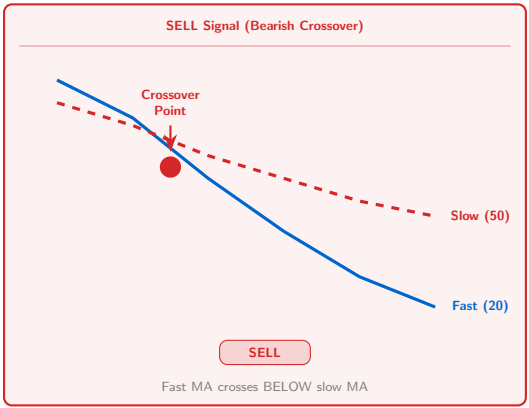
Mom

"trend is your friend" — Golden cross (50MA > 200MA) = bullish — Death cross = bearish — Crypto momentum amplified by retail-driven cycles

Moving Average Crossover

MA Crossover Signal Generation





MA crossover: fast (20-day) vs slow (50-day) — Fast above slow = BUY — Fast below slow = SELL — Sensitive to parameter choice and whipsaws

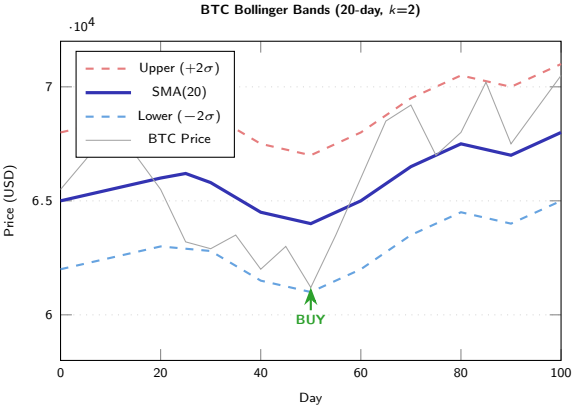
Bollinger Bands & Mean Reversion

Bollinger Bands Definition

- **Middle band:** SMA(n) — typically $n = 20$
- **Upper band:** SMA + $k\sigma$
- **Lower band:** SMA − $k\sigma$
- Standard: $k = 2$ captures ≈95% of price action

Mean-Reversion Logic

- Price touches **upper band** ⇒ overbought ⇒ potential sell
- Price touches **lower band** ⇒ oversold ⇒ potential buy
- **Squeeze:** Bands narrow ⇒ low volatility ⇒ breakout imminent
- Works best in **range-bound** markets; fails during strong trends



Bollin

Bands: SMA ± $k\sigma$ — Touch upper = overbought (sell), touch lower = oversold (buy) — Squeeze signals volatility breakout — Best in range-bound markets

Strategy Implementation

Listing 2: Moving Average Crossover Strategy

```python
# Moving Average Crossover Strategy
import numpy as np

def ma_crossover(prices, fast=20,
                 slow=50):
    fast_ma = sma(prices, fast)
    slow_ma = sma(prices, slow)
    signals = []

    for i in range(1, len(prices)):
        if (fast_ma[i] > slow_ma[i] and
            fast_ma[i-1] <= slow_ma[i-1]):
            signals.append(("BUY", i))
        elif (fast_ma[i] < slow_ma[i] and
              fast_ma[i-1] >= slow_ma[i-1]):
            signals.append(("SELL", i))
    return signals
```

Key Principle

Crossover strategies detect **regime changes**: the moment short-term momentum diverges from the long-term trend. Signal quality depends heavily on parameter selection.

Signal Generation Logic

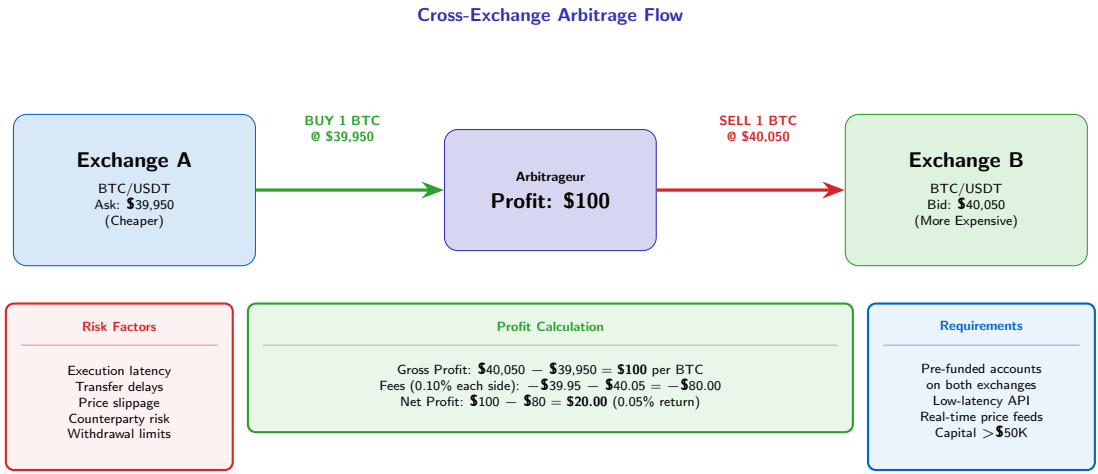
- **BUY:** Fast MA crosses above slow MA at time t (bullish momentum shift)
- **SELL:** Fast MA crosses below slow MA at time t (bearish momentum shift)
- **Detection:** Compare current and previous bar to identify exact crossover point

Parameter Sensitivity

- **Fast window (20):** Shorter = more signals but more whipsaws; longer = fewer but later signals
- **Slow window (50):** Anchors the trend baseline; 50/200 is traditional, 20/50 common in crypto
- **Overfitting risk:** Optimising parameters on historical data often fails out-of-sample
- **Mitigation:** Walk-forward optimisation, cross-validation across market regimes

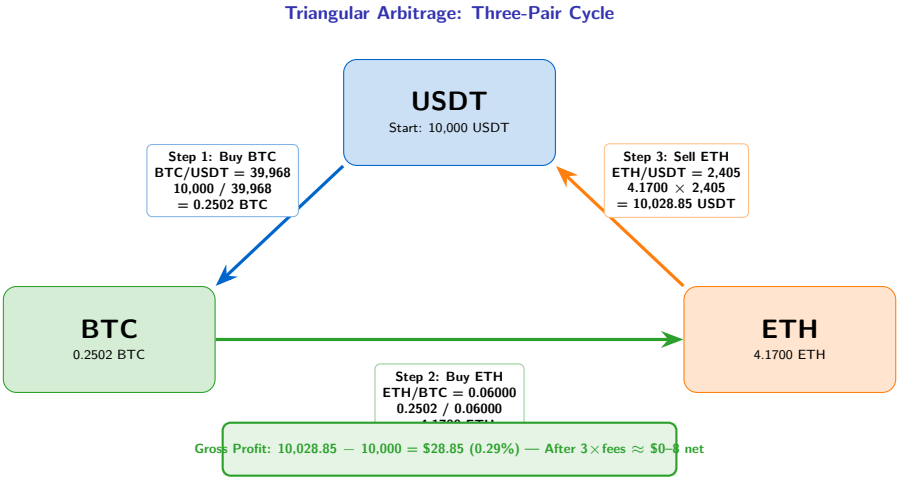
MA

Cross-Exchange Arbitrage



Cross-exchange arb: buy low on Exchange A, sell high on Exchange B simultaneously — Net profit after fees: $\sim$0.05% — Requires pre-funded accounts and fast execution

Triangular Arbitrage



Note: Bots execute all three legs in <100ms — Opportunities last milliseconds — Ultra-low latency required

Trian

arb: USDT → BTC → ETH → USDT cycle exploiting cross-pair mispricing — Gross 0.29% but fees erode profit — Bot-only, <100ms execution

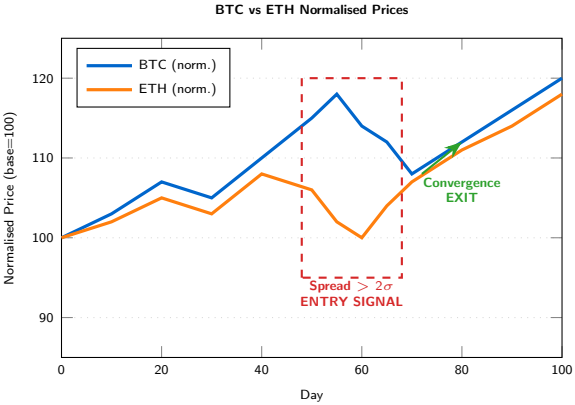
Statistical Arbitrage (Pairs Trading)

Pairs Trading Concept

- **Idea:** Two correlated assets (e.g., BTC and ETH) tend to move together
- **Spread:** $S_t = P_t^{\text{BTC}} - \beta \cdot P_t^{\text{ETH}}$
- **Signal:** When spread deviates $> 2\sigma$ from mean, bet on convergence
- **Entry:** Long the underperformer, short the outperformer
- **Exit:** Spread returns to mean (or stop-loss at 3σ)

Crypto Pairs

Popular pairs: BTC/ETH, SOL/AVAX, stablecoin depegs (USDT/USDC). Crypto pairs show higher correlation during drawdowns (correlation breakdown risk).



Stat

arb: long underperformer + short outperformer when spread $> 2\sigma$ — Exit on mean reversion — Risk: regime change breaks correlation

Technical Indicators Overview

Key Technical Indicators for Crypto Trading

RSI	Momentum	Range 0–100; >70 overbought, <30 oversold	Mean-reversion signals; divergence detection; 14-period standard
MACD	Trend	MACD = EMA(12) − EMA(26); Signal = EMA(9) of MACD	Crossover signals; histogram shows momentum strength; lag indicator
Volume Profile	Volume	Volume distribution at each price level; POC = highest volume node	Support/resistance zones; value area (70% of volume); institutional interest
OBV	Accumulation	Cumulative volume: +vol on up days, −vol on down days	Confirms trends; divergence = weakening trend; smart money tracking
Fibonacci	Support/Resist	Retracement levels: 23.6%, 38.2%, 50%, 61.8%, 78.6%	Key reversal zones; self-fulfilling due to widespread use; extensions for targets

5

indicator families: RSI (momentum), MACD (trend), Volume Profile (structure), OBV (accumulation), Fibonacci (levels) — Combine multiple for confluence

Backtesting Principles

Common Backtesting Pitfalls

Look-ahead bias: Using future data in past decisions. Fix: strict chronological order, no peeking at future bars

Survivorship bias: Only testing on assets that survived. Fix: include delisted tokens and failed projects

Overfitting: Tuning params to noise, not signal. Fix: walk-forward analysis, out-of-sample testing

Ignoring costs: Fees, slippage, market impact. Fix: realistic cost models

Back

pipeline: data → strategy → signals → execution sim → metrics — Key pitfalls: look-ahead bias, survivorship bias, overfitting, ignoring costs

Section 2 Summary

1. **Trend following** exploits momentum via MA crossovers; crypto's retail-driven cycles amplify momentum effects

2. **Mean reversion** uses Bollinger Bands and stat arb; works best in range-bound regimes, fails in strong trends

3. **Arbitrage** (cross-exchange, triangular, statistical) exploits mispricing; profits shrink with competition and fees

4. **Technical indicators** (RSI, MACD, OBV, Fibonacci) provide confluence signals; no single indicator is reliable alone

5. **Backtesting** validates strategies before deployment but is plagued by pitfalls: look-ahead bias, survivorship bias, overfitting, and ignoring transaction costs

Secti

2 complete — 5 key takeaways — Proceed to Section 3: Portfolio Theory & Risk Management

Section 3: Portfolio Theory & Risk Management

Quantitative frameworks for constructing and managing crypto portfolios

What You Will Learn

- Modern Portfolio Theory applied to crypto asset classes
- Value at Risk (VaR) and Conditional VaR (Expected Shortfall)
- Sharpe ratio, Sortino ratio, and risk-adjusted performance
- Maximum drawdown analysis and position sizing strategies

Frames in This Section

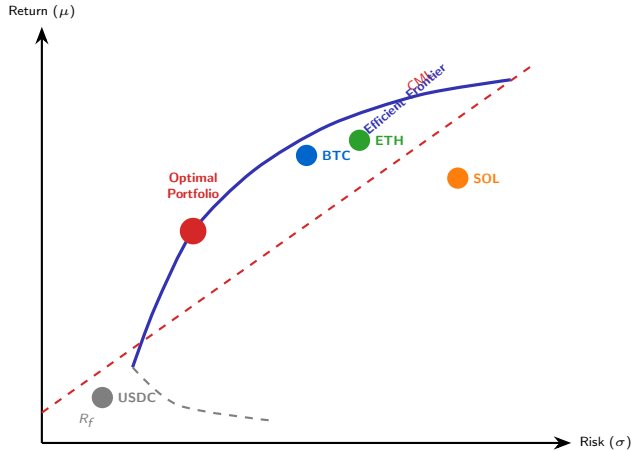
Modern Portfolio Theory in Crypto

MPT Core Concepts

- **Diversification:** Combine assets with imperfect correlations to reduce portfolio variance
- **Efficient frontier:** Set of portfolios offering maximum return for each risk level
- **Optimal portfolio:** Tangency point with the Capital Market Line (highest Sharpe ratio)
- **Inputs:** Expected returns μ_i, volatilities σ_i, correlations ρ_{ij}

Crypto Challenge

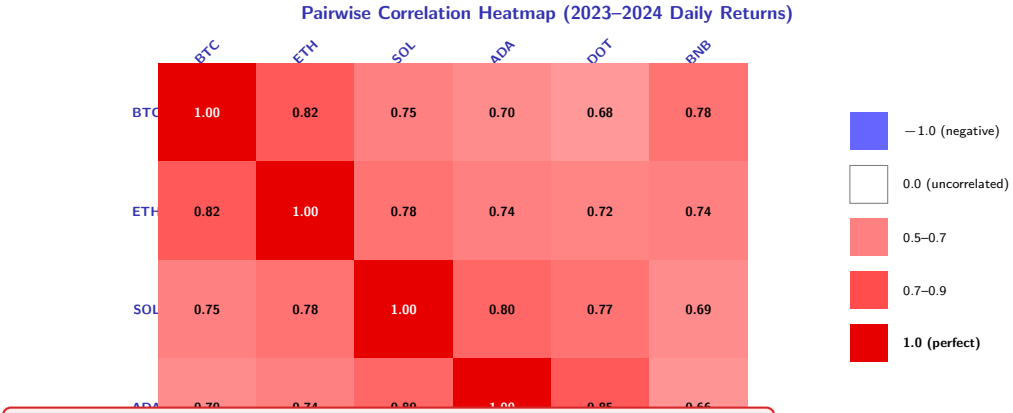
MPT assumes stationary returns and normal distributions. Crypto returns exhibit **fat tails**, **regime shifts**, and **high intra-class correlation**—limiting diversification benefits during crashes.



MPT

Markowitz (1952) — Efficient frontier maximises return per unit risk — Crypto's high correlation limits diversification, especially in drawdowns

Crypto Correlation Matrix



Key Insight: Most crypto pairs exhibit correlations of 0.6–0.9. During market stress, correlations converge toward 1.0, severely limiting diversification benefits precisely when they are needed most.

Value at Risk (VaR)

Listing 3: Historical VaR Calculation

```python
# Historical VaR Calculation
import numpy as np

def calculate_var(returns,
                  confidence=0.95,
                  horizon=1):
    sorted_returns = np.sort(returns)
    index = int((1 - confidence)
                * len(sorted_returns))
    var_1d = abs(sorted_returns[index])

    # Scale to horizon (sqrt-T rule)
    var_hd = var_1d * np.sqrt(horizon)

    # Portfolio VaR
    portfolio_value = 100000  # USD
    dollar_var = portfolio_value * var_hd
    return var_hd, dollar_var
```

Key Principle

VaR answers: "What is the **maximum loss** I should expect at a given confidence level over a given horizon?" It does *not* tell you how bad things can get beyond that threshold.

VaR Interpretation

- **95% 1-day VaR = 5%:** On 95% of days, the portfolio loses $\leq$5%; on 5% of days, losses exceed 5%
- **99% VaR:** More conservative; captures extreme tail events but requires more data
- **Horizon scaling:** $\text{VaR}_T = \text{VaR}_1 \times \sqrt{T}$ assumes i.i.d. returns (often violated in crypto)

Confidence Levels

- **95%:** Standard for internal risk management; 1 breach per 20 trading days
- **99%:** Basel regulatory standard; 1 breach per 100 days
- **Crypto caveat:** Fat tails mean breaches occur 2–5$\times$ more often than predicted

Limitations

- Not sub-additive (portfolio VaR can exceed sum of

Expected Shortfall (CVaR)

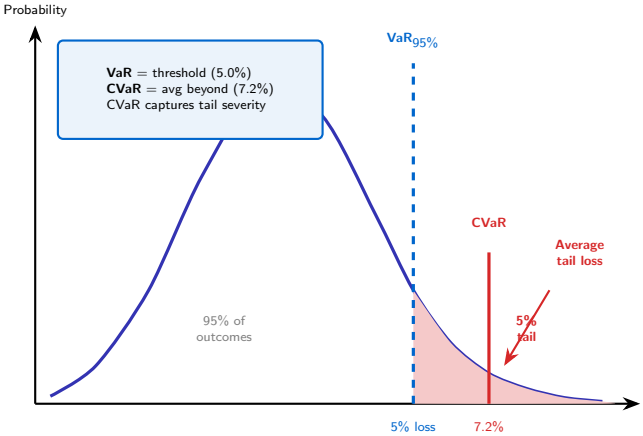
Definition

- **CVaR** (Conditional VaR) = average loss *given that* the loss exceeds VaR
- Also called **Expected Shortfall** (ES) or **Tail VaR**
- Answers: "When things go wrong, *how wrong* do they go?"

Formula

$$\text{ES}_\alpha = \mathbb{E}\big[L \mid L > \text{VaR}_\alpha\big]$$

- α = confidence level (e.g., 0.95)
- L = loss random variable
- ES is always $\geq$ VaR at same confidence



Why CVaR > VaR

CVaR is **sub-additive** (satisfies coherent risk measure axioms), making it suitable for

Sharpe Ratio & Risk-Adjusted Returns

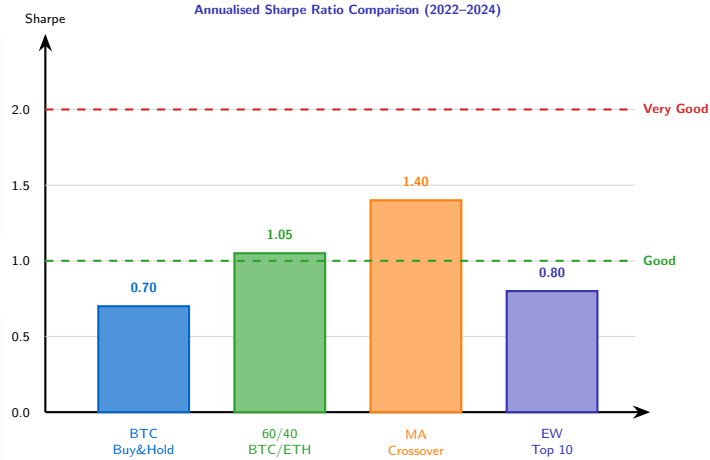
Sharpe Ratio Formula

$$S = \frac{R_p - R_f}{\sigma_p}$$

- R_p = portfolio return (annualised)
- R_f = risk-free rate (T-bills, ≈4–5%)
- σ_p = portfolio volatility (annualised)

Interpretation

- $S < 0$: Worse than risk-free
- $0 < S < 1$: Positive but mediocre
- $1 < S < 2$: Good risk-adjusted return
- $S > 2$: Very good (rare in crypto)
- $S > 3$: Exceptional or likely overfitted



Sharp

= excess return per unit risk — >1 good, >2 very good — Penalises both upside and downside volatility — Use Sortino for asymmetric returns

Sortino Ratio & Downside Risk

Sortino Ratio Formula

$$\text{Sortino} = \frac{R_p - R_f}{\sigma_{\text{downside}}}$$

- σ_{downside} = standard deviation of *negative* returns only
- Does not penalise upside volatility
- More appropriate for skewed return distributions

Why It Matters for Crypto

- Crypto returns are **positively skewed**: large upside moves are common
- Sharpe penalises these equally to downside moves
- Sortino isolates **harmful volatility** from beneficial volatility
- Typical crypto: Sortino > Sharpe (upside > downside vol)

Two Strategies: Same Sharpe, Different Sortino

Strategy A	Strategy B
Return: 25%	Return: 25%
Total σ: 20%	Total σ: 20%
Down σ: 15%	Down σ: 20%
Sharpe: 1.00	**Sharpe: 1.00**
Sortino: 1.33	**Sortino: 1.00**

Verdict: Strategy A is Superior

Same Sharpe (1.00) but Strategy A has lower downside volatility.
Its excess volatility comes from **upside** moves — desirable!
Sortino ratio correctly identifies A as the better risk-adjusted choice.

Rule of thumb: If Sortino $\gg$ Sharpe, the strategy has favourable skew.

Sorti

Maximum Drawdown

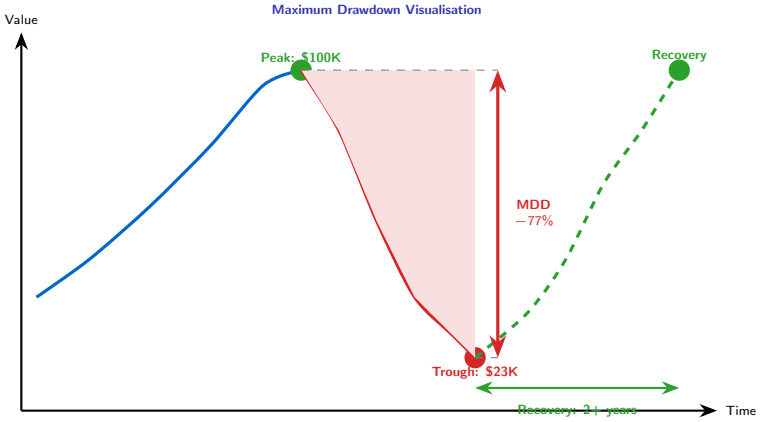
Definition

$$\text{MDD} = \frac{\text{Trough} - \text{Peak}}{\text{Peak}} \times 100\%$$

- Largest peak-to-trough decline
- Measures worst-case loss experience
- Recovery time equally important

Historical Crypto MDD

- **BTC 2017–18:** −84%
- **BTC 2021–22:** −77%
- **ETH 2022:** −82%
- **LUNA 2022:** −99.9%
- Recovery: 2–3 years typical for majors



MDD worst peak-to-trough loss — **BTC** historically −77% to −84% — Recovery takes years — Critical metric for investor psychology and fund survival

Position Sizing

Kelly Criterion

$$f^* = \frac{p \cdot b - q}{b}$$

- f^* = optimal fraction of capital to bet
- p = probability of winning
- $q = 1 - p$ = probability of losing
- b = win/loss ratio (payoff odds)

Worked Example

- Win rate $p = 0.55$, loss rate $q = 0.45$
- Win/loss ratio $b = 1.5$ (risk \$1 to make \$1.50)
- $f^* = \frac{0.55 \times 1.5 - 0.45}{1.5} = \frac{0.375}{1.5} = 0.25$
- **Full Kelly:** Bet 25% of capital per trade
- **Half-Kelly:** Bet 12.5% (safer in practice)

Position Sizing Methods

Fixed Fractional (1–2% Rule)

Risk a fixed % of capital per trade. E.g., \$100K portfolio, 2% risk = \$2K max loss. Position size = Risk amount / (Entry − Stop loss). Simple, conservative, widely used.

Volatility-Based (ATR Method)

Size inversely proportional to volatility. Position = Target risk / ATR(14). High-vol assets (SOL) get smaller positions; low-vol (BTC) get larger. Equalises risk contribution.

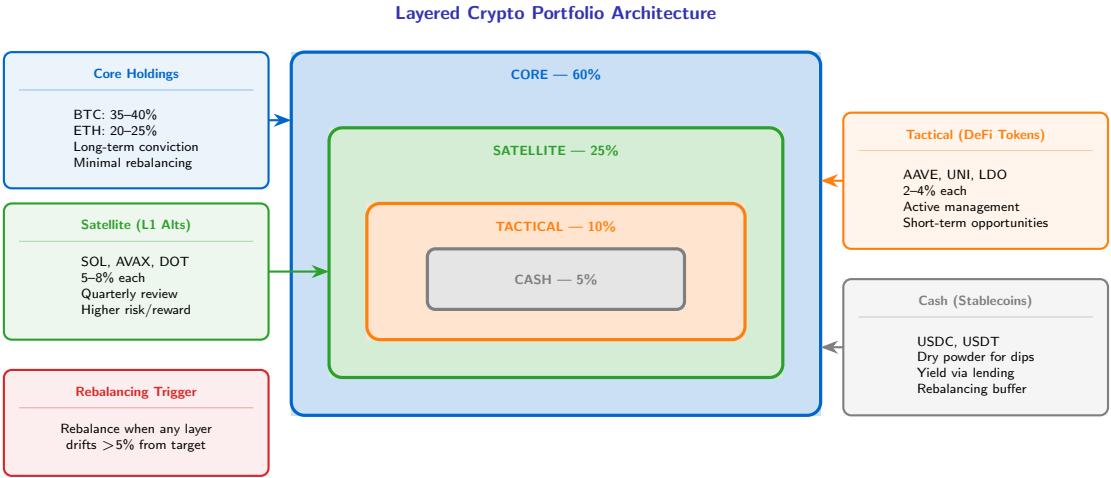
Warning: Full Kelly Is Aggressive

Full Kelly assumes perfect parameter estimation. In practice, use **half-Kelly** or less. Over-betting leads to ruin; under-betting merely slows growth. Err on the side of caution.

Kelly

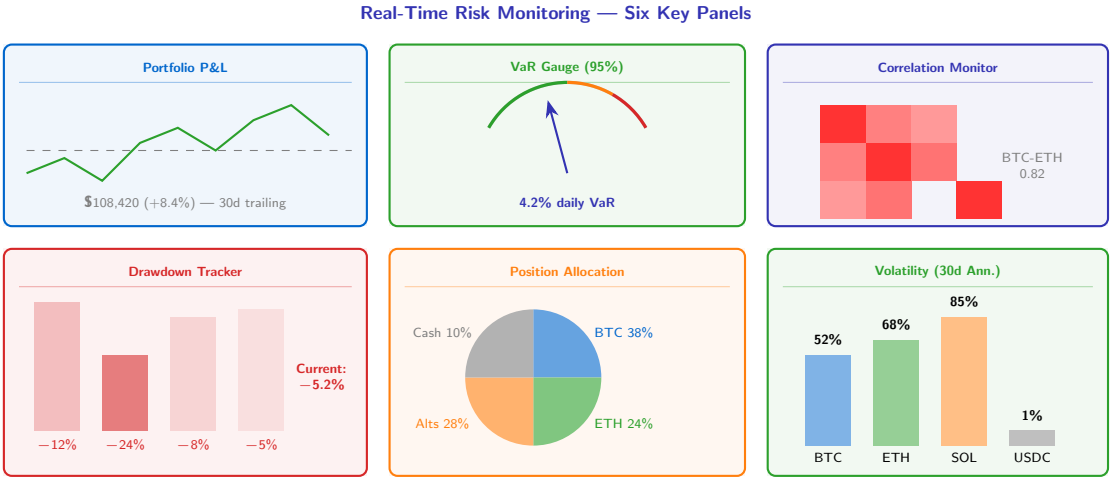
optimal growth-rate sizing — Half-Kelly common in practice — Fixed fractional: 1–2% per trade standard — Volatility-based: equalises risk across assets

Portfolio Construction



Core-satellite: 60% BTC+ETH, 25% L1 alts, 10% DeFi tactical, 5% stablecoin cash — Rebalance on >5% drift — Layered approach manages risk exposure

Risk Monitoring Dashboard



6-panel dashboard: P&L, VaR gauge, correlation, drawdown, allocation, volatility — Real-time monitoring essential for active crypto portfolio management

Section 3 Summary

1. **Modern Portfolio Theory** provides the diversification framework, but crypto's high correlations (0.6–0.9) limit its effectiveness during crashes

2. **VaR and CVaR** quantify tail risk; CVaR (Expected Shortfall) is preferred as a coherent risk measure and is mandated by Basel III/IV regulations

3. **Sharpe and Sortino** ratios measure risk-adjusted returns; Sortino is more appropriate for crypto due to positively skewed return distributions

4. **Maximum drawdown** (-77% to -84% for BTC) is the critical survivability metric; position sizing (Kelly, fixed fractional) controls ruin probability

5. **Portfolio construction** uses a core-satellite approach (60% BTC+ETH, 25% alts, 10% tactical, 5% cash) with systematic rebalancing and real-time risk monitoring across VaR, drawdown, correlation, and volatility

Secti

3 complete — 5 key takeaways — Proceed to Section 4: DEX vs CEX & Market Manipulation

Section 4: DEX vs CEX & Market Manipulation

Exchange architectures and the dark side of crypto markets

What You Will Learn

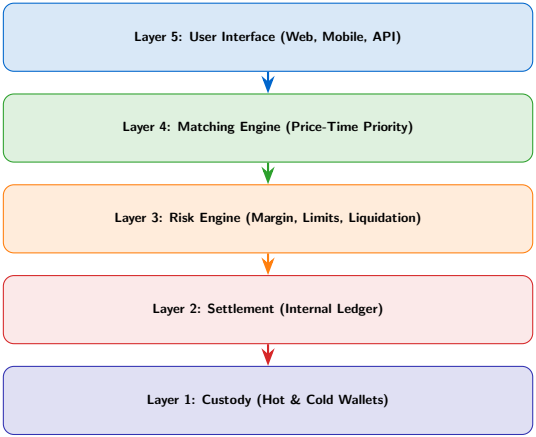
- CEX architecture, advantages, and catastrophic failure modes
- DEX mechanics: Automated Market Makers (AMMs) and on-chain CLOBs
- Manipulation tactics: wash trading, spoofing, and front-running
- MEV extraction and sandwich attacks on decentralised exchanges

Frames in This Section

Secti

4 of 5 — Frames 39–48 — Exchange architectures, manipulation tactics, and MEV in crypto markets

CEX Architecture



Centralisation Risks

Single Point of Failure:
One entity controls all layers

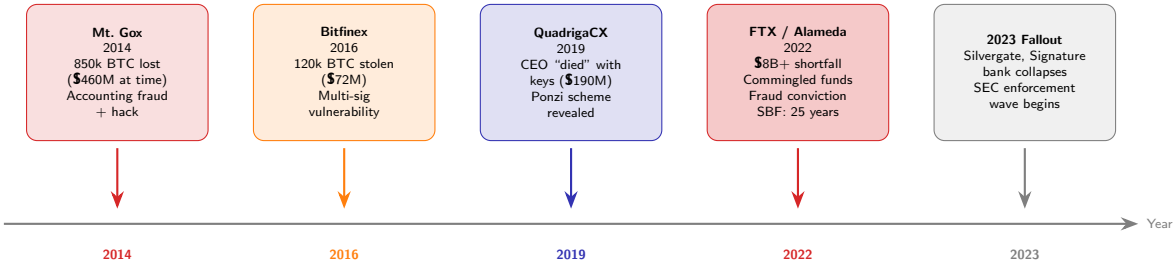
Hack Vectors:
Hot wallets, API keys, insider access

Insolvency Risk:
Commingled funds, off-book lending
(FTX: $8B+ customer shortfall)

Regulatory Seizure:
Governments can freeze accounts instantly

5-layer CEX stack: UI, matching, risk, settlement, custody — Centralisation creates single-point-of-failure risk across all layers

CEX Risks & Failures



"Not your keys, not your coins" — Cumulative CEX losses exceed $10B since 2011

CEX failure timeline: Mt. Gox to FTX — Cumulative losses exceed $10B — Self-custody eliminates counterparty risk

Listing 4: Constant Product AMM (x * y = k)

```python
# Constant Product AMM (x * y = k)
def swap_exact_input(reserve_x,
                     reserve_y,
                     amount_in,
                     fee=0.003):
    amount_in_with_fee = (
        amount_in * (1 - fee))
    k = reserve_x * reserve_y

    new_reserve_x = (
        reserve_x + amount_in_with_fee)
    new_reserve_y = k / new_reserve_x
    amount_out = (
        reserve_y - new_reserve_y)
    return amount_out

# Example: ETH/USDC pool
# reserve_x = 1000 ETH
# reserve_y = 2,000,000 USDC
# k = 2,000,000,000
out = swap_exact_input(
    1000, 2_000_000, 10)
# out ~ 19,880 USDC (0.6% slippage)
```

Constant Product Invariant

- **Formula:** $x \cdot y = k$ (Uniswap V2)
- Price $P = \frac{y}{x}$; moves along hyperbola
- Larger pools $\Rightarrow$ lower slippage per trade
- Fee accrues to liquidity providers (LPs)

Impermanent Loss

- LPs lose value vs. holding when prices diverge
- $\text{IL} = 2\frac{\sqrt{r}}{1+r} - 1$ where $r = \frac{P_1}{P_0}$
- $2\times$ price change $\Rightarrow$ 5.7% loss
- $5\times$ price change $\Rightarrow$ 25.5% loss

Concentrated Liquidity (Uniswap V3)

LPs allocate capital to specific price ranges, increasing capital efficiency up to 4000$\times$ but amplifying impermanent loss within the range.

Code

Figure 4: Constant product AMM: $x*y=k$. Impermanent loss is the hidden cost of passive liquidity provision.

CEX vs DEX Comparison

CEX (Centralised)

Custody: Exchange holds funds (custodial)
KYC/AML: Required for fiat on-ramp
Speed: $<$1ms matching (off-chain)
Throughput: 100k+ TPS
Fiat Support: Yes (bank, card)
Liquidity: Deep order books
Risk: Counterparty, hack, insolvency
Examples: Binance, Coinbase, Kraken

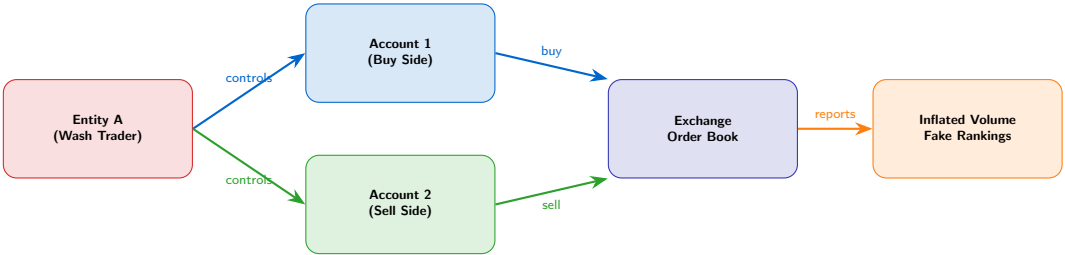
DEX (Decentralised)

Custody: User holds keys (non-custodial)
KYC/AML: None (permissionless)
Speed: 1–12s (block time dependent)
Throughput: 10–1000 TPS (chain limit)
Fiat Support: No native fiat rails
Liquidity: AMM pools, fragmented
Risk: Smart contract bugs, MEV
Examples: Uniswap, Curve, dYdX

Latency: CEX $<$1ms vs DEX 1–12s — **Throughput:** CEX 100k+ vs DEX $\sim$1k TPS — **Liquidity:** CEX \$50B+ daily vs DEX \$2–5B daily — **Trend:** Hybrid models emerging

CEX vs DEX: custodial speed vs non-custodial sovereignty — Trade-off between performance and decentralisation

Wash Trading



Scale of the Problem

Estimated **50–90%** of reported crypto volume is fake (Bitwise 2019)

CoinMarketCap adjusted volume: 10–20× lower than reported

Token projects pay exchanges for wash trading to appear liquid

NFT wash trading: 80%+ of volume on some platforms

Detection Methods

Volume-price divergence: High volume with zero price impact

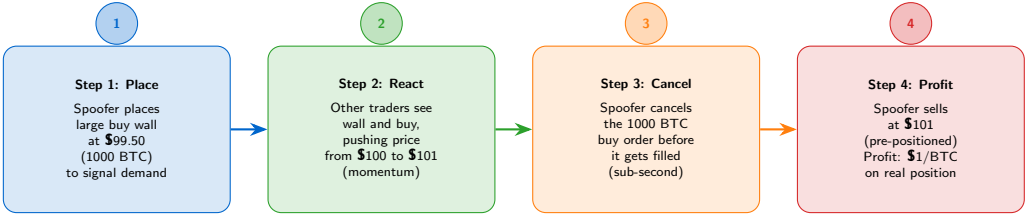
Order-size clustering: Repetitive identical trade sizes

Timestamp analysis: Suspiciously regular intervals

Network analysis: Linked wallets / KYC accounts

Wash trading inflates 50–90% of crypto volume — Detection: volume-price divergence, order clustering, timestamp regularity

Spoofing & Layering



Before (Order Book)

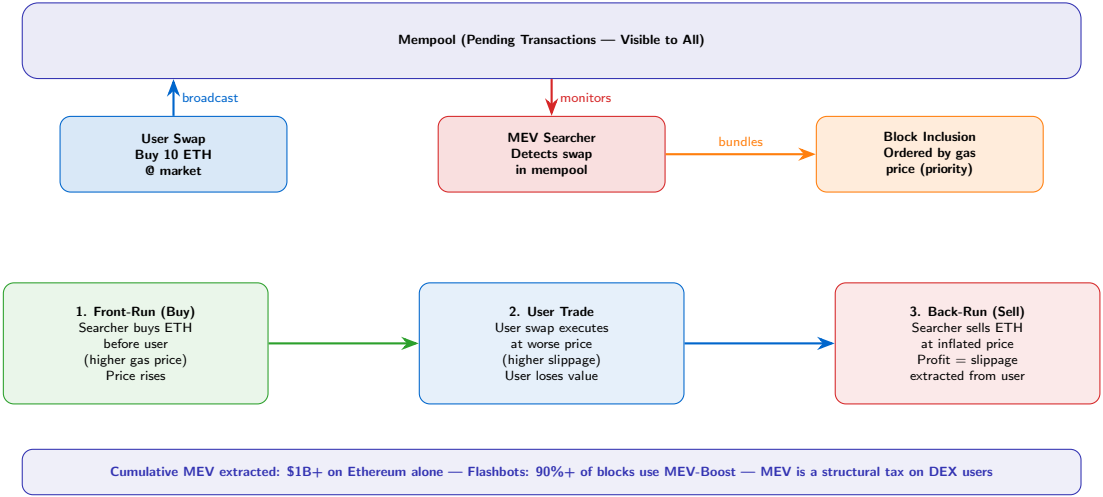
Bid	$100.00	50 BTC
Bid	$99.50	**+1000 BTC (spoof)**
Ask	$100.10	30 BTC

After (Order Book)

Bid	$100.50	45 BTC
Bid	$99.50	**CANCELLED**
Ask	$101.00	30 BTC

4-step spoofing cycle: place wall, trigger reaction, cancel, profit — Layering uses multiple price levels for greater deception

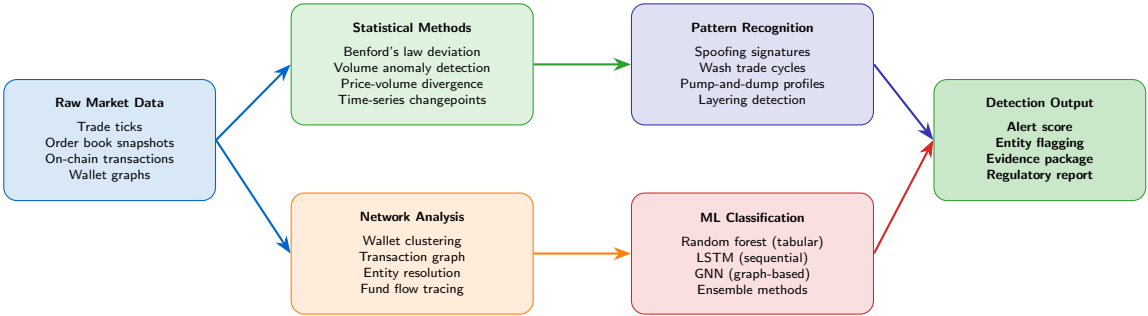
Front-Running & MEV



Sand

attack: front-run buy, user trade at worse price, back-run sell — MEV exceeds $1B cumulative on Ethereum

Market Manipulation Detection



Regulatory Challenge: Cross-jurisdiction enforcement — Pseudonymous actors — DEX manipulation outside legal frameworks — No consolidated audit trail — Evolving tactics outpace detection

Dete

pipeline: raw data, statistical and network analysis, pattern recognition, ML classification — Cross-jurisdiction enforcement remains the core challenge

Section 4 Summary

1. **CEX architecture** stacks 5 layers (UI to custody) under one entity; centralisation creates hack, insolvency, and regulatory seizure risk

2. **DEX AMMs** use $x \cdot y = k$ for permissionless trading; impermanent loss and MEV are the hidden costs for LPs and users

3. **Wash trading** inflates 50–90% of reported crypto volume; detection relies on volume-price divergence and network analysis

4. **Spoofing and sandwich attacks** exploit order book psychology and mempool transparency; MEV extraction exceeds $1B on Ethereum

5. **Market manipulation detection** combines statistical methods, network analysis, and ML classifiers but cross-jurisdiction enforcement and pseudonymous actors remain the fundamental regulatory challenge

Secti

4 complete — 5 key takeaways — Proceed to Section 5: Regulation & Future of Crypto Trading

Section 5: Regulation & Future of Crypto Trading

Regulatory frameworks shaping the future of digital asset markets

What You Will Learn

- Major global regulatory frameworks and their impact on trading
- EU MiCA and US SEC/CFTC approaches to crypto markets
- Institutional adoption milestones and market structure evolution
- Algorithmic trading regulation and the future of crypto markets

Frames in This Section

Secti

5 of 5 — Frames 49–55 — Regulatory frameworks, institutional adoption, and future market evolution

Global Regulatory Landscape

Jurisdiction	Framework	Key Focus	Strictness
European Union (27 member states)	MiCA (Markets in Crypto-Assets)	Comprehensive: licensing, market abuse, stablecoins	**High (Comprehensive)**
United States (Federal + State)	SEC + CFTC (fragmented jurisdiction)	Securities classification, enforcement actions	**High (Enforcement-led)**
Singapore (MAS)	Payment Services Act (PSA) amended 2025	Licensing, consumer protection, AML	**Medium (Balanced)**
Japan (FSA / JFSA)	FIEA + PSA (post-Mt. Gox reforms)	Exchange registration, cold storage mandates	**High (Prescriptive)**

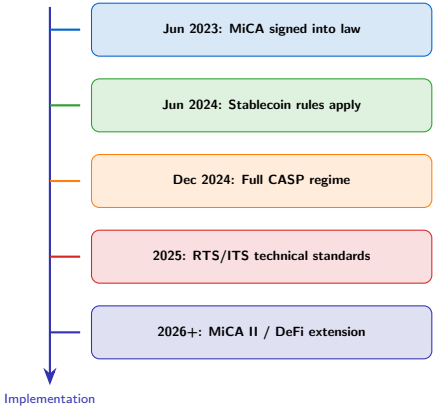
Globa

regulatory landscape: EU (MiCA), US (SEC/CFTC), Singapore (MAS), Japan (FSA) — Convergence toward comprehensive frameworks

MiCA Trading Provisions

Key Provisions

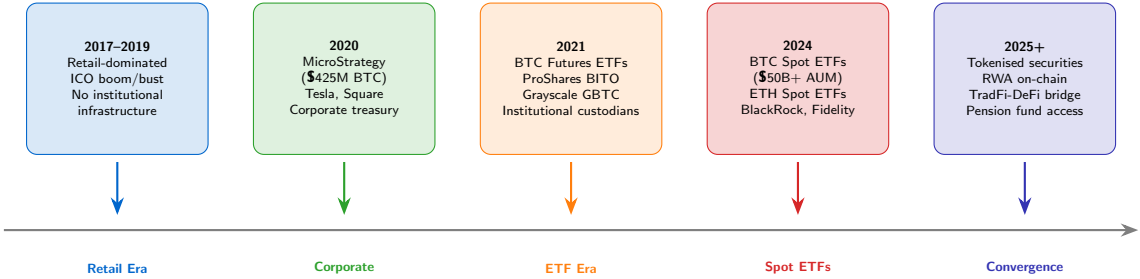
- **Market Abuse:** Insider dealing, market manipulation, and unlawful disclosure of inside information prohibited (Title VI)
- **CASP Authorization:** All crypto-asset service providers must obtain authorization from national competent authorities
- **Custody Rules:** Segregation of client assets; CASPs liable for losses including cyber attacks
- **Transparency:** Pre- and post-trade transparency for trading platforms; white paper requirements
- **Stablecoins:** E-money tokens and asset-referenced tokens face reserve and redemption rules



MiCA

first comprehensive crypto regulation — Market abuse, CASP licensing, custody segregation, stablecoin reserves — Full enforcement Dec 2024

Institutional Adoption



Market Structure Impact: Tighter spreads — Lower volatility — Deeper liquidity — Prime brokerage — Regulated derivatives — Institutional-grade custody

Instit

adoption timeline: retail (2017) to spot ETFs (2024) to tokenised securities (2025+) — Each milestone compresses spreads and deepens liquidity

Algorithmic Trading Regulation

TradFi: MiFID II Requirements

- **Authorization:** Algo firms must register and maintain capital
- **Kill Switches:** Mandatory circuit breakers to halt runaway algos
- **Risk Limits:** Pre-trade checks on price, size, and credit
- **Testing:** Backtesting and stress testing in sandbox before live
- **Record Keeping:** Full order audit trail retained 5+ years
- **Market Making:** Obligations to provide liquidity continuously

Key Gap

Most crypto exchanges have no algo trading regulations. Flash crashes (e.g., BTC −87% on Binance.US, 2021) occur without circuit breakers.

Crypto: Emerging Requirements

- **MiCA Art. 76–80:** Market abuse rules apply to algo trading
- **No Kill Switch Mandate:** Most DEXs have no halt mechanism
- **MEV Regulation:** Not yet addressed in any framework
- **DeFi Bots:** Autonomous smart contracts outside legal scope
- **Cross-Border:** Jurisdiction arbitrage by algo operators

Future: Convergence Path

- Kill switches for CASPs under MiCA II
- Pre-trade risk controls for API traders
- MEV-specific regulation (EIP proposals)
- On-chain algo registration requirements
- Unified TradFi-crypto surveillance

Algo

The Future of Crypto Trading

Market Structure

2025–2027:
Hybrid CEX-DEX models
Institutional prime brokers
Cross-chain liquidity aggregation

2027–2030:
Tokenised equities on-chain
Unified order books (CeFi+DeFi)
Sub-second finality L2s

2030+:
Fully regulated on-chain markets
AI-driven market making

Technology

ZK Proofs:
Private on-chain trading
Compliant dark pools

Intent-Based Systems:
Users express intent, solvers compete
CoW Protocol, UniswapX

AI Agents:
Autonomous portfolio managers
On-chain execution bots
LLM-driven strategy generation

Account Abstraction:
Gasless trading UX

Regulation

MiCA II (2026–2027):
DeFi-specific provisions
MEV regulation

US Framework (2025+):
FIT21 or equivalent bill
Clear security vs commodity line

Global Convergence:
IOSCO crypto standards
Cross-border enforcement
Unified stablecoin rules

Impact:
Lower barriers for institutions

Three pillars of crypto trading evolution: market structure convergence, technology innovation (ZK, intents, AI), regulatory clarity (MiCA II, FIT21)

Key Takeaways and Course Summary

1. **Microstructure** defines the playing field: order books, spreads, slippage, and fee structures vary $10\times$ across 500+ fragmented venues

2. **Trading strategies** must be rigorously backtested; momentum, mean reversion, and ML models each suit different regimes and time horizons

3. **Risk management** is survival: VaR, CVaR, max drawdown, and Kelly position sizing prevent ruin in a market with 70–84% drawdowns

4. **DEX vs CEX** trade-offs and manipulation (wash trading, spoofing, MEV) are structural features that every trader must understand

5. **Regulation** is converging globally (MiCA, SEC/CFTC, MAS, FSA); institutional adoption via spot ETFs and tokenised assets is transforming crypto from a speculative frontier into mainstream financial infrastructure

Next: Advanced topics in DeFi risk management and quantitative crypto finance

Cours

complete — 5 sections, 55 frames — From microstructure to regulation: a quantitative framework for crypto trading