Balancer: The Self-Balancing DeFi Protocol Revolutionizing Liquidity Pools

April 23, 2025

1 Introduction to Balancer

Balancer is a decentralized exchange (DEX) and automated market maker (AMM) protocol on Ethereum, enabling token trading and liquidity provision through customizable liquidity pools. Unlike Uniswap's 50/50 pools, Balancer supports up to eight tokens with arbitrary weights (e.g., 80% BTC, 20% ETH), acting as a **self-balancing portfolio manager**. Arbitrageurs' trades maintain target weights, mimicking active management without manual intervention. Launched in 2020, Balancer supports trading, yield farming, and token launches, integrating with protocols like Aave and Yearn, and providing on-chain price oracles.

2 Architecture: Vaults and Pools

Balancer V2 (2021) separates token management from pool logic, enhancing gas efficiency and flexibility.

2.1 Vault

The Vault, Balancer V2's core smart contract, manages all token operations:

- Stores tokens, reducing redundant transfers.
- Handles swaps, deposits, and withdrawals, minimizing gas costs.
- Uses **netting** to calculate net token movements, e.g., in multi-token swaps.
- Supports flash loans, enabling borrowing within a transaction if repaid.

This design supports high transaction volumes efficiently.

2.2 Features

- **Gas Efficiency**: Netting lowers Ethereum fees.
- **Internal Balances**: Traders keep balances in the Vault, reducing gas for frequent trades.
- **Customizability**: Developers create custom pool types, fostering innovation.

3 Pools in Balancer

Liquidity pools hold tokens for trading or investment, with diverse types for trading, token launches, yield strategies, and oracles.

4 Pool Types

4.1 Weighted Pools

Supporting up to eight tokens with custom weights (e.g., 60% ETH, 30% DAI, 10% USDC), Weighted Pools are ideal for diversified portfolios. Arbitrage ensures balance maintenance.

4.2 Two-Token Weighted Oracle Pools

These emit **on-chain price oracles** via time-weighted average prices (TWAPs), supporting DeFi integrations like Aave.

4.3 Stable Pools

Optimized for stablecoins (e.g., DAI, USDC), Stable Pools use the **StableSwap** curve for low-slippage trading.

4.4 Liquidity Bootstrapping Pools (LBPs)

LBPs enable token launches with dynamic pricing, shifting weights (e.g., 95% USDC to 50/50) for **gradual price discovery**.

4.5 MetaStable Pools

For assets with price drift (e.g., DAI, cDAI), MetaStable Pools adjust for variations, ensuring efficient swaps.

4.6 Investment Pools

Public pools with **DAO governance** for weights and fees, supporting community-driven strategies.

5 How Balancer Maintains Balance

Balancer's self-balancing leverages arbitrage to maintain pool ratios.

5.1 The Value Function

$$V = \prod_{t=1}^{n} B_t^{W_t} \tag{1}$$

This ensures token values align with weights, e.g., a 50/50 ETH/DAI pool adjusts via trades.

5.2 Arbitrage Example: 50/50 ETH–DAI

- Rising ETH price: Arbitrageurs sell ETH for DAI.
- Falling ETH price: Arbitrageurs buy ETH, restoring balance.

6 Trading Mechanics

Trading mechanics balance theoretical and real-world pricing, accounting for slippage.

6.1 Spot Price (No Slippage)

$$SP_i^o = \frac{B_i/W_i}{B_o/W_o} \tag{2}$$

The **Spot Price** is the theoretical exchange rate for a negligible trade, derived from normalized balances:

$$SP_i^o = \frac{B_i W_o}{B_o W_i}$$

For a 50/50 ETH/DAI pool (10 ETH, 5000 DAI), $SP_{\text{ETH}}^{\text{DAI}} = \frac{10/0.5}{5000/0.5} = 500$ DAI per ETH. It guides small trades, arbitrage, and oracles but ignores slippage.

6.2 Effective Price (With Slippage)

$$EP_i^o = \frac{A_i}{A_o} \tag{3}$$

where:

- A_i: Amount of token i sent
- A_o: Amount of token o received

The **Effective Price** reflects the actual rate, including slippage. For 1 ETH in the above pool, the Out-Given-In formula yields $A_o \approx 454.55$ DAI, so $EP_{\text{ETH}}^{\text{DAI}} \approx 454.55$ DAI per ETH, less than the Spot Price due to slippage.

7 Core Mathematics

The mathematical formulas governing Balancer's swaps ensure fairness, preserve the pool's invariant, and align prices with external markets. These equations are critical for executing trades and maintaining pool stability through arbitrage.

7.1 Out-Given-In

$$A_o = B_o \cdot \left(1 - \left(\frac{B_i}{B_i + A_i}\right)^{\frac{W_i}{W_o}}\right) \tag{4}$$

The **Out-Given-In** formula calculates the output amount A_o of token o received when inputting amount A_i of token i. It ensures trades preserve the invariant, accounting for slippage. For a 50/50 ETH/DAI pool (10 ETH, 5000 DAI), swapping 1 ETH yields $A_{\text{DAI}} \approx 454.55$ DAI, reflecting slippage.

7.2 In-Given-Out

$$A_i = B_i \cdot \left(\left(\frac{B_o}{B_o - A_o} \right)^{\frac{W_o}{W_i}} - 1 \right) \tag{5}$$

The **In-Given-Out** formula calculates the input amount A_i for a desired output A_o. For 1000 DAI in the same pool, $A_{\text{ETH}} = 2.5$ ETH, with an Effective Price of 400 DAI/ETH due to slippage.

7.3 Arbitrage Adjustment

$$A_i = B_i \cdot \left(\left(\frac{SP_i^{o'}}{SP_i^o} \right)^{\frac{W_o}{W_i + W_o}} - 1 \right) \tag{6}$$

The **Arbitrage Adjustment** aligns the pool's Spot Price with the market price. For a market price of 600 DAI/ETH (vs. 500 DAI/ETH), inputting 0.95 ETH adjusts balances, supporting rebalancing.

8 How Liquidity Providers Earn

Liquidity providers (LPs) contribute tokens to Balancer pools, receiving **Balancer Pool Tokens (BPT)**, ERC-20 tokens representing their share of pool assets and fees. BPTs allow LPs to earn passive income from swap fees (0.01%–1%) while benefiting from Balancer's self-balancing, which minimizes impermanent loss compared to traditional AMMs. The following subsections detail deposit and withdrawal mechanics, highlighting flexibility and risks.

8.1 All-Asset Deposit

$$P_{\text{issued}} = P_{\text{supply}} \cdot \left(\frac{V'}{V} - 1 \right) \tag{7}$$

where:

- V: Current value function, $V = \prod_{t=1}^{n} B_t^{W_t}$
- V': New value function after deposit
- P_{supply}: Existing BPTs

The **All-Asset Deposit** formula calculates BPTs issued when an LP deposits all pool tokens proportionally to current balances, maintaining the pool's weights and invariant with no slippage or fees.

Mechanism: The deposit increases each token's balance, raising the pool's value ($V' > V$). The BPTs issued reflect the proportional increase in value. For example, in a 50/50 ETH/DAI pool (10 ETH, 5000 DAI, $P_{\text{supply}} = 100$ BPT), an LP deposits 1 ETH and 500 DAI, matching the pool's 1:500 ratio to maintain weights:

- Current $V = 10^{0.5} \cdot 5000^{0.5} \approx 70.71 \cdot 70.71 = 5000$
- New balances: 11 ETH, 5500 DAI

- New $V' = 11^{0.5} \cdot 5500^{0.5} \approx 74.16 \cdot 74.16 = 5500$
- BPTs issued:

$$P_{\text{issued}} = 100 \cdot \left(\frac{5500}{5000} - 1 \right) = 100 \cdot (1.1 - 1) = 10 \text{ BPT}$$

The LP receives 10 BPTs, owning $\frac{10}{110} \approx 9.09\%$ of the pool. Compared to the Single-Asset Deposit of 1 ETH (yielding 4.88 BPTs), this deposit provides more BPTs because it avoids slippage and internal swap fees, as the input matches the pool's ratios.

Practical Implications:

- **Simplicity**: Proportional deposits are straightforward, ideal for LPs holding both tokens.
- **No Slippage**: The deposit preserves weights, avoiding price impact.
- **Risks**: LPs face impermanent loss if ETH/DAI prices diverge, though Balancer's rebalancing mitigates this.
- **Comparison**: Unlike the Single-Asset Deposit, which incurs fees and slippage, All-Asset Deposits maximize BPTs for the same ETH contribution, incentivizing balanced contributions.

My understanding is that this mechanism encourages balanced liquidity provision, aligning LP contributions with pool stability and offering higher rewards than single-asset deposits.

8.2 Single-Asset Deposit

$$P_{\text{issued}} = P_{\text{supply}} \cdot \left(\left(1 + \frac{A_t}{B_t} \right)^{W_t} - 1 \right) \tag{8}$$

The **Single-Asset Deposit** formula calculates BPTs issued when depositing one token, adjusting the pool to maintain the invariant. This introduces slippage, as the pool swaps the input to balance weights internally.

Mechanism: The deposit increases the token's balance, raising the pool's value. The formula accounts for the weight (W_t) to determine the BPT share. For the same pool, depositing 1 ETH ($A_{\text{ETH}} = 1$, $B_{\text{ETH}} = 10$, $W_{\text{ETH}} = 0.5$):

$$P_{\text{issued}} = 100 \cdot \left(\left(1 + \frac{1}{10} \right)^{0.5} - 1 \right) = 100 \cdot \left(1.1^{0.5} - 1 \right) \approx 100 \cdot (1.0488 - 1) = 4.88 \text{ BPT}$$

Internally, the pool swaps part of the ETH for DAI to maintain weights, incurring a fee (paid to existing LPs). The LP receives fewer BPTs than an equivalent All-Asset Deposit due to slippage and fees.

Practical Implications:

- **Flexibility**: LPs can deposit a single token, ideal for those holding one asset.
- **Slippage and Fees**: The internal swap introduces slippage and fees, reducing BPTs issued.
- **Risks**: LPs face exposure to pool rebalancing and potential losses if prices shift significantly.

8.3 Single-Token Withdrawal

$$A_t = B_t \cdot \left(1 - \left(1 - \frac{P_{\text{redeemed}}}{P_{\text{supply}}}\right)^{\frac{1}{W_t}}\right) \tag{9}$$

The **Single-Token Withdrawal** formula calculates the amount of token t withdrawn when redeeming BPTs, adjusting the pool to maintain the invariant.

Mechanism: Redeeming BPTs reduces the LP's share, decreasing the pool's value. For the same pool, redeeming 10 BPT ($P_{\text{redeemed}} = 10$, $P_{\text{supply}} = 100$, $B_{\text{ETH}} = 10$, $W_{\text{ETH}} = 0.5$):

$$A_{\text{ETH}} = 10 \cdot \left(1 - \left(1 - \frac{10}{100}\right)^{\frac{1}{0.5}}\right) = 10 \cdot \left(1 - (0.9)^2\right) = 10 \cdot (1 - 0.81) = 1.9 \text{ ETH}$$

The pool swaps other tokens internally to provide ETH, incurring fees and slippage.

Practical Implications:

- **Flexibility**: LPs can withdraw one token, simplifying exits.
- **Slippage and Fees**: Internal swaps reduce the output, impacting returns.
- **Risks**: Withdrawals during price volatility may amplify losses.

9 Fee Structure

- **Swap Fees**: 0.01%–1%, distributed to LPs.
- **Exit Fees**: 0%–0.5%, often waived to attract LPs.

10 Why Balancer Is a Game-Changer

- Arbitrage-based self-balancing
- Flexible token weights
- Capital efficiency for LPs
- On-chain oracles and flash loans
- Gas-efficient internal balances
- DAO-friendly structures

11 Explore More

- Balancer App
- Whitepaper
- GitHub