Decentralized Finance, Automated Market Makers, and Maximal Extractable Value!

Öz, B., Hoops, F., Gebele, J., & Matthes, F. (2024). “Blockchain-based Systems Engineering”. Lecture Slides. TU Munich.

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Outline

1. Decentralized Finance
2. Automated Market Makers
3. Maximal Extractable Value

The Birth of Decentralized Finance

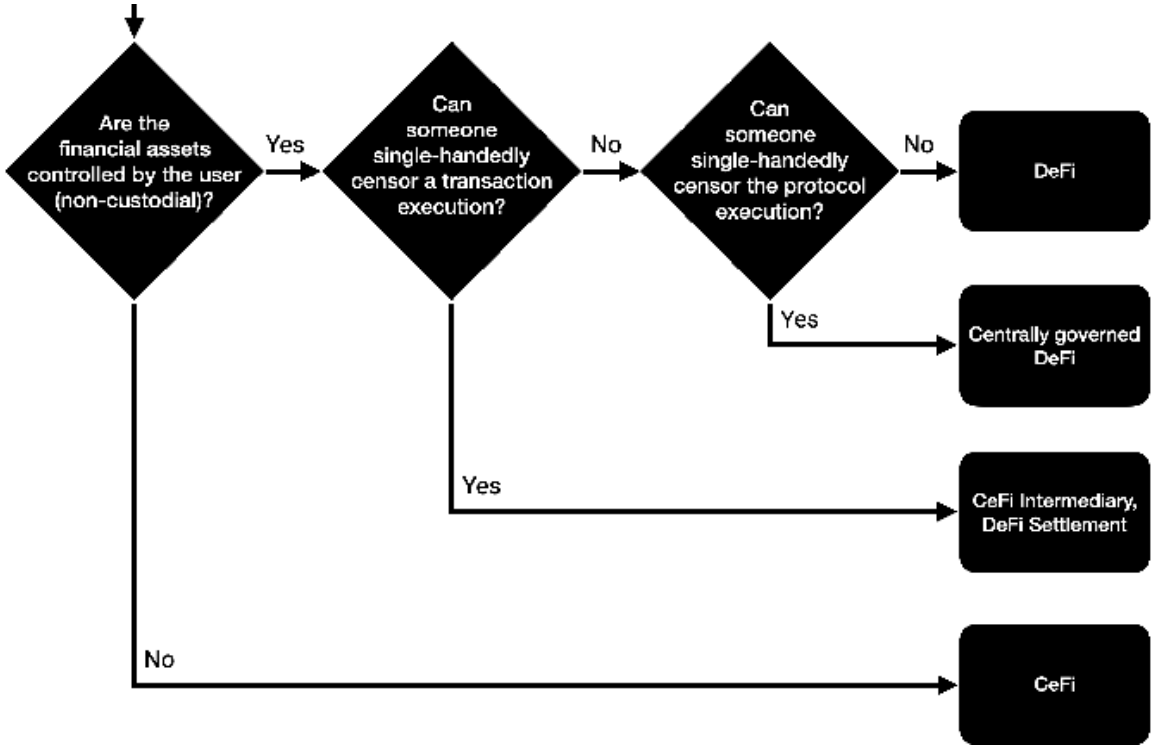
The emergence of Bitcoin enabled users to be in the custody of their money and do intermediary-free transfers. However, the capabilities of the Bitcoin Script limited the range of the financial interactions a user can do.

With the development of smart contract platforms, mainly Ethereum, the doors of financial services on blockchains opened widely as smart contracts enabled **programmable money** and financial assets like fungible and non-fungible tokens.

Decentralized Finance (DeFi) refers to the public, permissionless, interoperable finance ecosystem built on smart contract-enabled blockchains.

DeFi applications currently make up the **primary use case for blockchains** as they offer similar services to traditional/centralized finance (TradFi, CeFi) products but do it in a way where users;

- **maintain the custody** of their assets and
- have close to full **transparency** of every action.



Qin, Kaihua, Liyi Zhou, Yaroslav Afonin, Ludovico Lazzaretti and Arthur Gervais. "CeFi vs. DeFi - Comparing Centralized to Decentralized Finance." ArXiv abs/2106.08157 (2021): n. pag.

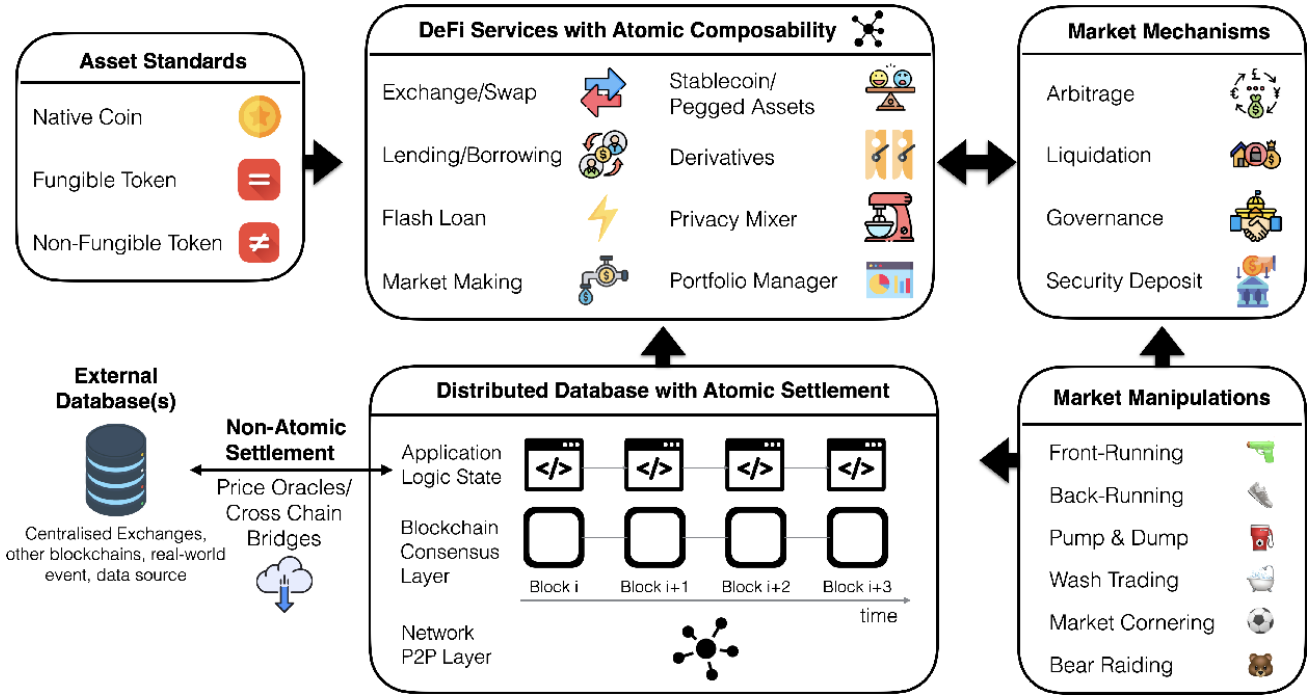
High-level Overview of DeFi

DeFi protocols use blockchain-based assets to enable various financial instruments and services.

- Exchanges
- Lending/Borrowing protocols
- Derivative Trading platforms
- Staking platforms

These protocols implement their business logic using the **state structure** of the underlying blockchain. With every confirmed transaction, the protocols sequentially execute certain operations which **transition the DeFi state into a new one in an atomic way**.[1]

DeFi protocols also do **non-atomic interactions** with protocols living outside the blockchain using oracles and cross-chain bridges[2].



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[1] Atomicity refers to a transaction being fully executed (with all the interactions it does) or none at all based on certain conditions.

[2] Cross-chain bridges are infrastructures that enable asset transfer between two blockchains through token locking/burning and unlocking/minting on smart contracts.

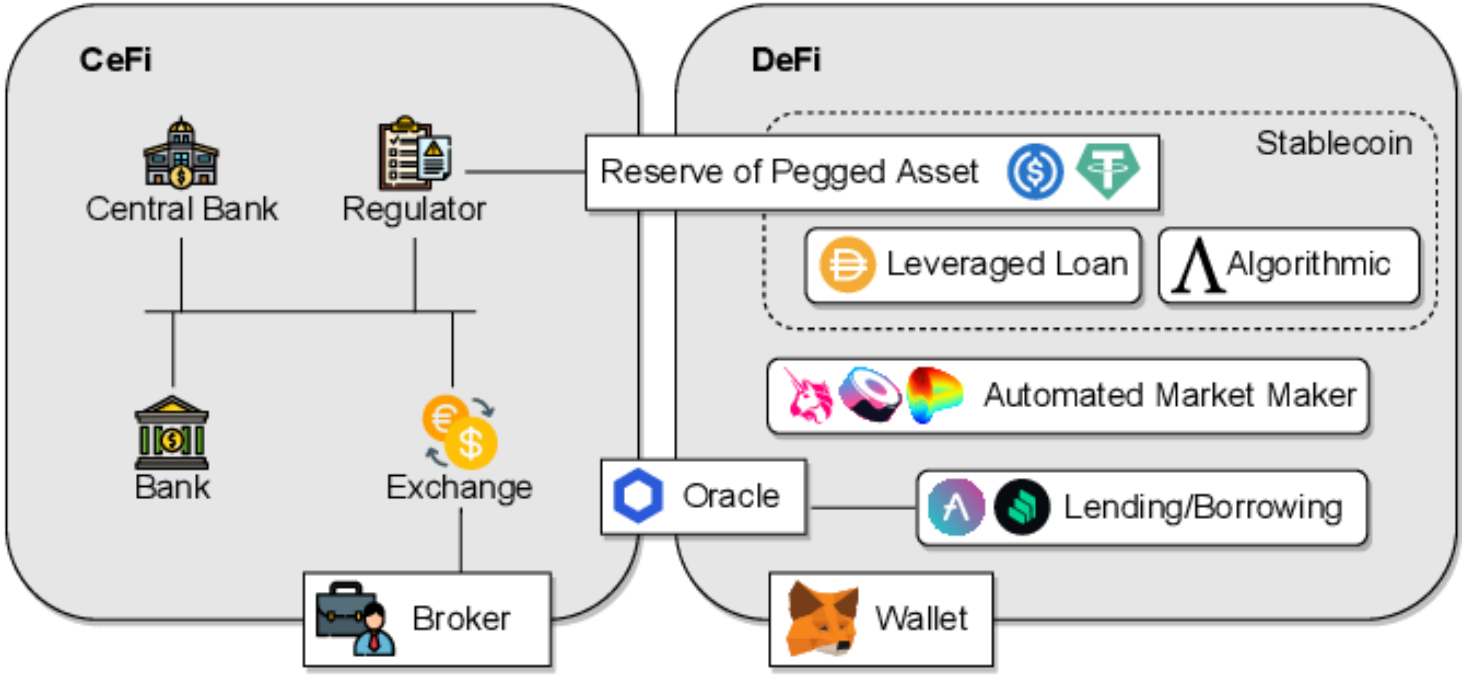
DeFi vs CeFi

Property	DeFi	CeFi
Custody	▪ Users retain complete control of the assets and determine how they are spent. ▪ Users are responsible for key management to utilize the assets.	▪ Companies store the assets for the users. ▪ Users have to trust the companies.
Transparency	As the underlying blockchain which hosts the smart contracts is public and transparent, all interactions and data are publicly visible and verifiable.	▪ Operational logic is black box; execution steps cannot be traced. ▪ Historical data is not publicly available unless the protocol explicitly publishes it. Even then, users have to trust the correctness of the data.
Privacy	Pseudonymous	KYC/AML
Availability	Open 7/24	Business hours, Monday to Friday
Fees	Blockchain transaction fees and protocol-specific fees	Protocol-specific fees

DeFi vs CeFi (cont.)

Although CeFi and DeFi have fundamental differences, they can co-exist and enable features for each other.

- Reserve-based stablecoins like USDC or USDT
- Oracles fetching data (e.g., price info) from CeFi exchanges



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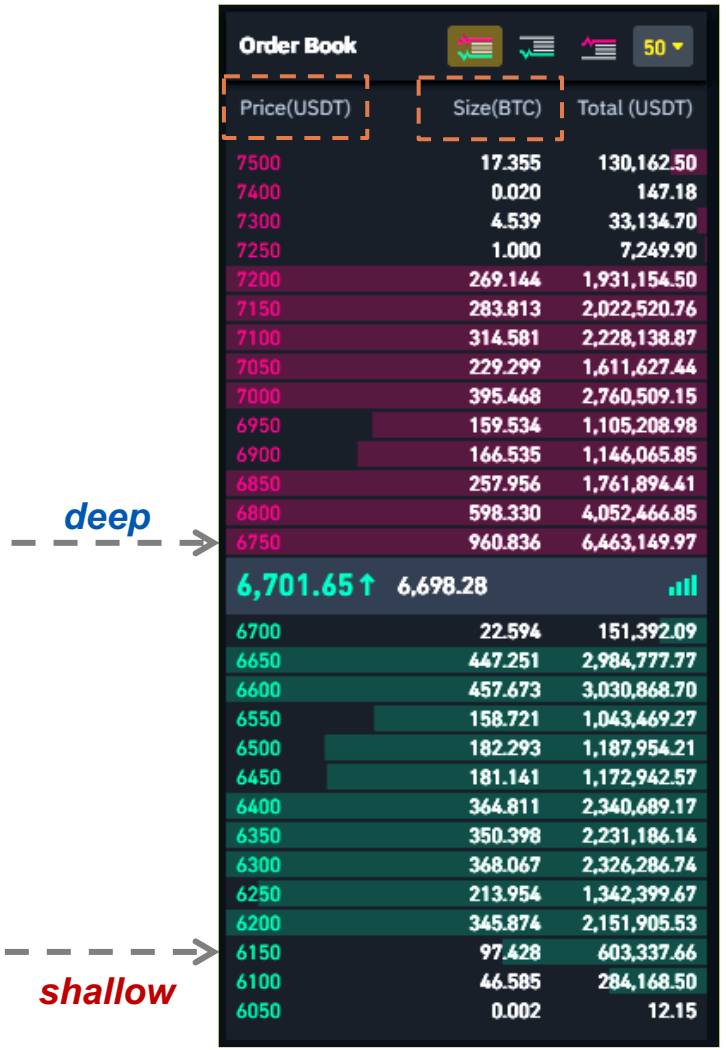
Exchanges

An *exchange* is a marketplace where users can trade assets. In traditional finance, the **order book** is the de facto exchange design where market makers provide liquidity by placing limit orders on both sides of the market (**bid** and **ask**).

- Market orders are filled either by the lowest ask price or the highest bid price.
- Works efficiently when there is **enough liquidity** of assets traded, enabling a **low bid-ask spread**[1] and **fast order filling**.
- **Liquid markets** have order books with **sufficient depth**[2], making individual orders **less likely to affect the price**.
- Depth of an order book shows the **robustness** of the market!

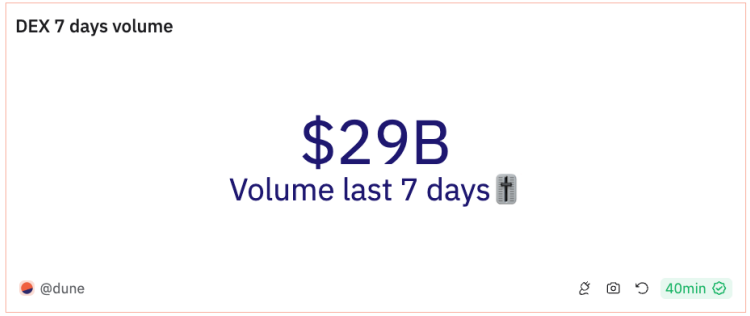


[1] Spread: The price difference between the lowest ask and the highest bid
[2] Depth: Quantity of assets traded at each price level (price * size)

Order book image taken from: https://academy.binance.com/en/glossary/order-book

Decentralized Exchanges

Like centralized exchanges in traditional finance, DeFi supports **decentralized exchanges** (DEX). DEXs are some of the most popular applications on Ethereum with nearly $3.32b cumulative daily trading volume.



The first DEX implementations on Ethereum also **followed the familiar order book design**. However, soon it was realized that such DEXs suffer from **slow execution** of the underlying blockchain and **high transaction fees due to complex on-chain operations** like order matching.

EtherDelta was one of the first DEXs operating on Ethereum. It followed the order book model. In 2018, U.S. Securities and Exchange Commission charged its founder for operating an unregistered national securities exchange, and the platform shut down.

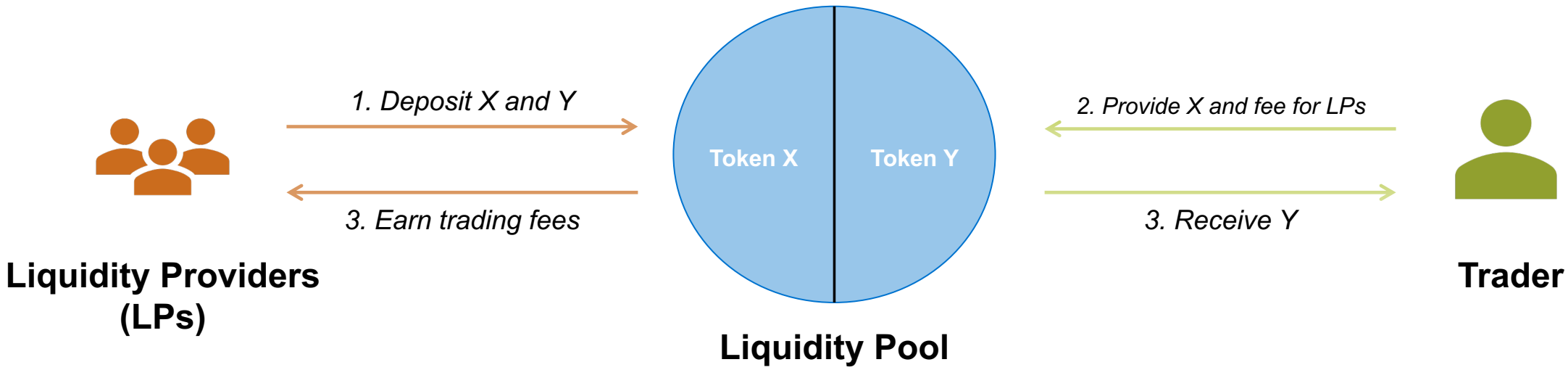
See more metrics about DEXs here: https://dune.com/hagaetc/dex-metrics

Automated Market Makers

The **Automated Market Maker** (AMM) design emerged to enable efficient trading in DeFi through intermediary-free, algorithmic market-making using smart contracts.

- AMMs **replace order books with liquidity pools** where liquidity providers (LPs) deposit assets to both sides of the pools, and the smart contracts automatically handle **market-making** and **price discovery**.

- LPs earn rewards based on their share in the pool and the trading volume, as every trade pays a fee (≈ 0.3%).



This slide is inspired from the DeFi MOOC by UC Berkeley.

Automated Market Makers (cont.)

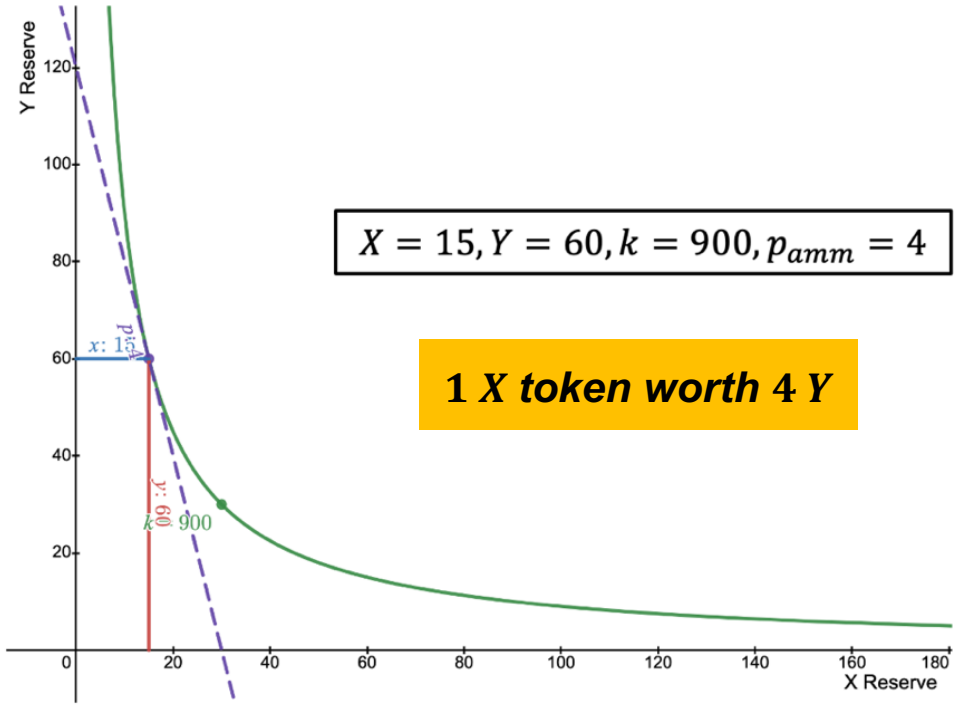
The smart contract of an AMM is programmed to follow a **market-making function** to **determine the input/output amount** given a trade request.

- The most popular market-making function is the **constant product**.

Constant Product AMM

In a two-token, constant product market, say a market for X and Y, the **product of the assets' reserves** (x, y) is **constant** k, and their relative ratio determines the price p_{amm}.

$$x * y = k\ (const)$$
$$p_{amm} = y/x$$



$X = 15, Y = 60, k = 900, p_{amm} = 4$

1 *X* token worth 4 *Y*

The curve of a constant product AMM which has 15 X *and* 60 Y *tokens.*

The figure is created using the Uniswap math (with LVR) Desmos graph.
This slide is inspired from: Öz, B.: Die Kosten der Automated Market Makers. *BSDEX*. 2023.

Automated Market Makers (cont.)

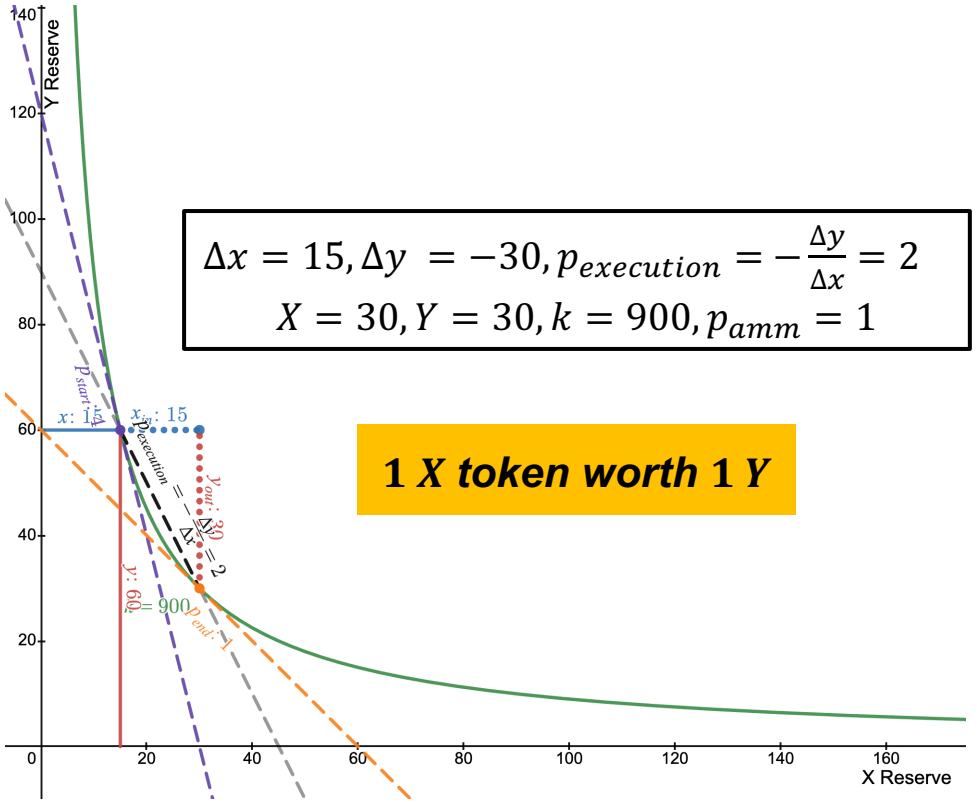
Each new trade on an AMM **changes pool reserves** $(\Delta x, \Delta y)$ **while keeping** k **constant**.

$$(x + \Delta x) * (y + \Delta y) = k$$

Example Trade

Assume the same AMM from the previous slide; let's calculate the output amount (Δy) for a trade of $15\ X$. *(For simplicity, we ignore the DEX fees)*

1.	$X=15,\ Y=60,\ x*y=k=15*60=900$	*Initial state*
2.	$\Delta x = 15$	*Trader inputs 15 X*
3.	$(x + \Delta x) * (y + \Delta y) = k$	*Trade must keep k constant*
4.	$\Delta y = \frac{k}{(x+\Delta x)} - y = \frac{900}{30} - 60 = -30$	*AMM returns 30 Y*
5.	$p_{execution} = -\frac{\Delta y}{\Delta x} = 2$	*Trader receives 2 Y for 1 X*
6.	$X = 30, Y = 30, k = 900, p_{amm} = 1$	*Final state*



The updated price of the AMM after a trade of $15\ X$ *for* $30\ Y$.

Depending on the size of the trade, the AMM price p_{amm} also changes!

- For an infinitely small trade, p_{amm} would remain constant and match the execution price $p_{execution}$.
- With the increasing trade size, the difference between p_{amm} and $p_{execution}$ also grows, resulting in **expected slippage**.[1]

[1] There is also an *unexpected slippage* which refers to the difference between the price when the order was placed and when it was confirmed.

The figure is created using the Uniswap math (with LVR) Desmos graph.
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Automated Market Makers (cont.)

Unlike trades on an AMM, liquidity addition or withdrawal (L_x, L_y) **keeps the AMM price p_{amm} constant while updating k.**

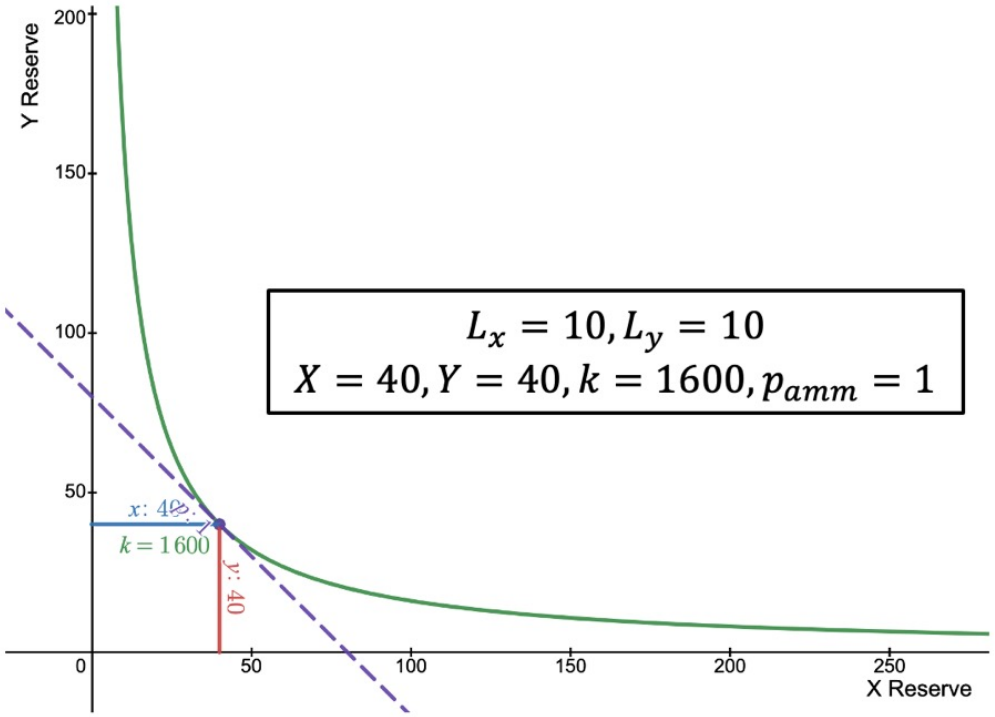
- To keep p_{amm} unchanged, an LP must **supply an equal value of assets** to both liquidity pools.

$$p_{amm} = \frac{y}{x} = \frac{y + L_y}{x + L_x}$$

Example Liquidity Addition

Assume the same AMM from the previous slide; let's calculate the new AMM state after an LP deposits $10\ X$ and $10\ Y$ tokens.

1. $X = 30, Y = 30, k = 900, p_{amm} = 1$ *Initial state*
2. $p_{amm} = \frac{y}{x} = \frac{y + L_y}{x + L_x}$ *LP must keep p_{amm} constant*
3. $p_{amm} = 1 \Rightarrow L_x = L_y = 10$
   $p_{amm} = \frac{30 + 10}{30 + 10} = 1$ *p_{amm} remains constant*
4. $X = 40, Y = 40, k = 1600, p_{amm} = 1$ *Final state*



The updated curve of the AMM after a liquidity provision of $10\ X$ and $10\ Y$.

Remember that LPs earn rewards from each trade based on their share in the pool.

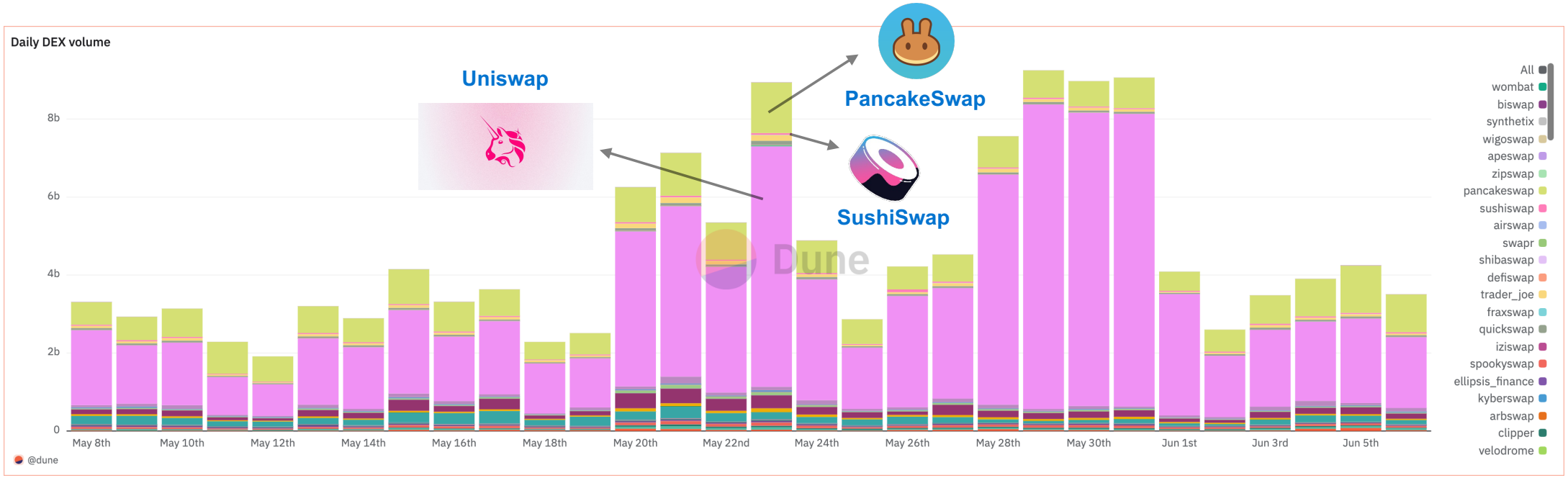
The figure is created using the Uniswap math (with LVR) Desmos graph.
This slide is inspired from: Öz, B.: Die Kosten der Automated Market Makers. *BSDEX*. 2023.

Automated Market Makers (cont.)

AMMs are considered more suitable for fully on-chain implementation and adoption than order books.

- Instant liquidity (no need to wait for a matching order)
- No maintenance is required by LPs to keep the prices up-to-date
- Simple implementation (x*y=k)

Today, AMMs such as **Uniswap** take the dominant market share of the DEX trading space.



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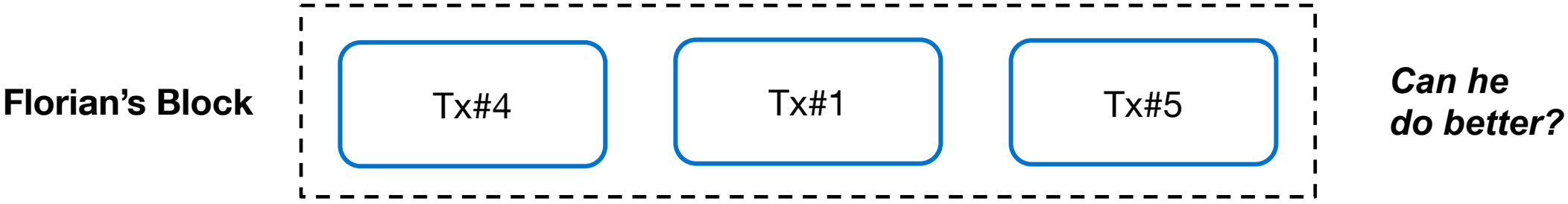
Building the Most Profitable Block

Assume that Florian is the next block proposer and has the following **mempool**.
Which transactions should he include in his block to maximize his profits? (block size = 3 Txs)

ID	Content	Gasprice
1	Alice transfers Bob 500 USDC	0.3 Gwei
2	Charlie transfers the ownership of a Bored Ape NFT to Bob	0.15 Gwei
3	Dennis swaps 2 ETH for 3000 USDC on Uniswap and swaps the 3000 USDC for 3.5 ETH on Sushiswap (makes 1.5 ETH profit)	0.1 Gwei
4	Alice deploys a new ERC20 contract	0.55 Gwei
5	Charlie calls a vulnerable contract to drain the funds in it (makes 10 ETH profit)	0.2 Gwei

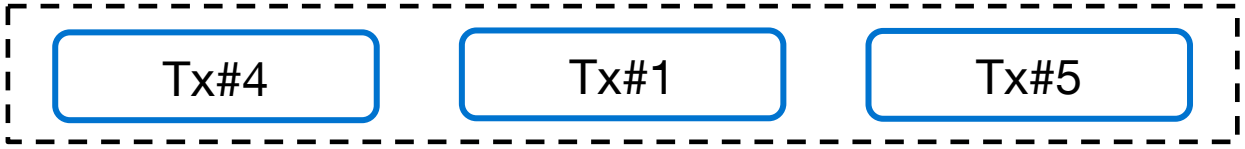
As Florian is a **rational player**, we would expect him to pick the transactions which have the **highest gasprice**.



Building the Most Profitable Block (cont.)

Think of **all the things that Florian can do when building his block**; does the following block actually **maximize his profits**?

Florian's Block



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What stops Florian from copying Tx#3 and Tx#5 and earning the profits himself?

Florian's Profit Maximizing Block (+11.5 ETH)

Maximal Extractable Value

The 11.5 ETH that Florian earns by inserting his own transactions and ignoring the original Tx#3 and Tx#5 is known as **Maximal Extractable Value** (**MEV**).

- MEV refers to the **maximum value** a **privileged actor**, like a block proposer, can **extract** from the protocol by **inserting**, **reordering**, or **censoring transactions**.

- However, **MEV is not specific to block proposers**; anyone monitoring the mempool could have also attempted to **copy the profitable transactions** and **prioritize** them by offering a higher gasprice.[1]

- Currently, MEV is the **most prominent incentive** on permissionless, smart-contract-enabled blockchains, which grows with the expanding DeFi ecosystem.

> *"Super linear return from MEV extraction results in significant **economy of scale** in block construction, creating **incentives for centralization**. Block producers who integrate with trading firms can get an inherent advantage in building the best blocks. The endgame in which a few large players making all the blocks - is an '**MEV dystopia**' that had to be prevented at all costs."*
>
> *Flashbots*[2]

[1] Block proposers on Ethereum refrain from collecting MEV themselves as this could harm their reputation. Instead, they profit from the fees MEV searchers pay for prioritizing their transactions.

[2] Flashbots is a research and development organization formed to mitigate the negative externalities posed by MEV.

Maximal Extractable Value (cont.)

$675,623,114
Total Extracted MEV before the merge ⓘ

$2,401,586
Last 30 days Extracted MEV before the merge

$175k
Last 24h Extracted MEV before the merge

Pre-merge MEV data on [MEV-Explore](#) by Flashbots

Maximal Extractable Value (cont.)

Maximal Extractable Value

Extractable Value

Extracted Value

This visualization is not to scale!

The figure is inspired from Alex Obadia (Flashbots).

Outlook

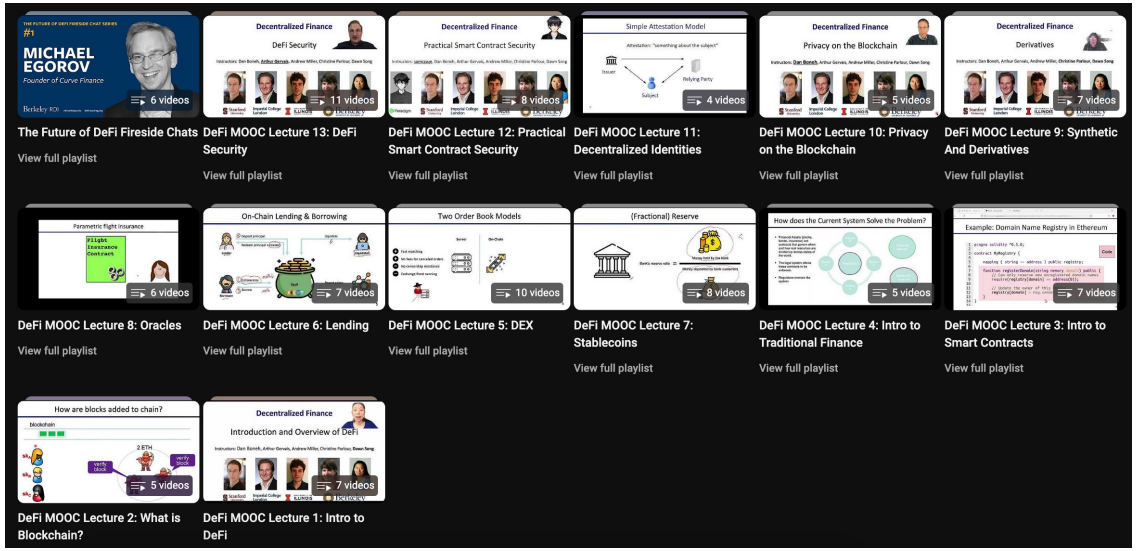
- MEV influences blockchains on various layers:

Incentive Mechanisms	Economics	Consensus Security	App Design

- The MEV research space is studied by many groups, including the Ethereum Foundation.
- At *sebis*, we conduct research on the following topics:
  - SOON **Cross-chain MEV Extraction**
  - ☑ **Ethereum Block Building Economics**
  - ☑ **MEV in First-Come-First-Served Networks**
  - ☑ **The Role of Time in MEV Rewards**
- If you are interested in working on MEV problems, contact Burak Öz

Useful Resources

DeFi MOOC by Berkeley (YouTube)



Articles on AMMs, The Merge, and MEV (GitHub)

More MEV Resources (Notion)