

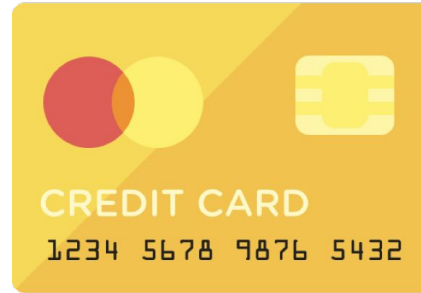
Decentralized Finance

Lending and Borrowing

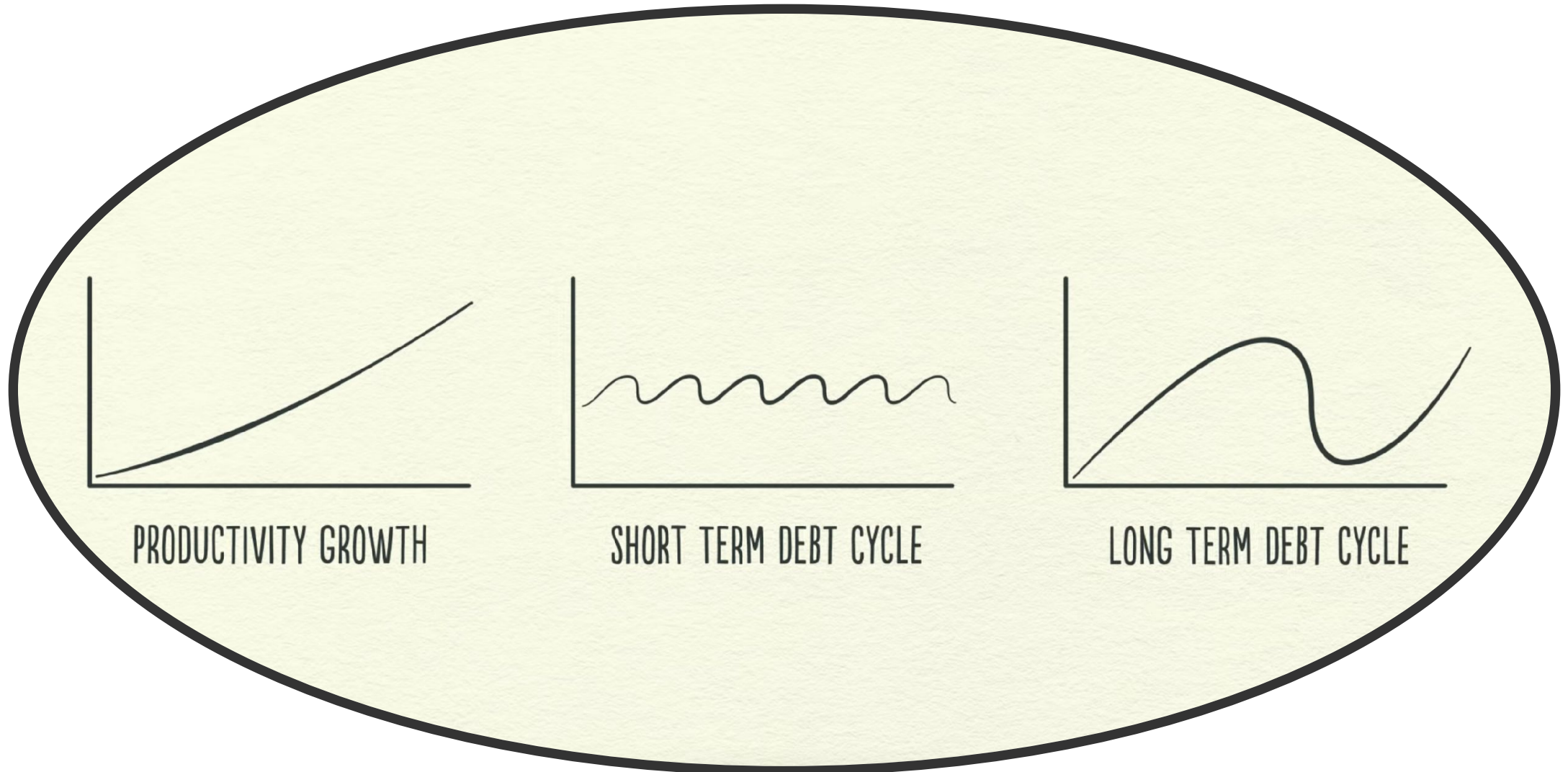
Instructors: Dan Boneh, Arthur Gervais, Andrew Miller, Christine Parlour, Dawn Song



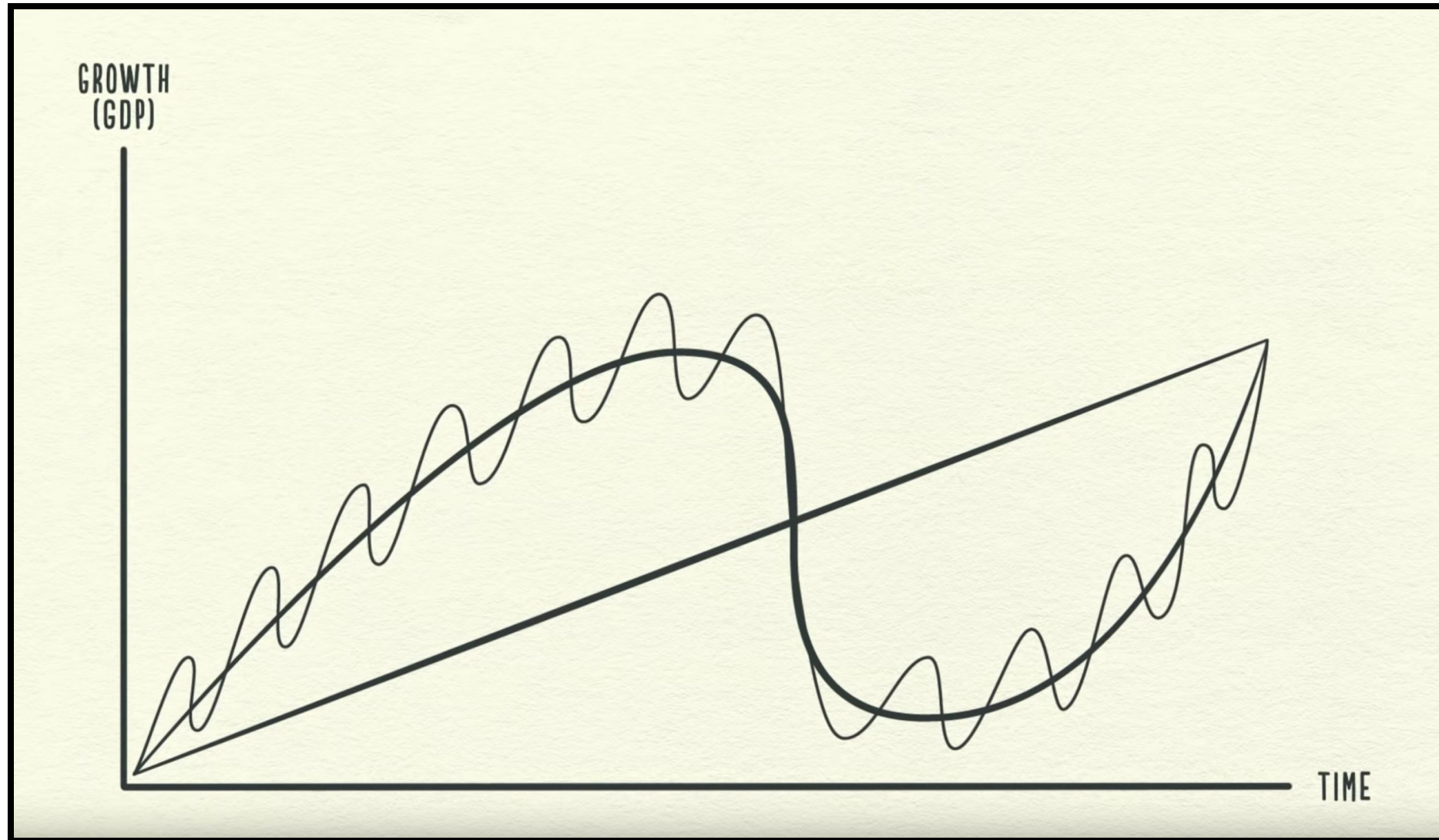
Why lending?



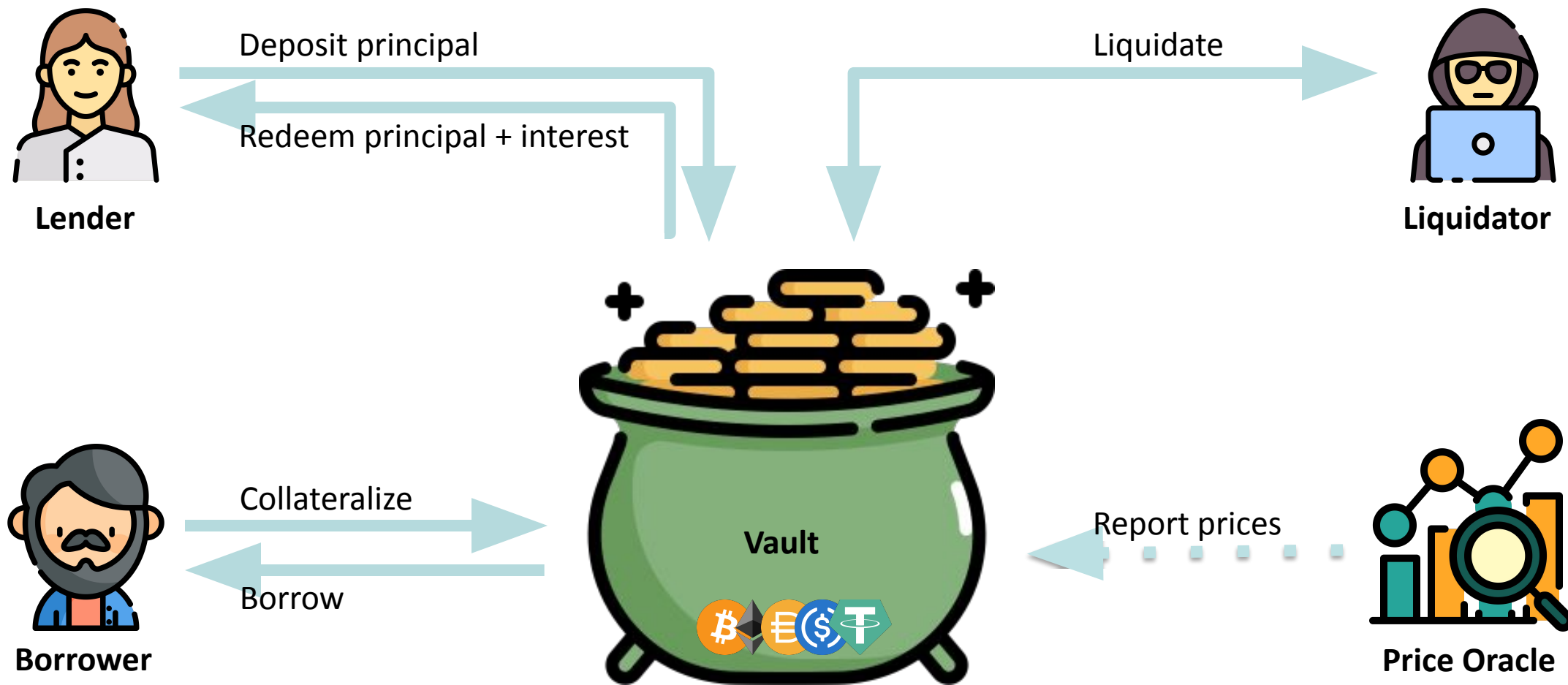
How the “Economic Machine” works?



How the “Economic Machine” works?



On-Chain Lending & Borrowing



Leverage == A debt multiplier

Assets	Market size	Total borrowed	Deposit APY	Variable Borrow APR	Stable Borrow APR		
DAI	\$ 1.55B	\$ 1.2B	2.77% <small>1.09% APR</small>	3.89% <small>1.41% APR</small>	11.95%	Deposit	Borrow
Gemini Dollar (GUSD)	\$ 38.17M	\$ 30.64M	3.89% <small>2.40% APR</small>	5.39% <small>2.99% APR</small>	—	Deposit	Borrow
USD Coin (USDC)	\$ 5.59B	\$ 4.18B	2.27% <small>0.93% APR</small>	3.32% <small>1.26% APR</small>	10.66%	Deposit	Borrow
USDT Coin (USDT)	\$ 1.15B	\$ 1.04B	9.02% <small>2.83% APR</small>	10.99% <small>3.15% APR</small>	18.99%	Deposit	Borrow
Wrapped ETH (WETH)	\$ 4.51B	\$ 206.35M	0.02% <small>0.54% APR</small>	0.56% <small>0.63% APR</small>	3.70%	Deposit	Borrow
WBTC Coin (WBTC)	\$ 1.58B	\$ 96.71M	0.04% <small>1.24% APR</small>	0.75% <small>1.07% APR</small>	3.94%	Deposit	Borrow

Sushiswap USDC/ETH	16.86%	Alpha APR	22.98%	FARM
Sushiswap MKR/ETH	7.28%	Trading Fee	3.80%	FARM
Sushiswap ETH/USDT	15.48%	Alpha APR	13.37%	FARM
Sushiswap DAI/ETH	16.46%	Alpha APR	22.98%	FARM
Curve 3pool	4.26%	Alpha APR	46.74%	FARM

17.47%
4.26%

7x leverage

Pool	Base APY	Rewards APY	Volume
tricrypto CRYPTO V2 [?] USDT + wBTC + WETH	2.61%	+2.27% → -5.67% CRV	\$15.2m
3pool USD DAI + USDC + USDT	1.08%	+3.16% → -7.90% CRV	\$226.1m
ust USD UST + 3Crv	5.72%	+3.77% → -9.42% CRV	\$21.9m
bbtc BTC BBTC + sbtcCrv	0.53%	+3.13% → -7.81% CRV	\$9.5m
sUSD USD DAI + USDC + USDT + sUSD	0.48%	+2.74% → -6.86% CRV +2.04% SNX	\$8.7m
lUSD USD LUSD + 3Crv	1.04%	+6.17% → -15.43% CRV	\$8.7m
aLUSD USD aLUSD + 3Crv	0.78%	+1.85% → -4.64% CRV +11.18% ALCX	\$5.8m
tricrypto2 CRYPTO V2 [?] USDT + wBTC + WETH	2.88%	+0.00% → -0.00% CRV	\$4.8m
seth ETH ETH + sETH	2.19%	+2.02% → -5.06% CRV	\$3.8m
steth ETH ETH + stETH	2.91%	+0.15% → -0.37% CRV +6.03% LDO	\$2.6m

See All Pools My Dashboard



Terminology

Terminology

- Collateral
 - Assets that serve as a security deposit
- Over-collateralization
 - Borrower has to provide
 $value(collateral\ assets) > value(granted\ loan)$
- Under-collateralization
 - $value(collateral) < value(debt)$
- Liquidation
 - If $value(collateral) \leq 150\% \times value(debt)$
 - Anyone can liquidate the debt position

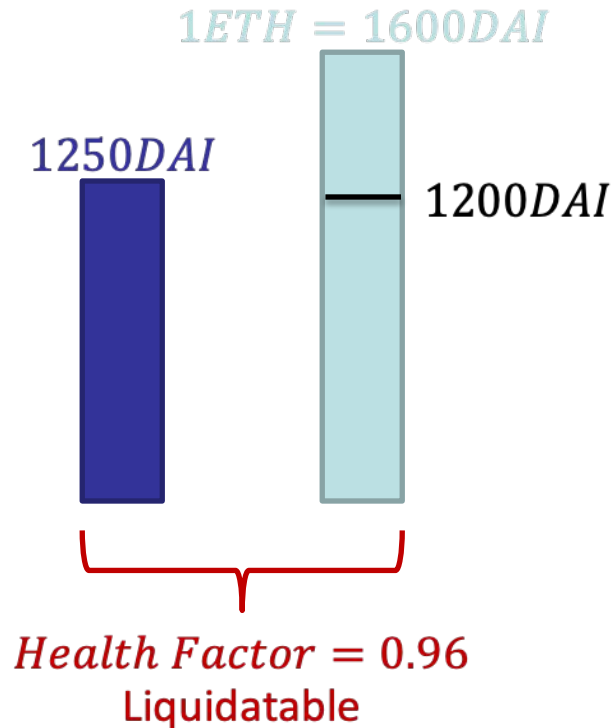
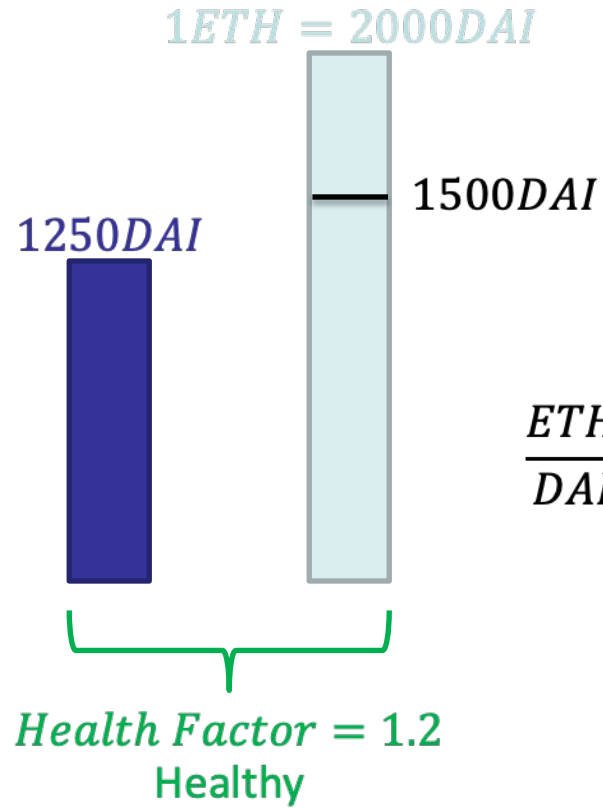
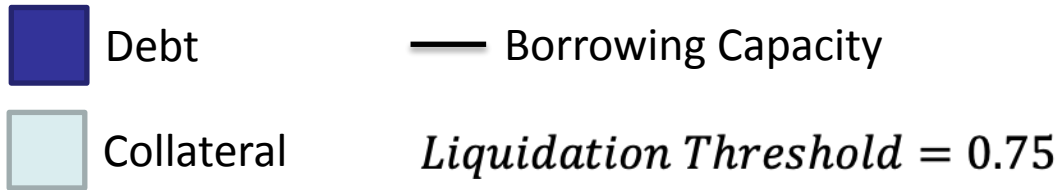
Health Factor

$$\text{Health Factor} = \frac{\sum \text{Value of Collateral}_i \times \text{Liquidation Threshold}_i}{\text{Total Value of Debts}}$$

↓
Borrowing Capacity

- $0 < \text{Liquidation Threshold} < 1$
- The **liquidation threshold** provides a “secure” margin
- When the health factor declines below 1, a borrowing position becomes liquidatable

Health Factor



Terminology

- **Liquidation Spread LS** : bonus, or discount, that a liquidator can collect when liquidating collateral

$$\textit{Value of Collateral to Claim} = \textit{Value of Debt to Repay} \times (1 + LS)$$

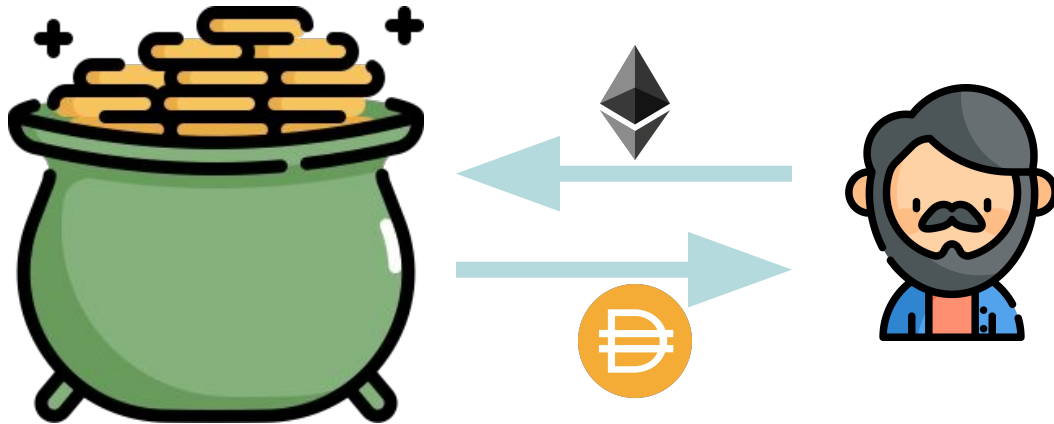
- **Close Factor CF** : the maximum proportion of the debt that is allowed to be repaid in a single fixed spread liquidation

$$\textit{Value of Debt to Repay} < CF \times \textit{Total Value of Debts}$$



Over-collateralized Borrowing

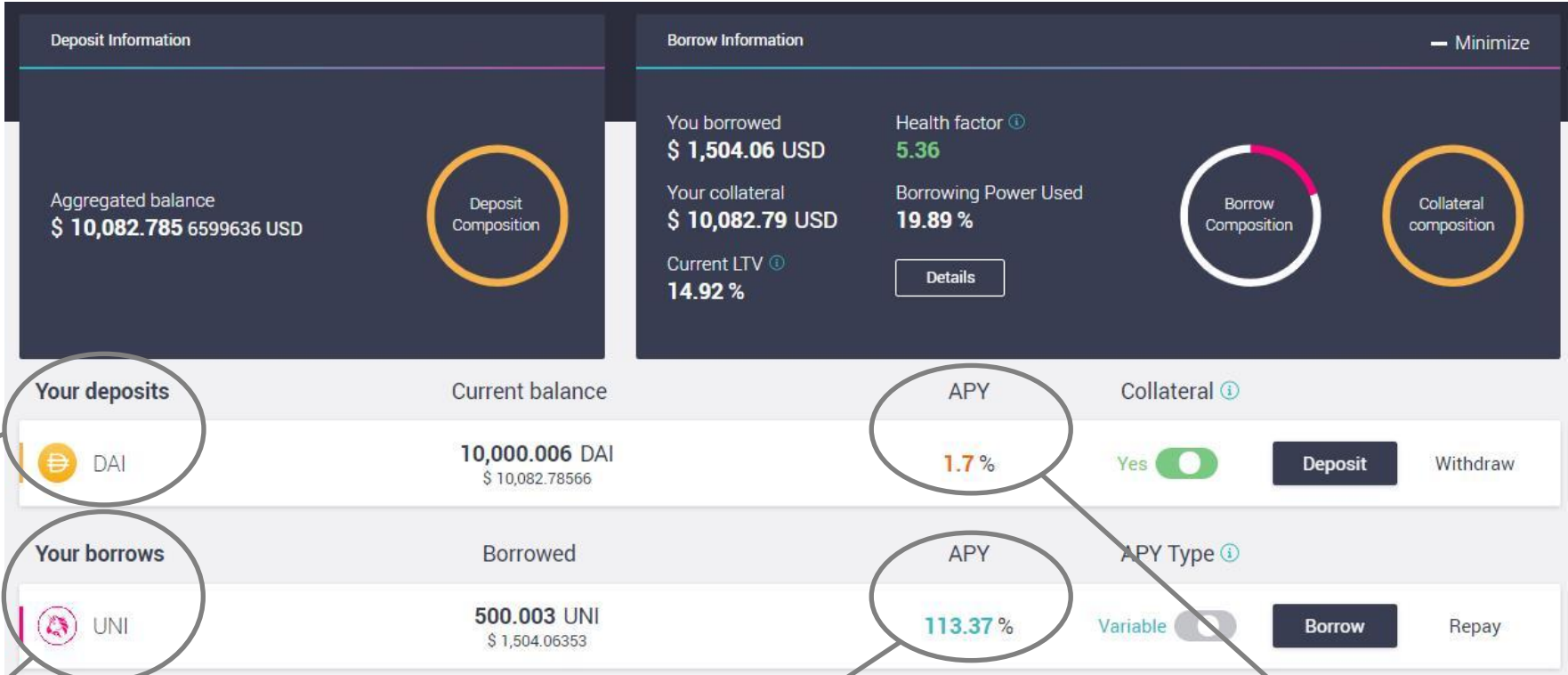
Over-collateralized Borrowing



- E.g., the borrower collateralizes ETH and borrows DAI
- The value of ETH exceeds the value of DAI
- The borrower can use the borrowed DAI arbitrarily/freely

Over-collateralized Borrowing

Aave Dashboard Screenshot



DAI is deposited as collateral

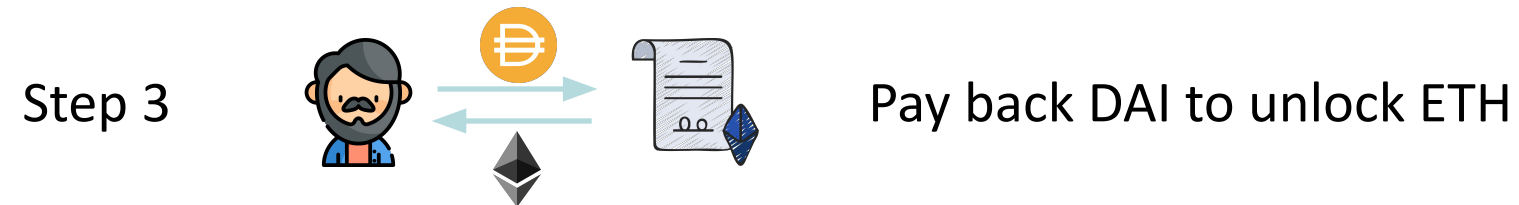
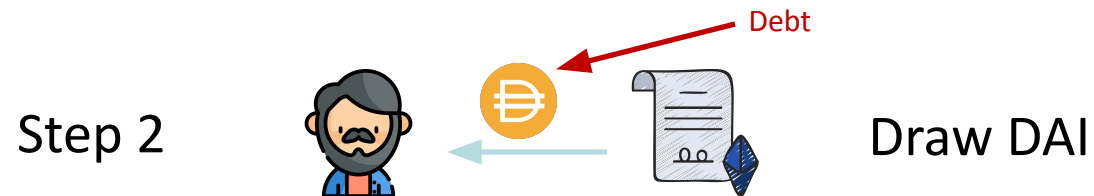
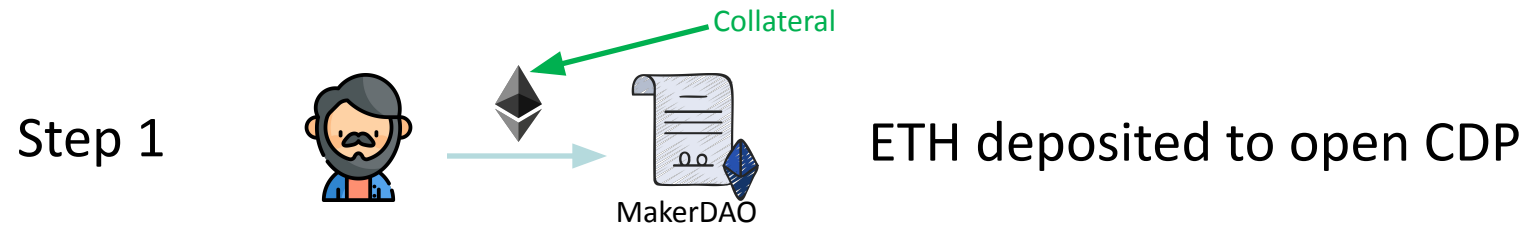
UNI is borrowed

The borrowing interests the borrower needs to pay

In Aave, the collateral is also lent out. Hence the borrower can also earn interests.

Over-collateralized Borrowing

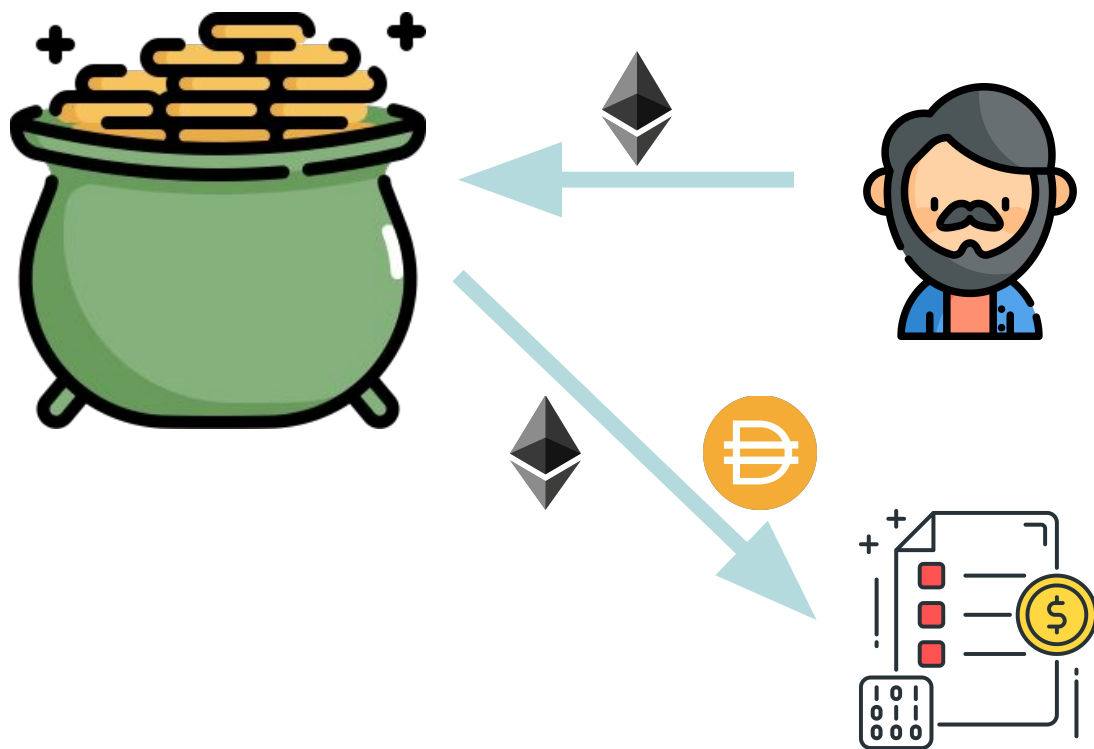
Stablecoin





Under-collateralized Borrowing

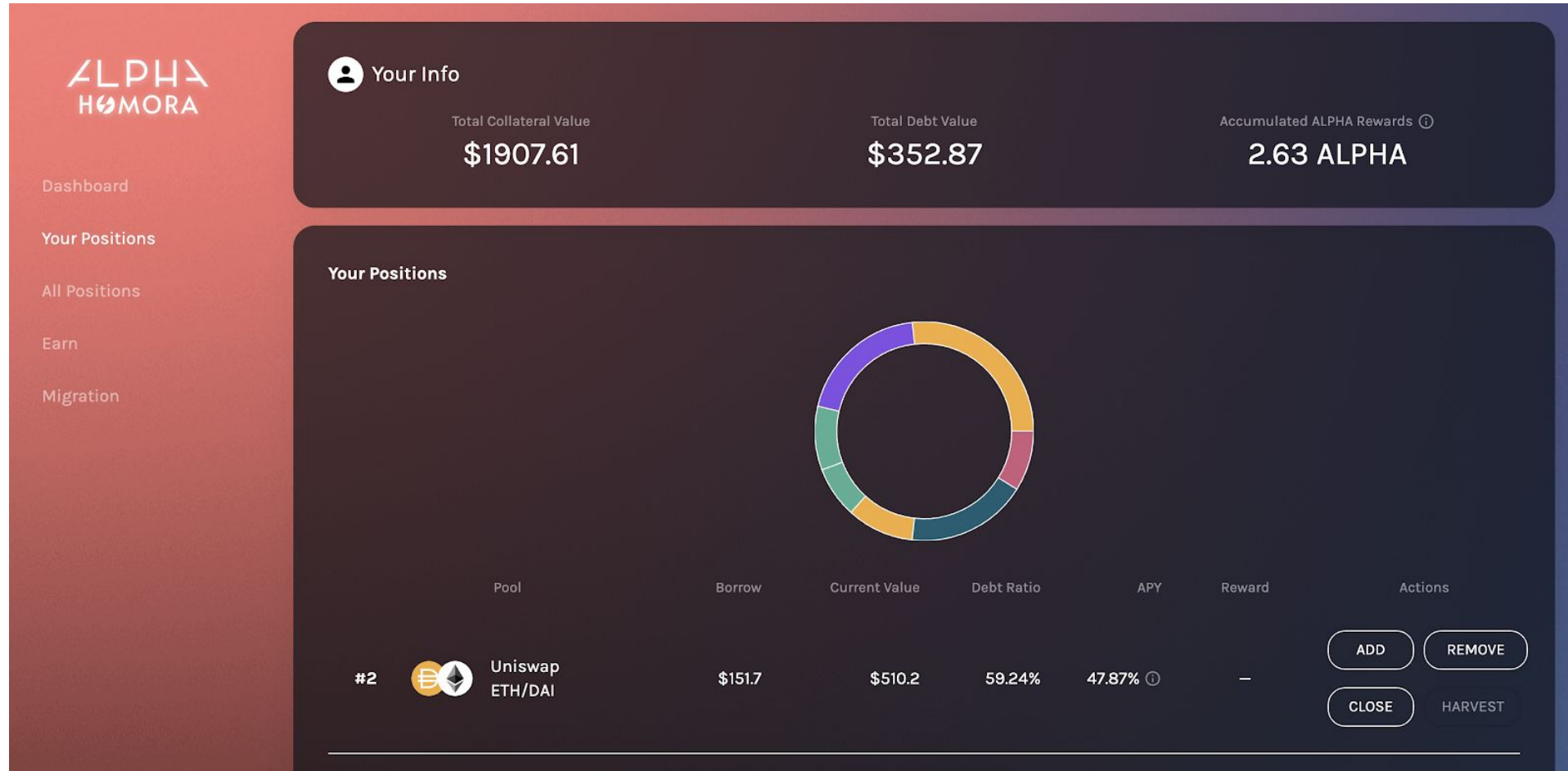
Under-collateralized Borrowing



- E.g., the borrower collateralizes ETH and borrows DAI
- The value of DAI (debt) can exceed the value of ETH (collateral)
- The collateralized ETH and borrowed DAI are restricted to be used with pre-designed smart contracts. Those are typically farming contracts.
- The vault remains in control of all assets.

Under-collateralized Borrowing























Alpha Homora Dashboard Screenshot



Under-collateralized Borrowing

Alpha Homora All Positions

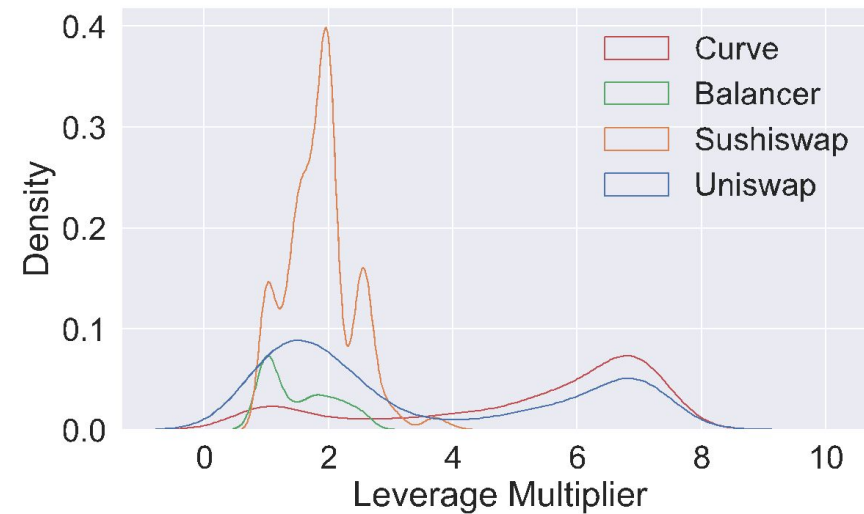
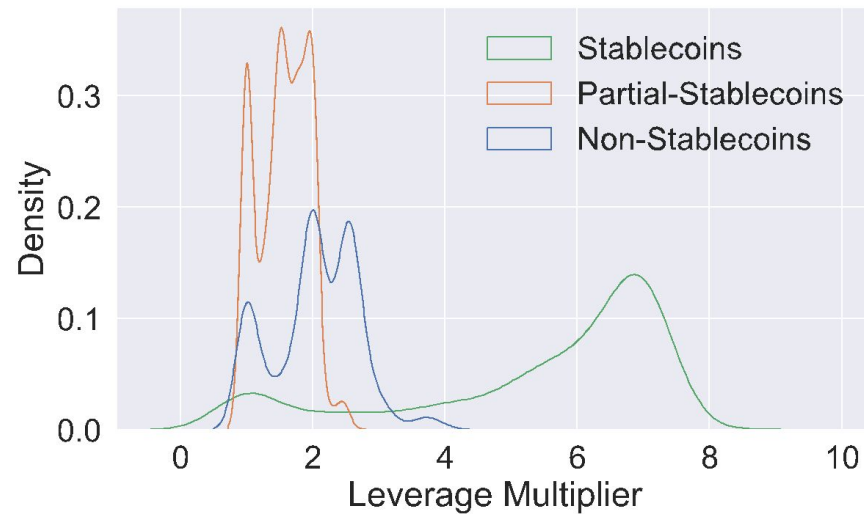
All Positions

#	Pool	Collateral Value	Borrow Credit ⓘ	Collateral Credit ⓘ	Debt Ratio ⓘ	Action
#457	 Sushiswap YFI/ETH	\$1,071,645.78	352.51	358.95	98.20% 	LIQUIDATE
#852	 Sushiswap ETH/CRV	\$55,776.51	15.34	15.71	97.67% 	LIQUIDATE
#1425	 Uniswap ETH/CRV	\$9,500.32	2.60	2.68	97.12% 	LIQUIDATE
#1967	 Sushiswap DAI/ETH	\$10,679,094.22	3,763.38	3,879.48	97.01% 	LIQUIDATE
#366	 Curve 3pool	\$57,460.63	24.22	25.04	96.72% 	LIQUIDATE
#1922	 Sushiswap SNX/ETH	\$29,583.59	8.81	9.11	96.69% 	LIQUIDATE
#492	 Uniswap UNI/ETH	\$27,551.56	7.50	7.76	96.67% 	LIQUIDATE
#247	 Curve 3pool	\$69,507.61	29.28	30.29	96.66% 	LIQUIDATE
#245	 Uniswap USDC/USDT	\$565,634.18	238.22	246.52	96.63% 	LIQUIDATE
#936	 Sushiswap WBTC/ETH	\$27,944.79	9.81	10.15	96.61% 	LIQUIDATE
#129	 Curve 3pool	\$35,263.71	14.84	15.37	96.58% 	LIQUIDATE

AH Statistics

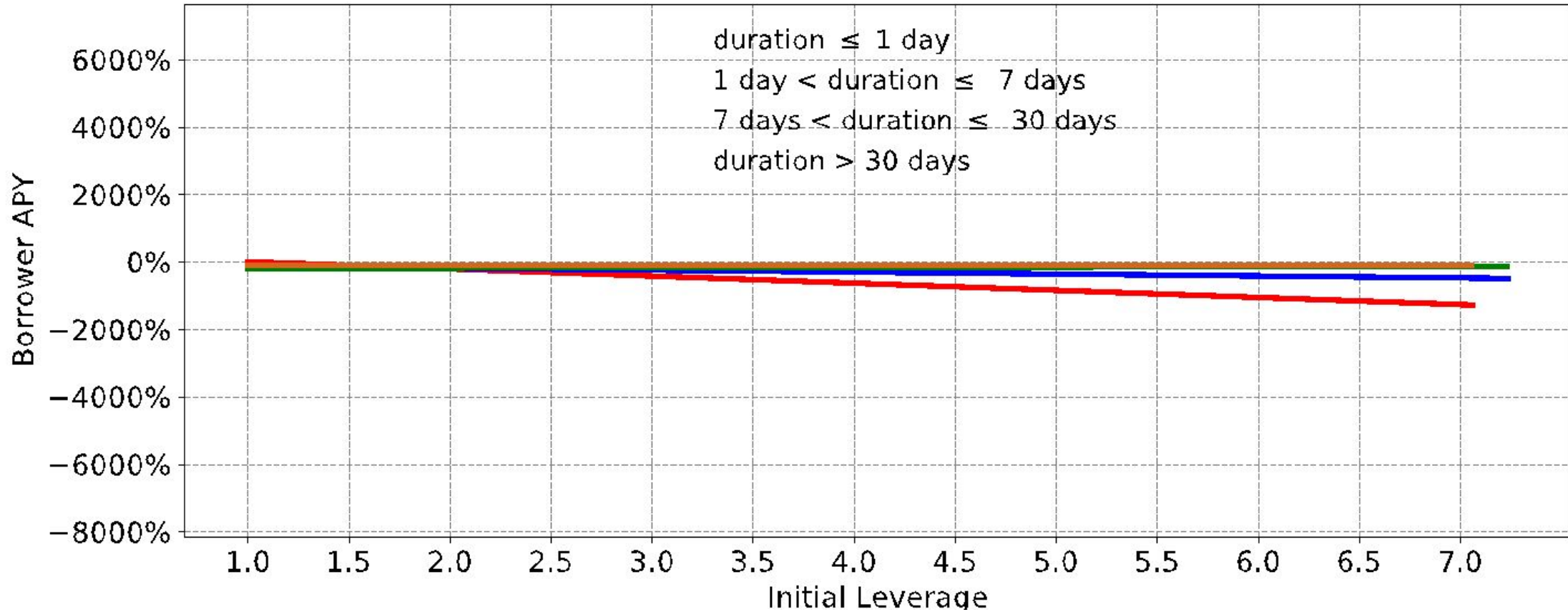
- Opened Positions (October 2020 – August 2021)
 - 3800 borrowers
 - 10,430 leverage positions
- Leverage multipliers
 - AHv1: 2.01x
 - AHv2: 3.07x
- Stablecoin leverage multipliers
 - 5.39x

How are borrowers choosing leverage multipliers?



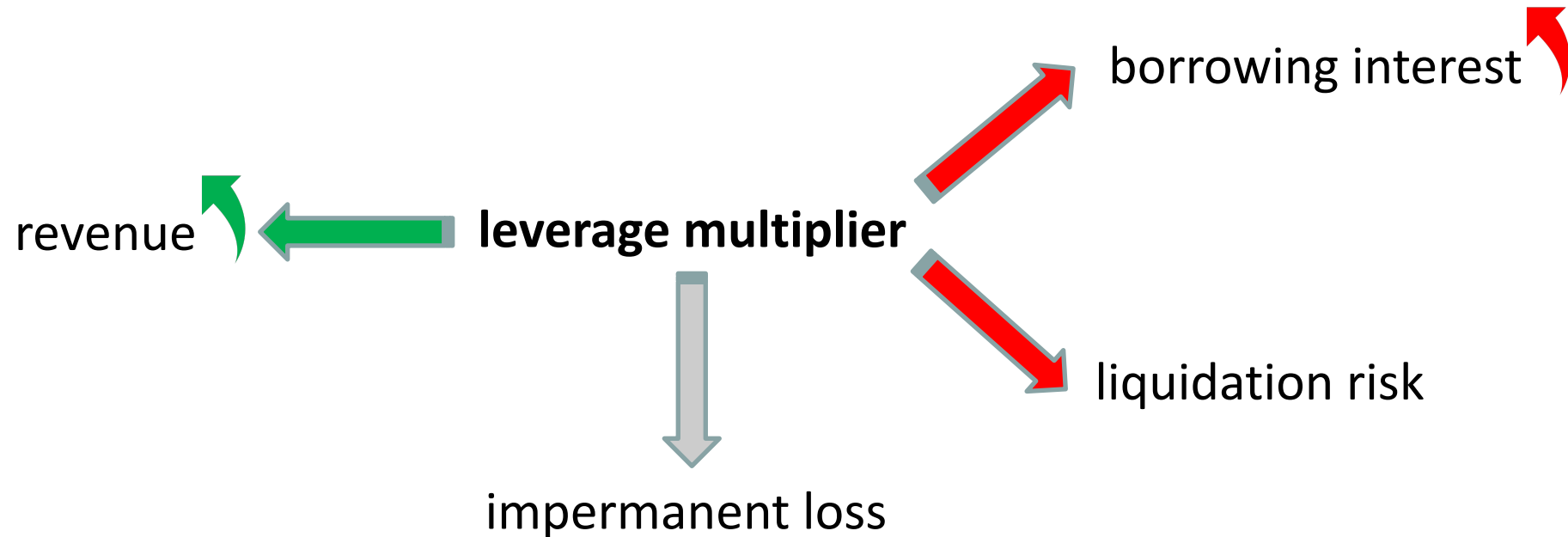
- Distributions of leverage multipliers in Alpha Homora V2 (2581 positions).

APY under Leverage



APY under Leverage

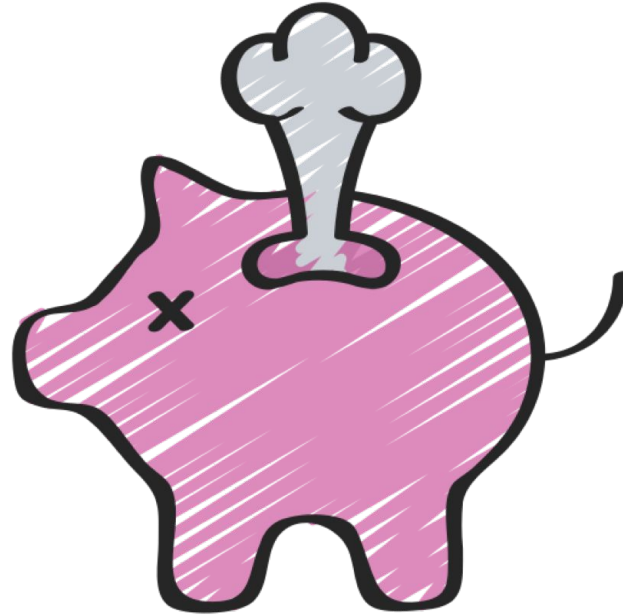
Why does leverage not amplify APY in practice?





Liquidation

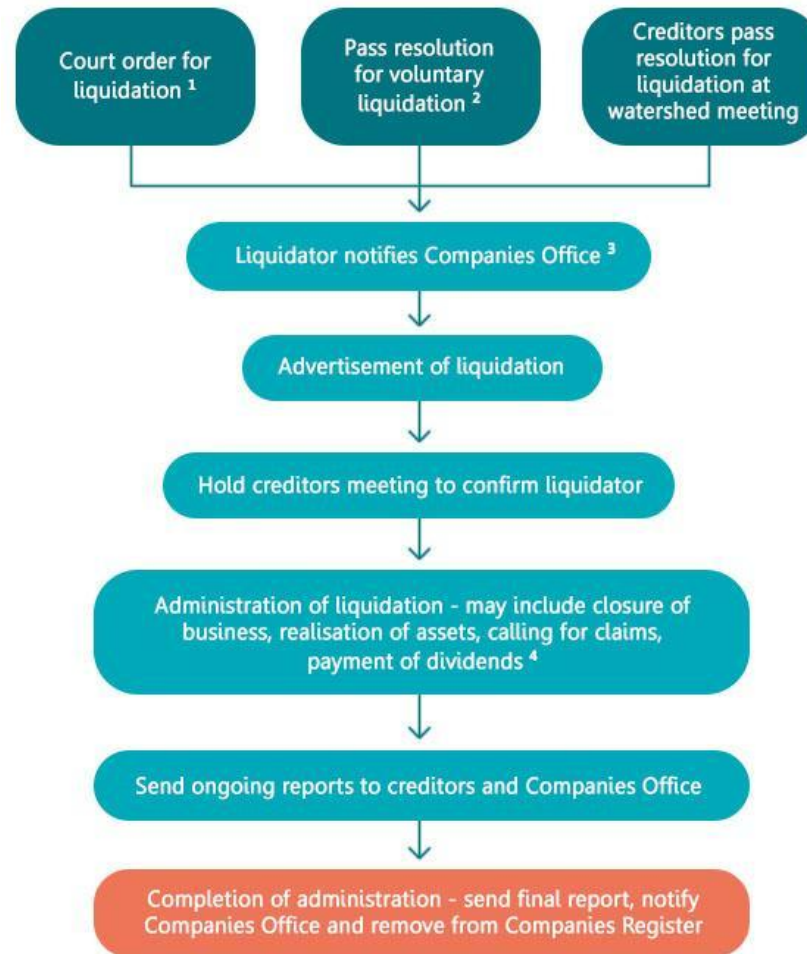
What could go wrong?



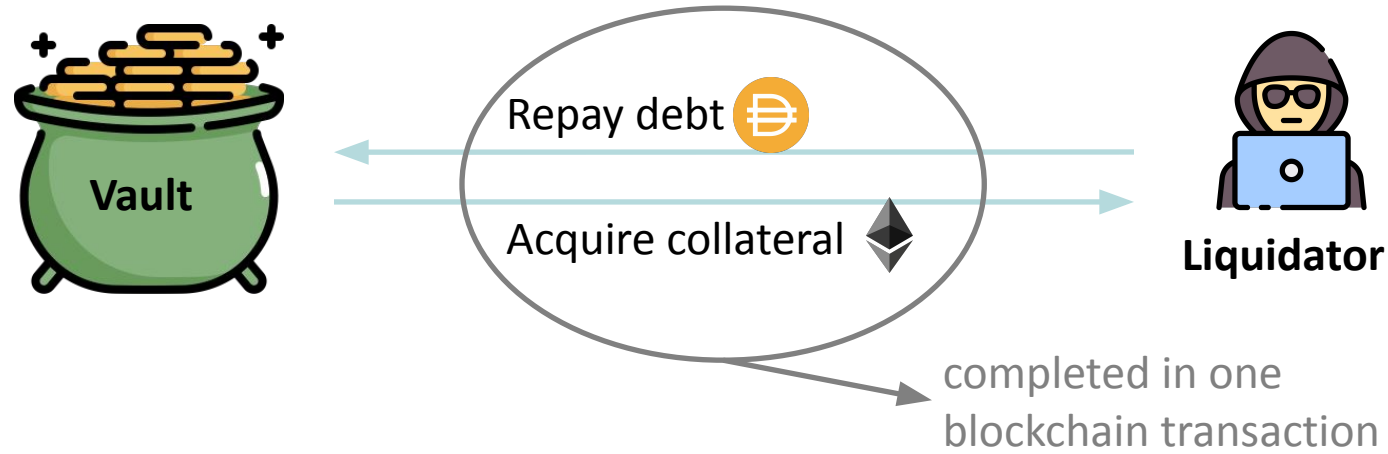
Liquidation

- Liquidation == Selling collateral from the borrower
- Liquidation Spread
 - Bonus, or discount for liquidator
 - Fixed spread, or variable (auction based)

Liquidation in Traditional Finance



Fixed Spread Liquidation



- Repays the debts of a borrowing position
- Acquires the collateral at a discounted price from the position in return
 - Typical discounts are e.g., 5-15% in Aave

Fixed Spread Liquidation



Debt

— Borrowing Capacity

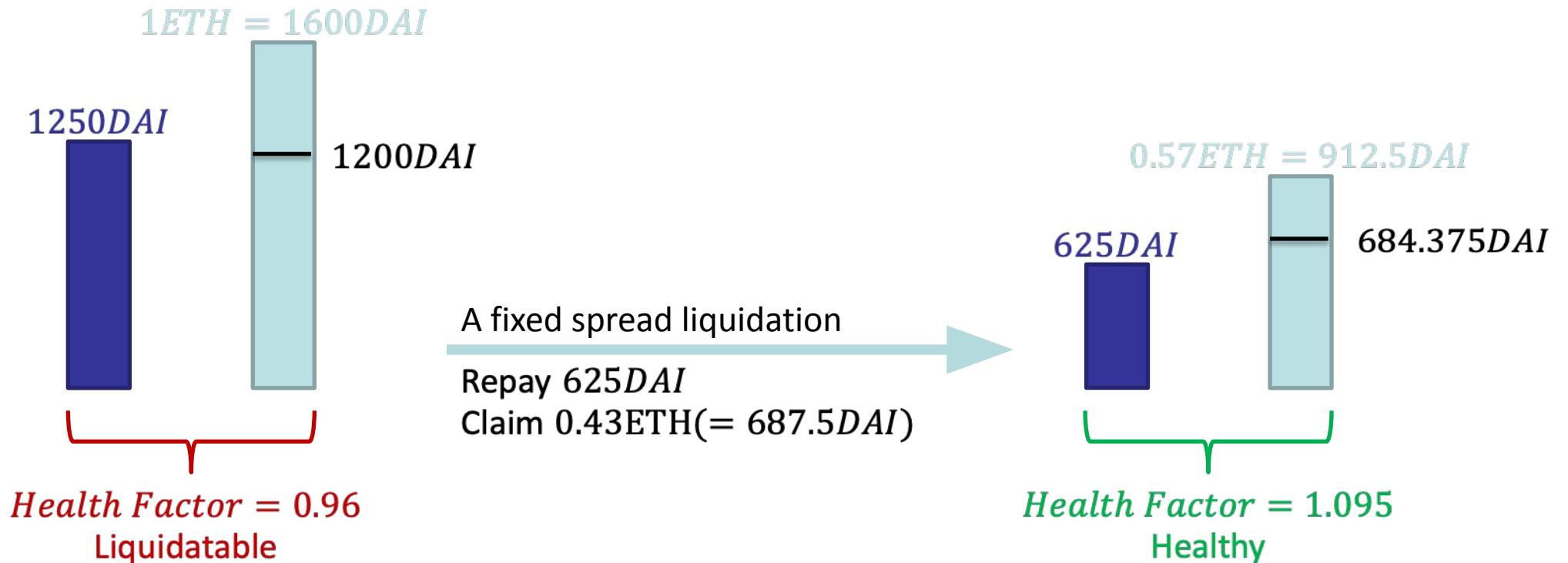
Close Factor = 0.5



Collateral

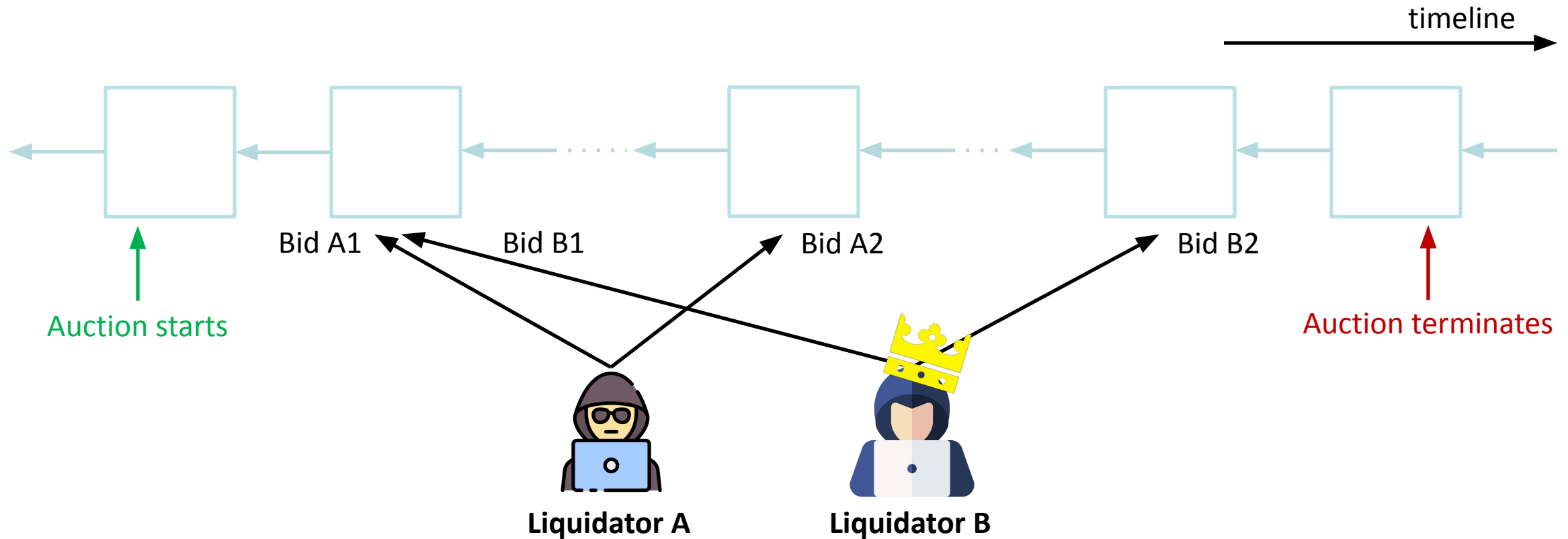
Liquidation Threshold = 0.75

Liquidation Spread = 0.1



Auction Liquidation

- Various liquidators bid over time until the auction terminates
- Requires multiple blockchain transactions.



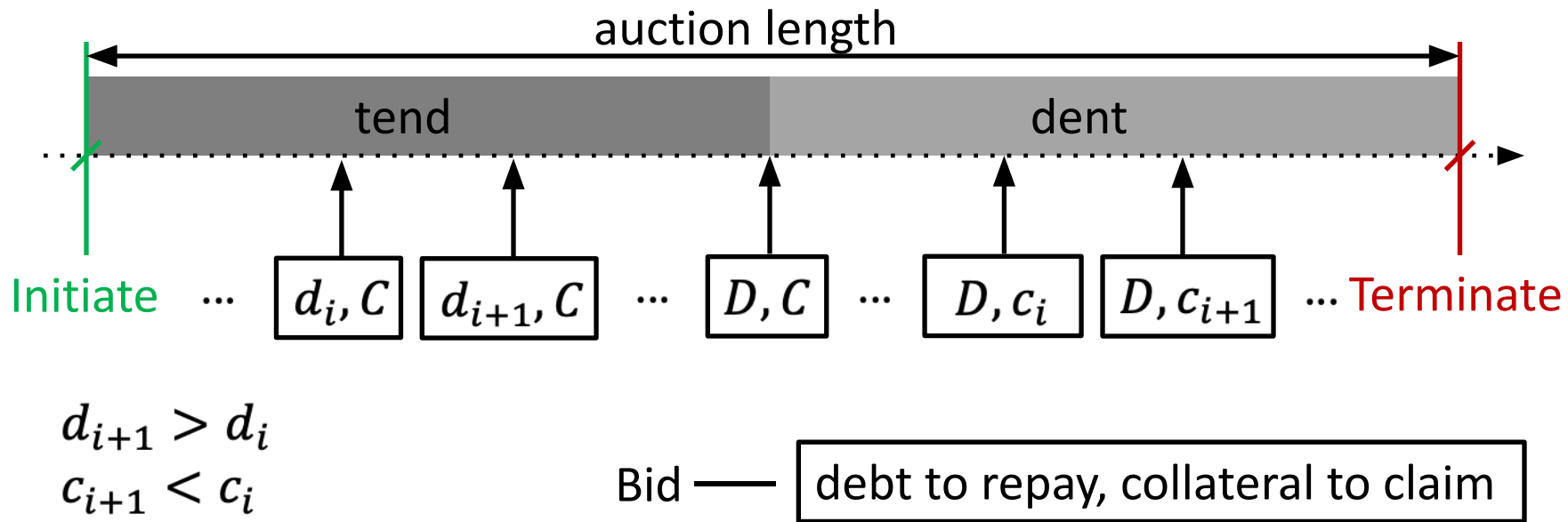
Auction Liquidation

- English Auction
 - bidders outbid each other increasingly
- Dutch Auction
 - auction begins with a high asking price and the price lowers until the auction terminates

Auction Liquidation

MakerDAO tend-dent English auction (Day one – April 2021)

- A position with D debt and C collateral



Auction Liquidation

MakerDAO Dutch auction (April 2021 — Present)

■ Instant Settlement

- Unlike English auction which are operated in multiple transactions, the MakerDAO Dutch auction is settled instantly in one atomic transaction.



■ Flash Lending of Collateral

- No upfront DAI (i.e., the debt) is required (i.e., a flash loan used specifically for MakerDAO liquidations).



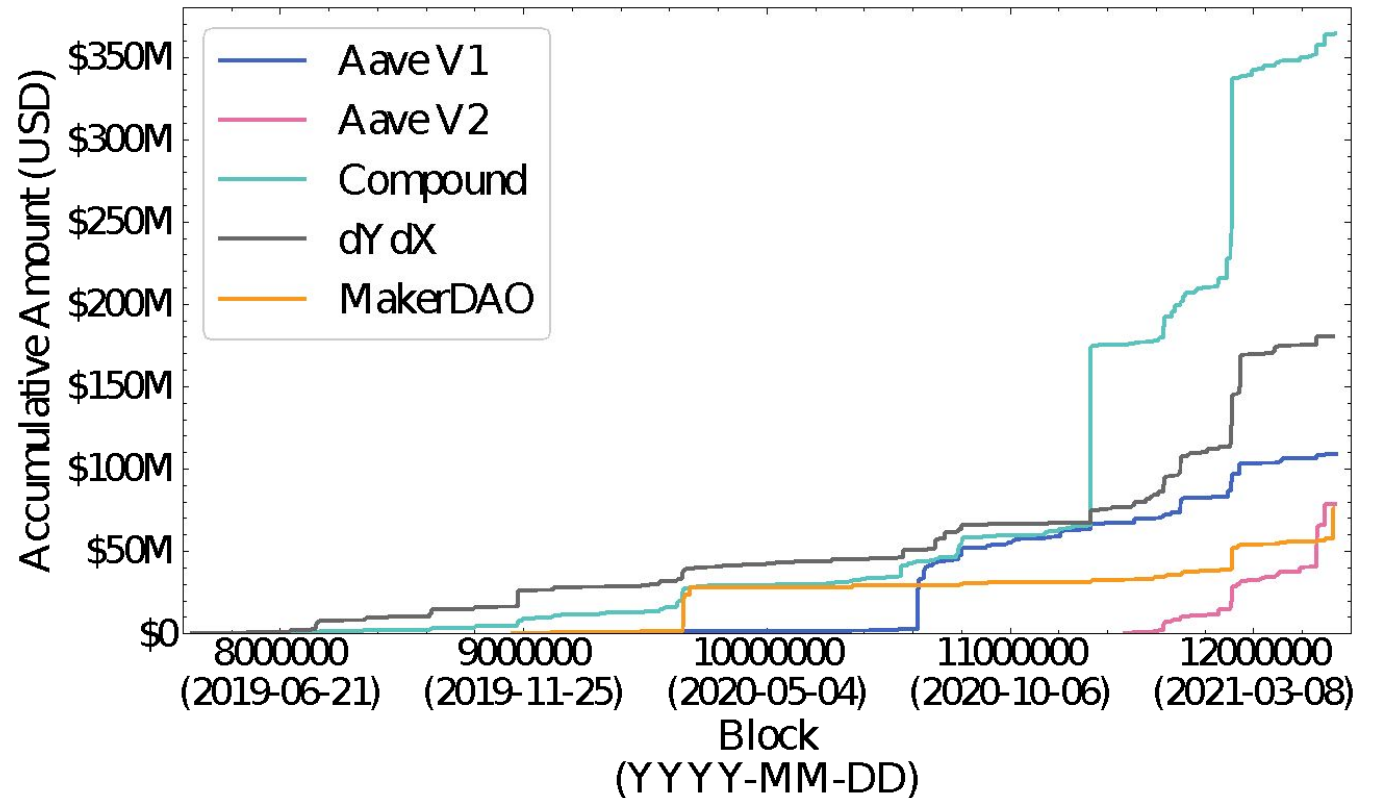
■ Price as a Function of Time

- Collateral price decreases over time nobody can get the collateral for free by accident



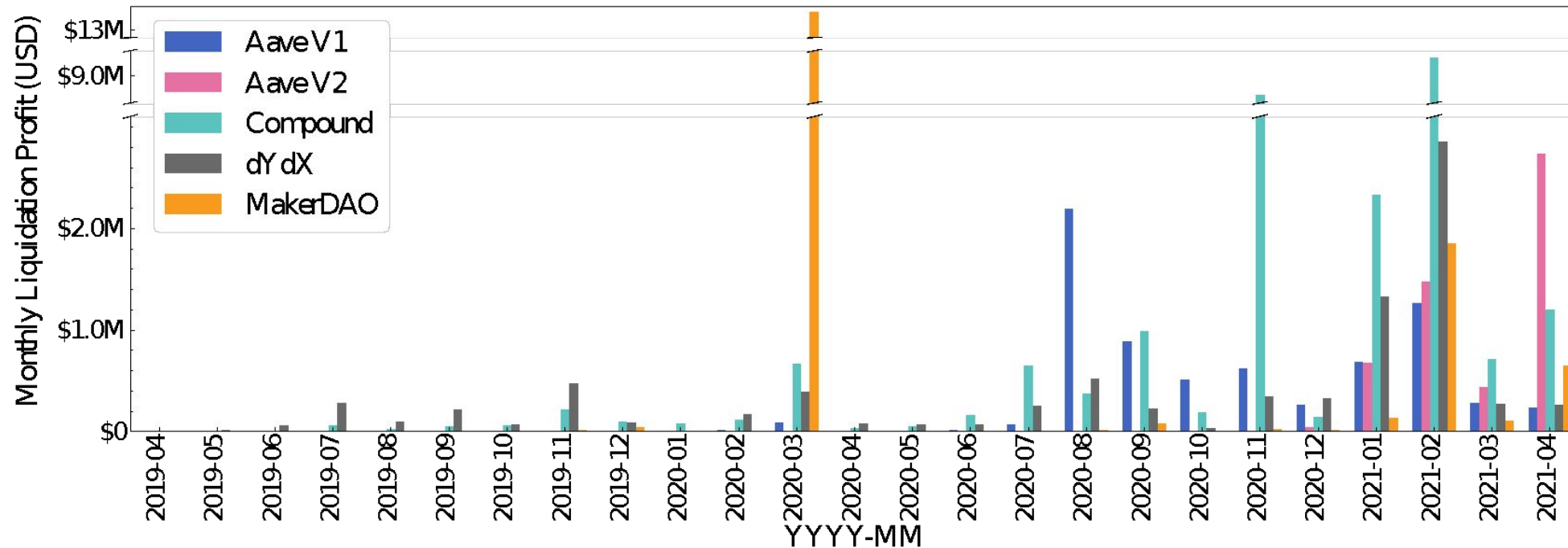
Liquidation Statistics

- April 2019 - April 2021 (2 years)
- Aave (V1 & V2), Compound, dYdX, and MakerDAO
- 28138 successful liquidations
- 807.46M USD of collateral sold through liquidations



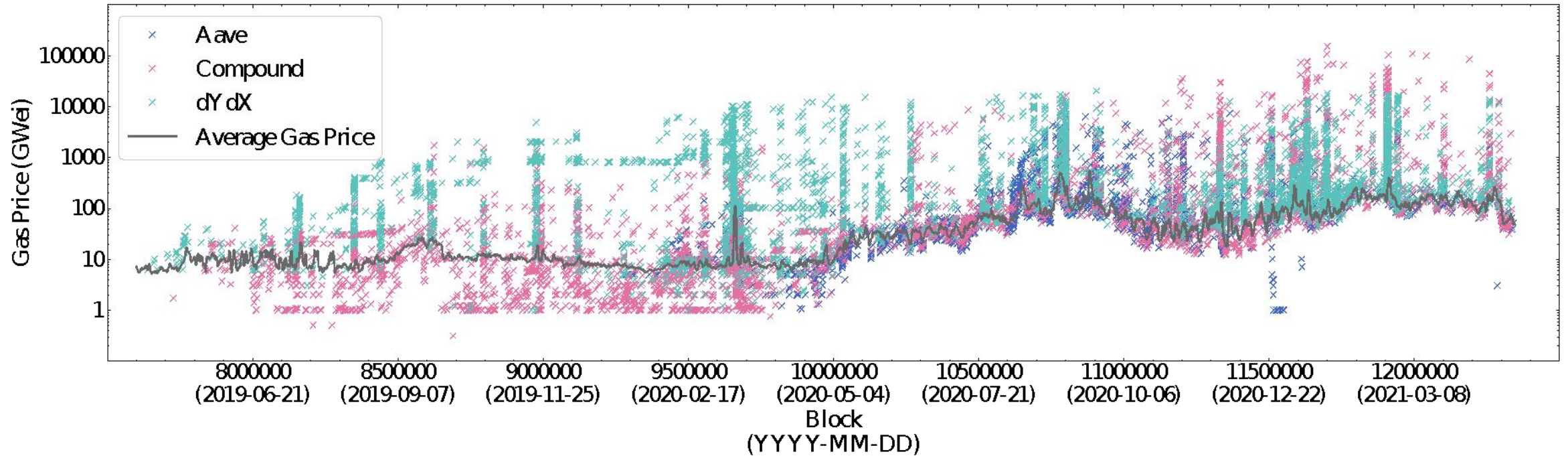
Liquidation Statistics

- Total profit: 63.59M USD
- MakerDAO outlier in March 2020, caused by bot failure.



Liquidation Statistics

- Liquidators typically pay significant gas fees, indicating severe competition.

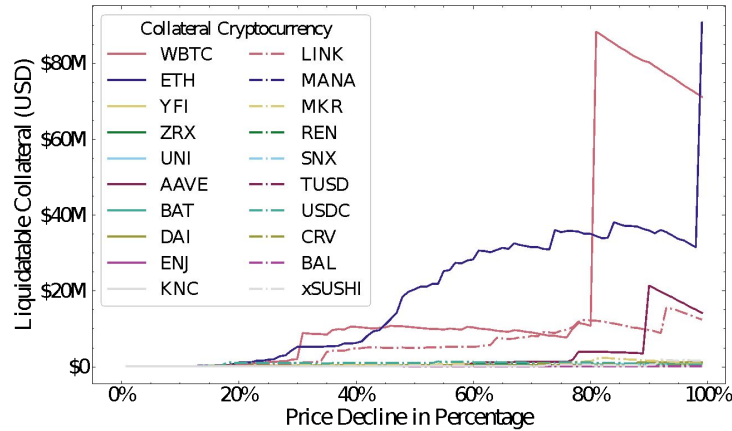


Liquidation Statistics

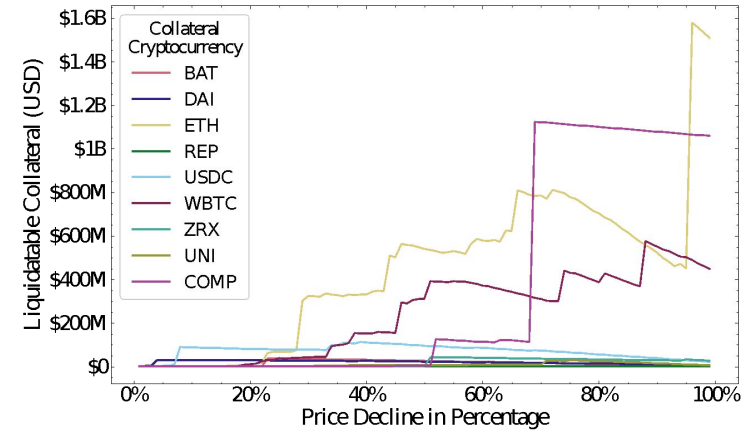
- Liquidation Sensitivity

- liquidated collateral upon a hypothetical price decline.

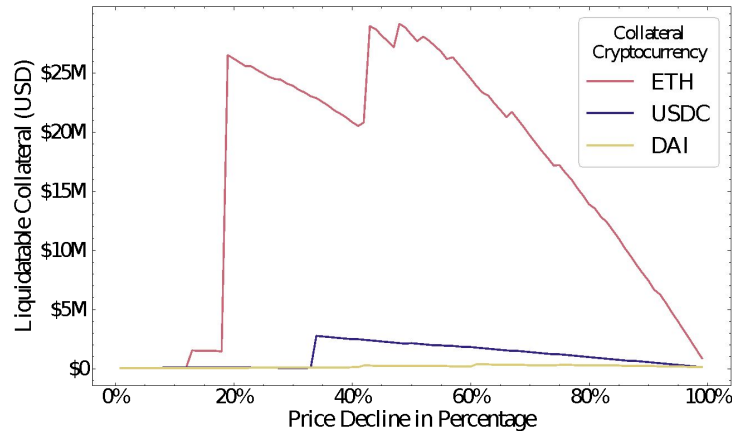
Aave



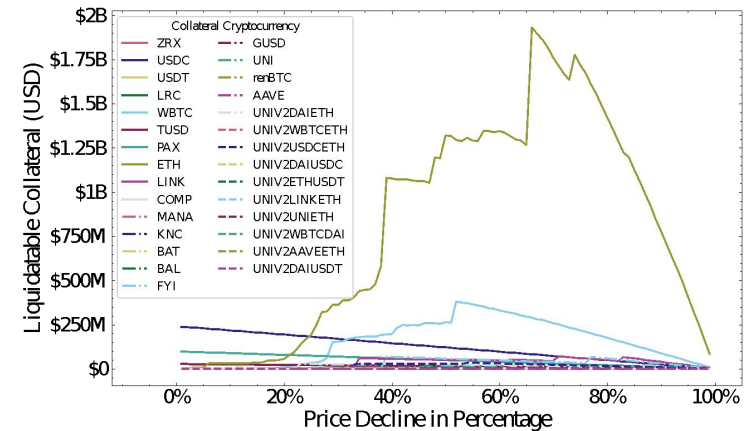
Compound



dYdX



MakerDAO

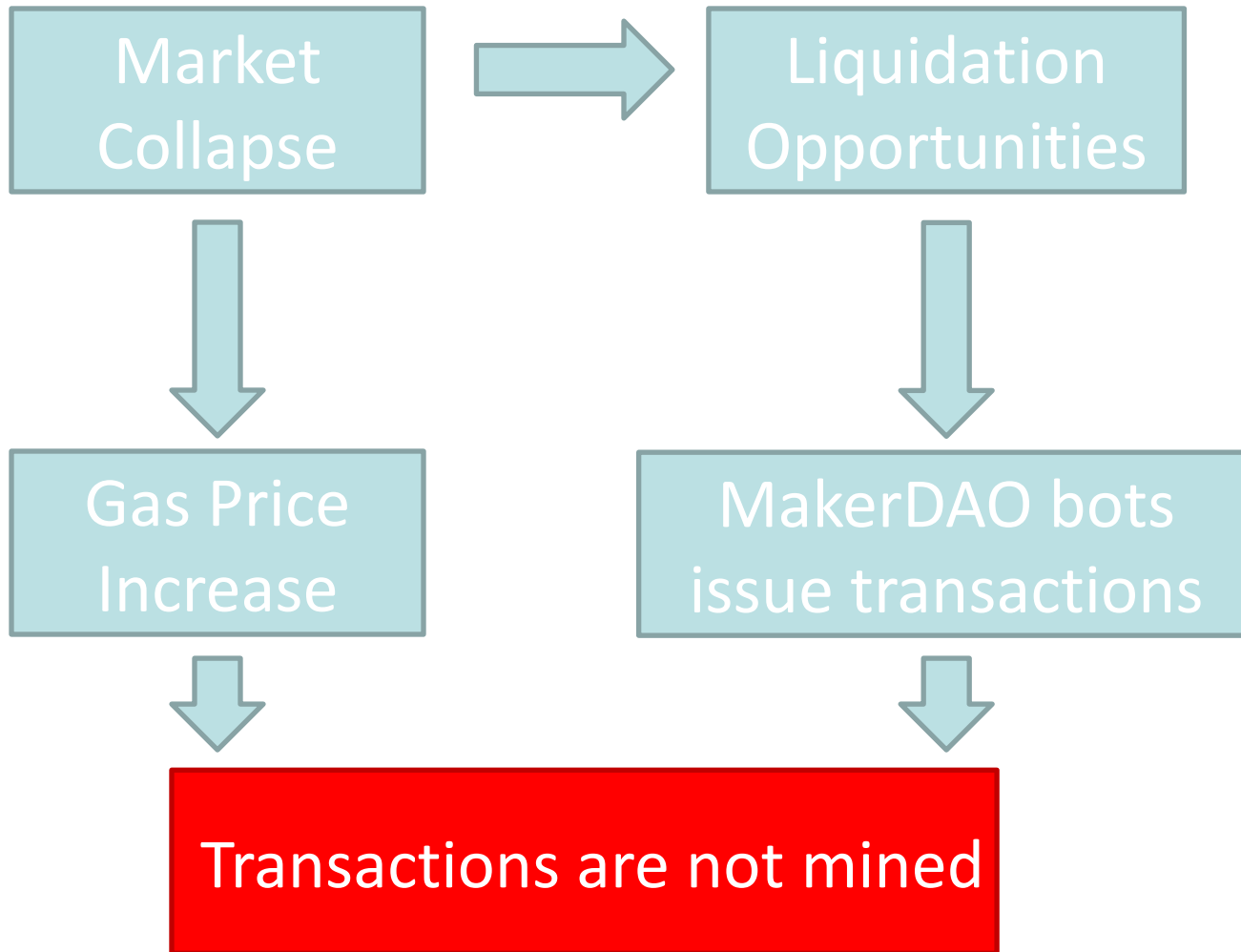




Liquidation Case Study & Insights

<https://defi-learning.org>

Maker DAO Bot Failure



Black Thursday for MakerDAO: \$8.32 million was liquidated for 0 DAI

whiterabbit Mar 15, 2020 · 6 min read



Photo by [slon_pics](#) on [Pixabay](#)

TL;DR

- Maker DAO liquidations on March 12 and 13 resulted in protocol losses of **5.67 million DAI**
- This happened due to the opportunity to win liquidation auctions with zero bids, which was **36%** of all liquidations
- The greatest Vault has lost **~35 000 ETH** whereas the most successful liquidator has had a profit of **30 000 ETH**
- **\$8.32 million** was withdrawn through zero bids auctions in total

Liquidation Insights


■ Health Factor

- A fixed spread liquidation does not necessarily increase the health factor

■ Over-liquidation

- Liquidations sell excessive amounts of borrower's collateral

■ Optimal Liquidation strategy

- Liquidating up to the close factor is not necessarily the best strategy.
- Instead, two successive liquidations might offer more profits. 

Optimal Fixed Spread Liquidation Algorithm

Input : A liquidatable position $\mathcal{POS} = \langle C, D \rangle$, where C represents the collateral value, while D represents the debt value; Liquidation threshold LT ; Liquidation spread LS ; Close factor CF .

Output: Amount of debt to repay in the two optimal successive liquidations, $repay_1$ and $repay_2$.

Function Liquidatable(\mathcal{POS}):

```
| return  $\frac{\mathcal{POS}.C \times LT}{\mathcal{POS}.D} > 1$ ;  
end
```

Function Liquidate($\mathcal{POS}, repay$):

```
|  $\mathcal{POS}' \leftarrow \langle C - repay \times (1 + LS), D - repay \rangle$ ;  
| return  $\mathcal{POS}'$ ;  
end
```

$repay_1 \leftarrow \operatorname{argmax}_r \text{Liquidatable}(\text{Liquidate}(\mathcal{POS}, r))$;

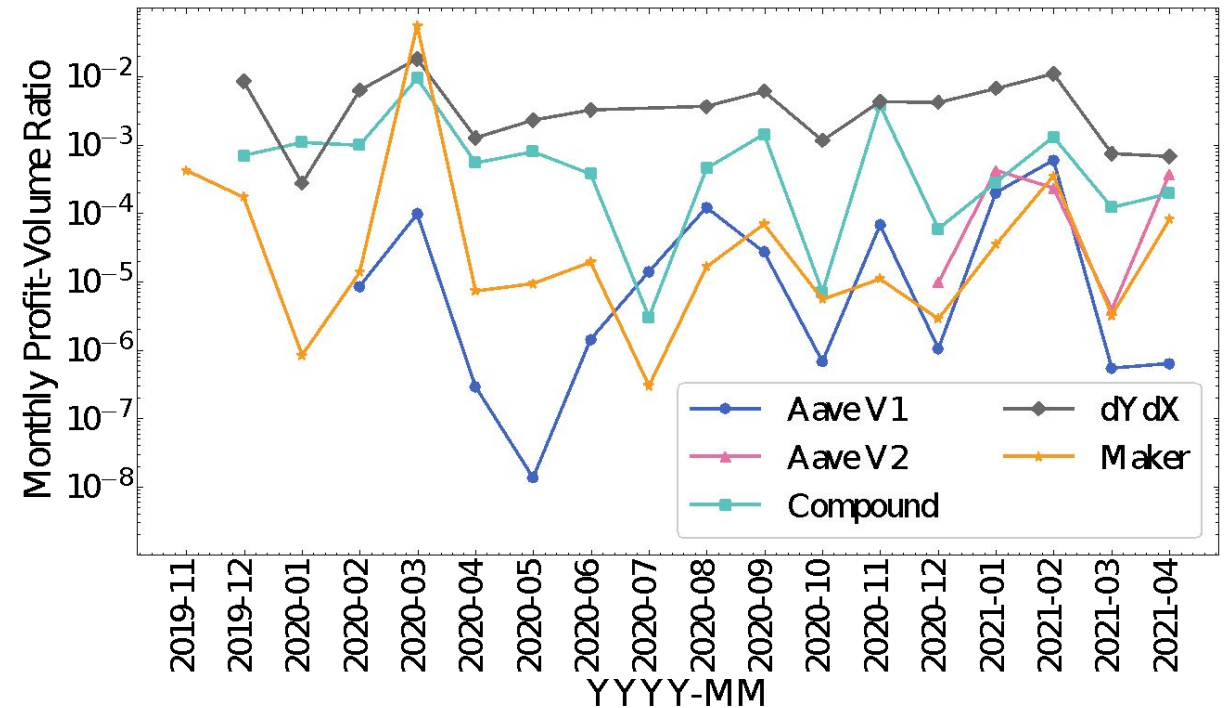
$\mathcal{POS}' \leftarrow \text{Liquidate}(\mathcal{POS}, repay_1)$;

$repay_2 \leftarrow \mathcal{POS}'.D \times CF$;

Liquidation Insights

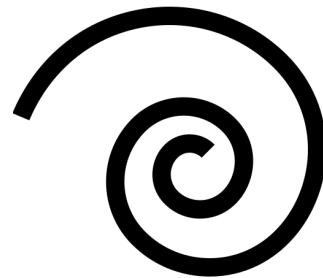
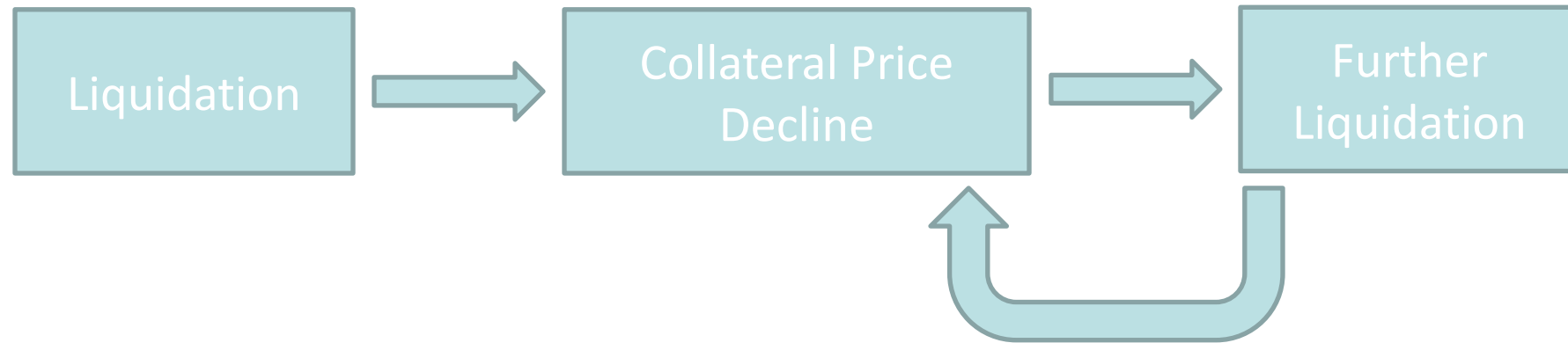
Comparison of liquidation mechanisms

- **Metrics:** the ratio between monthly liquidation profit and volume
- Data suggests that auction liquidations might be more borrower friendly
- dYdX does not have a close factor



Liquidation Insights

- Deleveraging Spiral




Is liquidation a good solution to secure lending pools?

Case Study: Optimal Fixed Spread Liquidation

- Compound
- November 26, 2020
- $LT = 0.75$

Token	Collateral	Debt	Price (USD)	
			Block 11333036	After price update
DAI	108.51M	93.22M	1.08	1.095299
USDC	17.88M	506.64K	1	1
Total Collateral (USD)			135.07M	136.73M
Borrowing Capacity (USD)			101.30M	102.55M
Total Debt (USD)			101.18M	102.61M


Healthy Liquidatable

Case Study: Optimal Fixed Spread Liquidation

Original liquidation	Repay 46.14M USD	
	Receive 49.83M DAI	
	Profit 3.69M DAI	
Up-to-close-factor strategy	Repay 46.61 DAI	
	Receive 50.34M DAI	
	Profit 3.73M DAI	
Optimal strategy	Liquidation 1	Liquidation 2
	Repay 296.61K DAI	Repay 46.46M DAI
	Receive 320.34K DAI	Receive 50.18M DAI
	Profit 23.73K DAI	Profit 3.72M DAI

Optimal strategy yields 3.743M DAI instead of 3.69M DAI

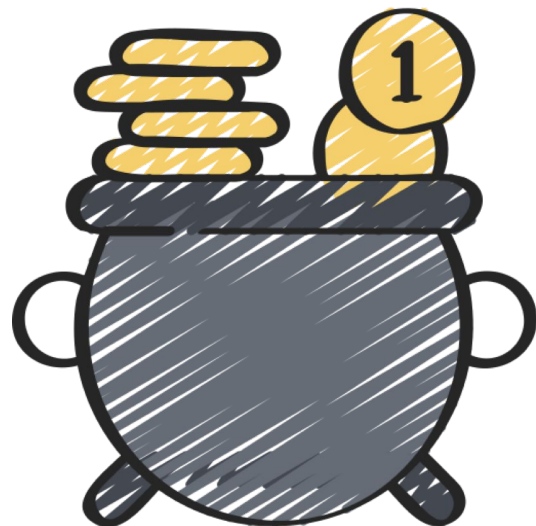
What ideas do you have to avoid liquidations?



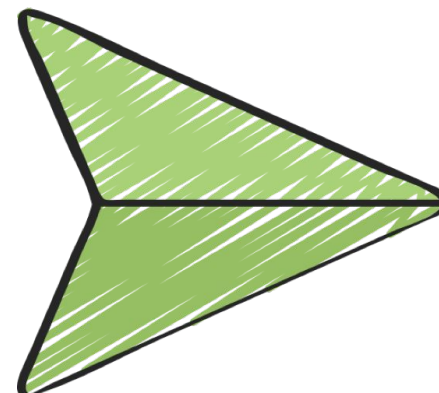
Flash Loans

What if Bart can grant a loan to Bob,
without the risk of Bob defaulting on the debt?

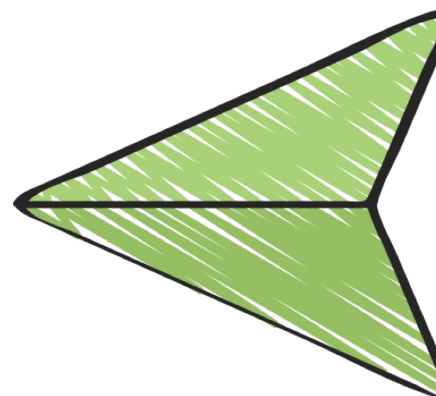
Flash Loan



1. Take flash loan

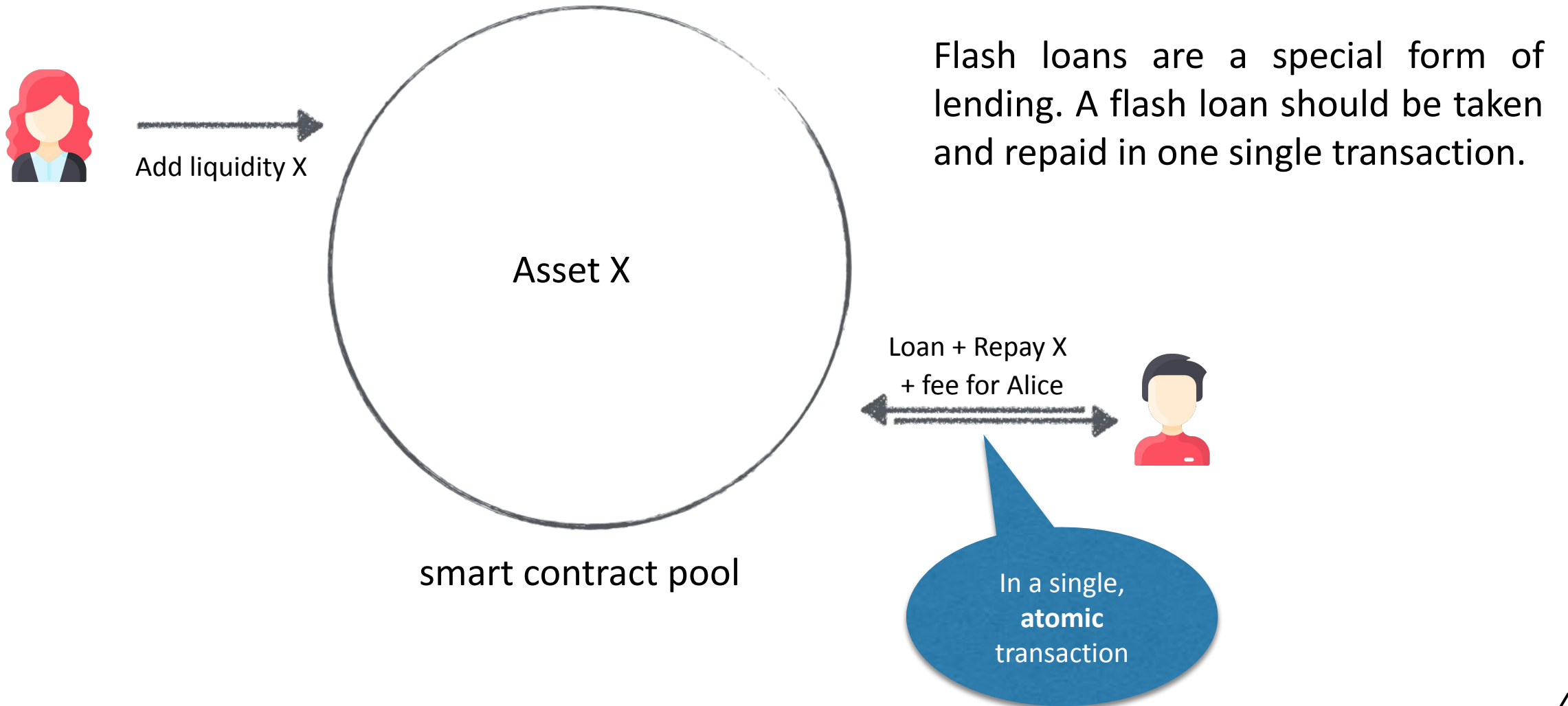


2. go-Wild(loan);



3. Repay loan + interest

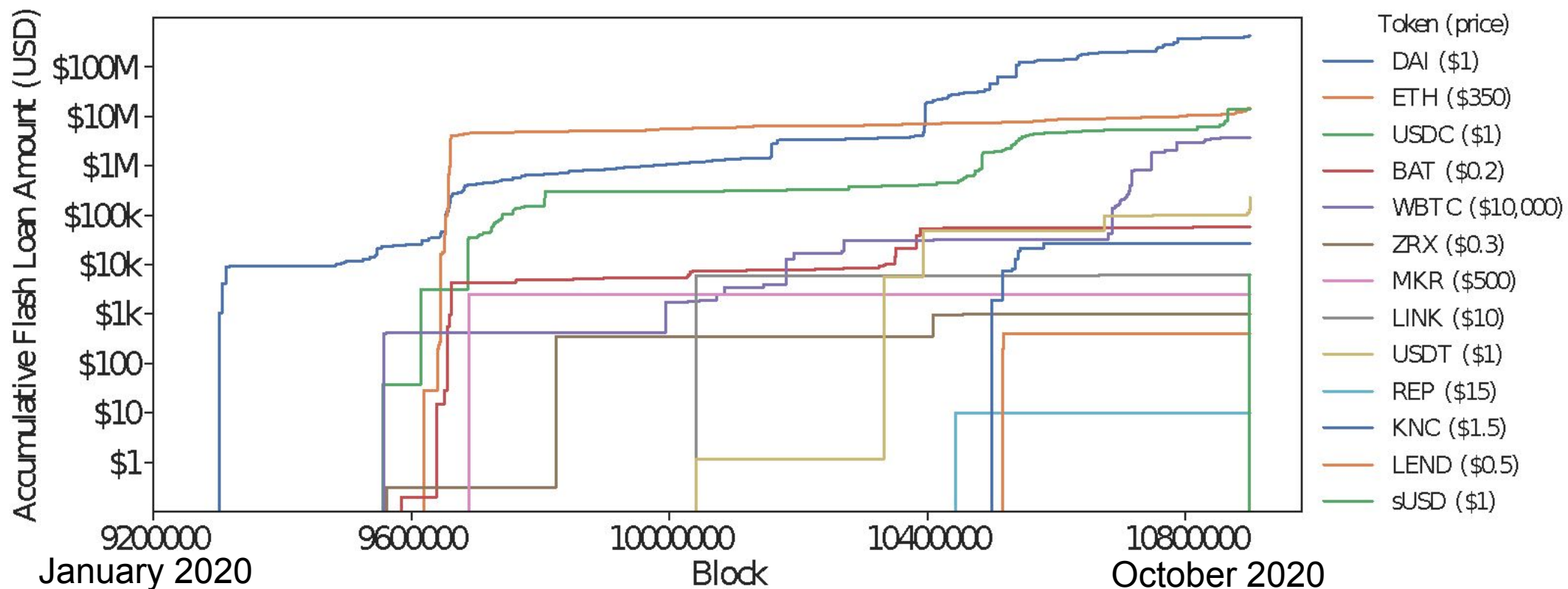
Flash Loan



Flash Loan Pools

- Uniswap – 0.3% fees
 - V2 - 5B USD
 - V3 - 2.2B USD
- Aave – 0.3% fees
 - 10B USD
- dYdX – constant fee of 1 Wei
 - about 100M USD

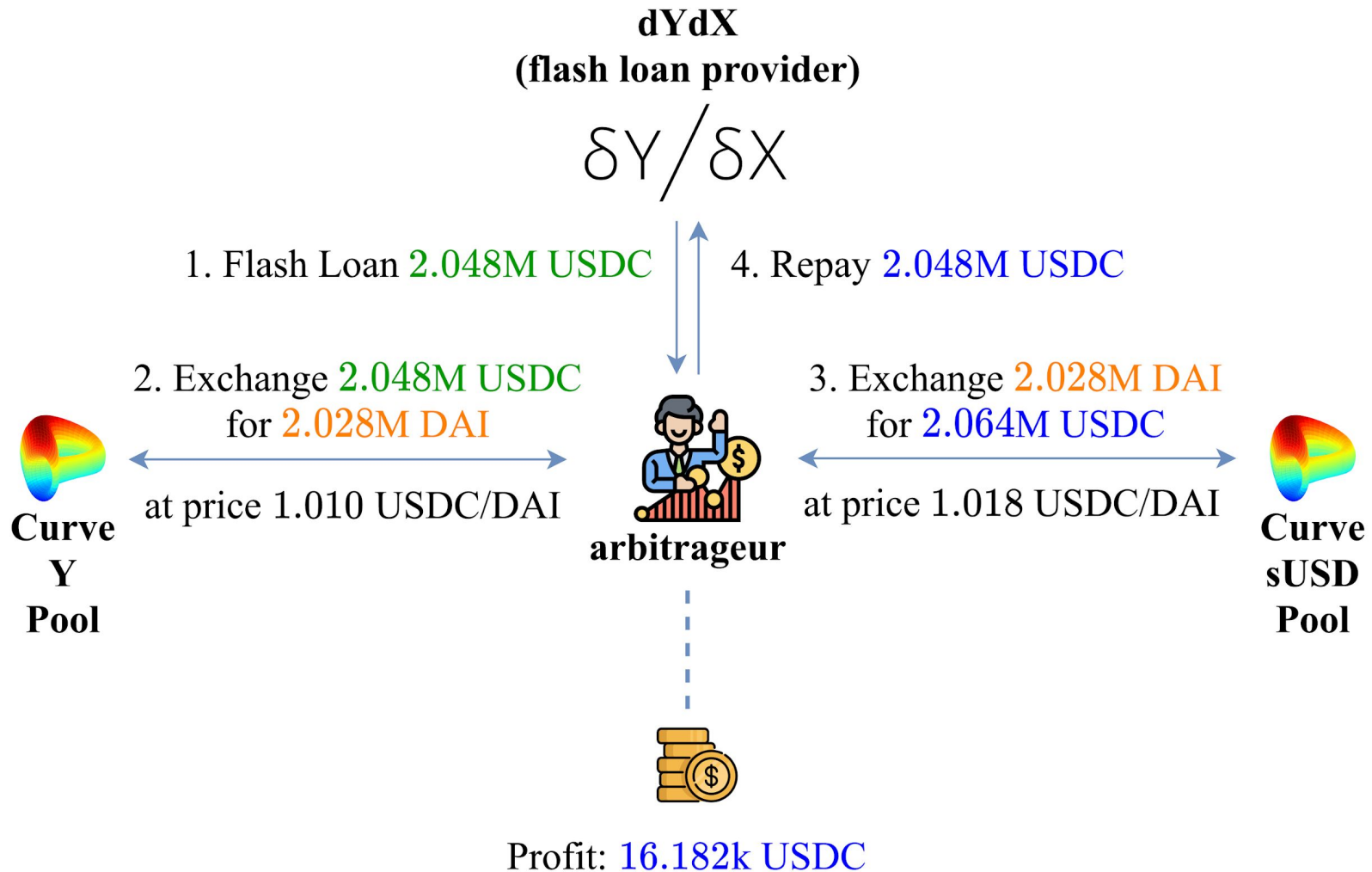
Flash Loan Sizes



Flash Loan Use Cases

- DeFi attacks
 - Price Oracle Manipulation
 - Pump and Dump
- (Risk-free) Arbitrage
- Washtrading
- Flash Minting
- Collateral swapping

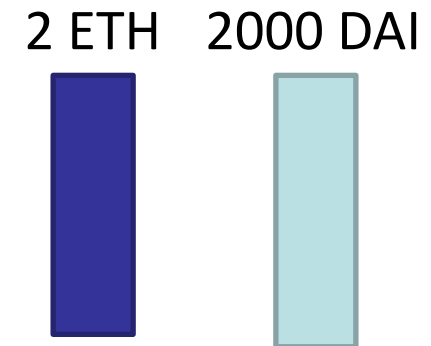
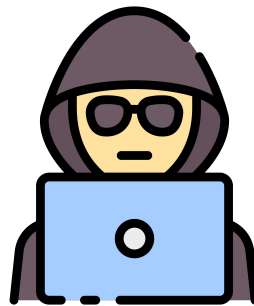
Flash Loan Arbitrage



Flash Loan Based Liquidation

- When a liquidator does not have the cryptocurrency upfront to repay
- Only works when the liquidation completes in one transaction

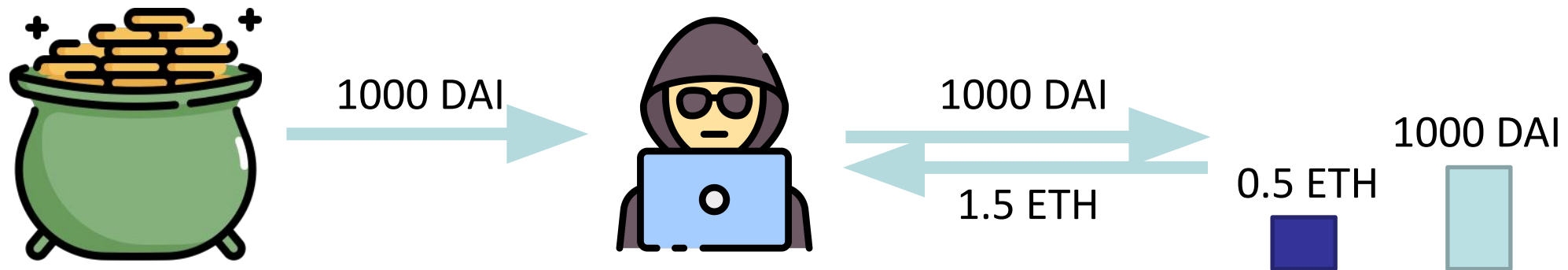
Given a liquidatable borrowing position with a debt of 2000 DAI collateralized by 2 ETH



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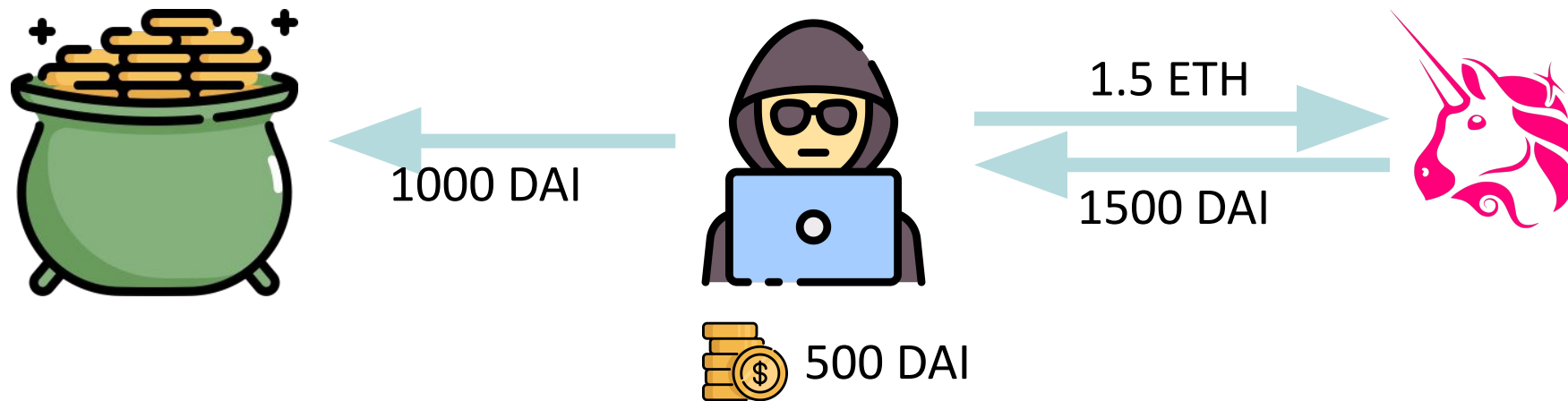
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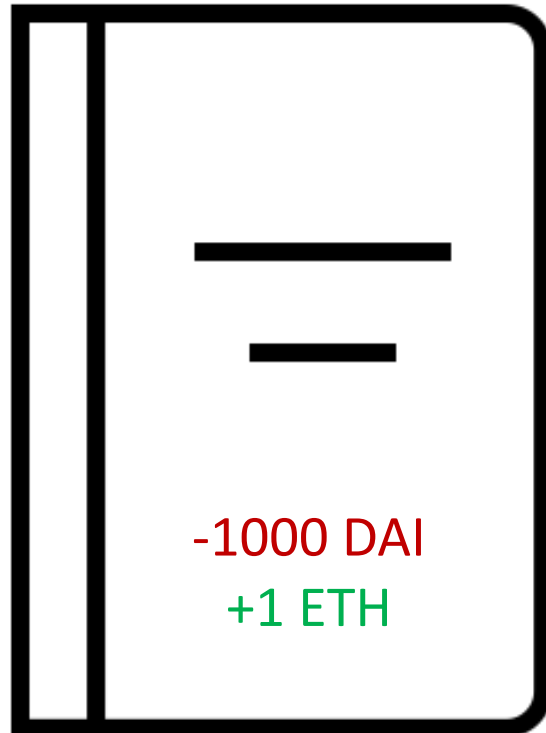
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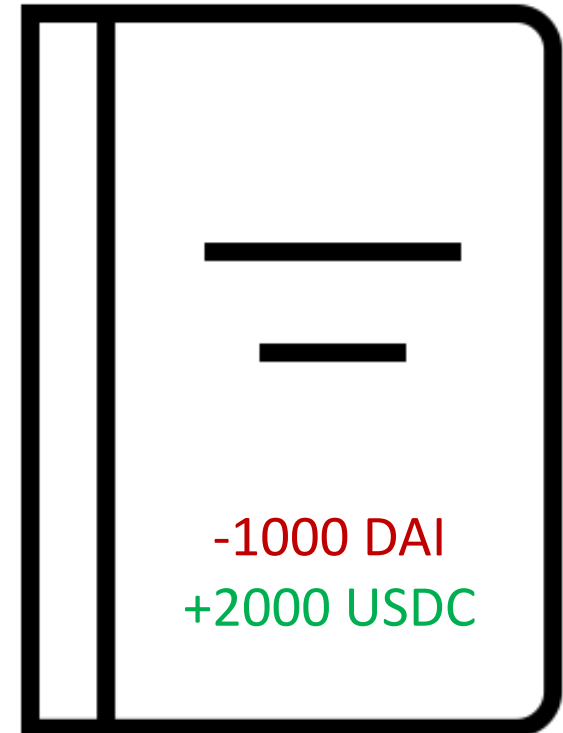


Collateral Swap



Dept Position

1. Take a flash loan of 1000 DAI
2. Repay 1000 DAI
3. Redeem 1 ETH
4. Swap 1 ETH to 2000 USDC
5. Collateralize 2000 USDC
6. Borrow 1000 DAI



Dept Position