How to design an arbitrage bot

Arbitrage within Uniswap

Tang Keying && Tang Zhushou

Agenda:

- A living example.
- How to design a flexible arbitrage contract.
- How to search for arbitrage opportunities.

Before getting started, we recommend reader to read documents of uniswap:

- https://uniswapv3book.com/index.html
- https://docs.uniswap.org/

A living example

- `0x53663b0649dd238f1e0434adec853ce405af108595155e950027e2ec9e1ba68a` at block 22185681.
- https://etherscan.io/tx/0x53663b0649dd238f1e0434adec853ce405af108595155e950027e2ec9e1ba68a
- https://app.blocksec.com/explorer/tx/eth/0x53663b0649dd238f1e0434adec853ce405af108595155e950027e2ec9e1ba68a?line=1

Balance changes of this transaction

Balance Changes

Addresses	Token	TokenID	Balance
0x00af7ad1bad0c331d30175cdd461c19709219b10 [Sender]	Ether	-	-0.000000000000000957
0x1409262a7a05c7b1ca7675c12721b18328686022 [Receiver]	Ether	-	+0.000202609345363525
Uniswap V3: BITCOIN	Wrapped Ether	-	-0.158754775792494336
	HarryPotterObamaSonic10Inu: BITCOIN Token	-	+6,907.46543731
Titan Builder	Ether	-	+0.000716396547493442
Uniswap V2: BITCOIN-SPX	SPX6900: SPX Token	-	+633.24318672
	HarryPotterObamaSonic10Inu: BITCOIN Token	-	-6,907.46543731
Uniswap V3: SPX 2	SPX6900: SPX Token	-	-633.24318672
	Wrapped Ether	-	+0.158480668596983 04
GLP	Circle: USDC Token	-	+3,428.866681
	Tether: USDT Stablecoin	-	-3,429.14269
Wrapped Ether	Ether	-	-0.000919005892856 01
	Wrapped Ether	-	+0.000919005892856 01
Uniswap V3: USDT 9	Wrapped Ether	-	-1.876609404854217972
	Tether: USDT Stablecoin	-	+3,429.14269
Uniswap V3: USDC 4	Circle: USDC Token	-	-3,428.866681
	Wrapped Ether	-	+1.875964506156873258

A human readable workflow (Part1)

Balance Changes

Addresses	Token	TokenID	Balance
0x00af7ad1bad0c331d30175cdd461c19709219b10 [Sender]	Ether	-	-0.000000000000000957
0x1409262a7a05c7b1ca7675c12721b18328686022 [Receiver]	Ether	-	+0.000202609345363525
Uniswap V3: BITCOIN	Wrapped Ether	-	-0.158754775792494336
	HarryPotterObamaSonic10Inu: BITCOIN Token	-	+6,907.46543731
Titan Builder	Ether	-	+0.000716396547493442
Uniswap V2: BITCOIN-SPX	SPX6900: SPX Token	-	+633.24318672
	HarryPotterObamaSonic10Inu: BITCOIN Token	-	-6,907.46543731
Uniswap V3: SPX 2	SPX6900: SPX Token	-	-633.24318672
	Wrapped Ether	-	+0.15848066859698304
GLP	Circle: USDC Token	-	+3,428.866681
	Tether: USDT Stablecoin	-	-3,429.14269
Wrapped Ether	Ether	-	-0.00091900589285601
	Wrapped Ether	-	+0.00091900589285601
Uniswap V3: USDT 9	Wrapped Ether	-	-1.876609404854217972
	Tether: USDT Stablecoin	-	+3,429.14269
Uniswap V3: USDC 4	Circle: USDC Token	-	-3,428.866681
	Wrapped Ether	-	+1.875964506156873258

①*Assemble the payload and lunch the tx.*

④ *`sell` 6907 BITCOIN for 0.15875 WETH token*

③ *`sell` 633 SPX for 6907 BITCOIN token*

② *`sell` 0.15848 WETH for 633 SPX token*

A human readable workflow (Part1)

Balance Changes

Addresses	Token	TokenID	Balance
0x00af7ad1bad0c331d30175cdd461c19709219b10 [Sender]	Ether	-	-0.000000000000000957
0x140	Ether	-	+0.000202609345363525
Unisw	Wrapped Ether	-	-0.158754775792494336
	HarryPotterObamaSonic10Inu: BITCOIN Token	-	+6,907.46543731
Titan	Ether	-	+0.000716396547493442
Unisw	SPX6900: SPX Token	-	+633.24318672
	HarryPotterObamaSonic10Inu: BITCOIN Token	-	-6,907.46543731
Uniswap V3: SPX 2	SPX6900: SPX Token	-	-633.24318672
	Wrapped Ether	-	+0.15848066859698304
GLP	Circle: USDC Token	-	+3,428.866681
	Tether: USDT Stablecoin	-	-3,429.14269
Wrapped Ether	Ether	-	-0.00091900589285601
	Wrapped Ether	-	+0.00091900589285601
Uniswap V3: USDT 9	Wrapped Ether	-	-1.876609404854217972
	Tether: USDT Stablecoin	-	+3,429.14269
Uniswap V3: USDC 4	Circle: USDC Token	-	-3,428.866681
	Wrapped Ether	-	+1.875964506156873258

The arbitrator gains profit of 0.158754775792494336 - 0.15848066859698304 =0.000274

However, 0.000274 is not enough for paying the transaction fee (0.000716396547493442)

①*Assemble the payload and lunch the tx.*

④ *`sell` 6907 BITCOIN for 0.15875 WETH token*

③ *`sell` 633 SPX for 6907 BITCOIN token*

② *`sell` 0.15848 WETH for 633 SPX token*

A human readable workflow (Part2)

Balance Changes

Addresses	Token	TokenID	Balance
0x00af7ad1bad0c331d30175cdd461c19709219b10 [Sender]	Ether	-	-0.000000000000000957
0x1409262a7a05c7b1ca7675c12721b18328686022 [Receiver]	Ether	-	+0.000202609345363525
Uniswap V3: BITCOIN	Wrapped Ether	-	-0.158754775792494336
	HarryPotterObamaSonic10Inu: BITCOIN Token	-	+6,907.46543731
Titan Builder	Ether	-	+0.000716396547493442
Uniswap V2: BITCOIN-SPX	SPX6900: SPX Token	-	+633.24318672
	HarryPotterObamaSonic10Inu: BITCOIN Token	-	-6,907.46543731
Uniswap V3: SPX 2	SPX6900: SPX Token	-	-633.24318672
	Wrapped Ether	-	+0.15848066859698304
GLP	Circle: USDC Token	-	+3,428.866681
	Tether: USDT Stablecoin	-	-3,429.14269
Wrapped Ether	Ether	-	-0.00091900589285601
	Wrapped Ether	-	+0.00091900589285601
Uniswap V3: USDT 9	Wrapped Ether	-	-1.876609404854217972
	Tether: USDT Stablecoin	-	+3,429.14269
Uniswap V3: USDC 4	Circle: USDC Token	-	-3,428.866681
	Wrapped Ether	-	+1.875964506156873258

①*Assemble the payload and lunch the tx.*

④ *`sell` 6907 BITCOIN for 0.15875 WETH token*

③ *`sell` 633 SPX for 6907 BITCOIN token*

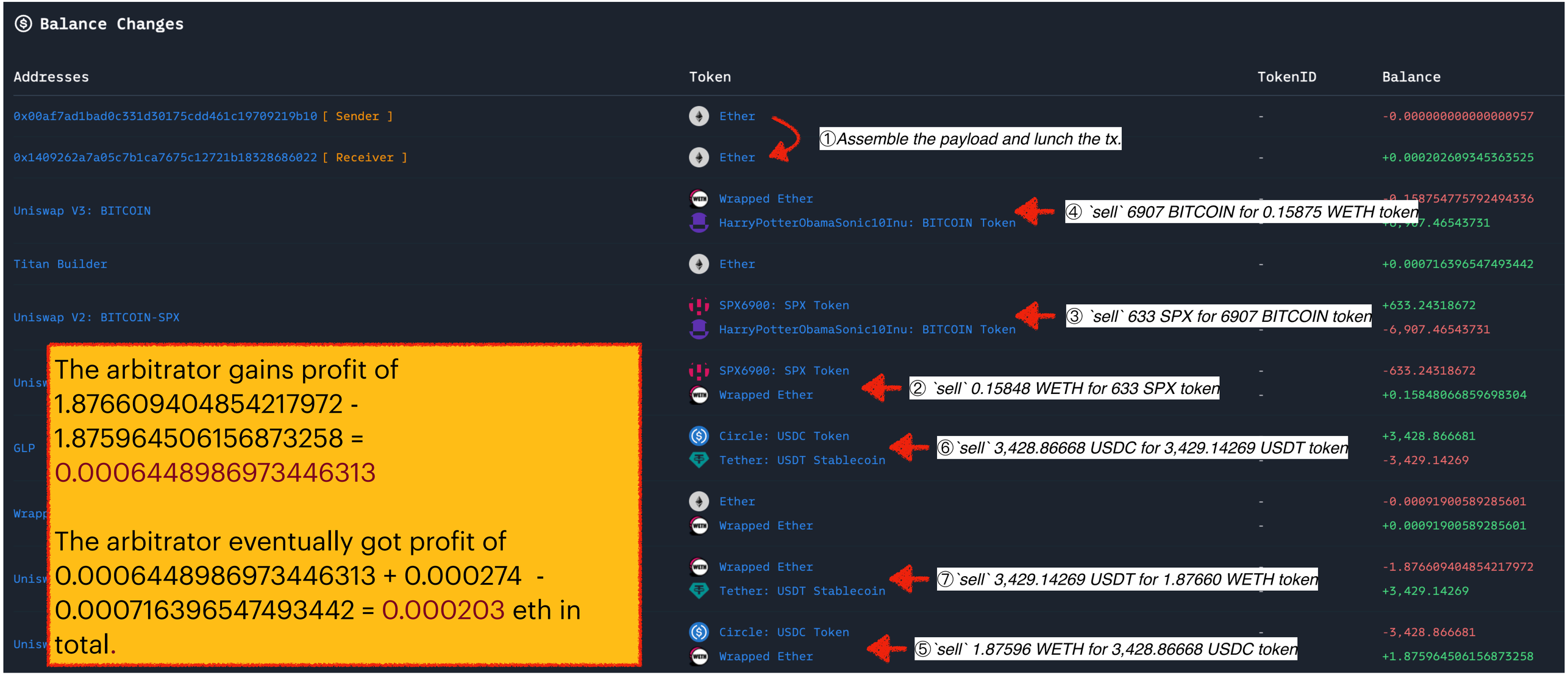
② *`sell` 0.15848 WETH for 633 SPX token*

⑥ *`sell` 3,428.86668 USDC for 3,429.14269 USDT token*

⑦ *`sell` 3,429.14269 USDT for 1.87660 WETH token*

⑤ *`sell` 1.87596 WETH for 3,428.86668 USDC token*

A human readable workflow (Part2)



The price deviation of different pools makes the transaction profitable.

The price of the token of uniswap v2 follows the formula of P_{1} = liquidity of token0 / liquidity of token1. Such that P_{b}^{s} of `Uniswap V2: BITCOIN-SPX` is 472805360475 75 / 51798234892 3589 = 0.09127827646217664.

The price of tokens of uniswap v3 is kind of complex, however, we can find it out in `sloto`. By using the formula of Price = (sqrtPriceX96 / 2^96) ^ 2, we got P_{w}^{b} = 232181.66726585582 (`Uniswap V3: BITCOIN`) and P_{s}^{w} = 4.008805707997408e-07 (Uniswap V3: SPX 2).

The P_{s}^{b} derived from pools `Uniswap V3: BITCOIN` and `Uniswap V3: SPX 2` is P_{s}^{b} = P_{w}^{b} * P_{s}^{w} = 0.09307711930277178.

It is observed that the SPX token is more cheaper by trading against the joint pools of `Uniswap V3: BITCOIN` and `Uniswap V3: SPX 2` than the pool of `Uniswap V2: BITCOIN-SPX`. This is why the arbitrator by SPX from `Uniswap V3: BITCOIN` and sell them to the counterpart.

The actual workflow

- From Uniswap V3: BITCOIN To 0x1409262A...328686022 For 0.158754775792494336 ($290.40) Wrapped Ethe... (WETH)
- From Uniswap V3: SPX 2 To Uniswap V2: BITCOIN-SPX For 633.24318672 ($321.94) SPX6900 (SPX)
- From 0x1409262A...328686022 To Uniswap V3: SPX 2 For 0.15848066859698304 ($289.90) Wrapped Ethe... (WETH)
- From Uniswap V2: BITCOIN-SPX To Uniswap V3: BITCOIN For 6,907.46543731 ($302.75) HarryPotterO... (BITCOI...)
- From Uniswap V3: USDT 9 To 0x1409262A...328686022 For 1.876609404854217972 ($3,432.80) Wrapped Ethe... (WETH)
- From Uniswap V3: USDC 4 To 0xB9A44069...3A040152e For 3,428.866681 ($3,428.56) USDC (USDC)
- From 0x1409262A...328686022 To Uniswap V3: USDC 4 For 1.875964506156873258 ($3,431.62) Wrapped Ethe... (WETH)
- From 0xB9A44069...3A040152e To Uniswap V3: USDT 9 For 3,429.14269 ($3,428.43) Tether USD (USDT)

The actual workflow

From Uniswap V3: BITCOIN To 0x1409262A...328686022 For 0.158754775792494336 ($290.40) Wrapped Ethe... (WETH)

From Uniswap V3: SPX 2 To Uniswap V2: BITCOIN-SPX For 633.24318672 ($321.94) SPX6900 (SPX)

From 0x1409262A...328686022 To Uniswap V3: SPX 2 For 0.15848066859698304 ($289.90) Wrapped Ethe... (WETH)

From Uniswap V2: BITCOIN-SPX To Uniswap V3: BITCOIN For 6,907.46543731 ($302.75) HarryPotterO... (BITCOI...)

From Uniswap V3: USDT 9 To 0x1409262A...328686022 For 1.876609404854217972 ($3,432.80) Wrapped Ethe... (WETH)

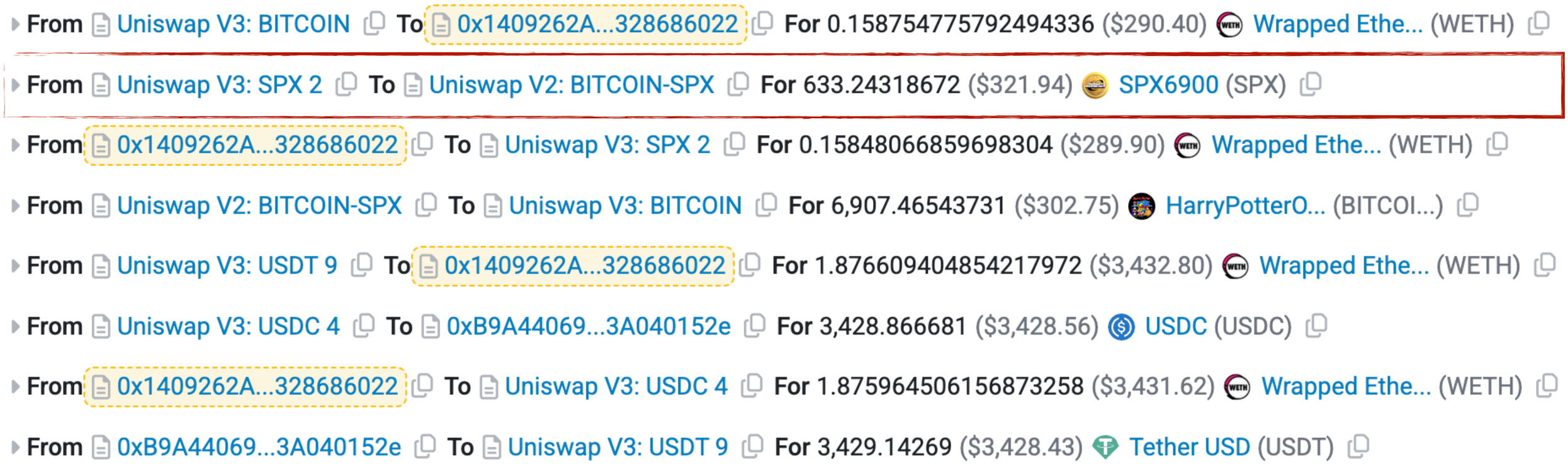
From Uniswap V3: USDC 4 To 0xB9A44069...3A040152e For 3,428.866681 ($3,428.56) USDC (USDC)

From 0x1409262A...328686022 To Uniswap V3: USDC 4 For 1.875964506156873258 ($3,431.62) Wrapped Ethe... (WETH)

From 0xB9A44069...3A040152e To Uniswap V3: USDT 9 For 3,429.14269 ($3,428.43) Tether USD (USDT)

Arbitrator sell BITCOIN for WETH token, after receiving the WETH token, the arbitrage contract shall send the BITCOIN token to the pool of `Uniswap V3: BITCOIN` in it's `uniswapV3SwapCallback` function.

The actual workflow



In order to get the BITCOIN token for the pool of `Uniswap V3: BITCOIN`, the arbitrage contract turns to pool of `Uniswap V3: SPX 2` to get SPX token, by setting the parameter of `tokenOut` to the pool of `Uniswap V2: BITCOIN-SPX`, the bought SXP token is send to that pool directly.

The actual workflow

From Uniswap V3: BITCOIN To 0x1409262A...328686022 For 0.158754775792494336 ($290.40) Wrapped Ethe... (WETH)

From Uniswap V3: SPX 2 To Uniswap V2: BITCOIN-SPX For 633.24318672 ($321.94) SPX6900 (SPX)

From 0x1409262A...328686022 To Uniswap V3: SPX 2 For 0.15848066859698304 ($289.90) Wrapped Ethe... (WETH)

From Uniswap V2: BITCOIN-SPX To Uniswap V3: BITCOIN For 6,907.46543731 ($302.75) HarryPotterO... (BITCOI...)

From Uniswap V3: USDT 9 To 0x1409262A...328686022 For 1.876609404854217972 ($3,432.80) Wrapped Ethe... (WETH)

From Uniswap V3: USDC 4 To 0xB9A44069...3A040152e For 3,428.866681 ($3,428.56) USDC (USDC)

From 0x1409262A...328686022 To Uniswap V3: USDC 4 For 1.875964506156873258 ($3,431.62) Wrapped Ethe... (WETH)

From 0xB9A44069...3A040152e To Uniswap V3: USDT 9 For 3,429.14269 ($3,428.43) Tether USD (USDT)

`Uniswap V3: SPX 2` pool ask the arbitrage contract to send the WETH to finish this trade (by calling the `uniswapV3SwapCallback` function within the arbitrage contract), and the arbitrage contract do it this time.

The actual workflow

From Uniswap V3: BITCOIN To 0x1409262A...328686022 For 0.158754775792494336 ($290.40) Wrapped Ethe... (WETH)

From Uniswap V3: SPX 2 To Uniswap V2: BITCOIN-SPX For 633.24318672 ($321.94) SPX6900 (SPX)

From 0x1409262A...328686022 To Uniswap V3: SPX 2 For 0.15848066859698304 ($289.90) Wrapped Ethe... (WETH)

From Uniswap V2: BITCOIN-SPX To Uniswap V3: BITCOIN For 6,907.46543731 ($302.75) HarryPotterO... (BITCOI...)

From Uniswap V3: USDT 9 To 0x1409262A...328686022 For 1.876609404854217972 ($3,432.80) Wrapped Ethe... (WETH)

From Uniswap V3: USDC 4 To 0xB9A44069...3A040152e For 3,428.866681 ($3,428.56) USDC (USDC)

From 0x1409262A...328686022 To Uniswap V3: USDC 4 For 1.875964506156873258 ($3,431.62) Wrapped Ethe... (WETH)

From 0xB9A44069...3A040152e To Uniswap V3: USDT 9 For 3,429.14269 ($3,428.43) Tether USD (USDT)

Uniswap v2 works differently from v3, that is `tokens must be transferred to pairs before swap is called`. Since SPX token is send to the `Uniswap V2: BITCOIN-SPX` pool before (step 2), the arbitrage contract lunch the swap and the required BITCOIN token (step 1) is send to the `Uniswap V3: BITCOIN` pool.

At last, all pools are satisfied with no revert!

Parse the arbitrage payload

Compared with the human readable workflow, the actual workflow is hard to read, for the trading path is optimized for saving gas (without transferring tokens back and forth). This task is accomplished via delivering the `data` in between the arbitrage contract and the pool.

0xff000000

0000000000000000000000007c

010d

0c30062368eefb96bf3ade1218e685306b8e89fa <- Uniswap V3: BITCOIN

00000000000023402a0a1822700 <- amountSpecified arg

0113

7c706586679af2ba6d1a9fc2da9c6af59883fdd3 <- Uniswap V3: SPX 2

00000000000000000ebe6c6bd0 <- amountSpecified arg

000000000000233095413 81a8f30000

7c1c4a2cf81d2fc83b89bfd34f4d2c7e90044b32 <- Uniswap V2: BITCOIN-SPX

00000000000000000a0d3b3ce73 <- amountoOut arg

—-

Arguments are packed with some indicators control the flow of the task, e.g., which `selector` should be used for current swap.

How to design a flexible arbitrage contract (TODO)

How to search for arbitrage opportunities (TODO)