Conditional Tokens Documentation

Release 0.5.4

Gnosis

Nov 04, 2019

Contents:

Smart contracts for conditional tokens.

→ Github source repository

CHAPTER 1

License

All smart contracts are released under the LGPL 3.0 license.

1.1 Security and Liability

All contracts are **WITHOUT ANY WARRANTY**; *without even* the implied warranty of MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.

1.1.1 Motivation

Conditional tokens were originally designed to enable combinatorial prediction markets more fully. These sorts of markets enable deeper information discovery with respect to conditional probabilities of events and conditional expected values. Prediction markets like this may be represented by nesting traditional prediction markets in systems like Augur or the first version of Gnosis prediction market contracts. However, they weren't designed to maximize fungibility in deeper combinatorial markets.

Existing Approach to Combinatorial Markets

For example, let's suppose there are two oracles which report on the following questions:

1. Which **choice** out of Alice, Bob, and Carol will be made?
2. Will the **score** be high or low?

There are two ways to create conditional tokens backed by a collateral token denoted as `$`, where the value of these conditional tokens depend on *both* of the reports of these oracles on their respective assigned questions:

Although the outcome tokens in the second layer should represent value in collateral under the same conditions irrespective of the order in which the conditions are specified, they are in reality separate entities. Users may hold separate balances of each even though that balance should theoretically be redeemable under the same conditions.

The order in which operations are done on these "deeper" tokens matters as well. For example, partial redemptions to the first layer are only possible if that specific outcome token's second layer condition has been resolved.

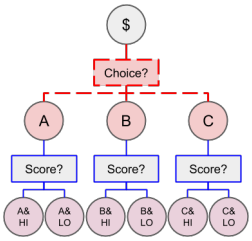


Fig. 1: **Choice**, then **Score**

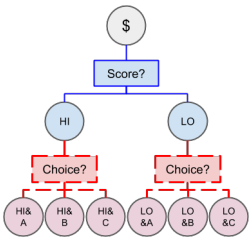


Fig. 2: **Score**, then **Choice**

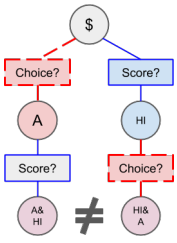
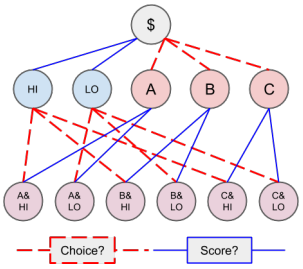


Fig. 3: These tokens should be the same, but aren't.

Combinatorial Markets with Conditional Tokens

For conditional tokens, because all conditions are held in a single contract and are not tied to a specific collateral token, fungibility in deeper layers may be preserved. Referring to the example, the situation using conditional tokens looks more like this:



It can be seen that the deeper outcome tokens which were different tokens in older systems are now the same token:

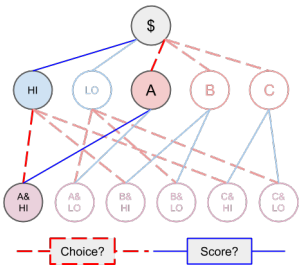


Fig. 4: Contrast this with the older approach.

1.1.2 Developer Guide

Prerequisites

Usage of the `ConditionalTokens` smart contract requires some proficiency in Solidity.

Additionally, this guide will assume a Truffle based setup. Client-side code samples will be written in JavaScript assuming the presence of a web3.js instance and various TruffleContract wrappers.

The current state of this smart contract may be found on Github.

Installation

Via NPM

This developmental framework may be installed from Github through NPM by running the following:

```
npm i '@gnosis.pm/conditional-tokens-contracts'
```

Preparing a Condition

Before conditional tokens can exist, a *condition* must be prepared. A condition is a question to be answered in the future by a specific oracle in a particular manner. The following function may be used to prepare a condition:

function **prepareCondition**(*address oracle*, *bytes32 questionId*, *uint outcomeSlotCount*) *external*

This function prepares a condition by initializing a payout vector associated with the condition.

Parameters

- **oracle** – The account assigned to report the result for the prepared condition.
- **questionId** – An identifier for the question to be answered by the oracle.
- **outcomeSlotCount** – The number of outcome slots which should be used for this condition. Must not exceed 256.

Note: It is up to the consumer of the contract to interpret the question ID correctly. For example, a client may interpret the question ID as an IPFS hash which can be used to retrieve a document specifying the question more fully. The meaning of the question ID is left up to clients.

If the function succeeds, the following event will be emitted, signifying the preparation of a condition:

event **ConditionPreparation**(*bytes32 indexed conditionId*, *address indexed oracle*, *bytes32 indexed questionId*, *uint outcomeSlotCount*)

Emitted upon the successful preparation of a condition.

Parameters

- **conditionId** – The condition's ID. This ID may be derived from the other three parameters via `keccak256(abi.encodePacked(oracle, questionId, outcomeSlotCount))`.
- **oracle** – The account assigned to report the result for the prepared condition.
- **questionId** – An identifier for the question to be answered by the oracle.
- **outcomeSlotCount** – The number of outcome slots which should be used for this condition. Must not exceed 256.

Note: The condition ID is different from the question ID, and their distinction is important.

The successful preparation of a condition also initializes the following state variable:

mapping (bytes32 => uint[]) *public* **payoutNumerators**

Mapping key is an condition ID. Value represents numerators of the payout vector associated with the condition. This array is initialized with a length equal to the outcome slot count. E.g. Condition with 3 outcomes [A, B, C] and two of those correct [0.5, 0.5, 0]. In Ethereum there are no decimal values, so here, 0.5 is represented by fractions like 1/2 == 0.5. That's why we need numerator and denominator values. Payout numerators are also used as a check of initialization. If the numerators array is empty (has length zero), the condition was not created/prepared. See getOutcomeSlotCount.

To determine if, given a condition's ID, a condition has been prepared, or to find out a condition's outcome slot count, use the following accessor:

function **getOutcomeSlotCount**(*bytes32 conditionId*) *external*

Gets the outcome slot count of a condition.

Parameters

- **conditionId** – ID of the condition.

Return Number of outcome slots associated with a condition, or zero if condition has not been prepared yet.

The resultant payout vector of a condition contains a predetermined number of *outcome slots*. The entries of this vector are reported by the oracle, and their values sum up to one. This payout vector may be interpreted as the oracle's answer to the question posed in the condition.

A Categorical Example

Let's consider a question where only one out of multiple choices may be chosen:

> Who out of the following will be chosen?
>
> - Alice
> - Bob
> - Carol

Through some commonly agreed upon mechanism, the detailed description for this question becomes strongly associated with a 32 byte question ID: `0xabcabcabcabcabcabcabcabcabcabcabcabcabcabcabcabcabcabcabcabc1234`

Let's also suppose we trust the oracle with address `0x1337aBcdef1337abCdEf1337ABcDeF1337AbcDeF` to deliver the answer for this question.

To prepare this condition, the following code gets run:

```
await conditionalTokens.prepareCondition(
    '0x1337aBcdef1337abCdEf1337ABcDeF1337AbcDeF',
    '0xabcabcabcabcabcabcabcabcabcabcabcabcabcabcabcabcabcabcabcabc1234',
    3
)
```

The condition ID may be determined off-chain from the parameters via `web3`:

```
web3.utils.soliditySha3({
    t: 'address',
    v: '0x1337aBcdef1337abCdEf1337ABcDeF1337AbcDeF'
}, {
    t: 'bytes32',
    v: '0xabcabcabcabcabcabcabcabcabcabcabcabcabcabcabcabcabcabcabcabc1234'
}, {
    t: 'uint',
    v: 3
})
```

A helper function for determining the condition ID also exists on both the contract and the `CTHelpers` library:

function **`getConditionId`**(*address oracle*, *bytes32 questionId*, *uint outcomeSlotCount*) *external*

Constructs a condition ID from an oracle, a question ID, and the outcome slot count for the question.

Parameters

- **`oracle`** – The account assigned to report the result for the prepared condition.
- **`questionId`** – An identifier for the question to be answered by the oracle.
- **`outcomeSlotCount`** – The number of outcome slots which should be used for this condition. Must not exceed 256.

This yields a condition ID of `0x67eb23e8932765c1d7a094838c928476df8c50d1d3898f278ef1fb2a62afab63`.

Later, if the oracle `0x1337aBcdef1337abCdEf1337ABcDeF1337AbcDeF` makes a report that the payout vector for the condition is `[0, 1, 0]`, the oracle essentially states that Bob was chosen, as the outcome slot associated with Bob would receive all of the payout.

A Scalar Example

Let us now consider a question where the answer may lie in a range:

> What will the score be? [0, 1000]

Let's say the question ID for this question is `0x777def777def777def777def777def777def777def777def777def777def777de` and that we trust the oracle `0xCafEBAbECAFEbAbEcaFEbabECAfebAbEcAFEBaBe` to deliver the results for this question.

To prepare this condition, the following code gets run:

```
await conditionalTokens.prepareCondition(
    '0xCafEBAbECAFEbAbEcaFEbabECAfebAbEcAFEBaBe',
    '0x777def777def777def777def777def777def777def777def777def777def7890',
    2
)
```

The condition ID for this condition can be calculated as `0x3bdb7de3d0860745c0cac9c1dcc8e0d9cb7d33e6a899c2c29834`

In this case, the condition was created with two slots: one which represents the low end of the range (0) and another which represents the high end (1000). The slots' reported payout values should indicate how close the answer was to these endpoints. For example, if the oracle `0xCafEBAbECAFEbAbEcaFEbabECAfebAbEcAFEBaBe` makes a report that the payout vector is `[9/10, 1/10]`, then the oracle essentially states that the score was 100, as the slot corresponding to the low end is worth nine times what the slot corresponding with the high end is worth, meaning the score should be nine times closer to 0 than it is close to 1000. Likewise, if the payout vector is reported to be `[0, 1]`, then the oracle is saying that the score was *at least* 1000.

Outcome Collections

The main concept for understanding the mechanics of this system is that of a *position*. We will build to this concept from conditions and outcome slots, and then demonstrate the use of this concept.

However, before we can talk about positions, we first have to talk about *outcome collections*, which may be defined like so:

> A nonempty proper subset of a condition's outcome slots which represents the sum total of all the contained slots' payout values.

Categorical Example Featuring Alice, Bob, and Carol

We'll denote the outcome slots for Alice, Bob, and Carol as `A`, `B`, and `C` respectively.

A valid outcome collection may be `(A|B)`. In this example, this outcome collection represents the eventuality in which either Alice or Bob is chosen. Note that for a categorical condition, the payout vector which the oracle reports will eventually contain a one in exactly one of the three slots, so the sum of the values in Alice's and Bob's slots is one precisely when either Alice or Bob is chosen, and zero otherwise.

`(C)` by itself is also a valid outcome collection, and this simply represents the case where Carol is chosen.

`()` is an invalid outcome collection, as it is empty. Empty outcome collections do not make sense, as they would essentially represent no eventuality and have no value no matter what happens.

Conversely, `(A|B|C)` is also an invalid outcome collection, as it is not a proper subset. Outcome collections consisting of all the outcome slots for a condition also do not make sense, as they would simply represent any eventuality, and should be equivalent to whatever was used to collateralize these outcome collections.

Finally, outcome slots from different conditions (e.g. `(A|X)`) cannot be composed in a single outcome collection.

Index Set Representation and Identifier Derivation

A outcome collection may be represented by an a condition and an *index set*. This is a 256 bit array which denotes which outcome slots are present in a outcome collection. For example, the value `3 == 0b011` corresponds to the outcome collection `(A|B)`, whereas the value `4 == 0b100` corresponds to `(C)`. Note that the indices start at the lowest bit in a `uint`.

A outcome collection may be identified with a 32 byte value called a *collection identifier*. Calculating the collection ID for an outcome collection involves hashing its condition ID and index set into a point on the alt_bn128 elliptic curve.

Note: In order to calculate the collection ID for `(A|B)`, the following steps must be performed.

1. An initial value for the point x-coordinate is set by hashing the condition ID and the index set of the outcome collection, and interpreting the resulting hash as a big-endian integer.

```
web3.utils.soliditySha3({
    // See section "A Categorical Example" for derivation of this condition ID
    t: 'bytes32',
    v: '0x67eb23e8932765c1d7a094838c928476df8c50d1d3898f278ef1fb2a62afab63'
}, {
    t: 'uint',
    v: 0b011 // Binary Number literals supported in newer versions of JavaScript
})
```

   This results in an initial x-coordinate of `0x52ff54f0f5616e34a2d4f56fb68ab4cc636bf0d92111de74d1ec99040a` or `37540785828268254412066351790903087640191294994197155621611396915481249947928`.

   An `odd` flag is set according to whether the highest bit of the hash result is set. In this case, because the highest bit of the hash result is not set,‘‘odd = false‘‘.

2. The x-coordinate gets incremented by one modulo the order of the alt_bn128 base field, which is `21888242871839275222246405745257275088696311157297823662689037894645226208583`.

   The first time, this results in an updated x-coordinate `x = 15652542956428979189819946045645812551494983836899331958922359020836023739368`

3. The x-coordinate is checked to see if it is the x-coordinate of points on the elliptic curve. Specifically, `x**3 + 3` gets computed in the base field, and if the result is a quadratic residue, the x-coordinate belongs to a pair of points on the elliptic curve. If the result is a non-residue however, return to step 2.

   When `x = 15652542956428979189819946045645812551494983836899331958922359020836023739346`, `x**3 + 3 == 71818246977512044166244051721484400005246650915998025364607451942859598748` is not a quadratic residue in the base field, so go back to step 2.

   When `x = 15652542956428979189819946045645812551494983836899331958922359020836023739347`, `x**3 + 3 == 19234863727839675005817902755221636205208068129817953505352549927470359854` is also not a quadratic residue in the base field, so go back to step 2.

   When `x = 15652542956428979189819946045645812551494983836899331958922359020836023739348`, `x**3 + 3 == 15761946137305644622699047885883332275379818402942977914333319312444771227` is still not a quadratic residue in the base field, so go back to step 2.

When `x = 1565254295642897918981994604564581255149498383689933195892235902083602373934 9, x**3 + 3 == 1865131479798838848951424630939080329973622706827269942609209124385442020 1` is a quadratic residue in the base field, so we have found a pair of points on the curve, and we may continue.

4. Note that the base field occupies 254 bits of space, meaning the x-coordinate we found also occupies 254 bits of space, and has two free bits in an EVM word (256 bits). Leave the highest bit unset, and set the next highest bit if `odd == true`. In our example, `odd` is unset, so we're done, and the collection ID for `(A|B)` is `15652542956428979189819946045645812551494983836899331958922359020836023739349`, or `0x229b067e142fce0aea84afb935095c6ecbea8647b8a013e795cc0ced3210a3d5`.

We may also combine collection IDs for outcome collections for different conditions by performing elliptic curve point addition on them.

Note: Let's denote the slots for range ends 0 and 1000 from our scalar condition example as `LO` and `HI`. We can find the collection ID for `(LO)` to be `0x560ae373ed304932b6f424c8a243842092c117645533390a3c1c95ff481587c2` using the procedure illustrated in the previous note.

The combined collection ID for `(A|B)&(LO)` can be calculated in the following manner:

1. Decompress the constituent collection IDs into elliptic curve point coordinates. Take the low 254 bits as the x-coordinate, and pick the y-coordinate which is even or odd depending on the value of the second highest bit.

   - `(A|B)`, which has a collection ID of `0x229b067e142fce0aea84afb935095c6ecbea8647b8a013e795cc0ced` gets decompressed to the point:

     ```
     (15652542956428979189819946045645812551494983836899331958922359020836023739349,
     ↪
     11459896044816691076313215195950563425899182565928550352639564868174527712586)
     ```

     Note the even y-coordinate is chosen here.

   - `(LO)`, which has a collection ID of `0x560ae373ed304932b6f424c8a243842092c117645533390a3c1c95ff4` gets decompressed to the point:

     ```
     (99701209612731093727665253054410555376956520518156368236755682065505240698 26,
     58718355977833514552851902734036656965561373920196548837873578117043602291 75)
     ```

     The odd y-coordinate indication bit was chopped off the compressed form before its use as the decompressed form's x-coordinate, and the odd y-coordinate is chosen here.

2. Perform point addition on the alt_bn128 curve with these points. The sum of these points is the point:

   ```
   (21460418698095194776649446887647175906168566678584695492252634897075584178441,
   45965366218068966592729410374104366056314476222932291686147695923762829833 23)
   ```

3. Compress the result by taking the x-coordinate, and setting the second highest bit, which should be just outside the x-coordinate, depending on whether the y-coordinate was odd. The combined collection ID for `(A|B)&(LO)` is `0x6f722aa250221af2eba9868fc9d7d43994794177dd6fa7766e3e72ba3c111909`.

Warning: Both bitwise XOR and truncated addition is not used in this scenario because these operations are vulnerable to collisions via a generalized birthday attack.

Similar to with conditions, the contract and the `CTHelpers` library also provide helper functions for calculating outcome collection IDs:

function **`getCollectionId`**(*bytes32 parentCollectionId*, *bytes32 conditionId*, *uint indexSet*) *external*

Constructs an outcome collection ID from a parent collection and an outcome collection.

Parameters

- **`parentCollectionId`** – Collection ID of the parent outcome collection, or bytes32(0) if there's no parent.
- **`conditionId`** – Condition ID of the outcome collection to combine with the parent outcome collection.
- **`indexSet`** – Index set of the outcome collection to combine with the parent outcome collection.

Defining Positions

In order to define a position, we first need to designate a collateral token. This token must be an ERC20 token which exists on the same chain as the ConditionalTokens instance.

Then we need at least one condition with a outcome collection, though a position may refer to multiple conditions each with an associated outcome collection. Positions become valuable precisely when *all* of its constituent outcome collections are valuable. More explicitly, the value of a position is a *product* of the values of those outcome collections composing the position.

With these ingredients, position identifiers can also be calculated by hashing the address of the collateral token and the combined collection ID of all the outcome collections in the position. We say positions are *deeper* if they contain more conditions and outcome collections, and *shallower* if they contain less.

As an example, let's suppose that there is an ERC20 token called DollaCoin which exists at the address `0xD011ad011ad011AD011ad011Ad011Ad011Ad011A`, and it is used as collateral for some positions. We will denote this token with `$`.

We may calculate the position ID for the position `$:(A|B)` via:

```
web3.utils.soliditySha3({
    t: 'address',
    v: '0xD011ad011ad011AD011ad011Ad011Ad011Ad011A'
}, {
    t: 'bytes32',
    v: '0x229b067e142fce0aea84afb935095c6ecbea8647b8a013e795cc0ced3210a3d5'
})
```

The ID for `$:(A|B)` turns out to be `0x5355fd8106a08b14aedf99935210b2c22a7f92abaf8bb00b60fcece1032436b7`.

Similarly, the ID for `$:(LO)` can be found to be `0x1958e759291b2bde460cdf2158dea8d0f5c4e22c77ecd09d3ca6a36f`
and `$:(A|B)&(LO)` has an ID of `0x994b964b94eb15148726de8caa08cac559ec51a90fcbc9cc19aadfdc809f34c9`.

Helper functions for calculating positions also exist:

function **`getPositionId`**(*IERC20 collateralToken*, *bytes32 collectionId*) *external*

Constructs a position ID from a collateral token and an outcome collection. These IDs are used as the ERC-1155 ID for this contract.

Parameters

- **`collateralToken`** – Collateral token which backs the position.
- **`collectionId`** – ID of the outcome collection associated with this position.

All the positions backed by DollaCoin which depend on the example categorical condition and the example scalar condition form a DAG (directed acyclic graph):

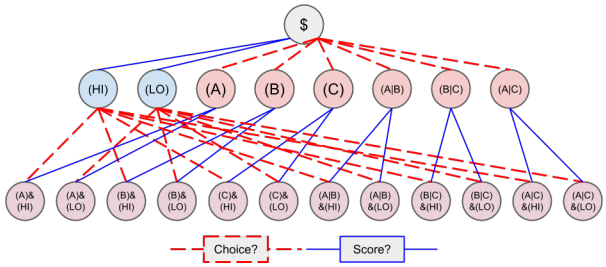


Fig. 5: Graph of all positions backed by `$` which are contingent on either or both of the example conditions.

Splitting and Merging Positions

Once conditions have been prepared, stake in positions contingent on these conditions may be obtained. Furthermore, this stake must be backed by collateral held by the contract. In order to ensure this is the case, stake in shallow positions may only be minted by sending collateral to the contract for the contract to hold, and stake in deeper positions may only be created by burning stake in shallower positions. Any of these is referred to as *splitting a position*, and is done through the following function:

function **splitPosition** (*IERC20 collateralToken*, *bytes32 parentCollectionId*, *bytes32 conditionId*, *uint[]external calldata partition*, *uint amount*)

This function splits a position. If splitting from the collateral, this contract will attempt to transfer *amount* collateral from the message sender to itself. Otherwise, this contract will burn *amount* stake held by the message sender in the position being split worth of EIP 1155 tokens. Regardless, if successful, *amount* stake will be minted in the split target positions. If any of the transfers, mints, or burns fail, the transaction will revert. The transaction will also revert if the given partition is trivial, invalid, or refers to more slots than the condition is prepared with.

Parameters

- **collateralToken** – The address of the positions' backing collateral token.
- **parentCollectionId** – The ID of the outcome collections common to the position being split and the split target positions. May be null, in which only the collateral is shared.
- **conditionId** – The ID of the condition to split on.
- **partition** – An array of disjoint index sets representing a nontrivial partition of the outcome slots of the given condition. E.g. A|B and C but not A|B and B|C (is not disjoint). Each element's a number which, together with the condition, represents the outcome collection. E.g. 0b110 is A|B, 0b010 is B, etc.
- **amount** – The amount of collateral or stake to split.

If this transaction does not revert, the following event will be emitted:

event **PositionSplit** (*address indexed stakeholder*, *IERC20 collateralToken*, *bytes32 indexed parentCollectionId*, *bytes32 indexed conditionId*, *uint[] partition*, *uint amount*)

Emitted when a position is successfully split.

To decipher this function, let's consider what would be considered a valid split, and what would be invalid:

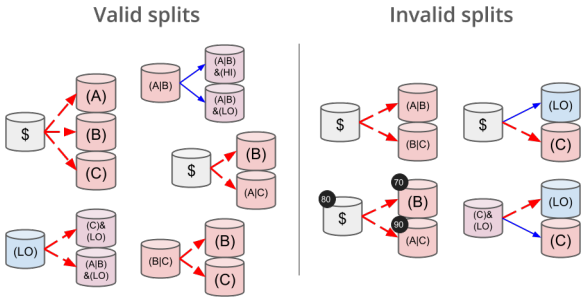


Fig. 6: Details for some of these scenarios will follow

Basic Splits

Collateral `$` can be split into conditional tokens in positions `$:(A)`, `$:(B)`, and `$:(C)`. To do so, use the following code:

```
const amount = 1e18 // could be any amount

// user must allow conditionalTokens to
// spend amount of DollaCoin, e.g. through
// await dollaCoin.approve(conditionalTokens.address, amount)

await conditionalTokens.splitPosition(
    // This is just DollaCoin's address
    '0xD011ad011ad011AD011ad011Ad011Ad011Ad011A',
    // For splitting from collateral, pass bytes32(0)
    '0x0000000000000000000000000000000000000000000000000000000000000000',
    // "Choice" condition ID:
    // see A Categorical Example for derivation
    '0x67eb23e8932765c1d7a094838c928476df8c50d1d3898f278ef1fb2a62afab63',
    // Each element of this partition is an index set:
    // see Outcome Collections for explanation
    [0b001, 0b010, 0b100],
    // Amount of collateral token to submit for holding
    // in exchange for minting the same amount of
    // conditional token in each of the target positions
    amount,
)
```

The effect of this transaction is to transfer `amount` DollaCoin from the message sender to the `conditionalTokens` to hold, and to mint `amount` of conditional token for the following positions:

- `$:(A)`
- `$:(B)`
- `$:(C)`

Note: The previous example, where collateral was split into shallow positions containing collections with one slot each, is similar to `Event.buyAllOutcomes` from Gnosis' first prediction market contracts.

The set of `(A)`, `(B)`, and `(C)` is not the only nontrivial partition of outcome slots for the example categorical condition. For example, the set `(B)` (with index set `0b010`) and `(A|C)` (with index set `0b101`) also partitions these outcome slots, and consequently, splitting from `$` to `$:(B)` and `$:(A|C)` is also valid and can be done with the

following code:

```
await conditionalTokens.splitPosition(
    '0xD011ad011ad011AD011ad011Ad011Ad011Ad011A',
    '0x0000000000000000000000000000000000000000000000000000000000000000',
    '0x67eb23e8932765c1d7a094838c928476df8c50d1d3898f278ef1fb2a62afab63',
    // This partition differs from the previous example
    [0b010, 0b101],
    amount,
)
```

This transaction also transfers `amount` DollaCoin from the message sender to the `conditionalTokens` to hold, but it mints `amount` of conditional token for the following positions instead:

- `$:(B)`
- `$:(A|C)`

Warning: If non-disjoint index sets are supplied to `splitPosition`, the transaction will revert.

Partitions must be valid partitions. For example, you can't split `$` to `$:(A|B)` and `$:(B|C)` because `(A|B)` (`0b011`) and `(B|C)` (`0b110`) share outcome slot `B` (`0b010`).

Splits to Deeper Positions

It's also possible to split from a position, burning conditional tokens in that position in order to acquire conditional tokens in deeper positions. For example, you can split `$:(A|B)` to target `$:(A|B)&(LO)` and `$:(A|B)&(HI)`:

```
await conditionalTokens.splitPosition(
    // Note that we're still supplying the same collateral token
    // even though we're going two levels deep.
    '0xD011ad011ad011AD011ad011Ad011Ad011Ad011A',
    // Here, instead of just supplying 32 zero bytes, we supply
    // the collection ID for (A|B).
    // This is NOT the position ID for $:(A|B)!
    '0x229b067e142fce0aea84afb935095c6ecbea8647b8a013e795cc0ced3210a3d5',
    // This is the condition ID for the example scalar condition
    '0x3bdb7de3d0860745c0cac9c1dcc8e0d9cb7d33e6a899c2c298343ccedf1d66cf',
    // This is the only partition that makes sense
    // for conditions with only two outcome slots
    [0b01, 0b10],
    amount,
)
```

This transaction burns `amount` of conditional token in position `$:(A|B)` (position ID `0x5355fd8106a08b14aedf99935210b2c22a7f92abaf8bb00b60fcece1032436b7`) in order to mint `amount` of conditional token in the following positions:

- `$:(A|B)&(LO)`
- `$:(A|B)&(HI)`

Because the collection ID for `(A|B)&(LO)` is just the sum of the collection IDs for `(A|B)` and `(LO)`, we could have split from `(LO)` to get `(A|B)&(LO)` and `(C)&(LO)`:

```
await conditionalTokens.splitPosition(
    '0xD011ad011ad011AD011ad011Ad011Ad011Ad011A',
    // The collection ID for (LO).
    // This collection contains an outcome collection from the example scalar␣
↪condition
    // instead of from the example categorical condition.
    '0x560ae373ed304932b6f424c8a243842092c117645533390a3c1c95ff481587c2',
    // This is the condition ID for the example categorical condition
    // as opposed to the example scalar condition.
    '0x67eb23e8932765c1d7a094838c928476df8c50d1d3898f278ef1fb2a62afab63',
    // This partitions { A, B, C } into [{ A, B }, { C }]
    [0b011, 0b100],
    amount,
)
```

The `$:(A|B)&(LO)` position reached is the same both ways.

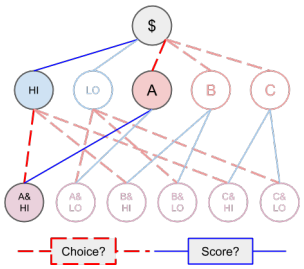


Fig. 7: There are many ways to split to a deep position.

Splits on Partial Partitions

Supplying a partition which does not cover the set of all outcome slots for a condition, but instead some outcome collection, is also possible. For example, it is possible to split `$:(B|C)` (position ID `0x5d06cd85e2ff915efab0e7881432b1c93b3e543c5538d952591197b3893f5ce3`) to `$:(B)` and `$:(C)`:

```
await conditionalTokens.splitPosition(
    '0xD011ad011ad011AD011ad011Ad011Ad011Ad011A',
    // Note that we also supply zeroes here, as the only aspect shared
    // between $:(B|C), $:(B) and $:(C) is the collateral token
    '0x0000000000000000000000000000000000000000000000000000000000000000',
    '0x67eb23e8932765c1d7a094838c928476df8c50d1d3898f278ef1fb2a62afab63',
    // This partition does not cover the first outcome slot
    [0b010, 0b100],
    amount,
)
```

Merging Positions

Merging positions does precisely the opposite of what splitting a position does. It burns conditional tokens in the deeper positions to either mint conditional tokens in a shallower position or send collateral to the message sender:

To merge positions, use the following function:

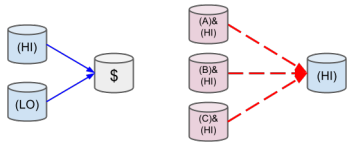


Fig. 8: Splitting positions, except with the arrows turned around.

function **mergePositions**(*IERC20 collateralToken*, *bytes32 parentCollectionId*, *bytes32 conditionId*,*external*
uint[] calldata partition, *uint amount*)

If successful, the function will emit this event:

event **PositionsMerge**(*address indexed stakeholder*, *IERC20 collateralToken*, *bytes32 indexed parentCollectionId*, *bytes32 indexed conditionId*, *uint[] partition*, *uint amount*)
Emitted when positions are successfully merged.

Note: This generalizes `sellAllOutcomes` from Gnosis' first prediction market contracts like `splitPosition` generalizes `buyAllOutcomes`.

Querying and Transferring Stake

The ConditionalTokens contract implements the ERC1155 multitoken interface. In addition to a holder address, each token is indexed by an ID in this standard. In particular, position IDs are used to index conditional tokens. This is reflected in the balance querying function:

function **balanceOf**(*address owner*, *uint256 positionId*) *external*

To transfer conditional tokens, the following functions may be used, as per ERC1155:

function **safeTransferFrom**(*address from*, *address to*, *uint256 positionId*, *uint256 value*, *bytes data*) *external*

function **safeBatchTransferFrom**(*address from*, *address to*, *uint256[] positionIds*, *uint256[] values*,*external*
bytes data)

These transfer functions ignore the `data` parameter.

Note: When sending to contract accounts, transfers will be rejected unless the recipient implements the `ERC1155TokenReceiver` interface and returns the expected magic values. See the ERC1155 multitoken spec for more information.

Approving an operator account to transfer conditional tokens on your behalf may also be done via:

function **setApprovalForAll**(*address operator*, *bool approved*) *external*

Querying the status of approval can be done with:

function **isApprovedForAll**(*address owner*, *address operator*) *external*

Redeeming Positions

Before this is possible, the payout vector must be set by the oracle:

function **reportPayouts** (*bytes32 questionId*, *uint[] calldata payouts*) *external*

Called by the oracle for reporting results of conditions. Will set the payout vector for the condition with the ID `keccak256(abi.encodePacked(oracle, questionId, outcomeSlotCount))`, where oracle is the message sender, questionId is one of the parameters of this function, and outcomeSlotCount is the length of the payouts parameter, which contains the payoutNumerators for each outcome slot of the condition.

Parameters

- **questionId** – The question ID the oracle is answering for
- **payouts** – The oracle's answer

This will emit the following event:

event **ConditionResolution** (*bytes32 indexed conditionId*, *address indexed oracle*, *bytes32 indexed questionId*, *uint outcomeSlotCount*, *uint[] payoutNumerators*)

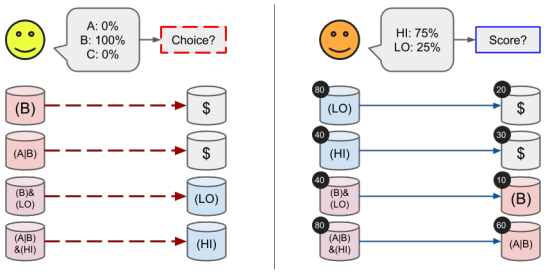
Then positions containing this condition can be redeemed via:

function **redeemPositions** (*IERC20 collateralToken*, *bytes32 parentCollectionId*, *bytes32 conditionId*,*uint[] calldata indexSets*) *external*

This will trigger the following event:

event **PayoutRedemption** (*address indexed redeemer*, *IERC20 indexed collateralToken*, *bytes32 indexed parentCollectionId*, *bytes32 conditionId*, *uint[] indexSets*, *uint payout*)

Also look at this chart:



1.1.3 Contributing

The source for the contracts can be found on Github.

To set up for contributing, install requirements with NPM:

```
npm install
```

Tip: Many of the following commands simply wrap corresponding Truffle commands.

Testing and Linting

The test suite may be run using:

```
npm test
```

In order to run a subset of test cases which match a regular expression, the `TEST_GREP` environment variable may be used:

```
TEST_GREP='obtainable conditionIds' npm test
```

The JS test files may be linted via:

```
npm run lint
```

Contracts may also be linted via:

```
npm run lint-contracts
```

Development commands

To compile all the contracts, obtaining build artifacts containing each containing their respective contract's ABI and bytecode, use the following command:

```
npm run compile
```

Running the migrations, deploying the contracts onto a chain and recording the contract's deployed location in the build artifact can also be done:

```
npm run migrate
```

Dropping into a Truffle develop session can be done via:

```
npm run develop
```

Network Information

Showing the deployed addresses of all contracts on all networks can be done via:

```
npm run networks
```

Extra command line options for the underlying Truffle command can be passed down through NPM by preceding the options list with `--`. For example, in order to purge the build artifacts of any unnamed network information, you can run:

```
npm run networks -- --clean
```

To take network info from `networks.json` and inject it into the build artifacts, you can run:

```
npm run injectnetinfo
```

If you instead wish to extract all network information from the build artifacts into `networks.json`, run:

```
npm run extractnetinfo
```

Warning: Extracting network info will overwrite `networks.json`.

Building the Documentation

(Will install Sphinx and Solidity Domain for Sphinx):

```
cd docs
pip install -r requirements.txt
make html
```

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1.1.4 Glossary

Condition

A question that a specific oracle reports on with a preset number of outcome slots. Analogous to events from Gnosis' first prediction market contracts.

For example, a condition with a categorical outcome, that is, one of N outcomes, may have N outcome slots, where the resolution of the condition sets one of the outcome slots to receive the full payout.

Another example: a condition with a scalar outcome, that is an outcome X in some range [A, B], may have two outcome slots which correspond to the ends of the range A and B. Both slots are set to receive a proportion of the payout according to how close the outcome X is to A or B.

Identified by keccak256(oracle . questionId . outcomeSlotCount)

Outcome Slot Defines the redemption rate of Conditional Tokens. Conditional Tokens convert to a proportion of collateral depending on the outcome resolution of a set of conditions.

Outcome Slots can either be unresolved (when the condition hasn't been reported on) or resolved (after condition resolution).

Index Set A bit array that represents a subset of Outcome Slots in one condition.

Example: Condition1 has Outcome Slots: A,B,C. It would have 7 possible indexSets: A, B, C, A|B, A|C, B|C, A|B,C

Partition A specific way to separate the subsets of the Outcome Slots in a condition, using a combination of indexSets.

Oracle The account which can report the results on the condition.

Outcome Resolution The process in which an oracle reports results for the Outcome Slots in a condition, setting the Outcome Slot value for each of the condition's Outcome Slots.

Position

A set of conditions, along with a non-empty proper subset of Outcome Slots for each condition (represents a combination of one or many Outcome Slots from multiple conditions) represented as a DAG (Directed Acyclic Graph) and tied to a specific stakeholder, Collateral Token, and amount of Conditional Tokens.

Representing a specific stakeholders stake in a certain condition(s) Outcome Slots as an ERC1155 token.

A position is made up of:

1. Stakeholder Collection Identifier Condition(s) IndexSet(s) CollateralToken Conditional Tokens

Identified by the hash of a H(Collateral Token, Collection Identifier)

Collection Identifier An identifier used by positions to target Condition(s) and indexSet(s).

Rather than target individual Conditions and IndexSets. The Condition Identifier can identify a DAG (Directed Acyclic Graph) of dependant Condition(s) and indexSet(s).

It is the abstract structure that identifies what Conditions and IndexSets, a position is representing, along with their heirarchy. Without being tied to any specific stakeholder or Collateral Token.

If the parentCollectionId is equal to 0, then it is a Root Position.

Identified by a sum(parentCollectionIdentifier, hash(ConditionIdentifier . indexSet)

Collateral Token An ERC20 token used to create stake in positions.

Conditional Tokens For a given Collection Identifier, a stakeholder may express a belief in what that Collection Identifier of Outcome Slots represents by using a collateral token to create a position from the Collection Identifier and holding Conditional Tokens in that slot.

For non-root positions, redemption will convert Conditional Tokens into stake in a shallower position. For root positions, redemption will convert Conditional Tokens into Collateral Tokens.

Position Depth The number of conditions a position is based off of. Terminology is chosen because positions form a DAG which is very tree-like. Shallow positions have few conditions, and deep positions have many conditions.

Root Position A position based off of only a single condition. Pays out depending on the outcome of the condition. Pays out directly to the Collateral Token

Non-Root Position A position based off of multiple conditions. Pays out depending on all of the outcomes of the multiple conditions. Pays out to a shallower Position.

Atomic Position A position is atomic with respect to a set of conditions if it is contingent on all of the conditions in that set. Pays out to a shallower Position.

Splitting a Position Stakeholders can split a position on an optional collection identifier and a condition.

For Root Positions, a collection identifier is not given (instead it is 0), and the stakeholder transfers an input amount of collateral tokens in order to get an equal amount of conditional tokens in each of the condition's outcome slots.

For Non-Root Positions, a parent Collection Identifier is provided, and the stakeholder transfers an input amount of Conditional Tokens from the Position corresponding to the parent Collection Identifier down to a set of new Non-Root Position(s).

Results in conditional tokens being transferred from the position being split to the positions resulting from the split.

Merging a Position Basically the opposite of splitting a position. Stakeholders can merge a position on an optional Outcome Slot and a Collection Identifier for non-root positions.

For Root Positions, if an Outcome Slot is not given, the stakeholder inputs an equal amount of Conditional Tokens in each of the condition's root Outcome Slots to receive an equal amount of Collateral Tokens.

For Non-Root Positions, a parent Collection Identifier is provided, and the stakeholder transfers an input amount of Conditional Tokens from all the Outcome Slots input in the partition[] either up to a position identified by the parent Collection Identifier or merged into a single Position.

Results in conditional tokens being transferred from the positions being merged to the position resulting from the merge.

Redeeming Positions Redeems (1 - all Index Sets) of Positions that are predicated on a single Condition and collection identifier.

Resulting in either more Conditional Tokens in a shallower position, or a conversion of Conditional Tokens into the Collateral Token, depending on whether it's a Root Position or Non-Root Position.

To redeem a position, you need:

1. The Collateral Token that position is tied to. It's parent positions Collection Identifier (if it has one), otherwise it would be a Root Position, and you would input 0 to receive back Collateral Tokens. The condition you want to redeem. The Index Sets[] you want to redeem.

This will redeem all of the Index Sets[] slots listed in the given condition, for only positions with a parent position that has a Collection Idenfier equal to parentCollectionId.

CHAPTER 2

Indices and tables

- genindex

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