



Bramah Systems

## dYdX Public Report

PROJECT: dYdX/solo

February 2019

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# dYdX “Solo” Assessment

## Executive Summary

### Scope of Engagement

Bramah Systems, LLC was engaged in late January of 2019 to perform a comprehensive security review of the dYdX Trading, Inc. “Solo” repository protocol. A review was conducted over the period by a member of the Bramah Systems, LLC. executive staff. During this period, all Solidity smart contract code (\*.sol) as of commit **77917ea86771ea3b2deec2f9c21ac0b587148b60** was included within scope, along with TypeScript files (\*.ts) relevant to testing. Bramah Systems completed the assessment using manual, static and dynamic analysis techniques.

### Timeline

Audit Commencement: February 11, 2019

Report Delivery: February 18, 2019

### Engagement Goals

The primary scope of the engagement was to evaluate and establish the overall security of the Solo system, with a specific focus on trading actions. In specific, the engagement sought to answer the following questions:

- Is it possible for an attacker to steal or freeze tokens?
- Is there a way to interfere with the trading mechanisms?
- Are the arithmetic calculations trustworthy?

### Protocol Specification

While minimal specification is proposed within the README, multiple checks and constants are presented through the Truffle project to ensure intended actions are successfully performed.

## Overall Assessment

Bramah Systems was engaged to evaluate and identify significant security concerns in the codebase of the dYdX protocol architecture. During the course of our engagement, Bramah Systems noted numerous instances wherein the protocol deviated from established best practices and procedures of secure software development. **With limited exceptions (as described below), these instances were a result of structural limitations of Solidity and not due to inactions on behalf of the development team.**

Overall, the code reviewed is of excellent quality, written with clear awareness of current smart contract development best practices, common security pitfalls, and overall readability. Its interfaces are well designed and its use of patterns display strong code maturity.

In particular, Bramah Systems notes that the code is well commented, particularly in sections where understanding the developer's intent is essential. Additionally, the overall contract organization is consistent throughout (within contracts themselves and their overarching interactions with others).

While during the course of the review Bramah Systems discovered areas worthy of attention by the dYdX team, these issues have since been addressed and no significant security concerns remain. We applaud the dYdX team on their immense dedication in following security best practices throughout the course of development of their protocol.

## Disclaimer

As of the date of publication, the information provided in this report reflects the presently held, commercially reasonable understanding of Bramah Systems, LLC.'s knowledge of security patterns as they relate to the dYdX Protocol, with the understanding that distributed ledger technologies ("DLT") remain under frequent and continual development, and resultantly carry with them unknown technical risks and flaws. The scope of the review provided herein is limited solely to items denoted within "Scope of Engagement" and contained within "Directory Structure". The report does NOT cover, review, or opine upon security considerations unique to the Solidity compiler, tools used in the development of the protocol, or distributed ledger technologies themselves, or to any other matters not specifically covered in this report. The contents of this report must NOT be construed as investment advice or advice of any other kind. This report does NOT have any bearing upon the potential economics of the dYdX protocol or any other relevant product, service or asset of dYdX or otherwise. This report is not and should not be relied upon by dYdX or any reader of this report as any form of financial, tax, legal, regulatory, or other advice.

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## Timeliness of Content

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# General Recommendations

## Best Practices & Solidity Development Guidelines

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### Usage of experimental Solidity version

A majority of the contracts associated with the protocol make usage of an experimental Solidity version (**pragma experimental ABIEncoderV2**) which enables usage of the new ABI encoder. **ABIEncoderV2** allows for the usage of structs and arbitrarily nested arrays (such as **string[]** and **uint256[][]**) in function arguments and return values.

As no present non experimental version for these constructs exists, one must acknowledge the associated risk in utilizing non release-candidate (“RC”) software. It is understood that software in the beta phase will generally have more bugs than completed software as well as speed/performance issues and may cause crashes or data loss.

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### nonReentrant functions not marked External

The **nonReentrant** modifier prevents a contract from calling itself, directly or indirectly. If you mark a function **nonReentrant**, you should also mark it **external**. Calling one **nonReentrant** function from another is not supported. Instead, you can implement a **private** function doing the actual work, and an **external** wrapper marked as **nonReentrant**.

**UPDATE:** Discussion with the dYdX team unveiled that current limitations within **ABIEncoderV2** restrict the ability to mark functions handling structs as both non-reentrant and external. This ideally will be patched in a later version of Solidity.

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### Choose “Base Currency” for consistency

Multiple digital currencies (and their respective components) are referenced throughout the project. In order to maintain consistency, a core currency should be chosen (such as Ether or Dai). As various stable-coins the protocol seeks to accept may differ in their relative price to the dollar (USD), pegging these entities to their relative price in Ether will allow for the most comprehensive price tracking.

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## Non-initialized Return Values

Within **protocol/lib/Storage.sol** in the **SetStatus** function, the function's signature only denotes

the type of the return value, but the function's body does not contain return statement. If the return value is not needed, the specification of the return type is not inherently necessary.

File: protocol/lib/Storage.sol

Lines: 531-540

## Completion of TODO's & Incomplete Functionality

Throughout the project, there are multiple instances in which TODO is referenced. In each, establish whether or not the goal of the file has been established (e.g. in **contracts\protocol\State.sol** it appears the state implementation is relatively feature complete). In particular, pricing oracles appear to be heavily referenced throughout the code but their actual implementation does not appear to be present at the time of review.

File: Numerous

## Usage of Block.timestamp

Miners can affect block.timestamp for their benefits. Thus, one should not rely on the exact value of block.timestamp. As a result of such, **block.timestamp** and **now** should traditionally only be used within inequalities (note: the protocol **does** follow this strategy).

Block numbers and average block time can be used to estimate time, but this is not future proof as block times may change (such as the changes expected during Casper).

File: protocol/lib/Time.sol

Lines: 46-46

## External call failure could be more verbose

There is a non-zero possibility that for numerous reasons an external contract call could fail. Especially when sending Ether, it is critical to check for relevant return values and ensure error handling. Without verbose logging of the potential error (and only the arguments, as is currently present), it may pose a large amount of difficulty to debug where potential errors may stem from.

File: protocol/impl/OperationImpl.sol

Lines: 811-815

## Highly Privileged Owner Accounts

Within the Admin.sol file, multiple onlyOwner gated actions exist, allowing configuration

changes of multiple market and risk functions. If the exchange/proxy owner is hacked, and their Ethereum private key is exposed, catastrophic damage could be caused to the protocol. It is suggested that a two week time-delay be added to new administrative actors in the event a new owner is added, allowing individuals to withdraw their funds from the protocol in case an untrusted address is authorized for administrative actions.

No changes are recommended to the contract system here, but we wish to underscore the importance of the surrounding systems. Ensuring that these keys are protected is of the utmost criticality.

File: protocol/Admin.sol

## NPM Module Usage

Throughout the project, NPM modules are utilized in order to import various functionality (notably, OpenZeppelin contracts). While this practice enables relatively minimal modifications to be made in order to invoke certain functions securely (such as with SafeMath), these libraries must be continuously updated in order to ensure they are used securely.

Virtually every non-blockchain application has these issues because most development teams do not focus on ensuring their components/libraries are up to date. In the case of blockchain codebases, however, knowing all outside components utilized is critical.

It is suggested the following steps are followed (as noted by the OWASP project):

1. Identify all components and the versions you are using, including all dependencies. (NPM package lock can help determine these).
2. Monitor the security of these components in public databases, project mailing lists, and security mailing lists, and keep them up to date.
3. Establish security policies governing component use, such as requiring certain software development practices, passing security tests, and acceptable licenses.
4. Where appropriate, consider adding security wrappers around components to disable unused functionality and/ or secure weak or vulnerable aspects of the component.

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## Toolset Warnings

In addition to our manual review, our process involves utilizing concolic analysis and dynamic testing in order to perform additional verification of the presence security vulnerabilities. An additional part of this review phase consists of reviewing any automated unit testing frameworks that exist.

The following sections detail warnings generated by the automated tools and confirmation of false positives where applicable, in addition to findings generated through manual inspection.

## Extensive Test Coverage

The contract repository heavily benefits from extensive unit test coverage throughout. This testing provides a variety of unit tests which encompass the various operational stages of the contract. The dYdX protocol (and its relevant components and their respective subcomponents) possesses numerous tests validating functionality and ensuring that certain behaviors (those relating to erroneous or overflow-prone input) do not see successful execution.

In particular, specific focus within the testing suite was placed upon validating that various actions (such as setting, getting, approval, and various market actions) cannot occur after a state change or as the result of bad input (such as an invalid address).

The dYdX team constructed tests in both TypeScript and native Solidity, allowing for a fairly robust test-suite.

## Excess Gas Consumption & Costly Loops

If the state variables **.balance** or **.length** are used several times, holding its value in a local variable is more gas efficient (as the variable does not need to be accessed every loop iteration).

Moreover, as Ethereum miners impose a limit on the total number of gas consumed in a block, if **array.length** is large enough, the function will exceed the block gas limit, and transactions calling it will never be confirmed. As a result, if an external entity is to influence **array.length**, this could pose issue. Where possible, avoiding loops with a large number of iterations (or an unknown number of iterations) is advised.

In particular, code concerning accounts on various markets within **OperationImpl.sol** appears to be impacted by these constraints. With an immensely high number of markets (yet still within the bounds of **uint256**), various requests began to fail.

File: external/proxies/PayableProxyForSoloMargin.sol

Lines: 92-115

File: protocol/lib/Storage.sol

Lines: 499-511

File: protocol/lib/Storage.sol  
Lines: 298-324  
File: protocol/Permission.sol  
Lines: 56-61  
File: protocol/impl/OperationImpl.sol  
Lines: 206-240  
File: protocol/impl/OperationImpl.sol  
Lines: 251-279  
File: protocol/impl/OperationImpl.sol  
Lines: 96-106  
File: protocol/impl/OperationImpl.sol  
Lines: 125-166  
File: protocol/impl/OperationImpl.sol  
Lines: 173-178

## Parsing Functions & Malformed Input

Parsing functions within Actions.sol do not appear to handle malformed input (no reverting statement within enforces such behavior). While this may be anticipated, as these contract functions are not intended to be called directly, they could benefit from the inclusion of logic to alert on missing arguments. Seen similarly within Token.sol, a number of instances exist in which success must be assumed due to the lack of verbose failure. **In general, these limitations exist as underlying structural issues with Solidity (and the Ethereum platform as a whole), as logging for each potential failure would require an exorbitant amount of gas, but not logging presents potential risk. Overall, the dYdX team made careful and concise points of inclusion for each potential area of alert.**

File: protocol/lib/Actions.sol

## ERC-20 Race Condition

A [known race condition](#) exists within the present implementation of the ERC20 standard. Due to the nature of this vulnerability being an inherent flaw in the ERC20 standard, considerations must be made for any divergence (as modifications made while no longer be ERC20 compliant).

**With this noted, the dYdX protocol makes appropriate mitigations and utilizes the suggested allowance approach in order to remove concern presented by this vulnerability.**

## Directory Structure

At time of review, the directory structure of the dYdX “Solo” contract repository was as follows:

Directory of \User\Audit\Documents\GitHub\solo\contracts

```
02/14/2019 03:39 PM <DIR>      external
02/14/2019 03:39 PM          1,221 Migrations.sol
02/14/2019 03:39 PM <DIR>      protocol
02/14/2019 03:39 PM <DIR>      testing
          1 File(s)      1,221 bytes
```

Directory of \User\Audit\Documents\GitHub\solo\contracts\external

```
02/14/2019 03:39 PM <DIR>      helpers
02/14/2019 03:39 PM <DIR>      proxies
02/14/2019 03:39 PM <DIR>      traders
          0 File(s)      0 bytes
```

Directory of \User\Audit\Documents\GitHub\solo\contracts\external\helpers

```
02/14/2019 03:39 PM          1,488 OnlySolo.sol
          1 File(s)      1,488 bytes
```

Directory of \User\Audit\Documents\GitHub\solo\contracts\external\proxies

```
02/14/2019 03:39 PM          3,724 PayableProxyForSoloMargin.sol
          1 File(s)      3,724 bytes
```

Directory of \User\Audit\Documents\GitHub\solo\contracts\external\traders

```
02/14/2019 03:39 PM          6,840 Expiry.sol
          1 File(s)      6,840 bytes
```

Directory of \User\Audit\Documents\GitHub\solo\contracts\protocol

```
02/14/2019 03:39 PM          4,867 Admin.sol
02/14/2019 03:39 PM          8,014 Getters.sol
02/14/2019 03:39 PM <DIR>      impl
02/14/2019 03:39 PM <DIR>      interfaces
02/14/2019 03:39 PM <DIR>      lib
```

02/14/2019	03:39 PM	1,423	Operation.sol
02/14/2019	03:39 PM	1,552	Permission.sol
02/14/2019	03:39 PM	1,354	SoloMargin.sol
02/14/2019	03:39 PM	839	State.sol
6 File(s)		18,049	bytes

Directory of \User\Audit\Documents\GitHub\solo\contracts\protocol\impl

02/14/2019	03:39 PM	8,835	AdminImpl.sol
02/14/2019	03:39 PM	25,825	OperationImpl.sol
2 File(s)		34,660	bytes

Directory of \User\Audit\Documents\GitHub\solo\contracts\protocol\interfaces

02/14/2019	03:39 PM	1,309	IAutoTrader.sol
02/14/2019	03:39 PM	1,016	ICallee.sol
02/14/2019	03:39 PM	2,139	IErc20.sol
02/14/2019	03:39 PM	2,925	IExchangeWrapper.sol
02/14/2019	03:39 PM	1,242	IInterestSetter.sol
02/14/2019	03:39 PM	1,425	IPriceOracle.sol
6 File(s)		10,056	bytes

Directory of \User\Audit\Documents\GitHub\solo\contracts\protocol\lib

02/14/2019	03:39 PM	1,410	Account.sol
02/14/2019	03:39 PM	9,481	Actions.sol
02/14/2019	03:39 PM	1,312	Decimal.sol
02/14/2019	03:39 PM	11,820	Events.sol
02/14/2019	03:39 PM	3,785	Exchange.sol
02/14/2019	03:39 PM	4,712	Interest.sol
02/14/2019	03:39 PM	2,829	Math.sol
02/14/2019	03:39 PM	1,797	Monetary.sol
02/14/2019	03:39 PM	6,191	Require.sol
02/14/2019	03:39 PM	17,199	Storage.sol
02/14/2019	03:39 PM	1,419	Time.sol
02/14/2019	03:39 PM	3,914	Token.sol
02/14/2019	03:39 PM	5,578	Types.sol
13 File(s)		71,447	bytes

Directory of \User\Audit\Documents\GitHub\solo\contracts\testing

02/14/2019 03:39 PM	1,011	ErroringOmiseToken.sol
02/14/2019 03:39 PM	1,042	ErroringToken.sol
02/14/2019 03:39 PM	3,146	OmiseToken.sol
02/14/2019 03:39 PM	7,546	TestAutoTrader.sol
02/14/2019 03:39 PM	3,251	TestCallee.sol
02/14/2019 03:39 PM	1,592	TestInterestSetter.sol
02/14/2019 03:39 PM	1,372	TestPriceOracle.sol
02/14/2019 03:39 PM	3,112	TestSoloMargin.sol
02/14/2019 03:39 PM	3,459	TestToken.sol
02/14/2019 03:39 PM	1,035	TokenA.sol
02/14/2019 03:39 PM	1,035	TokenB.sol
02/14/2019 03:39 PM	1,035	TokenC.sol
12 File(s)	28,636	bytes

Total Files Listed:

43 File(s)	176,121	bytes
29 Dir(s)		

# Appendix

## Mythril Detection Capabilities

Issue	Description	Mythril Detection Module(s)	References
Unprotected functions	Critical functions such as sends with non-zero value or suicide() calls are callable by anyone, or msg.sender is compared against an address in storage that can be written to. E.g. Parity wallet bugs.	<a href="#">Unchecked_suicide</a> , <a href="#">Ether_send</a> <a href="#">unchecked_retval</a>	
Missing check on CALL return value		<a href="#">unchecked_retval</a>	<a href="#">Handle errors in external calls</a>
Re-entrancy	Contract state should never be relied on if untrusted contracts are called. State changes after external calls should be avoided.	<a href="#">external calls to untrusted contracts</a>	<a href="#">Call external functions last</a> <a href="#">Avoid state changes after external calls</a>
Multiple sends in a single transaction	External calls can fail accidentally or deliberately. Avoid combining multiple send() calls in a single transaction.		<a href="#">Favor pull over push for external calls</a>

External call to untrusted contract		<a href="#">external calls to untrusted contracts</a>	
Delegatecall or callcode to untrusted contract		<a href="#">delegatecall_forward</a>	
Integer overflow/underflow		<a href="#">integer</a>	<a href="#">Validate arithmetic</a>
Timestamp dependence		<a href="#">Dependence on predictable variables</a>	<a href="#">Miner time manipulation</a>
Payable transaction does not revert in case of failure			
Use of tx.origin		<a href="#">tx_origin</a>	<a href="#">Solidity documentation, Avoid using tx.origin</a>
Type confusion			
Predictable RNG		<a href="#">Dependence on predictable variables</a>	
Transaction order dependence		<a href="#">Transaction order dependence</a>	<a href="#">Front Running</a>
Information exposure			
Complex fallback function (uses more than 2,300 gas)	A too complex fallback function will cause send() and transfer() from other contracts to fail. To implement this we first need to fully implement gas simulation.		

Use require() instead of assert()	Use assert() only to check against states which should be completely unreachable.	<a href="#">Exceptions</a>	<a href="#">Solidity docs</a>
Use of deprecated functions	Use revert() instead of throw(), selfdestruct() instead of suicide(), keccak256() instead of sha3()		
Detect tautologies	Detect comparisons that always evaluate to 'true', see also <a href="#">#54</a>		
Call depth attack	Deprecated		

## Oyente Detection Capabilities

Issue	Description
Re-entrancy	Contract state should never be relied on if untrusted contracts are called. State changes after external calls should be avoided.
Timestamp Dependence	The timestamp of the block can be manipulated by the miner, and so should not be used for critical components of the contract. Block numbers and average block time can be used to estimate time, but this is not future proof as block times may change (such as the changes expected during Casper).
Assertion Failure	An assertion is a boolean expression at a specific point in a program which will be true unless there is a bug in the program.



	Assertion failures as such denote critical instances in which assumptions made by the developer no longer hold to be true.
Callstack Depth Attack	Deprecated
Transaction Order Dependence (TOD)	Since a transaction is in the mempool for a short while, one can know what actions will occur, before it is included in a block. This can be troublesome for things like decentralized markets, where a transaction to buy some tokens can be seen, and a market order implemented before the other transaction gets included.
Parity Multisig Bug 2	Unchecked kill/selfdestruct functions, such as those within the Parity Multisig Bug 2 can lead to destruction of the contract, sending funds to the given address provided.