

PLATONIC.SYSTEMS

FOR PROJECT ARDANA

Audit

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I. Executive summary

Platonic.Systems has conducted an internal [Audit](#) parallel to the engineering efforts building Danaswap, Ardana stablecoins, and Dana governance token mechanisms.

I.1. Recommendations

Recommendations are assigned a five-valued confidence.

I.1.1. Keep the DeX closed source to prevent forking

This can play a role in reducing vampire attack risk. Confidence in importance: very low

I.1.2. Peg fee structure to governance (i.e. Dana holders) to avoid competition

This reduces vampire attack risk, details [IV.1.3](#). Confidence in importance: medium.

I.1.3. Monitor development of Cardano ecosystem for multi-step atomic transactions to guard against flashloan attacks

With mitigation strategy sketches provided in [IV.2.1](#). Confidence in importance: very high

I.2. Nonissues

During the audit process research was conducted to rule out the following attack vectors.

1. **Reentrancy**
2. **Flashloans** (modulo [IV.2.1](#))

I.3. Insufficient literature

As of this writing, the jury is still out on the following considerations or attack vectors.

1. **Transaction-ordering dependence:** waiting on publications or code from IOHK to determine network fee resolution and their impact on miner incentives. (This is blocking any confidence level regarding the frontrunning question). A comment in (Guillemont 2021) suggests that miner-type frontrunning will not be an issue, but our confidence is not high in everything shaking out that way.
2. Filler, need a second item to block a render bug.

II. Preamble

The audit is a preliminary effort to compensate for the fact that proper formal verification before launch is infeasible.

An audit means many things. Let's be precise about what we mean by audit in this document.

Definition II.0.1 (Audit). *An audit is a document provided to the community to guide them in taking informed risk.*

Definition II.0.2 (Community). *A community consists of liquidity providers, investors, swappers, arbitrageurs, governance token holders, and neighboring members/projects of the ecosystem.*

II.0.1. Desiderata

- **The community is the audience. The community is the customer.**
- I think we want to make an explicit demarcation of risks for whom. Some risks only effect Ardana internally, other risks effect the collective of Dana holders, other risks effect our neighbors in the ecosystem. I think there's a difference between risks we want to eliminate and risks we want to empower the community to take. I'm sort of imagining profiling these as separate *axes* of risk. The idea here is that I'm frustrated with the literature because it almost feels like it uses the word "attack" anytime someone loses money. This is not adequate- sometimes you just gambled and lost, sometimes the "attacker" followed the rules of the mechanism as designed. There's a morality/values question to each attack, and **the audit needs to provide disambiguation and clarity without taking sides on each values/morality question.**
- The audit is **as much as was possible to do before launch time, not exhaustive.**

II.1. Considerations

In this chapter we look at broad concepts and decisions and provide context into the way the team is thinking about them. This section should add indirect value to the process of taking informed risks.

II.2. Attacks

In this chapter we profile threat models, attack vectors, vulnerabilities; mostly on the economic and mechanism design levels, but occasionally on the software implementation level.

This audit will take on a bit of a code-is-law opinion; many things which are called “attacks” are in fact people using mechanisms as designed. However, it is still the responsibility of a platform (such as a DeX) to help the community make informed decisions about risk, even when the risk concerns unforeseen behaviors of a protocol or implementation.

Philosophically, be wary of morally charged language in the overall literature. It often implies that an attack is carried out by a summary enemy of the entire ecosystem, that the ecosystem is victimized, when clearer thinking shows that a small team or platform was the sole victim.

III. Considerations

III.1. Scalar types

III.1.1. Onchain components

We use `PlutusTx.Rational`¹ to represent numbers in the Danaswap contract. As of this writing, tolerance (number of decimals needed to evaluate equality) is set to 30.

For the smart contract, we require calculations which are highly precise and can handle very large numbers and can be reproduced exactly across different hardware. Using FLOPs (floating point operations) is not compatible with these requirements. We are not able to determine exactly how big or how precise our numbers need to be, so we cannot say that FLOPs allow for enough size and precision. We can say, however, that FLOPs are implemented slightly differently on different hardware and results may not be reproducible across different hardware. Additionally, FLOPs are not allowed to be used in Plutus on-chain code. These are the constraints which do not allow us to use `Double` to represent numbers in the smart contract.

III.1.2. Offchain components

`DanaswapStats` uses vanilla haskell's `Double` type to solve the invariant function.

III.2. Root-finding

Recall the **invariant equation** from the StableSwap Whitepaper (Egorov 2019, 5). In the formalism provided by our Danaswap Whitepaper (Thomas 2021a, 3), there exists a function $I : S \rightarrow \mathbb{R}$ for contract states S such that $I(s) = 0$ is equivalent to the invariant equation. Danaswap borrows everything from StableSwap to vary between

¹<https://github.com/input-output-hk/plutus/blob/master/plutus-tx/src/PlutusTx/Ratio.hs>

constant-product and constant-sum market-making according to a *leverage* parameter, for which we also accept the suggestion found in (Egorov 2019). Sometimes, we need to hold all balances constant to solve for D (which we call *the invariant*, having the semantics of total amount of coins **when** all coins have equal price). Other times, we consider a k and solve for $B(s)_k$ holding everything else (including D) constant, when $B : S \rightarrow \mathbb{R}^n$ is a function assigning in every state a balance to each of n assets (we will think of an $i \in 1..n$ as an *asset label*).

We define the **invariant polynomial** $n + 1$ times like so

Definition III.2.1 (Invariant polynomials).

$$I_D := D \mapsto D^{n+1} + (A + n^{-n})n^{2n}(\Pi B(s)_i)D + -An^{2n}(\Pi B(s)_i)\Sigma B(s)_i$$

$$\forall k \in 1..n, I_k := B(s)_k \mapsto B(s)_k^2 + \left(\Sigma_{i \neq k} B(s)_i + \left(\frac{1}{An^n} - 1 \right) D \right) x_k + \frac{-D^{n+1}}{An^{2n} \Pi_{i \neq k} B(s)_i}$$

The derivations beginning with (Egorov 2019) are in [Appendix A: invariant polynomial](#) (I_D , I_k).

We think the invariant equation is best represented as polynomials set to zero, depending on what you're solving for, for the following reasons

1. **Characterize the roots in terms of existence and uniqueness.** It can be shown that there is exactly one nonnegative real root for I_D and each I_k , and we'd like the onchain code to be close to the form that makes this easy to see.
2. **Trivially reason about derivatives.** Without my algebraic choices the derivatives (for Newton's method) are harder to see.
3. (Hypothesis): **Shrink the arithmetic tree size.** Leaving χ in a blackbox has the advantage of the codebase being able to plug in different leverage coefficients in the future just by supplying the leverage coefficient and its derivative. However, this puts more on the stack than is necessary. I haven't done any formal benchmarking of this, but I currently believe the invariant polynomials in these forms are simpler trees and should therefore result in lower fees. Note IOHK have not published nor pushed code on a cost semantics / gas model, so we might not be able to reason about this.
4. **Increase our ability to reason about alternatives to Newton's method.** For example, looking at this problem from a companion matrix point of view becomes possible when we have formal polynomials.

III.2.1. Newton’s algorithm

In Curve’s implementation of StableSwap, they use Newton’s algorithm for root finding, so that’s the first iteration of our codebase.

When the derivative can be found in a neighborhood of zero, Newton’s method does not enjoy convergence guarantees (Wikimedia 2021, para. 4.1). The probability that invariant polynomial derivatives are in such a neighborhood is tiny, but nonzero, with details in [V.1](#).

We currently solve in `DanaswapStats` and oblige onchain logic to provide an ϵ -proof that the root is valid.

III.3. Throughput

TODO: establish throughput problem with language from (Thomas 2021b).

Definition III.3.1 (Fairness). *A DeX’s concurrency solution is **fair** if when two people perform an action at the same time, that action is performed for roughly the same price.*

The Cardano mempool is designed to be “fair.” Transactions are processed in a FIFO order regardless of how much in fees they pay (the ledger spec does support a fee market, but cardano-node doesn’t take this into account) (Guillemont 2021)

TODO: language to discuss this quote.

Definition III.3.2 (Fragmented). *A UTXO state model is **fragmented** when there is more than one state UTXO in play at a time.*

Definition III.3.3 (Normalized). *A UTXO state model is **normalized** when there is neither disagreement nor redundancy regarding the data stored by the collection of UTXOs.*

Our UTXO state model design is *fragmented* yet *normalized*. In such a model, a fairness guarantee is impossible: to have a fairness guarantee, each pool would have to update each other, which isn’t possible to do in one transaction.

IV. Attacks

IV.1. Vampire attack

Definition IV.1.1 (Vampire attack). *Let Π and Π' be similar protocols, but Π launched and attracted investors and customers earlier, and Π' is somehow derivative of Π . Suppose Π' competes with Π such that Π' makes parameter choices or other measures to become more attractive to investors or customers than Π . A **vampire attack** is defined as the migration of value (liquidity or other assets) out of Π into Π' .*

IV.1.1. The literature

Consult a selection of stories about vampire attacks.

- $\Pi' = \text{SushiSwap}$; $\Pi = \text{UniSwap}$ ¹. SushiSwap was in fact a fork of UniSwap's code, and they provided incentives that directly targeted UniSwap investors and liquidity providers. This is the canonical notion of a vampire attack, with what appears to be the most written about it because of its scale of impact and how early on the DeFi scene it was found. Our present definition is generalized for analysis that applies outside of the specific conditions here.
- $\Pi' = \text{Swerve}$; $\Pi = \text{Curve}$ ². The term “vampire” does not occur in this article, but blaize.tech³ considers it to be a vampire attack. By forking Curve, Swerve offered a platform very similar to Curve's, and became competitive in TVL in a matter of days while people pulled out of Curve. There doesn't appear to be anything unique about Curve and Swerve being stablecoin DeXes.
- $\Pi' = \text{Artion}$; $\Pi = \text{Opensea}$ ⁴. At current writing it's too early to tell, but it's possible that Artion by providing a platform competitive with Opensea will be considered to have vampire attacked it. Unfolding events for this to be the case would have to be that Artion is successful at the expense of Opensea. My choice to

¹<https://youtu.be/UFjXwrCGuog>

²<https://finance.yahoo.com/news/swerve-finance-total-value-locked-075020390.html>

³<https://blaize.tech/services/how-to-prevent-liquidity-vampire-attacks-in-defi/>

⁴<https://www.coindesk.com/tech/2021/09/24/andre-cronjes-new-nft-marketplace-is-a-vampire-attack-su>

be influenced by a CoinDesk writer's choice to call this a vampire attack is up for debate, but my intention is to be consistent with the ecosystem and the literature and I don't see grounds to exclude this writer from either.

- Extended notes on forks⁵.

IV.1.1.1. Major takeaways

- Lack of vampire attack stories in the Cardano ecosystem is, according to my analysis, not a by-construction property of Cardano. I.e. it's a matter of time.
- Forking a codebase is often used as evidence in favor of the accusation that a given Π' conducted a vampire attack, though forking is not an intrinsic property of the attack.

IV.1.2. Scenario: reputational damage if we're considered Π'

Are there competing DeXs that beat us to market that could accuse us of vampire attacking them? Imagine if a bunch of Curve investors pull out their liquidity, exchange it for ADA on Coinbase, and start playing Danaswap. Would Curve think of that like a vampire attack?

IV.1.3. Scenario: value siphoned out if we become Π

Suppose another DeX for stablecoins launches with an incentive structure more attractive to our community than our own.

Suppose further that, having open sourced the DeX contract code, this competitor copies our onchain code, and makes offchain code similar to ours themselves.

IV.1.3.1. Mitigations

- Keeping the DeX code closed source. This is a minor payout in risk reduction
- Peg fee parameters to democracy via governance token holders (so we don't have to worry about the wants and needs of the community not being met, we don't have to worry about competitors siphoning them away from us).

⁵<https://newsletter.banklesshq.com/p/fork-defense-strategies-in-defi>

IV.1.4. Conclusion

In any kind of market, participants take on the unavoidable risk of competitors showing up with better rates. The factor of code forking presented by the open source software context doesn't change this much, and the factor of parameters like fees presented by the economics of DeFi context doesn't either.

IV.2. Flashloans

Flashloans are associated with something like \$136M⁶ in⁷ losses⁸.

Definition IV.2.1 (Flashloan attack). *Let a **flashloan** be some multi-step transaction that begins with an uncollateralized loan and ends with repayment of that loan, with arbitrary logic in between. Then, a **flashloan attack** is some method of manipulating prices during such a transaction and profiting.*

Ethereum offers flash loans because they have **multi-step atomic transactions**. There is no such mechanism in Cardano.

Belief IV.2.1 (No flashloans). *Flashloans will not be entering the Cardano ecosystem.*

As such, Danaswap, Ardana stablecoins, and mechanisms related to Dana governance tokens are not vulnerable to flashloan attacks.

IV.2.1. Action: monitoring Cardano for developments in multistep atomic transactions

Project Ardana will be monitoring the evolution of Cardano, because we believe that if multistep atomic transactions are introduced flashloans will be shortly around the corner.

⁶<https://peckshield.medium.com/bzx-hack-full-disclosure-with-detailed-profit-analysis-e6b1fa9b18fc>

⁷<https://news.bitcoin.com/defi-protocol-harvest-finance-hacked-for-24-million-attacker-returns-2-5>

⁸<https://www.coindesk.com/markets/2021/05/20/flash-loan-attack-causes-defi-token-bunny-to-crash-ov>

IV.2.1.1. In this event, the following mitigation strategy sketches will become urgent

- Onchain code only allow interop from one platform and users, not arbitrary platform.
- Lending products ought to require to collateralize in one whole transaction ahead of time before.
- Block price manipulation by disallowing mid-transaction information from updating prices.

IV.3. Reentrancy

A procedure is **reentrant** if it can be initiated while it's already running or a prior initiation has been interrupted and both runs can terminate, failing to raise an error. The infamous “DAO Hack” of 2016 occurred because Solidity allows the programmer to write reentrant smart contracts (Ma et al. 2019, 59–63).

Belief IV.3.1 (No reentrancy). *Plutus does not afford the freedom to write reentrant contracts.*

We can make a blanket statement that smart contracts in Cardano are invulnerable by construction to reentrancy. This is true because no transaction can be validated by (and it follows can require validation from) two different contracts. If you imagine Alice writes contract A and invokes it (executing the program \mathbf{Alice}_A) to validate transaction T , then Bob invokes A (\mathbf{Bob}_A) before Alice's invocation terminates, T will be validated by **at most** one of \mathbf{Alice}_A , \mathbf{Bob}_A .

As such, reentrancy attacks are not a threat to Danaswap, Ardana stablecoins, or any mechanism relating to Dana governance tokens.

V. Appendices

V.1. Appendix A: invariant polynomial

(Egorov 2019) gives us a way of easing between constant-sum and constant-product market-making by a coefficient χ called *leverage*, which turns out to be a function of D and $B(s)$, where $B : S \rightarrow \mathbb{R}^n$ ¹ is a function assigning in every state a balance to each of n assets. In what follows, let $x = B(s)$ such that $x_j = B(s)_j$ for each asset label j .

$$\chi D^{n-1} \sum x_i + \Pi x_i = \chi D^n + \left(\frac{D}{n} \right)^n$$

When χ is a blackbox, there is very little analysis available regarding the existence and behavior of roots or the convergence of any root-finding algorithm. We will forego any gains of abstracting over leverage coefficients, and let $\chi = \frac{A(\Pi x_i) n^n}{D^n}$ before proceeding.

V.1.1. Derivation of Invariant polynomials

First we derive I_D , the polynomial in unknown D .

¹Balances are strictly positive, so it's not really \mathbb{R}^n , however we enjoy some vector space properties in [DanaswapWhitepaper, p. 6] so we do not constrain the set.

Derivation V.1.1 (I_D).

$$\begin{array}{c}
\chi D^{n-1} \Sigma x_i + \Pi x_i = \chi D^n + \left(\frac{D}{n}\right)^n \\
\hline
\frac{A(\Pi x_i) n^n}{D^n} D^{n-1} \Sigma x_i + \Pi x_i = \frac{A(\Pi x_i) n^n}{D^n} D^n + \left(\frac{D}{n}\right)^n \\
\hline
\frac{A(\Pi x_i) n^n}{D} \Sigma x_i + \Pi x_i = A(\Pi x_i) n^n + \frac{1}{n^n} D^n \\
\qquad \qquad \qquad \times D \quad \times D \\
\hline
An^n(\Pi x_i) \Sigma x_i + (\Pi x_i) D = An^n(\Pi x_i) D + \frac{1}{n^n} D^{n+1} \\
- An^n(\Pi x_i) D - \frac{1}{n^n} D^{n+1} \quad - An^n(\Pi x_i) D - \frac{1}{n^n} D^{n+1} \\
\hline
An^n(\Pi x_i) \Sigma x_i + (\Pi x_i) D - An^n(\Pi x_i) D - \frac{1}{n^n} D^{n+1} = 0 \\
\hline
\frac{-1}{n^n} D^{n+1} + (1 - An^n)(\Pi x_i) D + An^n(\Pi x_i) \Sigma x_i = 0 \\
\qquad \qquad \qquad \times -n^n \quad \times -n^n \\
\hline
D^{n+1} - n^n(1 - An^n)(\Pi x_i) D - An^{2n}(\Pi x_i) \Sigma x_i = 0 \\
\hline
D^{n+1} + (A - n^{-n}) n^{2n}(\Pi x_i) D + -An^{2n}(\Pi x_i) \Sigma x_i = 0
\end{array}$$

We now have a polynomial in $x \mapsto x^{n+1} + ax + b$ form, for constants a and b which are functions of a balance sheet and the *amplification coefficient* A .

Next, we start from a similar place and derive a polynomial in unknown of $B(s)_k = x_k$.

Derivation V.1.2 (I_k). $\forall k \in 1..n$,

$$\begin{aligned}
& \frac{A(\Pi x_i)n^n}{D^n} D^{n-1} \Sigma x_i + \Pi x_i = \frac{A(\Pi x_i)n^n}{D^n} D^n + \left(\frac{D}{n}\right)^n \\
\hline
& \frac{An^n}{D} (\Pi_{i \neq k} x_i) x_k (x_1 + \dots + x_k + \dots + x_n) + (\Pi_{i \neq k} x_i) x_k = An^n (\Pi_{i \neq k} x_i) x_k + \frac{D^n}{n^n} \\
\hline
& \frac{An^n}{D} (\Pi_{i \neq k} x_i) x_k^2 + \frac{An^n}{D} (\Pi_{i \neq k} x_i) (\Sigma_{i \neq k} x_i) x_k + (\Pi_{i \neq k} x_i) x_k = An^n (\Pi_{i \neq k} x_i) x_k + \frac{D^n}{n^n} \\
& \quad - An^n (\Pi_{i \neq k} x_i) x_k - \frac{D^n}{n^n} \quad - An^n (\Pi_{i \neq k} x_i) x_k - \frac{D^n}{n^n} \\
\hline
& \frac{An^n}{D} (\Pi_{i \neq k} x_i) x_k^2 + \left((\Pi_{i \neq k} x_i) \left(\frac{An^n}{D} \Sigma_{i \neq k} x_i + 1 - An^n \right) \right) x_k + \frac{-D^n}{n^n} = 0 \\
& \quad \div \frac{An^n}{D} (\Pi_{i \neq k} x_i) \quad \div \frac{An^n}{D} (\Pi_{i \neq k} x_i) \\
\hline
& x_k^2 + \left(\Sigma_{i \neq k} x_i + \frac{D}{An^n} - D \right) x_k + \frac{-D^{n+1}}{An^{2n} \Pi_{i \neq k} x_i} = 0 \\
\hline
& x_k^2 + \left(\Sigma_{i \neq k} x_i - D \left(1 - \frac{1}{An^n} \right) \right) x_k + \frac{-D^{n+1}}{An^{2n} \Pi_{i \neq k} x_i} = 0
\end{aligned}$$

We now have a quadratic in $x \mapsto x^2 + ax + b$ form, for constants a and b which are each functions of D and the other assets on the balance sheet.

V.1.2. Analysis of roots and of derivatives

TODO (notes in longreports/rootfinding/newton-robustness.ipynb)

VI. Bibliography

10 Egorov, Michael. 2019. “StableSwap - Efficient Mechanism for Stablecoin Liquidity.” <https://curve.fi/files/stableswap-paper.pdf>.

Guillemont, Sebastien. 2021. “[FR] - Increase Network Throughput.” GitHub issue. 2021. <https://github.com/input-output-hk/cardano-node/issues/3247>.

Ma, Richard, Jan Gorzny, Edward Zulkoski, Kacper Back, and Olga V. Mack. 2019. *Fundamentals of Smart Contract Security*. Momentum Press.

Thomas, Morgan. 2021a. “Danaswap: A Scalable Decentralized Exchange for the Cardano Blockchain.” insert hyperlink here¹.

———. 2021b. “Transaction Throughput Scalability Strategies for Plutus Smart Contracts.” *Journal.Platonic.Systems*. <https://platonic.systems/papers/utxo-models-public.pdf>.

Wikimedia. 2021. “Newton’s Algorithm.” 2021. https://en.wikipedia.org/wiki/Newton's_method.

¹<https://insert%20hyperlink%20here>