DeFi composability as MEV non-interference

Does a new contract interact safely with the rest of the blockchain?

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DeFi composability

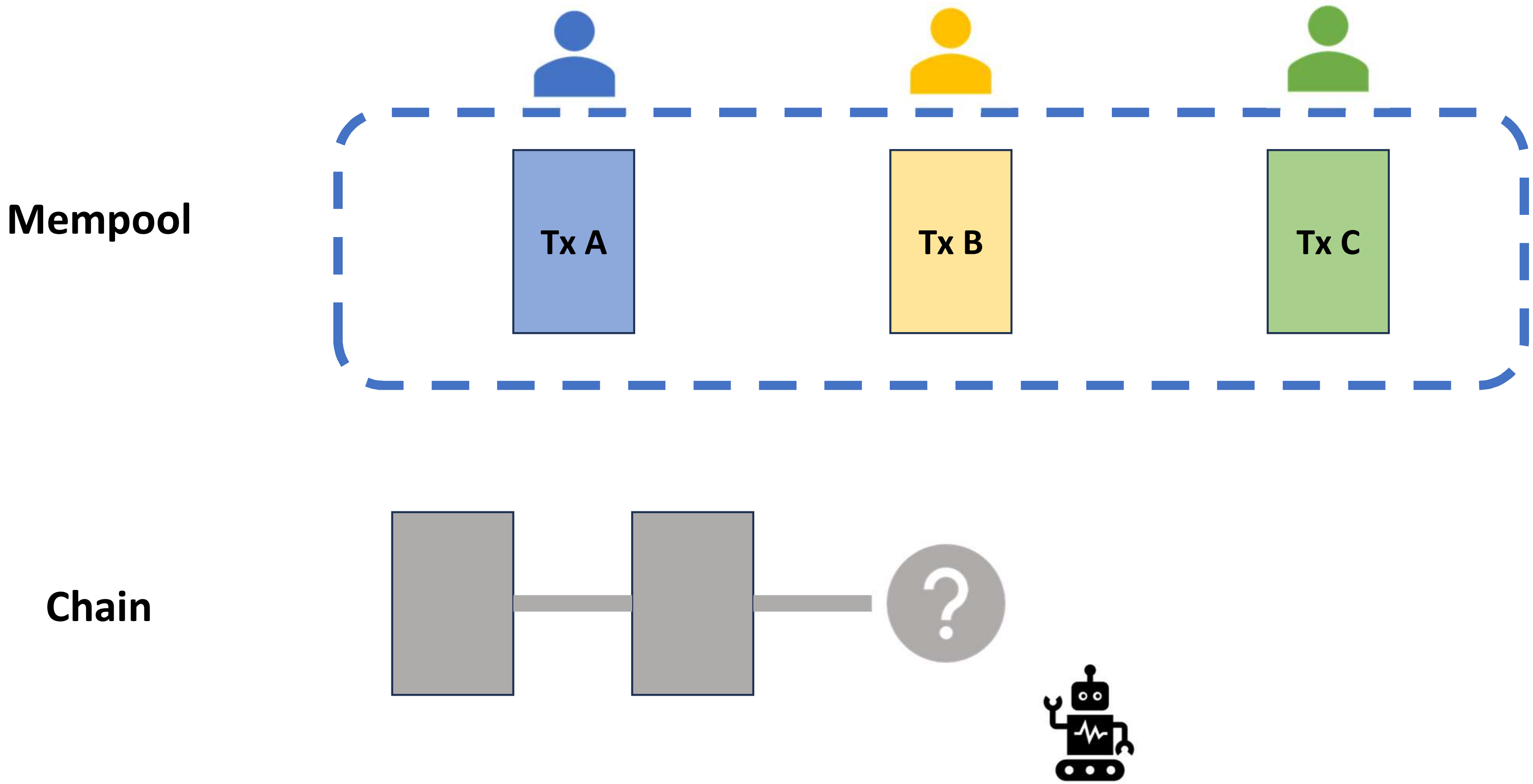
DeFi ecosystems have complex interactions and dependencies between protocols

Malicious users may exploit unintended forms of interaction

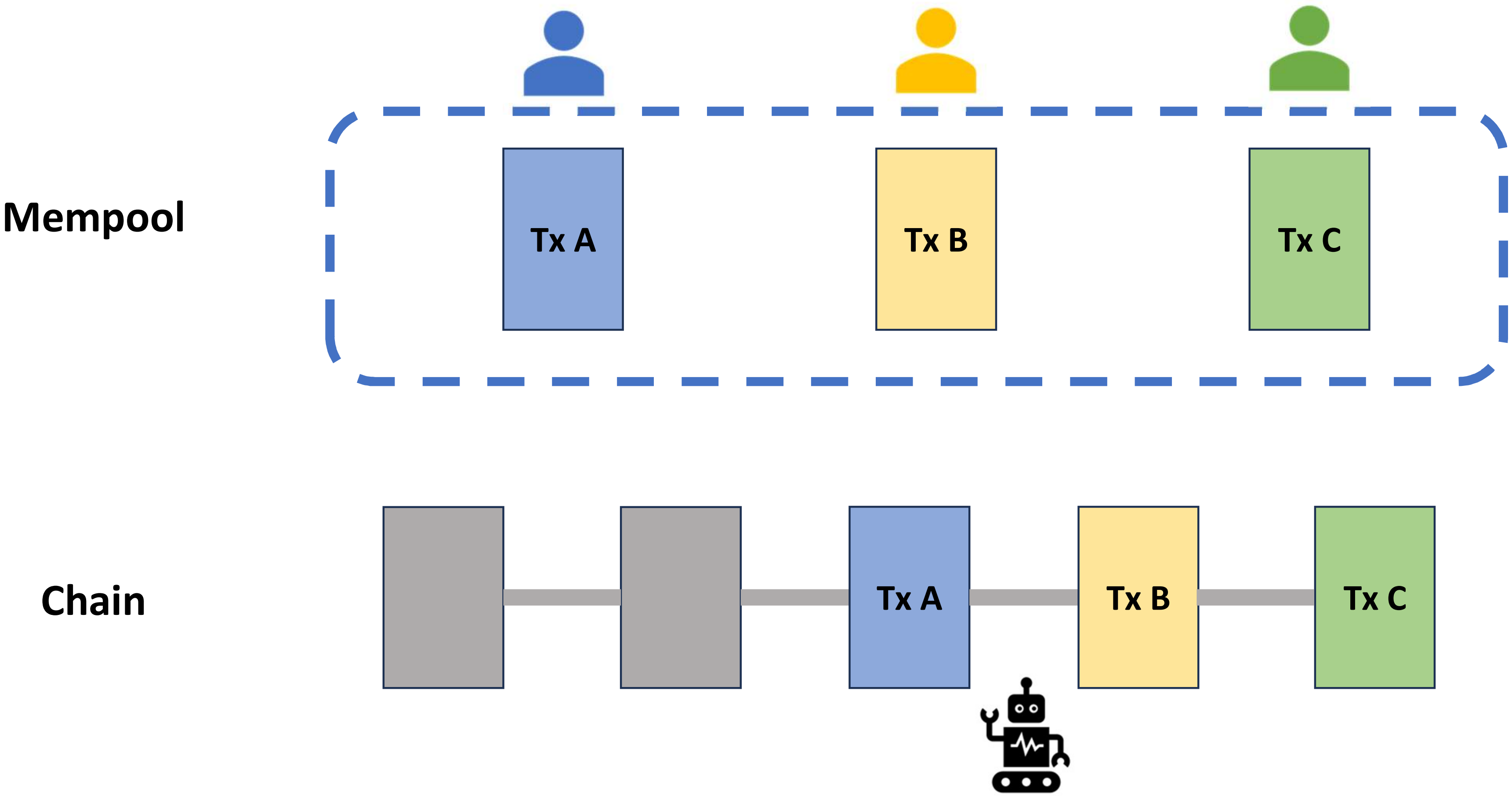
This is not limited to bugs: we also consider economic attacks

Background: MEV attacks

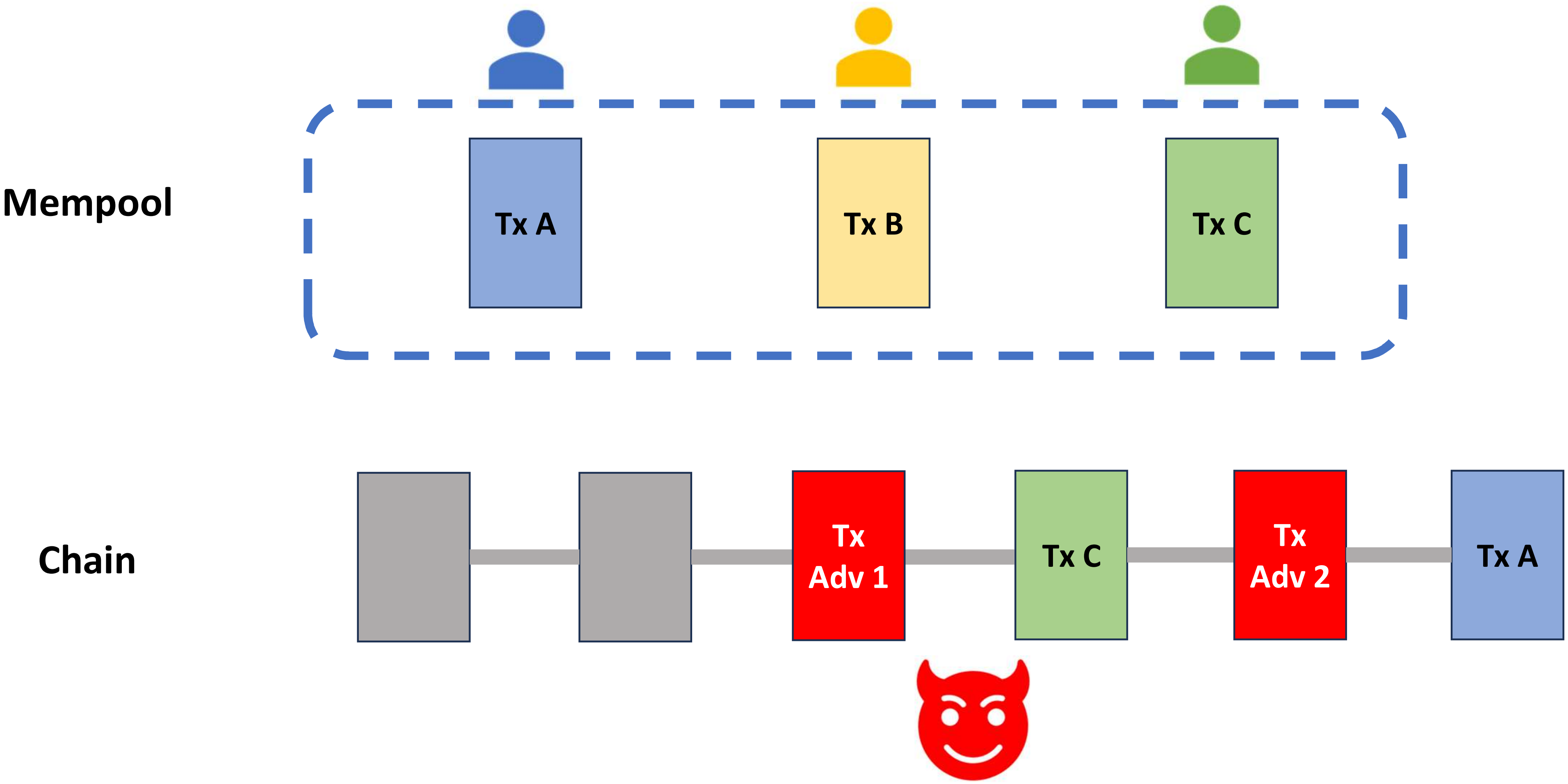
Transaction Ordering



Transactions ordering: expectation

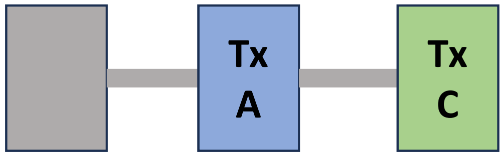


Transactions ordering: reality

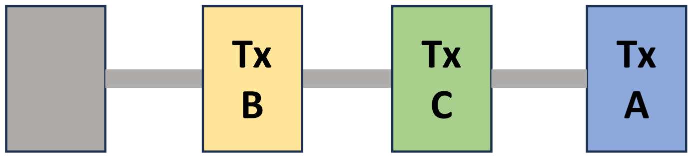


A malicious validator can…

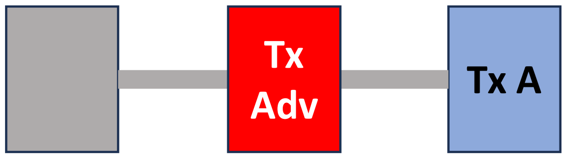
Drop transactions



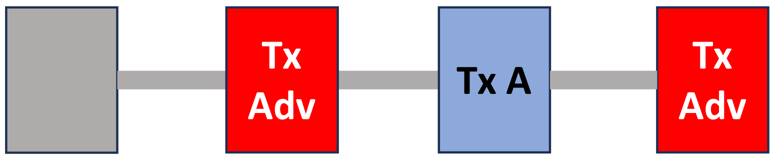
Rearrange transactions



Front-run transactions



Sandwich transactions



A vulnerable contract: the AMM

AMMs (Automated Market Makers) exchange two token types T0, T1 algorithmically adjusting the exchange rate (e.g. constant product between the amount of T0 and T1)

These attacks are **zero-risk** if performed by a validator

Attacks:

- A sends a transaction X to sell T0 and buy T1
- T0 will "lose value", T1 will "gain value"
- **Frontrunning**: Adv sell T0 to buy T1 before they gain value with X
- **Sandwiching**: Adv makes X unfavourable, put X, then balance AMM

Defining MEV

MEV = Maximal Extractable Value

$$MEV(S) = \max \{ gain_{Adv}(S, \underline{X}) \mid \underline{X} \in K(Adv)^* \}$$

- S is the blockchain state
- $\underline{X}$ is a sequence of transactions
- K(Adv) is the set of transactions craftable by Adv

Back to composability

ε-composability

A contract Δ is composable with a blockchain state S when it does not **significantly increase** MEV:

$$MEV(\, S \mid \Delta \,) \;\leq\; (1 + \varepsilon)\, MEV(S)$$

[“Clockwork Finance” paper by Babel, Daian, Kelkar, and Juels]

Drawbacks of ε-composability

- Computes the MEV of the **whole** blockchain state

  ➔ Inefficient

  ➔ Does not tell *from where* the MEV is extracted

- If Δ has MEV on its own, and does not interact with the rest of the system, is it fair to say it is non composable with S?

Composing AMMs (1)

- Adv[2:T0] | AMM[2:T0, 12:T1]

  Adv can sell 2:T0 and buy 6:T1

- Adv[2:T0] | AMM[2:T0, 12:T1] | AMM[2:T0, 12:T1]

  Adv can sell 1:T0 in each AMM and buy 4:T1 from each

Attacking both gives Adv more gain, but extracts less from each.

Are they composable?

Composing AMMs (2)

S = Adv[1:T0] | AMM1[1:T0, 2: T1] | AMM2[1:T1, 20:T2]

Adv can spend 1:T0, get 1:T1 and spend it again to get 10:T2

Attacking only AMM2 gives nothing. Having access to AMM1 helps Adv to extract a lot from AMM2.

Is AMM2 composable in S?

PriceBet

Consider a composed contract **PriceBet(C)**: bets on the exchange rate between two tokens, where the exchange rate is given by **C**

- PriceBet(AMM) where rate = ratio between amounts of tokens
- PriceBet(Exchange) where rate is set by an oracle

Are these compositions secure?

Hint: Adv can create volatility in the AMM to win the bet

(Bad) idea: adding MEVs

$$S = W \mid \Gamma \mid \Delta \quad \text{(W are wallets)}$$

Γ, Δ are composable iff

$$\mathrm{MEV}(S) \leq \mathrm{MEV}(\, W1 \mid \Gamma\,) + \mathrm{MEV}(\, W2 \mid \Delta)$$

(where $W1+W2 = W$)

Problem: We can’t always “break” S.

The expression MEV(Δ) is problematic when Δ that depends on Γ.

Local MEV

Local MEV = maximal loss of Δ

$$MEV(S,\Delta) = \max \{ loss_{\Delta}(S, \underline{\mathbf{X}}) \mid \underline{\mathbf{X}} \in K(Adv)^{*} \}$$

We are assuming a (potentially irrational) Adv who just wants to cause harm to the contract.

Restricted Local MEV

Restricted Local MEV = local MEV that Adv can extract from Δ by only targeting the contracts in Δ

$$MEV_{alone}(S,\Delta) = \max \{ loss_{\Delta}(S,\underline{\mathbf{X}}) \mid \underline{\mathbf{X}} \in (K(Adv) \cap tx(\Delta))^{*} \}$$

It is the loss caused to Δ "without help" from other contracts

Restricted local MEV

Restricted local MEV = value that an adversary can extract from Δ while only targeting contracts in Δ.

$$MEV_{alone}(S, \Delta) = \max\{ loss_{\Delta}(S, \underline{X}) \mid \underline{X} \in K_{\Delta}(Adv)^* \}$$

It is the loss caused to Δ “without help” from other contracts.

Composability as MEV non-interference

The state S does not interfere with new contracts Δ if

$$MEV(S \mid \Delta, \Delta) = MEV_{alone} (S \mid \Delta , \Delta)$$

Properties:

- Zero tokens in Δ implies non-interference
- Δ is independent from S (token & contract independence) implies non-interference

Composability w.r.t. rich adversaries

We also model a stronger adversary, with unbounded wealth.

Local MEV w.r.t. rich adversaries:

$$MEV^{\infty}(\Gamma, \Delta) = \max\{ MEV(S, \Delta) \text{ where } S = W|\Gamma \}$$

Non-interference w.r.t. rich adversaries:

$$MEV^{\infty}(\Gamma| \Delta, \Delta) = MEV^{\infty}_{alone}(\Gamma |\Delta, \Delta)$$

Non-interference w.r.t. rich adversaries

Results:

- $MEV^{\infty}(\Gamma, \Delta) = MEV^{\infty}(deps(\Delta), \Delta)$

  Front-running resistance: if Γ does not interfere with Δ then Γ| Γ’ does not interfere with Δ

- Zero-token composability
- Contract independence implies non-interference

A possible riformulation

States form a transition system, labeled by the transactions.

$\mathcal{T}$ set of transactions, $\mathcal{T}_\Delta$ transactions targeting delta.

Γ is MEV non-interfering with Δ

iff

$\forall\, W\ \forall\, \boldsymbol{T} \subseteq \mathcal{T}\ \exists\, \boldsymbol{T}' \subseteq \mathcal{T}_\Delta$ such that

$$W|\Gamma \xrightarrow{\boldsymbol{T}} S \ ,\ \ W|\Gamma \xrightarrow{\boldsymbol{T}'} S' \ \text{ and } \ \$(\Delta, S') \preccurlyeq \$(\Delta, S \quad)$$

Challenges

- Use more sofisticated non-interference methods to study attacks
- Model a rational adversary, while keeping some results
- Weaken well-formedness assumption on states/contracts

References

DeFi composability as MEV non-interference: https://arxiv.org/abs/2309.10781

Clockwork Finance: Automated Analysis of Economic Security in Smart Contracts: https://arxiv.org/abs/2109.04347