Blockchain Economics

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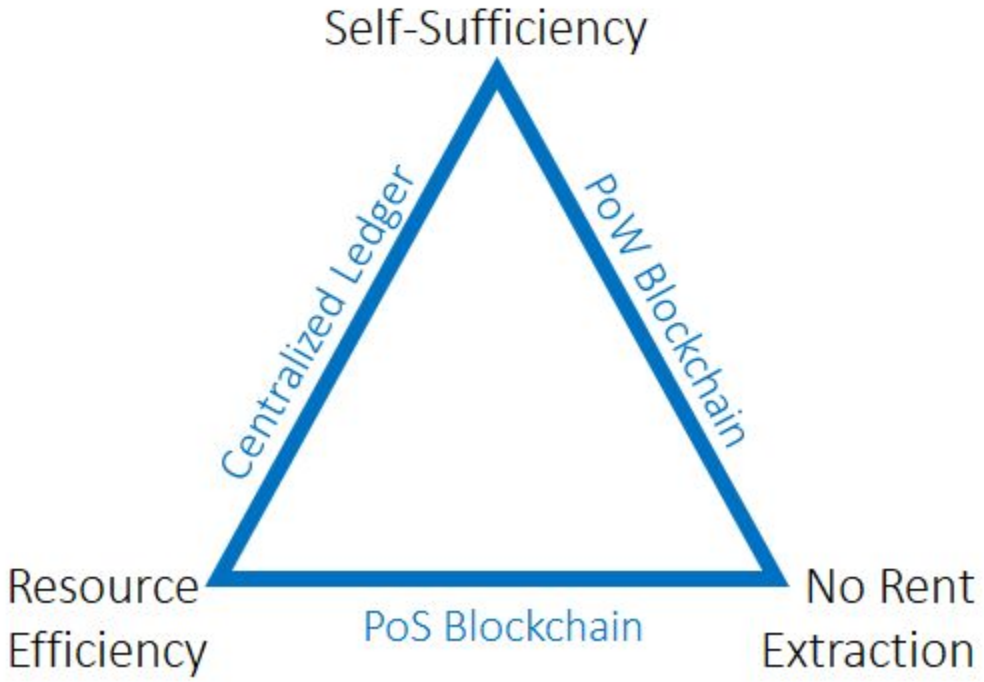
How can we generate consensus?

- Fundamental problem of record-keeping: Create trusted *ledger*

- What are the assumptions required to operate a trusted ledger?
  - Centralized ledger: **Rents**
  - PoS blockchain: **External trust**
  - PoW blockchain: **Resource costs**

- What are the **tradeoffs** and **constraints** in record-keeping?
  - When is PoW necessary?
  - How is PoS trust different from centralized trust?
  - Does the desired mechanism imply an optimal consensus algorithm?

Blockchain Trilemma



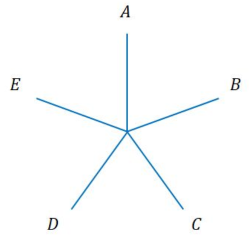
Self-sufficiency and external trust

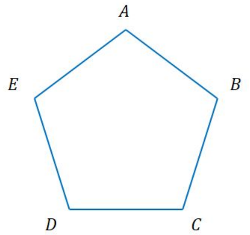
- External trust: Capacity to **punish** other agents
  a. Mutually beneficial relationships
    - Business relationships (news media, non-ledger related business)
    - Social connections (friends, colleagues)
    - Elected officials
  b. Legal enforcement relationships

- Tradeoff: Lose social trust ⇒ System collapses

- Different from traditional centralized trust model! **Local** trust can be **scaled globally**

Centralized trust





Scaled local trust

Summary of Trilemma

- Economic reasoning behind trilemma?
  - Three ways of distorting consensus
    1. Digital signatures (lose **rents**)
    2. Social messages (lose **external trust**)
    3. PoW (pay **resource cost**)

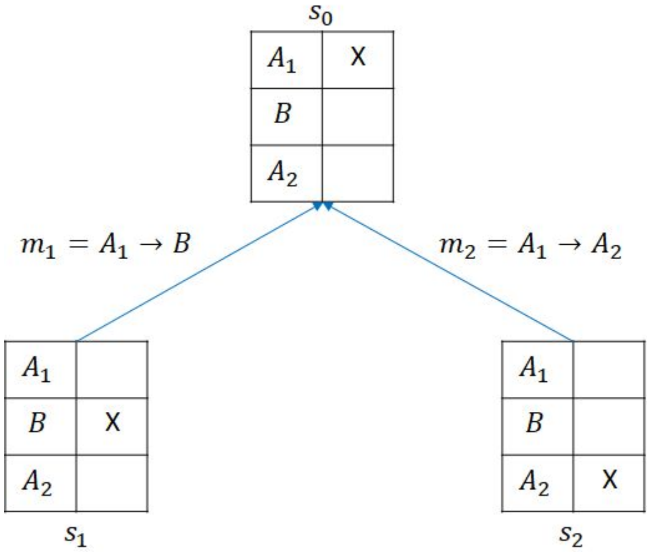
- Guiding framework about optimal record-keeping system
  - Small rent distortions ⇒ Centralized/Permissioned
  - Robust external trust ⇒ PoS, Ripple
  - No external trust + large rent distortions ⇒ PoW

Roadmap

- Challenge of digital record-keeping
- Key model ingredients
- Benchmark example
  a. Centralized
  b. PoS blockchain
  c. PoW blockchain
- Proof idea

Challenge of digital record-keeping

- Key issue: No scarcity of digital "assets"
  - Unlike physical tokens
  - Ordering of messages matters



Solution: Consensus algorithm

- Three types: Differ in **info. requirements** to determine state
  - **Objective**: Set of messages sufficient for all users to achieve consensus
    - E.g. PoW "longest chain rule"
  - **Weakly subjective**: Set of messages + recent past state needed
    - Attacker votes twice ⇒ "Checkpoint" might be necessary
    - E.g. PoS "supermajority rule"
  - **Subjective**: Different users can come to different conclusions
    - E.g. Centralized system, Ripple

- Consensus guaranteed by **incentive schemes**
  - **Objective**: Cost of participation
  - **Weakly subjective**: Short-run punishments + Long-run reputation
  - **Subjective**: Long-run reputation

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Model: Users and mechanism

- **Users**: (Large number *N*)
  - External **trust relationships** between users *i*, *j* ⇒ Bilateral utilities u_{ij}
    - Underlying graph G of social connections
  - Users may pay **physical cost** κw to produce *w* units of PoW
  - Two types of communication: Social messages + (pseudonymous) digital messages

- **Mechanism**:
  - State *s* summarized by token holdings in pseudonymously-owned addresses
  - Mechanism $\mathcal{M}$ specifies actions $a_i(s)$ as a function of state, address ownership
    - Implicitly defines **rents** r_{ij} extracted by user *i* when *j* is present
  - Utility of user *i*:

$$U_i = \underbrace{V_i(s)}_{\text{Tokens}} + \underbrace{\sum_j r_{ij}}_{\text{Rents}} + \underbrace{\sum_j u_{ij}}_{\text{Social trust}} - \underbrace{\kappa W_i(s)}_{\text{Exp. PoW}}$$

Model: Blocks and record-keeping

- **State** *s*: Allocation of tokens to addresses
  - Purpose of blockchain: Generate consensus on current state
- **Token transfer messages**: Message (n, n', q) transfers q tokens from n to n'
  - Also incorporate seignorage/block rewards
- **Votes**: Arbitrary collection of messages $\mathcal{V}$ used to update state
  - Two types of permissions:
    - **Digital signatures:** E.g. PoS: Fraction of validators who sign a checkpoint
    - **External Proof:** E.g. PoW: Expected quantity of work required
- **Blocks**: Tuple $b = (m, v, p)$
  - m Token transfer messages,
  - v Votes cast on block
  - p Pointer to previous block

Model: Consensus

- **Block tree:** Partially ordered set *B* of blocks
  - Ordering induced by block pointers *p*
  - Blockchain: Ordered subset $C \subset B$
- **Consensus algorithm**: Update consensus chain given previous consensus $C^*_{t'}$, blocks B_{t+1}
  - Function $C^*_{t+1} = g(C^*_{t'}, B_{t+1})$
  - Previous state may be needed to determine consensus chain
- Fundamental problem: Desire to distort consensus
  - Three ways of distorting consensus ⇒ Three types of costs

$$U_i = V_i(s) + r_i + u_i - \kappa W_i(s)$$

$$\Rightarrow \Delta V_i \leq \Delta r_i + \Delta u_i - \kappa \Delta W_i$$

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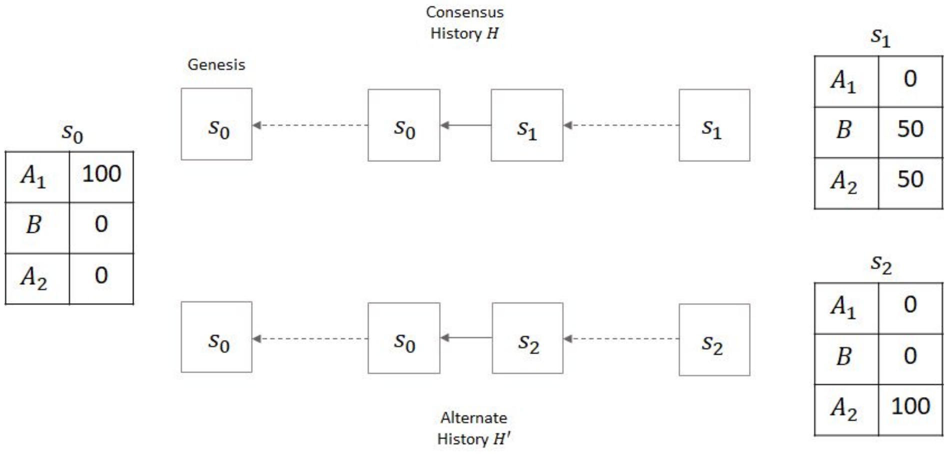
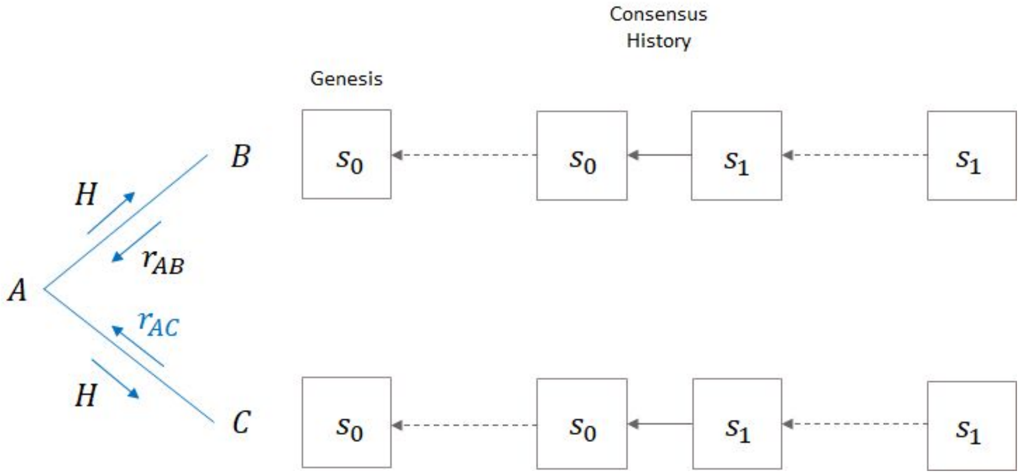
Benchmark example

- Consensus history (*H*): A sent 50 tokens to B and 50 tokens to own account
- Alternate history (*H'*): A sent tokens to own account only
  - Can A convince a new user C of the alternate history?
  - Can A generate consensus on alternate history?



Example: Centralized ledger

- Monopolist A communicates history to users (subjective)
  - Old user B: Knows state transitioned from s_0 to s_1
  - New user C: Can be fooled by fraudulent report

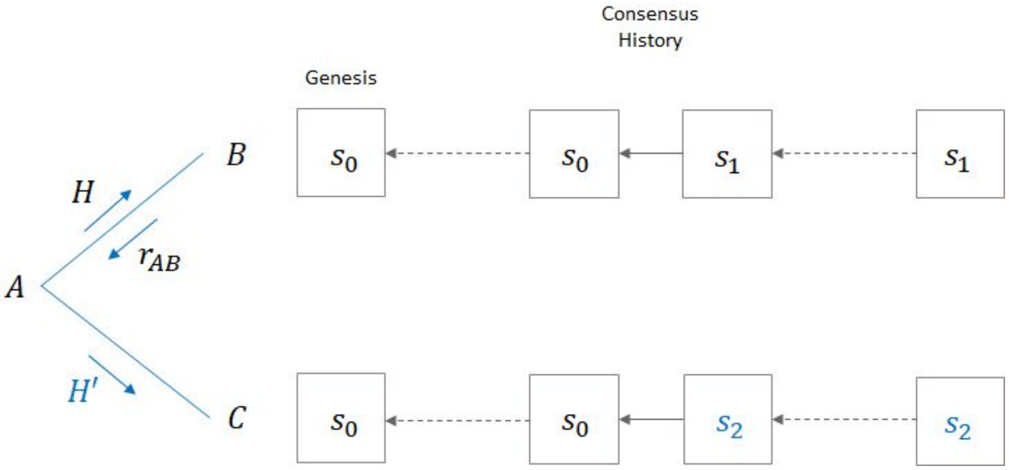


Honest reporting: A extracts rents from B and C

$$U_A = V(s_1) + r_{AB} + r_{AC}$$

Example: Centralized ledger

- Dishonest reporting: Send entirely different ledger to C
  - C is fooled by A initially but stops using the system afterwards



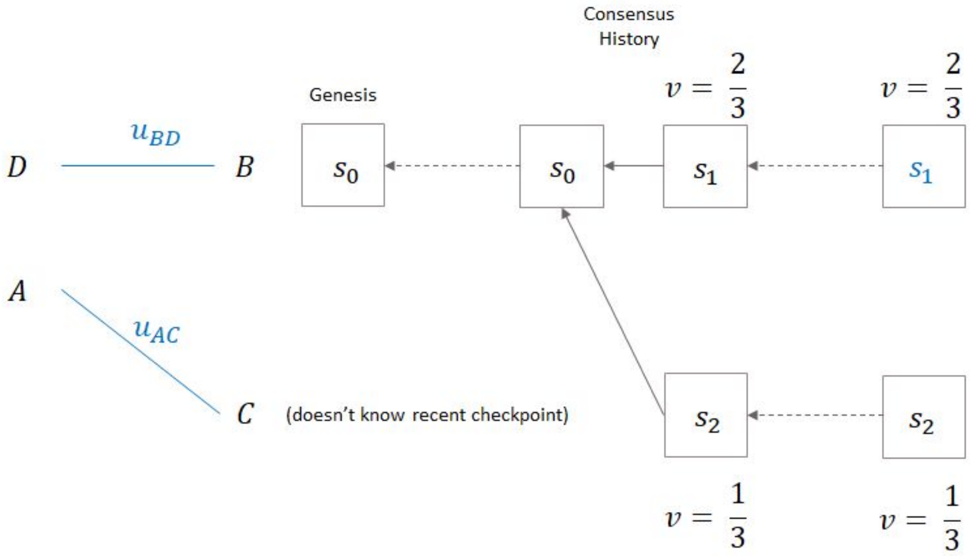
Dishonest reporting: Get value from attack, lose rents from C

$$U_A = V(s_1) + r_{AB} + V_A$$

$$\Rightarrow \text{IC: } V_A \leq r_{AC}$$

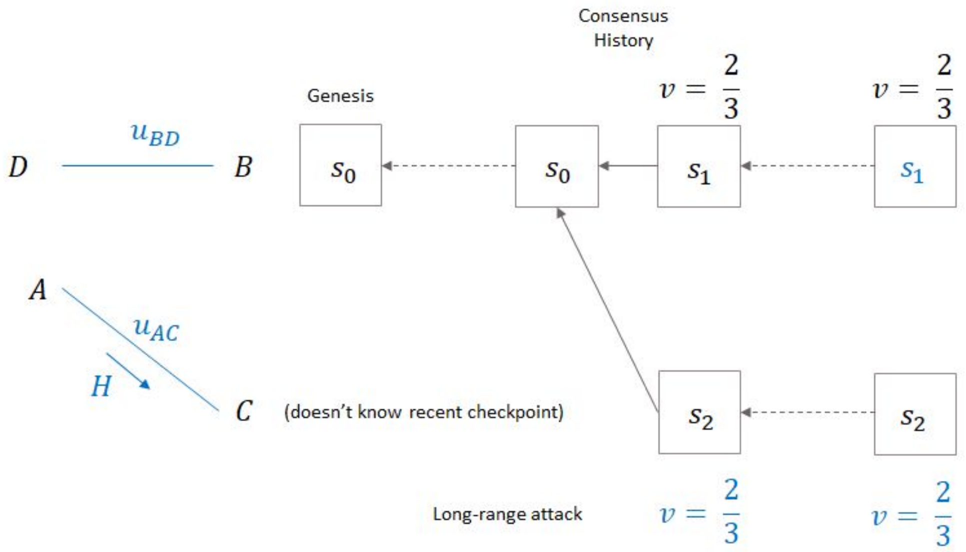
Example: PoS blockchain

- PoS consensus algorithm: Supermajority rule (weakly subjective)
  - Old user *B*: Knows state transitioned from s_0 to s_1
  - New user C: Concludes state is s_1 by supermajority rule



Example: PoS blockchain

- PoS consensus algorithm: Supermajority rule (weakly subjective)
  - Old user *B*: Knows state transitioned from s_0 to s_1
  - New user C: Needs input from trusted connection *A*



Honest reporting: *A* benefits from trust relationship with *C*

$$U_A = V(s_1) + u_{AB} + u_{AC}$$

Example: PoS blockchain

- PoS consensus algorithm: Supermajority rule (weakly subjective)
  - Old user *B*: Knows state transitioned from s_0 to s_1
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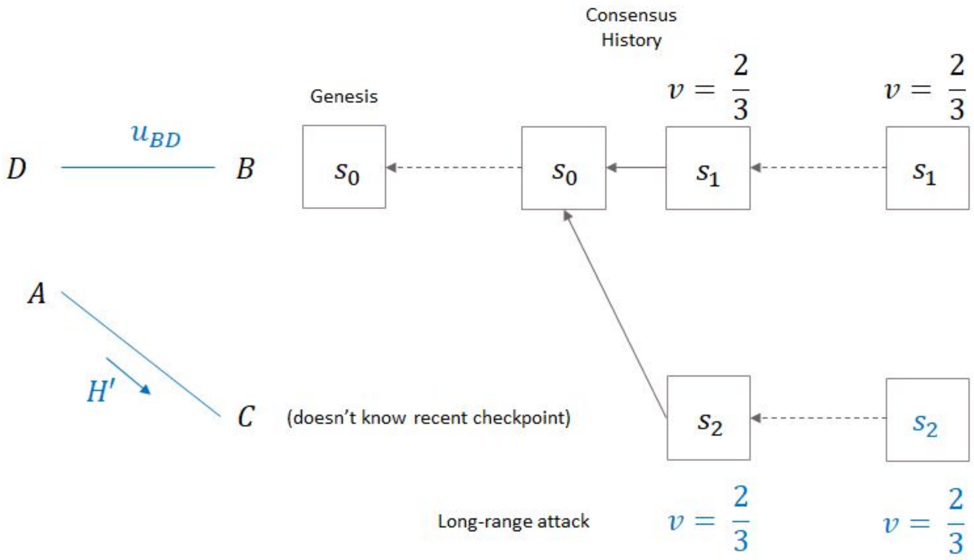


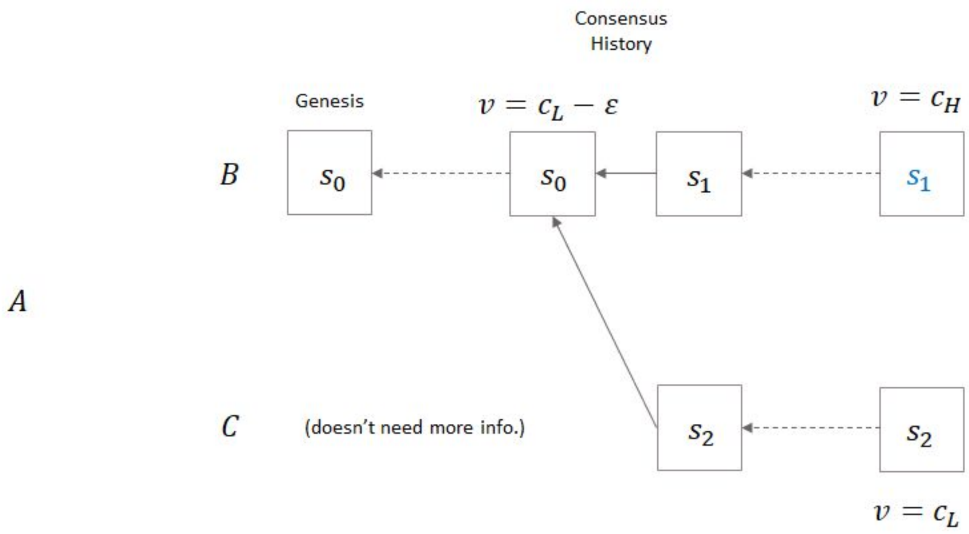
Long-range attack: *A* benefits from attack, loses trust with *C*

$$U_A = V(s_1) + V_A$$

$$\Rightarrow \text{IC: } V_A \leq u_{AC}$$

Example: PoW blockchain

- PoW consensus algorithm: Longest chain rule (objective)
  - Any user (old or new) can determine current state



Honest mining: Consensus is s_1

$$U_A = V(s_1)$$

Example: PoW blockchain

- PoW consensus algorithm: Longest chain rule (objective)
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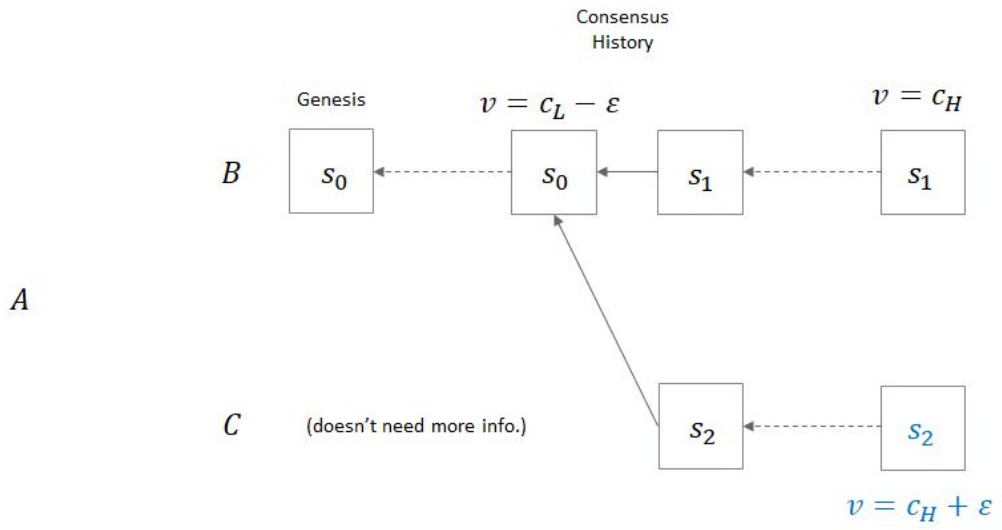

Double-spend: Consensus is s_2, pay physical resource cost

$$U_A = V(s_2) - (c_H - c_L)$$

$\Rightarrow$ IC: $V_A = V(s_2) - V(s_1) \leq c_H - c_L$

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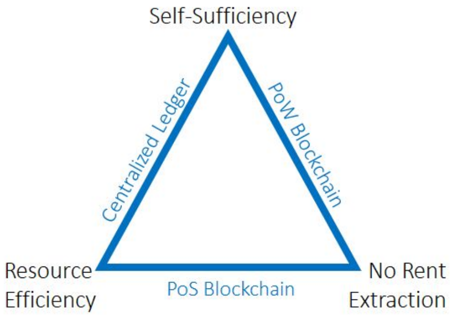
Statement of Blockchain Trilemma

- In order to achieve consensus in equilibrium, it must be that for any attacking coalition,

$$V_A \leq \underbrace{r}_{\text{rents}} + \underbrace{u}_{\text{ext. trust}} + \underbrace{c}_{\text{resource cost}}$$

- Impossible to have all three properties:



Statement of Blockchain Trilemma

- In order to achieve consensus in equilibrium, it must be that for any attacking coalition,

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- Depends on features of **mechanism**, **external environment**, and **consensus algorithm**
  - Rents/value of attack: Features of mechanism
  - External trust: Feature of environment
  - Resource cost: Feature of consensus algorithm

Proof sketch: Mimicking Lemma

- **Always possible to present new user with a cryptographically valid alternate history**
  - Centralized system: Give new user entirely different ledger
  - PoS blockchain: Long-range attack
  - PoW blockchain: Standard double-spend

- Extends to **arbitrary hybrid consensus algorithms**
  - Social messages + digital signatures + PoW are sufficient to create valid ledger
  - Who can attack?
    - Depends on writing permissions/possibilities for collusion
  - How much does it cost to attack?
    - Digital signature: Ex-post loss of **rents**
    - Social message: Ex-post loss of **external trust**
    - PoW: Ex-ante **resource cost**

Possession vs. Ownership: Enforcement

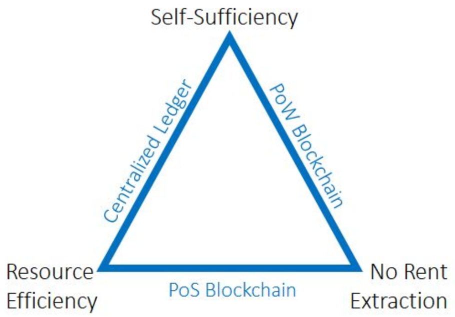
- Blockchain as a ledger for all kinds of assets– not just cryptocurrencies
- Who will enforce the ledger?

You see, in this world, there are two types of people, my friend– those with loaded guns, and those who dig. You dig.

- So far: Ignored distinction between **ownership** and **possession**
  - Ownership is traded in a market
  - Possession is conferred by previous possessor and must be **enforced**
    - E.g. Owning a house with squatters inside
- Cryptocurrency is special: No need to enforce any agreements

Conclusion

- Blockchain Trilemma:



- Guiding framework to answer questions about how records should be kept
  - What security assumptions underlie different models of record-keeping?
  - Local external trust: Globally scalable with blockchain
- Ownership vs. possession: Record-keeping is useful only if there's enforcement