Resource Burning for Permissionless Systems

Jared Saia

Joint with Diksha Gupta and Maxwell Young

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Permissionless System:

Participants are virtual IDs

Join and depart without scrutiny

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Resource Burning:

Verifiable consumption of a resource

↑ Permissionless Systems

Blockchains

Peer-to-peer

↑ Resource Burning

Proof of work

CAPTCHAs

Positions

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Resource burning is fundamental

Cybersecurity:

[Dwork and Naor ’92] combat spam

Blockchains, DDoS attacks, review spam, DHTs

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Biology

Economics/Game theory

Biology: Costly Signaling

Sexual selection: peacock tail, antlers

Predator/Prey signaling: stotting

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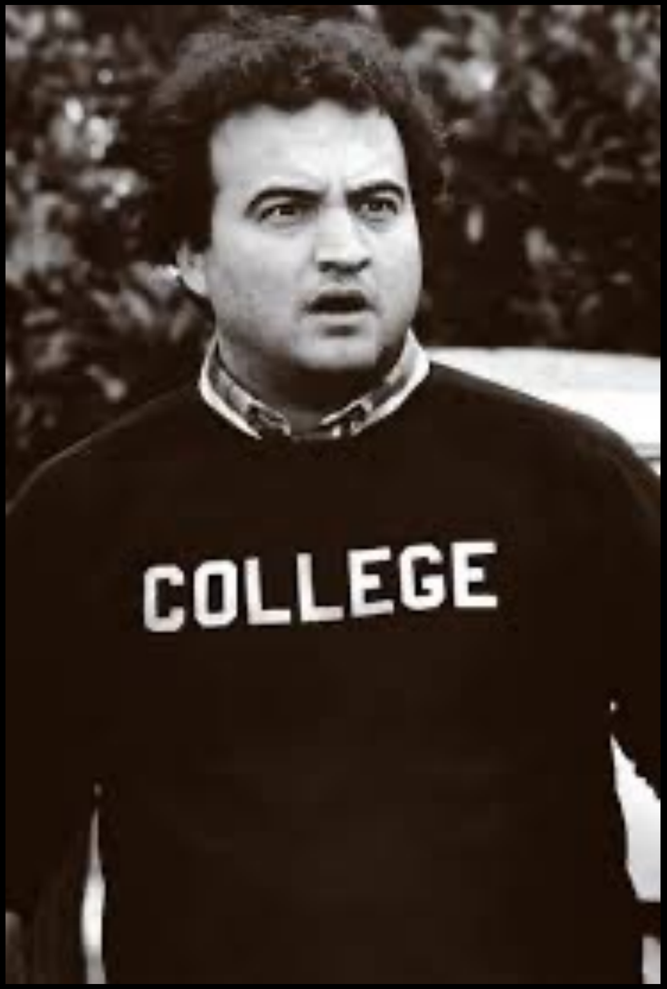
Game Theory: Money Burning

Purpose is to signal:

- Type of a player
- Commitment to an action

Signaling Type: College Game



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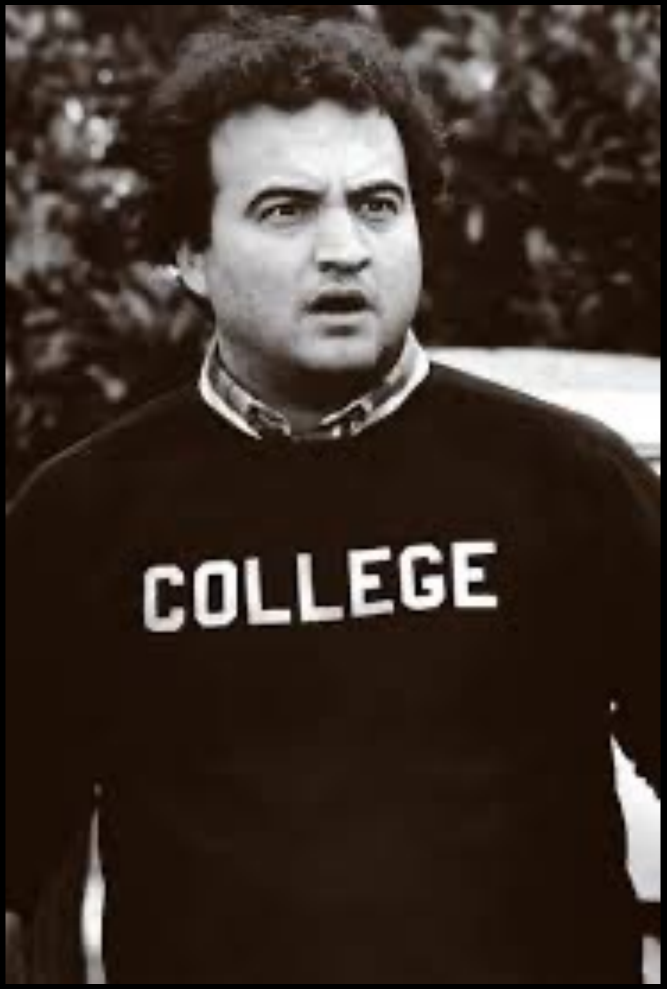

“Great! Seven years of college down the toilet.”

College?

	Smart	Daft
Attend	-1	-3

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Hire?

	Smart	Daft
Hire	2	-2

Student: Payoff of 2 if hired; else 0

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Nash equilibrium: (1) Only smart students attend college; (2) Employer hires only college attendees.

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Theoretical results suggest significant improvements possible

Can optimize RB like any other resource

T = Adversary's resource burning (RB) rate

$f(T)$ = Algorithm's resource burning rate

↓ RB = ↑ Security

Reduced Resource Burning cost can improve security

Can analyze using game theory

Zero-sum game between adversary and algorithm

Zero-sum Game

T = cost to attack

$f(T)$ = cost to defend

D = Cost of defeat

	Attack	¬Attack
Defend	$T - f(T)$	$-f(0)$
¬Defend	$-D$	0

T = cost to attack; $f(T)$ = cost to defend;

D = cost of defeat; p = probability to defend

To solve, set

$$p(T - f(T)) - (1 - p)D = p(-f(0))$$

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$p(T - f(T)) - (1 - p)D = p(-f(0))$

$$p = \frac{D}{T - f(T) + f(0) + D}$$

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Payoff:

$$\frac{-f(0)D}{T - f(T) + f(0) + D}$$

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Payoff:

$$\frac{-Df(0)}{T + f(0) - f(T) + D}$$

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Algorithm Cost | Game Payoff

$$f(T) = f(0) + o(T) \quad \rightarrow \quad O(-f(0))$$

$$f(T) = f(0) + \sqrt{Tf(0)} \quad \rightarrow \quad O\left(\frac{-f(0)D}{f(0) + D}\right)$$

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Resource Burned Shouldn’t Matter

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Resource burning must be

- Verifiable
- *Non-amortizable*
  - Solving x challenges of difficulty d requires $\approx xd$ resource consumption

RB Common Examples

Proof of work via SHA hashing

Proof of space & space-time

CAPTCHAs

Radio resource-testing (wireless networks)

RB can also do useful work

[Ball et al. ’18]: “Proof of Useful Work”

[Von Anh et al. ’08]: RECAPTCHA

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For Blockchains:

PoX: Matrix Multiplication

PrimeCoin: Finding primes

Permacoin: Maintaining blockchain

Piecework: Spam deterrence

Not RB: Proof of Stake

Used in: Algorand, Ouroboros, Ethereum

Proof of stake is a measurement

ID's stake must be known

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Proof of stake is a measurement

ID’s stake must be known

I think proof of stake is fundamentally vulnerable… In my opinion, it’s giving power to people who have lots of money - Dahlia Malkhi

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Permissioned = bounded bad fraction

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Permissioned = bounded bad fraction

Can leverage permissioned results if we bound fraction of bad IDs in permissionless

Bounding fraction of bad IDs

GenID Problem

n good, synchronized IDs; n unknown

Byzantine adversary has κ fraction of the RB resource for "sufficiently small" κ

Goal: All IDs have same set S that contains

- All good IDs
- At most $O(\kappa)$ fraction of bad IDs

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Adversary sees all messages, can inject any message into network, etc.

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All rely on SHA-style PoW
Open problem: Adapt these for arbitrary RB

What about Churn?

DefID

Goal: IDs **always** have same set S that contains

All good IDs

At most $O(\kappa)$ fraction of bad IDs

Our Result

DefID [Gupta et al. '20]

Theorem: Let **T** be adversarial spend rate and J_G be good join rate. Then can solve DefID with

$O(J_G + \sqrt{J_G T})$ algorithm spend rate

DefID [Gupta et al. '20]

Theorem: Let **T** be adversarial spend rate and $\mathbf{J_G}$ be good join rate. Then can solve DefID with

$$O(J_G + \sqrt{J_G T}) \text{ algorithm spend rate}$$

These results assume α, β churn for $\alpha, \beta = \Theta(1)$;
Still allows for exponential change in system size.

Assumptions

There is α, β churn for, $\alpha, \beta = \Theta(1)$

Adversary can't target specific good IDs

System size is always "sufficiently large"

Epoch

Define *epoch* to be time till set of good IDs (G_t) changes by constant fraction, e.g.
$|G_t - G_{t'}| \geq 3/4 |G_t|$

For some t and $t' > t$

α, β Churn

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ρ_j is good ID join rate in epoch j

Good join rate changes by at most α between epochs:

$$\frac{\rho_{j-1}}{\alpha} \leq \rho_j \leq \alpha\rho_{j-1}$$

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Good join rate changes by at most α between epochs:

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Let n_ℓ be # good IDs joining in ℓ seconds in epoch j. Then n_ℓ differs by at most β from expected value:

$$\left\lfloor \frac{\ell \rho_j}{\beta} \right\rfloor \leq n_\ell \leq \lceil \beta \ell \rho_j \rceil$$

Idea behind result

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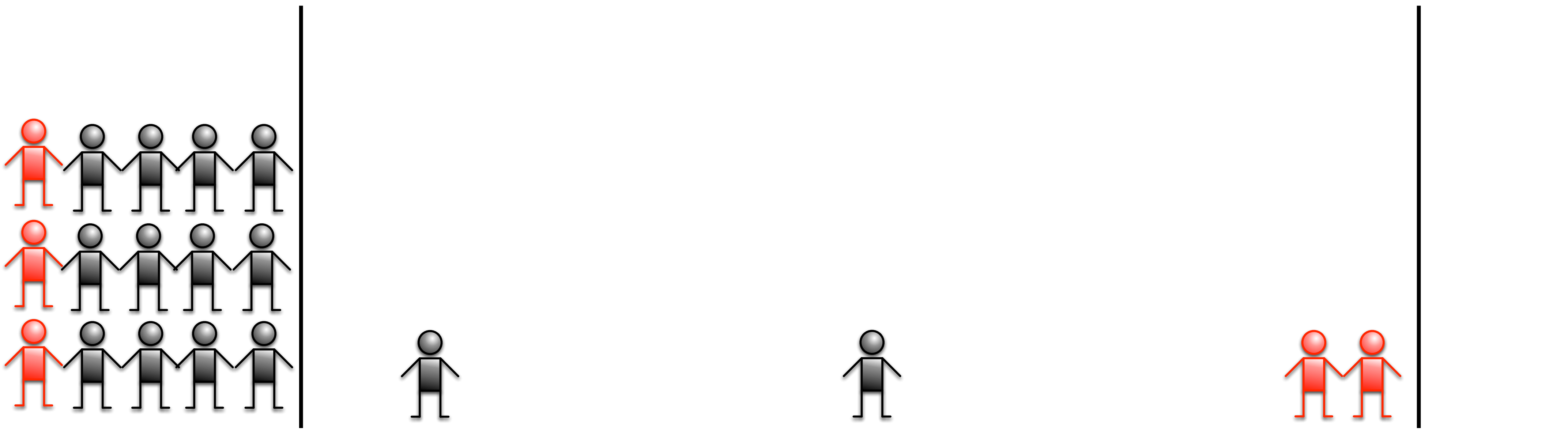
“Small” Committee runs algorithm

Maintenance/Coordination of Committee: in paper

Naive Algorithm



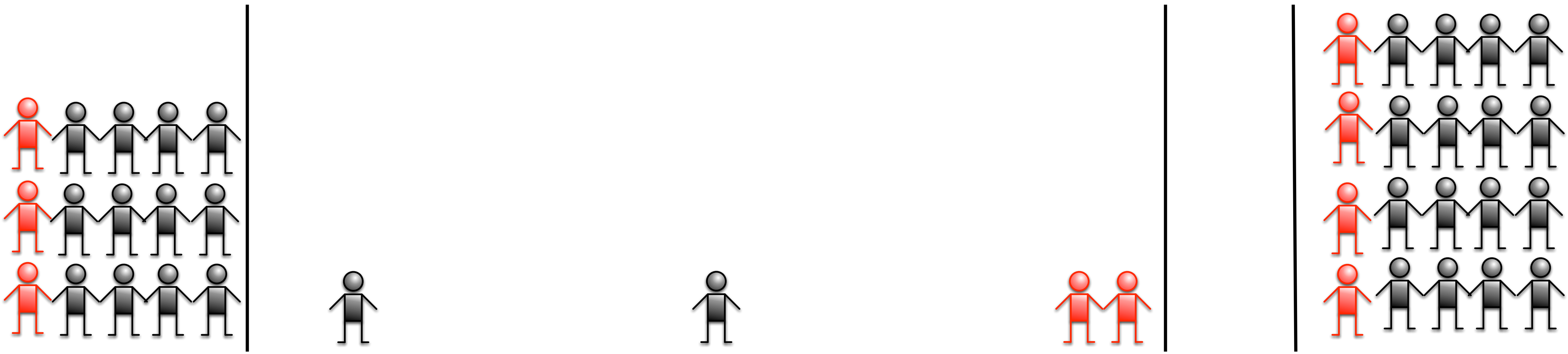
New IDs solve
Entrance Puzzle

All IDs solve **Purge Puzzle**
after constant fraction of churn

Purge Puzzle: Cost of 1

Entrance Puzzle: Cost of 1

Naive Algorithm



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Both Entrance and Purge puzzles cost 1

Algorithm spend rate is $O(T + J_G)$

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Can we do better?

Best Entrance Cost

Fix an iteration

T = adversarial spending rate

J = join rate for all IDs

$\mathbf{J_G}$ = join rate for good IDs

ξ = entrance cost

Solving for ξ (Entrance Cost)

Assume: $\mathbf{T} = \xi \mathbf{J}$

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Good spend rate for entrance: $\xi \mathbf{J_G}$

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To Balance:

$$\xi = \frac{\mathbf{J}}{\mathbf{J_G}}$$

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$$\mathbf{J} = \sqrt{\mathbf{J}^2} = \sqrt{\mathbf{J_G} \xi \mathbf{J}} = \sqrt{\mathbf{J_G} \mathbf{T}}$$

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Good spend rate for entrance: $\xi \mathbf{J_G}$

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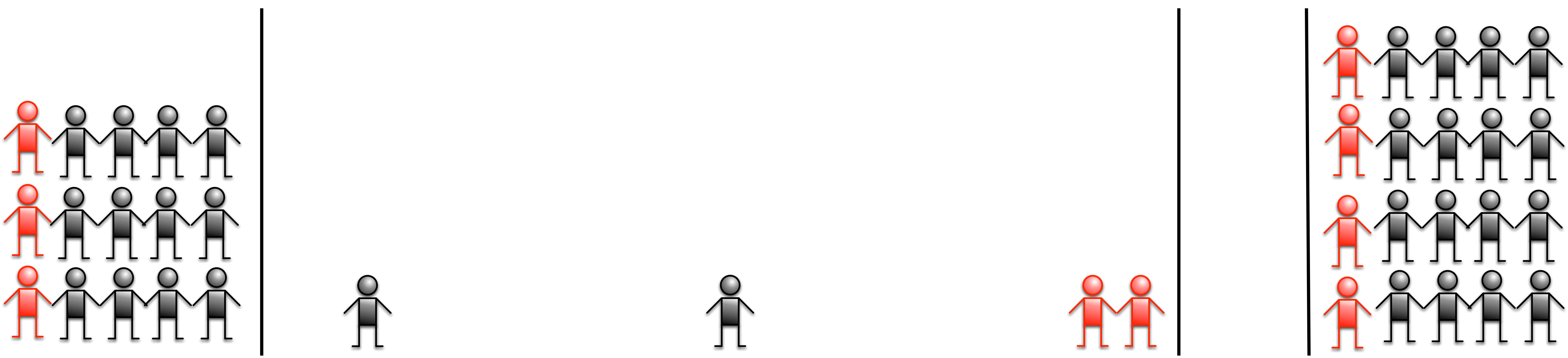
$$\mathbf{J} = \sqrt{\mathbf{J}^2} = \sqrt{\mathbf{J_G} \xi \mathbf{J}} = \sqrt{\mathbf{J_G} \mathbf{T}}$$

So good spend rate: $\mathbf{J_G} + \sqrt{\mathbf{J_G} \mathbf{T}}$

Our Algorithm: ERGO



New IDs solve
Entrance Puzzle

All IDs solve
Purge Puzzle

Purge Puzzles: Require 1 unit of computation

Entrance Puzzles: Require $\frac{\mathbf{J}}{\tilde{\mathbf{J}}_{\mathbf{G}}}$ units of computation

How to estimate J_G?

Problem: Don't know in advance which IDs are good or bad

We developed an algorithm that maintains a constant factor estimate of J_G assuming α, β-churn for $\alpha, \beta = \Theta(1)$

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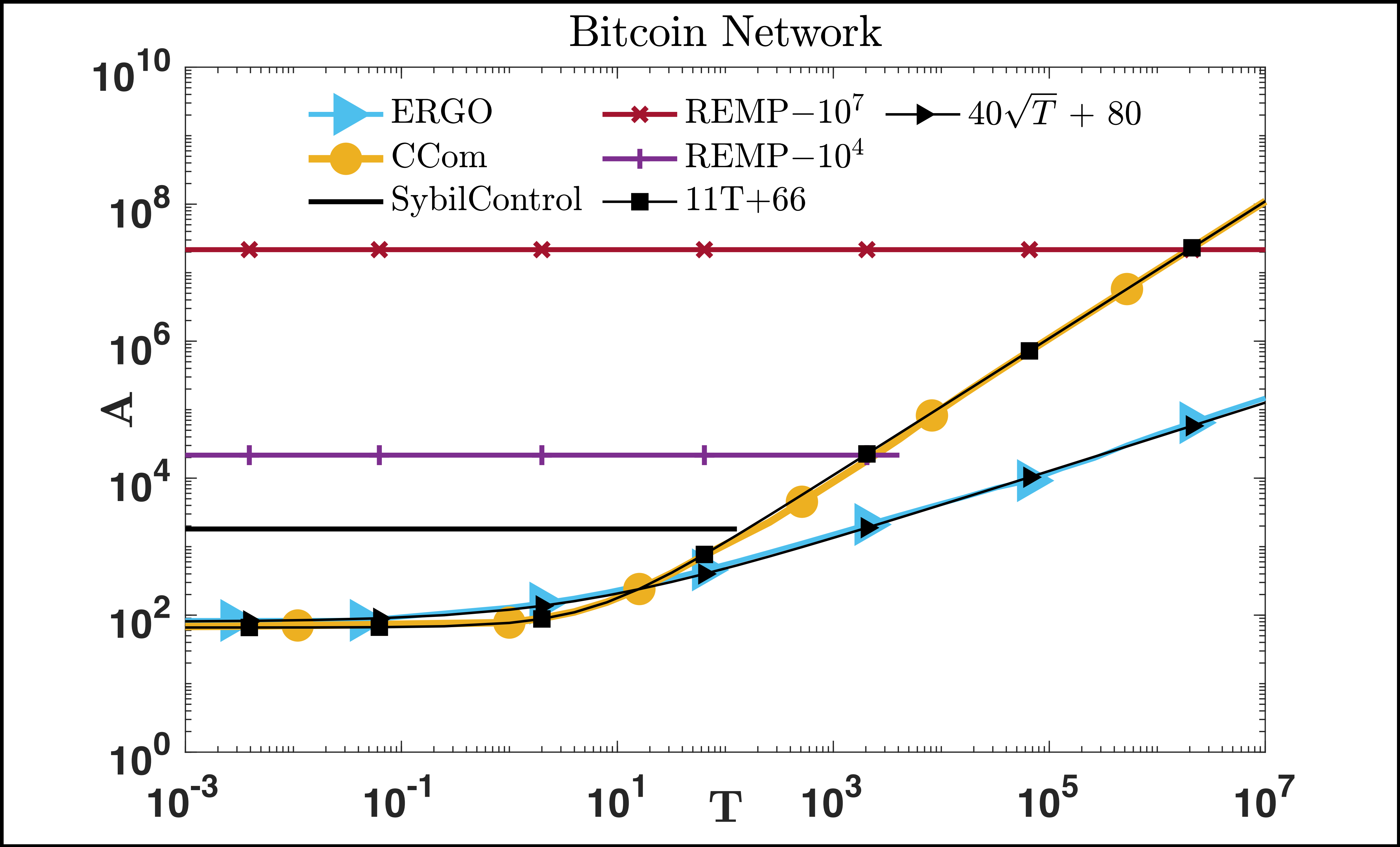
This algorithm for estimating J_G is key technical challenge of our work

Empirical Results

Four data sets: Bitcoin, Ethereum, Gnutella, Bittorrent

Tested **ERGO** vs

- **CCom**: ERGO-light: entrance cost is 1
- SybilControl: Puzzle every 5 seconds
- REMP: Puzzle every x seconds, where x is based on upper bound of adversary power



Bitcoin Network
ERGO
CCom
SybilControl
REMP−10^7
REMP−10^4
11T+66
40√T + 80
A
T
10^0
10^2
10^4
10^6
10^8
10^10
10^-3
10^-1
10^1
10^3
10^5
10^7

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Spam and DDoS

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Review Spam:

Weak Learner detects spam with accuracy $> 1/2$

Spam has social cost of 1; P_G is good posting rate

Recent Conjecture: Can achieve cost of $\mathrm{O}(\mathrm{T}^{2/3} + \mathrm{P}_\mathrm{G})$

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Application-layer DDoS Attack:

Goal: Good IDs obtain a $1 - \mathrm{O}(\kappa)$ fraction of service

Cost per service request set by server

Weak Conjecture: Can achieve cost of $\mathrm{o}(\mathrm{T})$

Conclusion

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Future Work

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Other application domains? (besides Blockchains, DDoS, Spam, DHTs)

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Better integration with game theory

- RB cost $\longleftrightarrow$ Payoff for security game
- Rational agents

Questions?

Backup Slides

Communication

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Diffuse:

Sends a message to all IDs

Communication time is negligible compared RB time

Messages signed with digital signatures

PoW

PoW

Random Oracle Assumption**:** We have a function, h, and h(x) is uniformly random on (0, 1) the first time bit string x is input to h

Computation Cost: Computational cost is number of times h is called

Committee

Logarithmic size

Use state-machine replication to get committee to act in concert

After every purge, old committee elects a new committee from set of current IDs, using Byzantine-resilient coin-flipping

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[Ball et al. ’18]: “Proof of Useful Work”

SETH → Hardness of challenge

Can use RB challenges for conjectured hard problems

[Von Anh et al. ’08]: RECAPTCHA

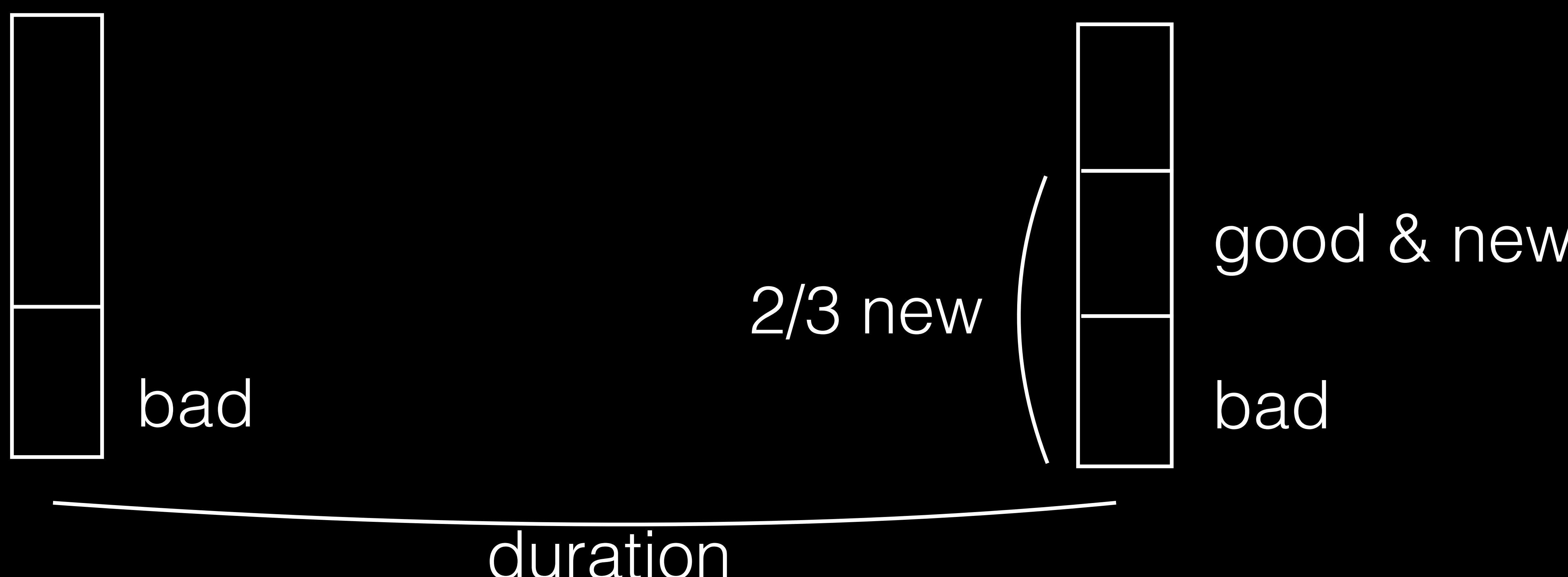
CAPTCHAs used to decipher scanned words

Digitized New York Times archive

$\tilde{J}_G$: Estimate of J_G

Duration: Length of time for set of all IDs to change by 2/3 factor

$$\tilde{J}_G = \frac{\text{number of IDs at start of last duration}}{\text{length of last duration}}$$



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