Scalable and Secure Computation Among Strangers: Message-Competitive Byzantine Protocols

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Permissionless Networks

Permissionless networks are large; nodes join and leave at will

Nodes are known by self-generated IDs

Adversarial (Byzantine) IDs common

Goal: Solve coordination problems with sub-quadratic messages

Scalability

Recent work* ensures solutions to Byzantine agreement/leader election where good nodes send $\tilde{O}(n)$ messages total

Assume KT_1 *model:* Each good node knows IDs of all neighbors.

How can we extend this result to churn?

One step is to extend it to KT_0 model

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*Braud-Santoni, et al. PODC ‘13

KT_0 Model

Nodes don't know their neighbors a priori

But they do learn a neighbors ID upon receiving a message from it

Can convert KT_0 to KT_1:

- Initial step where each node communicates with all neighbors solely to learn IDs
- But this is $\Theta(n^2)$ messages

Can we design Byzantine agreement/leader election protocols that require sub-quadratic messages in KT_0?

Our Model

Adversary is *static*, *rushing* and computationally-unbounded.

n nodes have distinct IDs in $[1, n^k]$. Byzantine nodes choose their IDs.

Synchronous, fully-connected KT_0 model

Upper Bound

Theorem: Our algorithm solves Byzantine agreement, leader and committee election in KT_0 with:

$O(\text{polylog}(n))$ latency

$O((T+n)\log n)$ expected messages

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Talking to Strangers

In fact, our algorithm only writes to unknown IDs (strangers) via two primitives:

(1) Random stranger

(2) All strangers

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Our alg optimal up to log terms

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Also show that if $T = n^{1+\alpha}$ for $\alpha \in (0,1]$, then any Las Vegas algorithm sends $\Omega(n^{1+\alpha/2})$ bits in expectation

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This talk: Byzantine agreement only
Paper: Leader and committee election

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$p \leftarrow (\log n)/n$

1. Each ID becomes active with probability p
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Success: $> t/n$ fraction of good IDs decide on correct bit, and remaining good do not decide

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Heavy-weight BA

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If adversary sends $\leq pn^2$ messages, then Implicit Agreement succeeds

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Each active ID, x, sets $S_x \leftarrow$ IDs received

Use LARGE-CORE-BA among the active IDs

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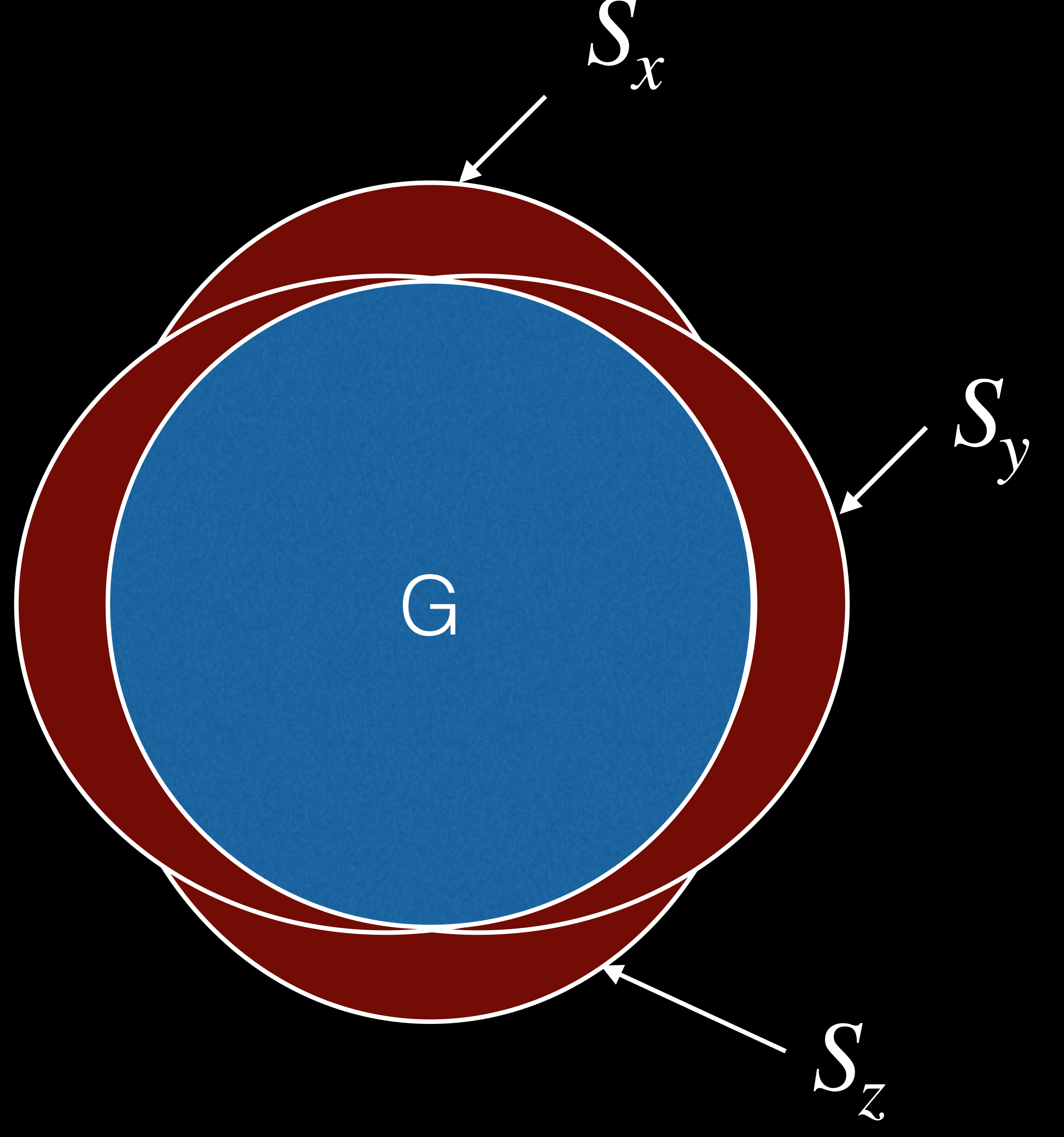
LARGE-CORE-BA:

Ensures agreement among nodes whose views “mostly” overlap

Requires IDs in range $[0,n^k]$, for fixed k

LARGE-CORE-BA (LCBA)



Lemma 1. Assume:

G = good IDs, B = bad IDs, i.e. $\cup_{x \in G} S_x$

$G \subseteq_x S_x$; B/G bounded away from 1/2

Then all but $1/\log n$ fraction reach agreement in:

Latency and per ID message cost polylog(|G|+|B|)

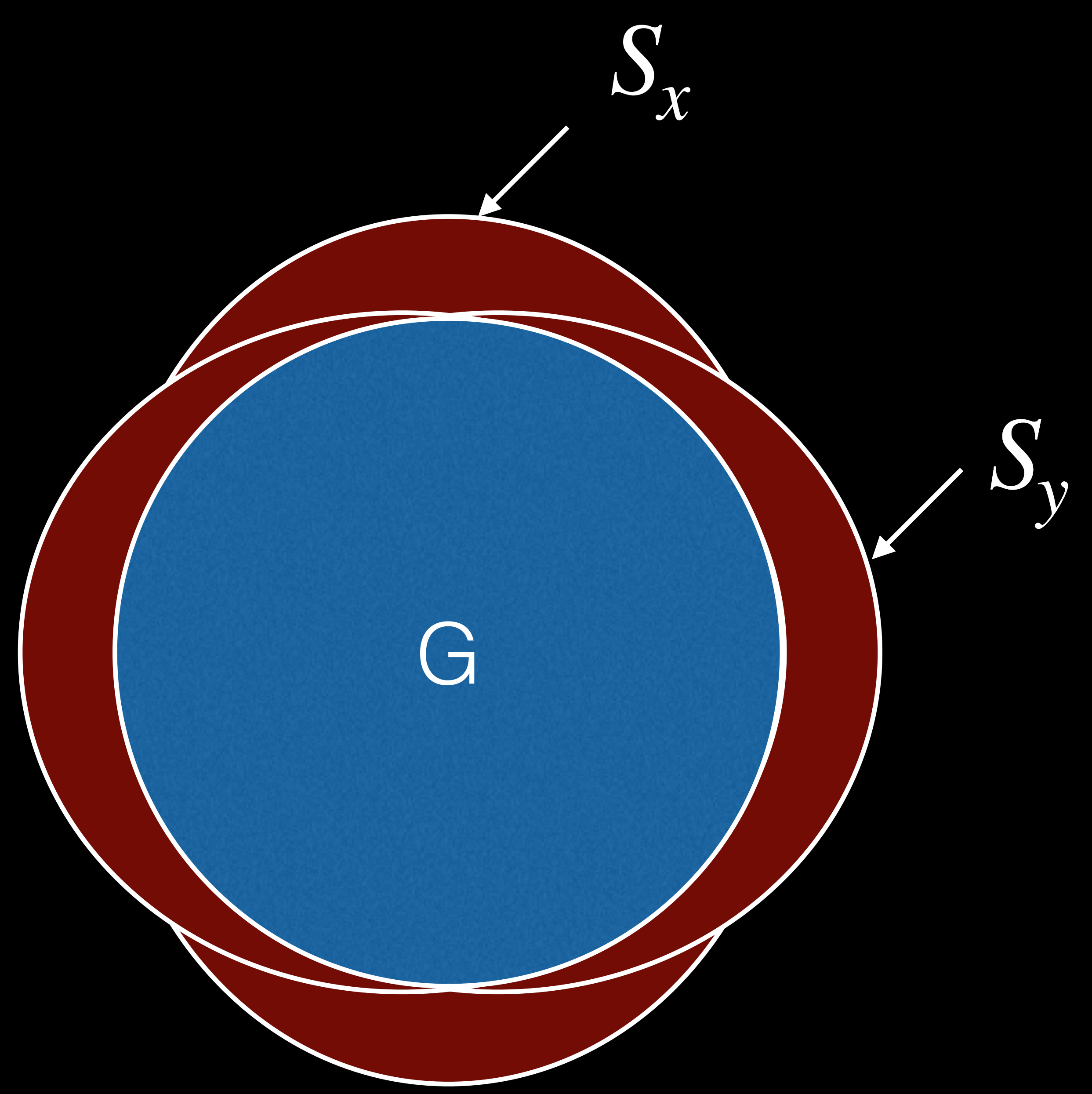
With high probability in |G| + |B|

Two problems

Problem 1: How does each active ID maintain a set S_x to meet LCBA requirements?

Problem 2: How can active IDs agree on whether conditions are favorable for agreement?

Problem 1: Meeting LCBA requirements



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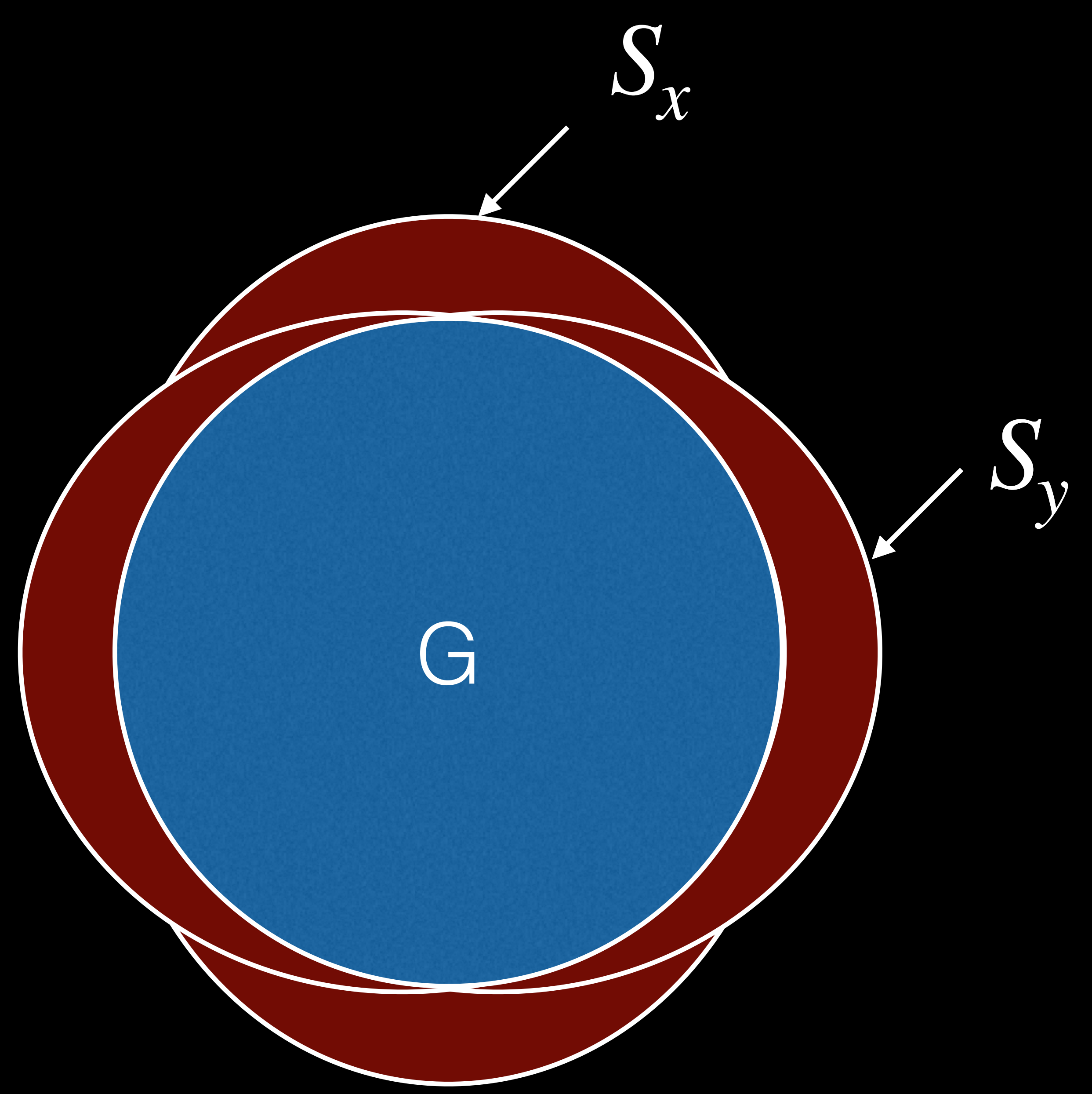

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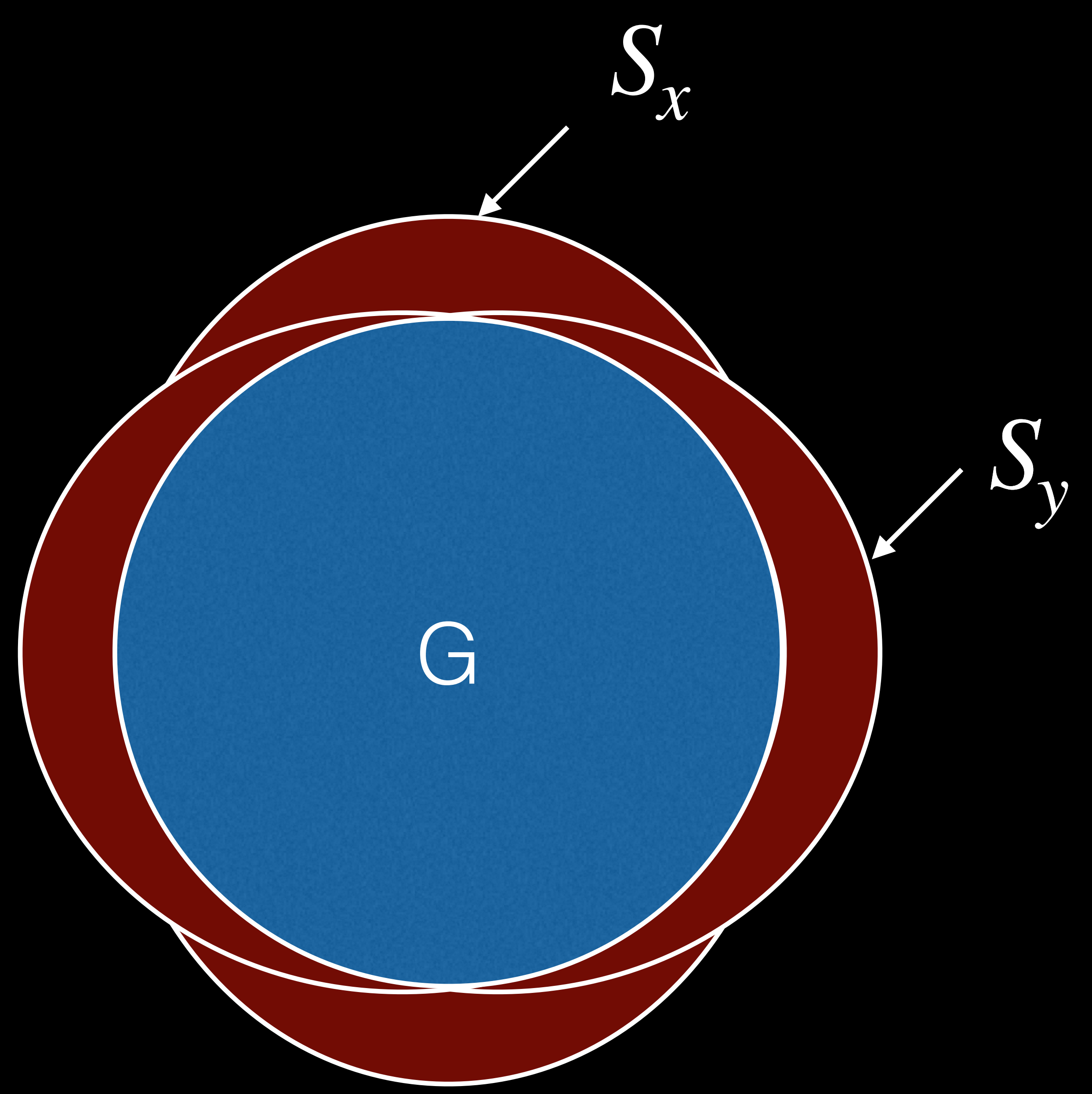

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Instead: Use non-active IDs to help out.

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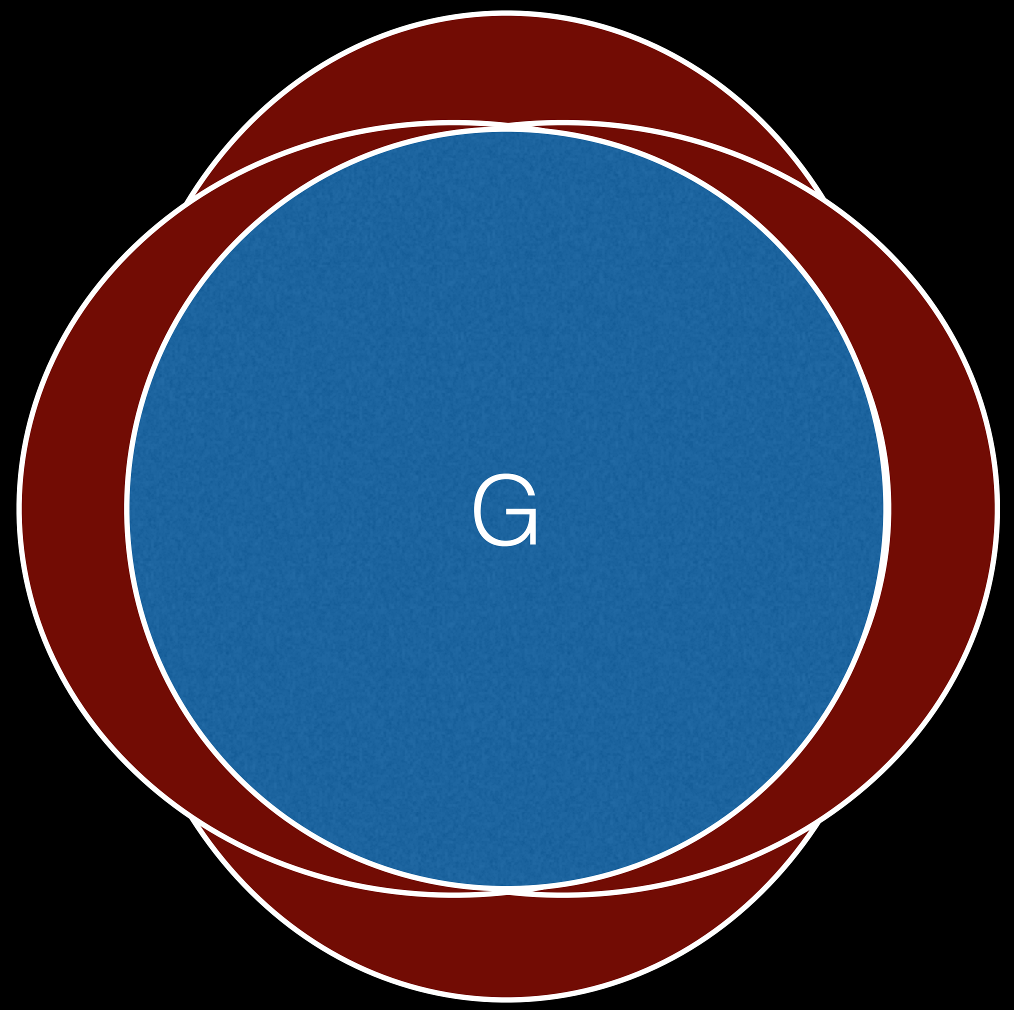

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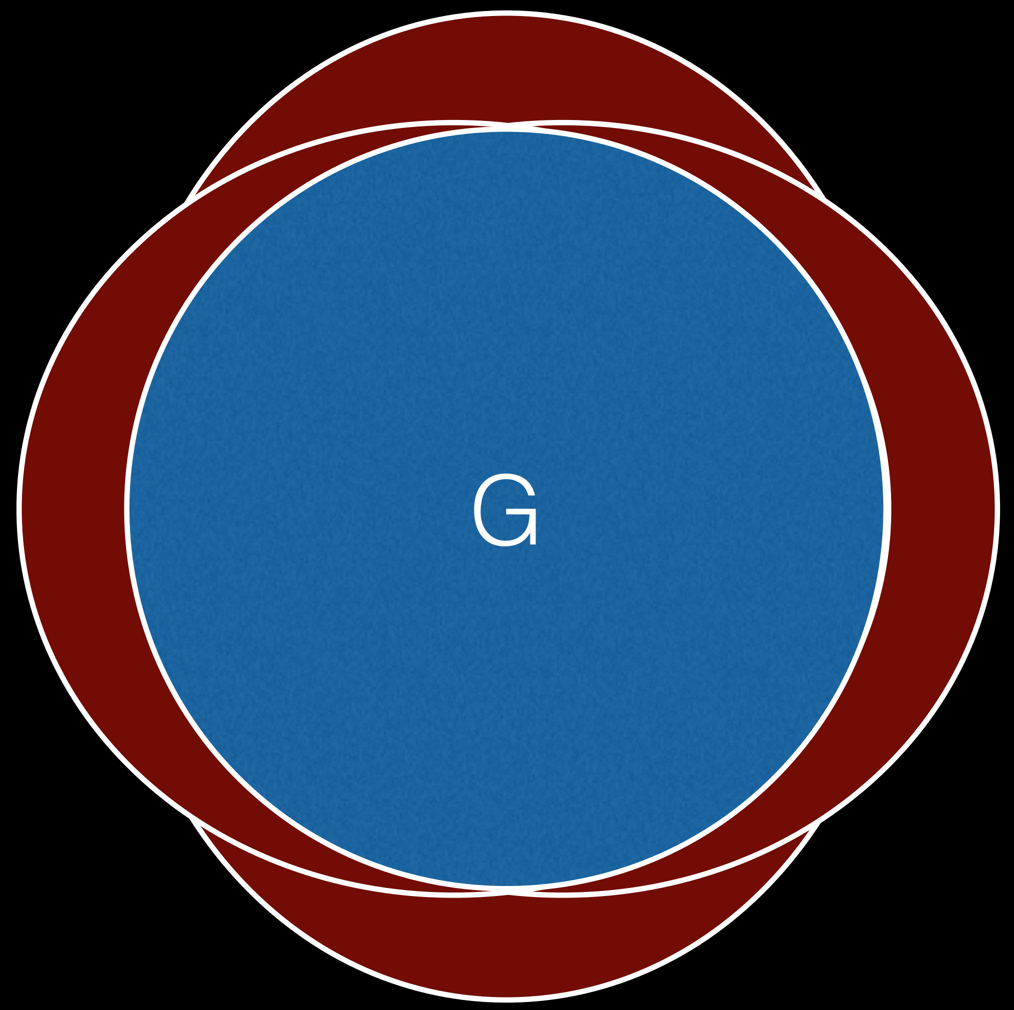

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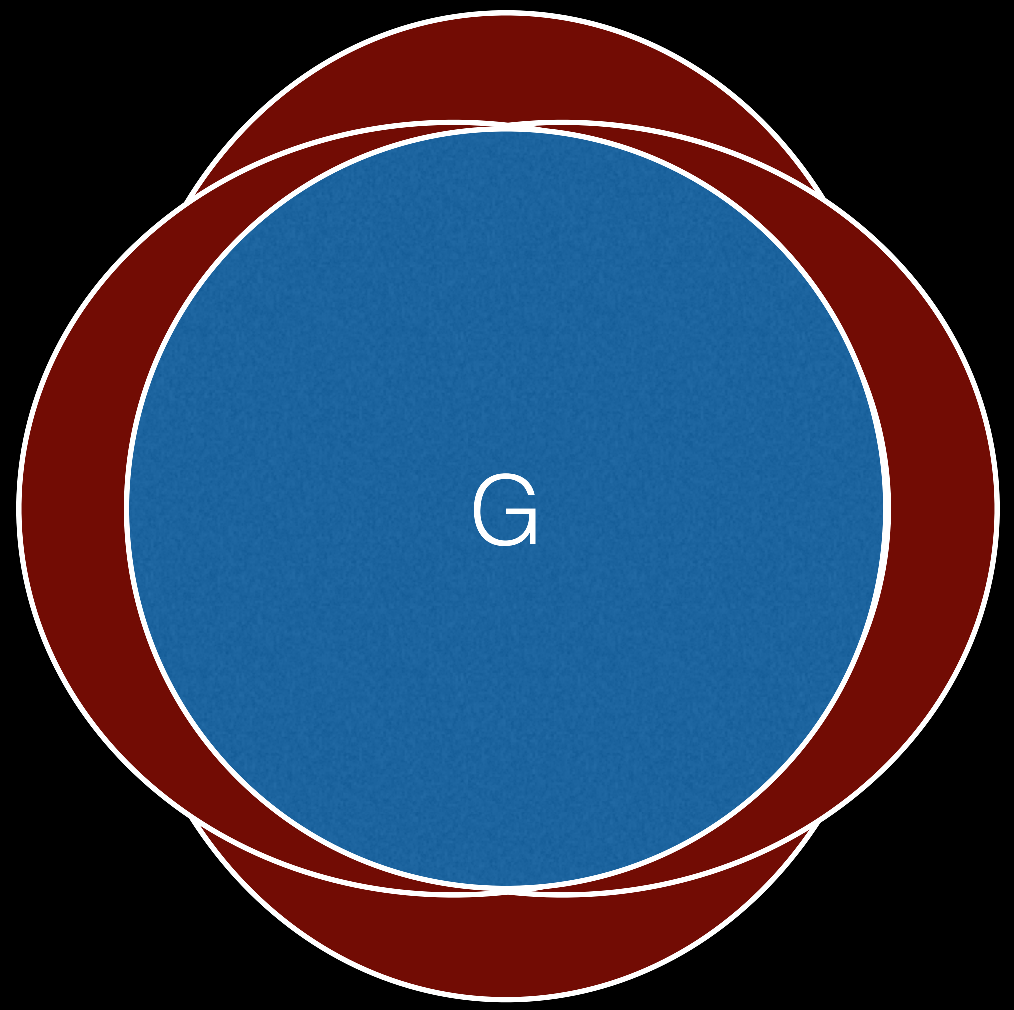

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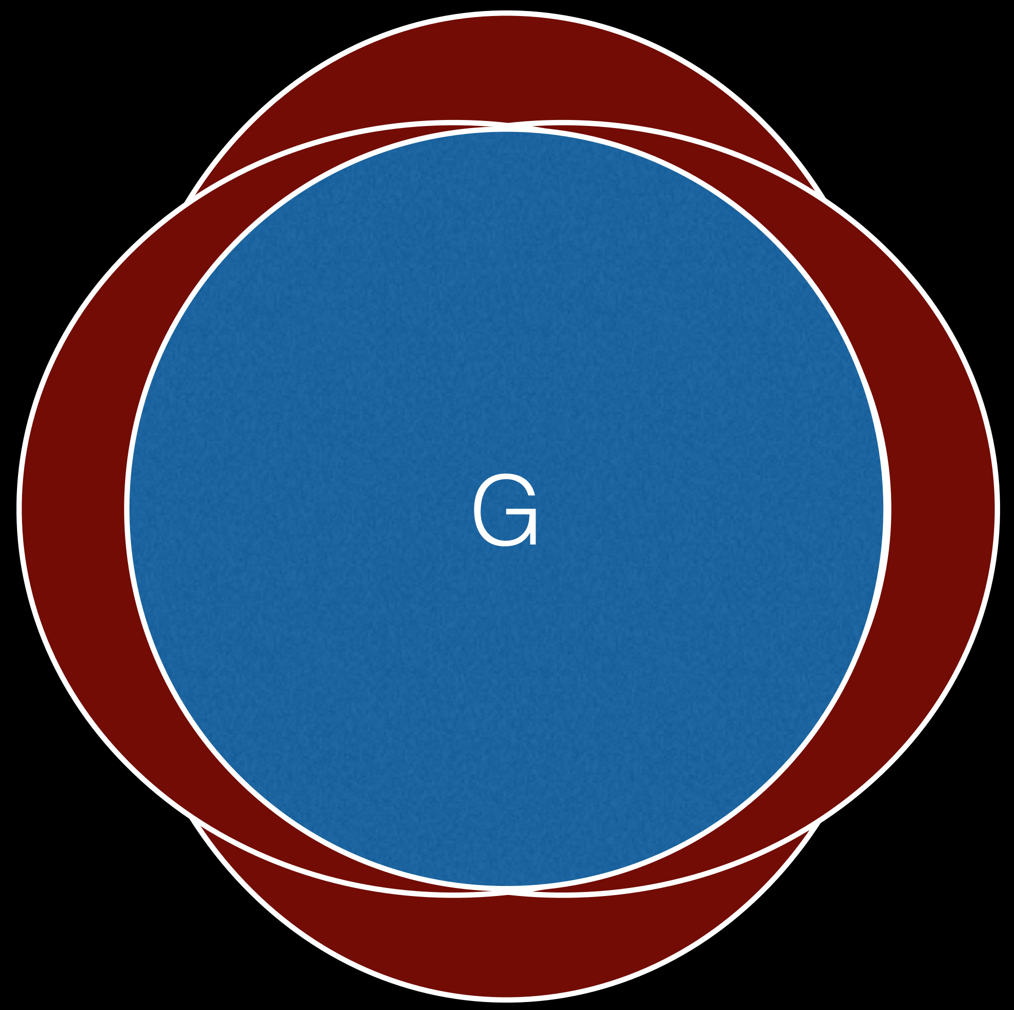

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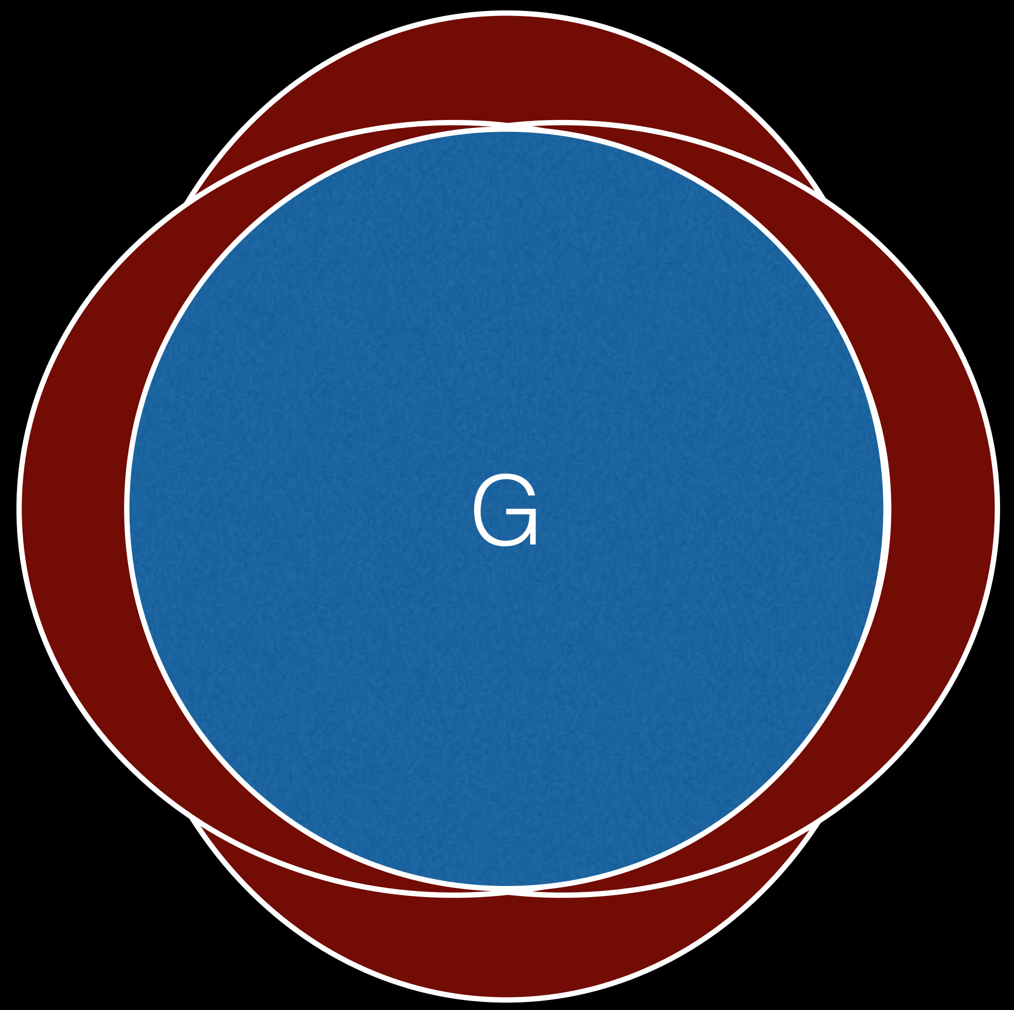

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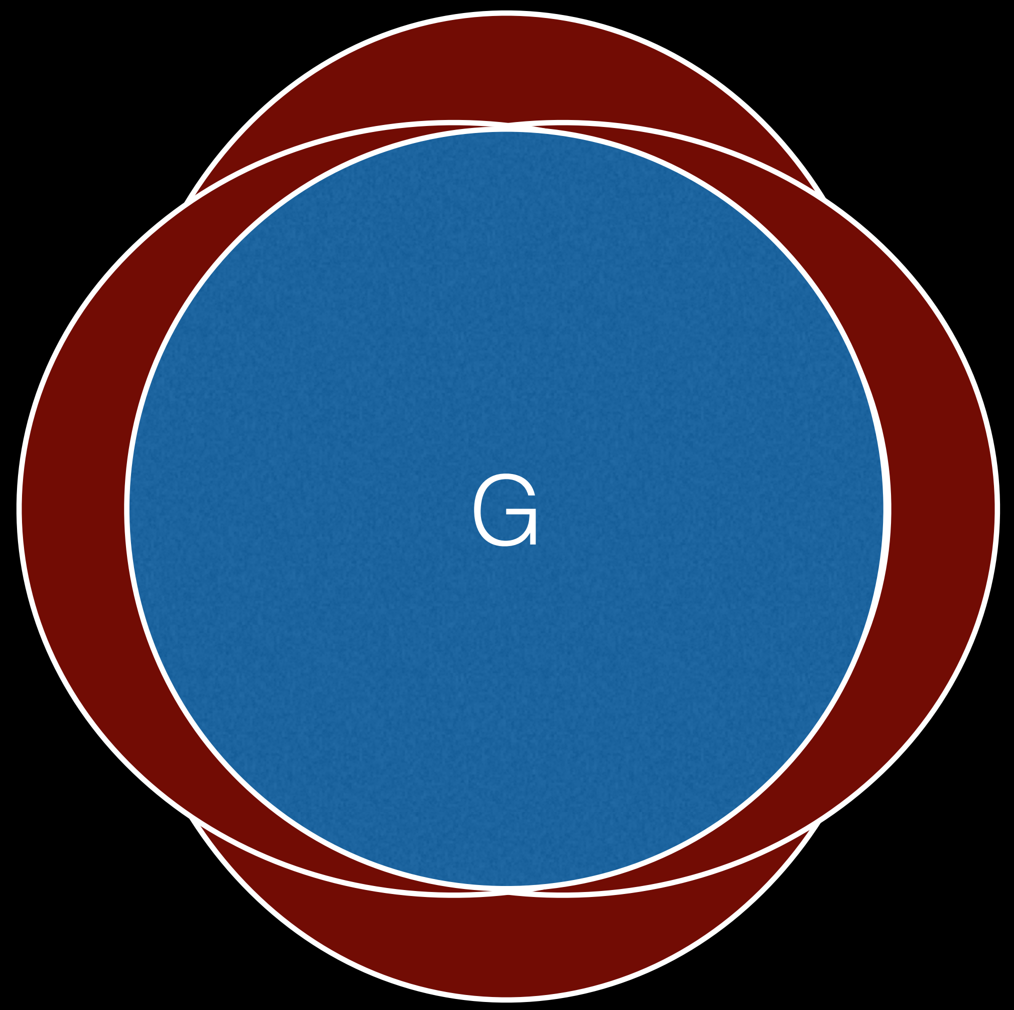

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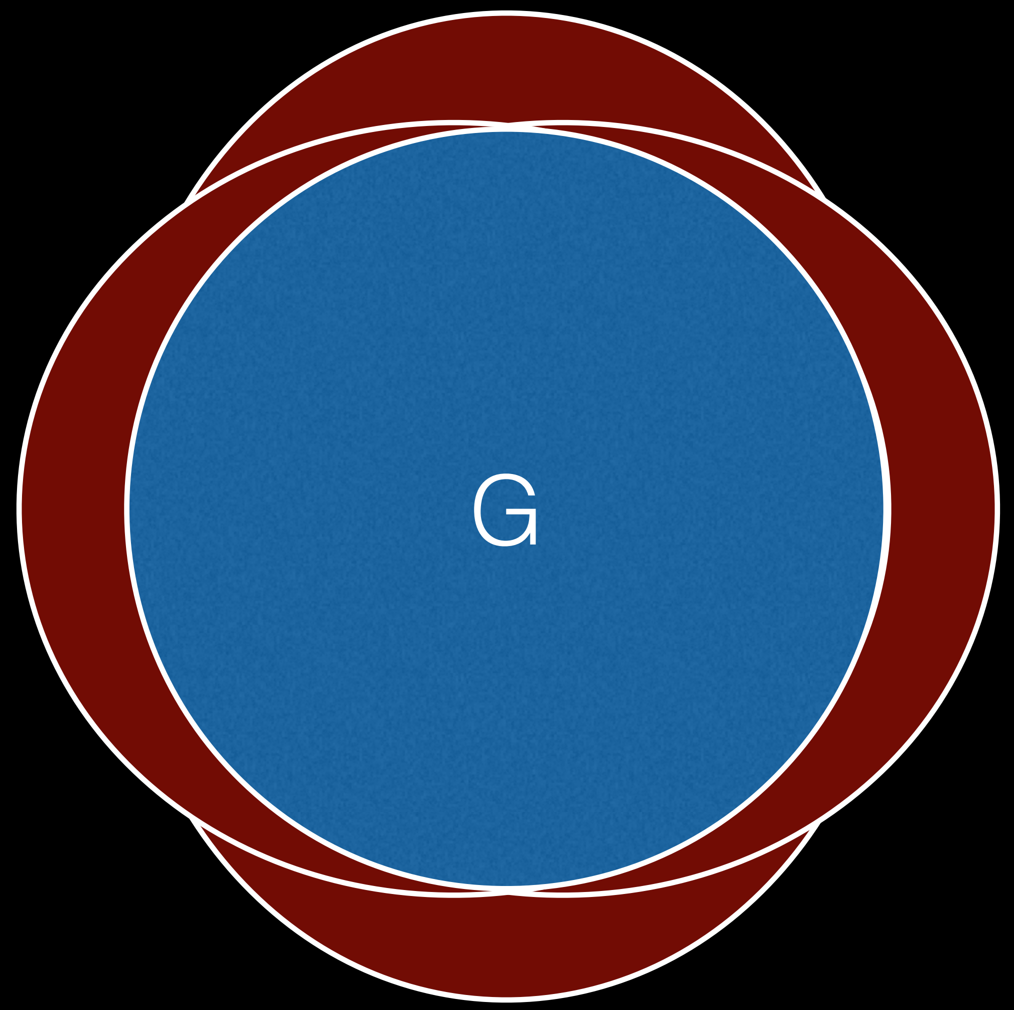

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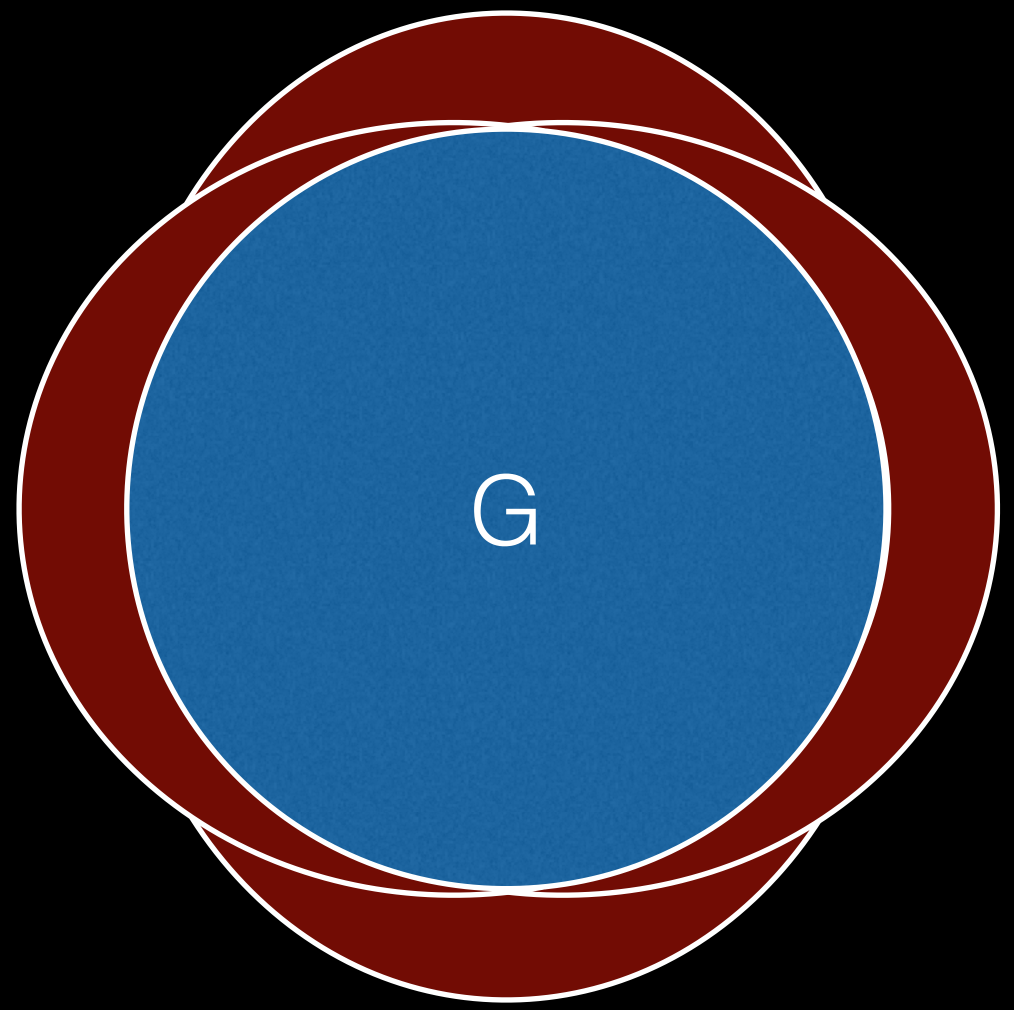

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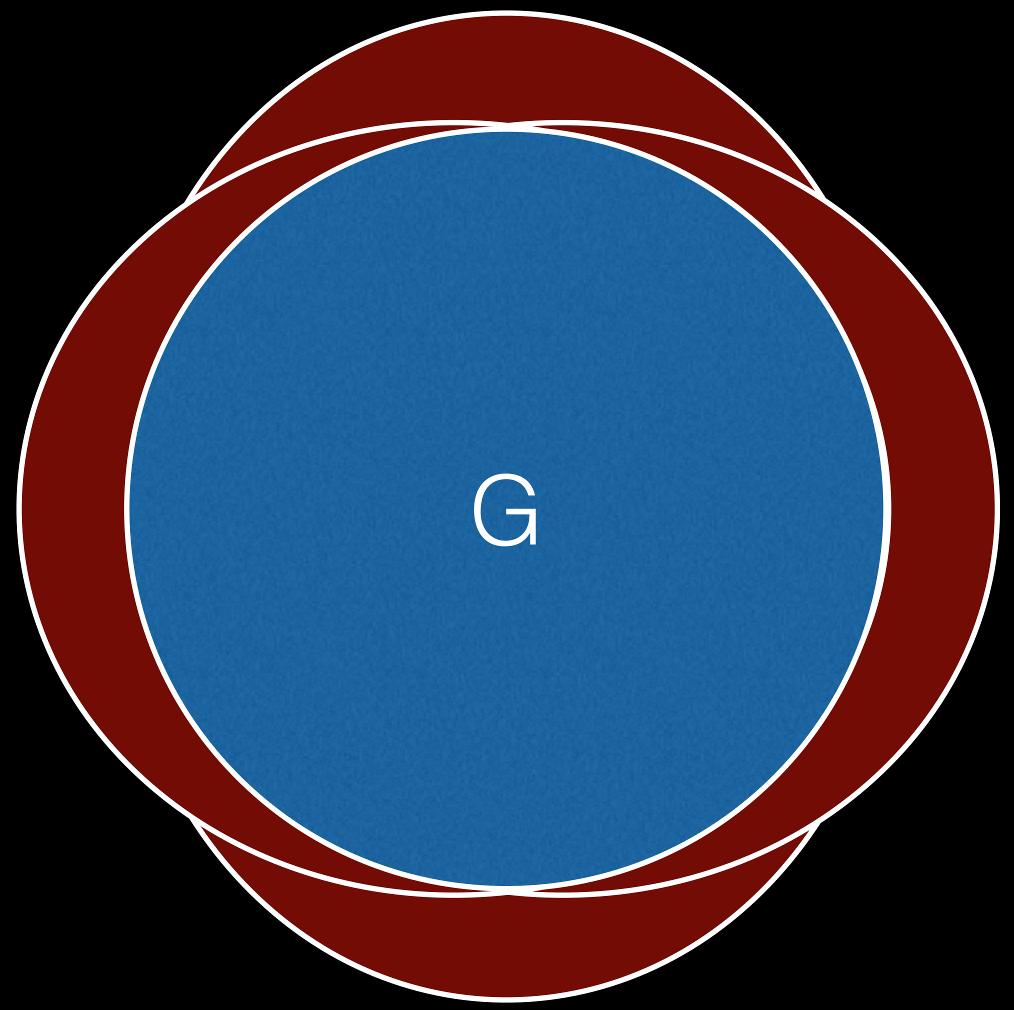

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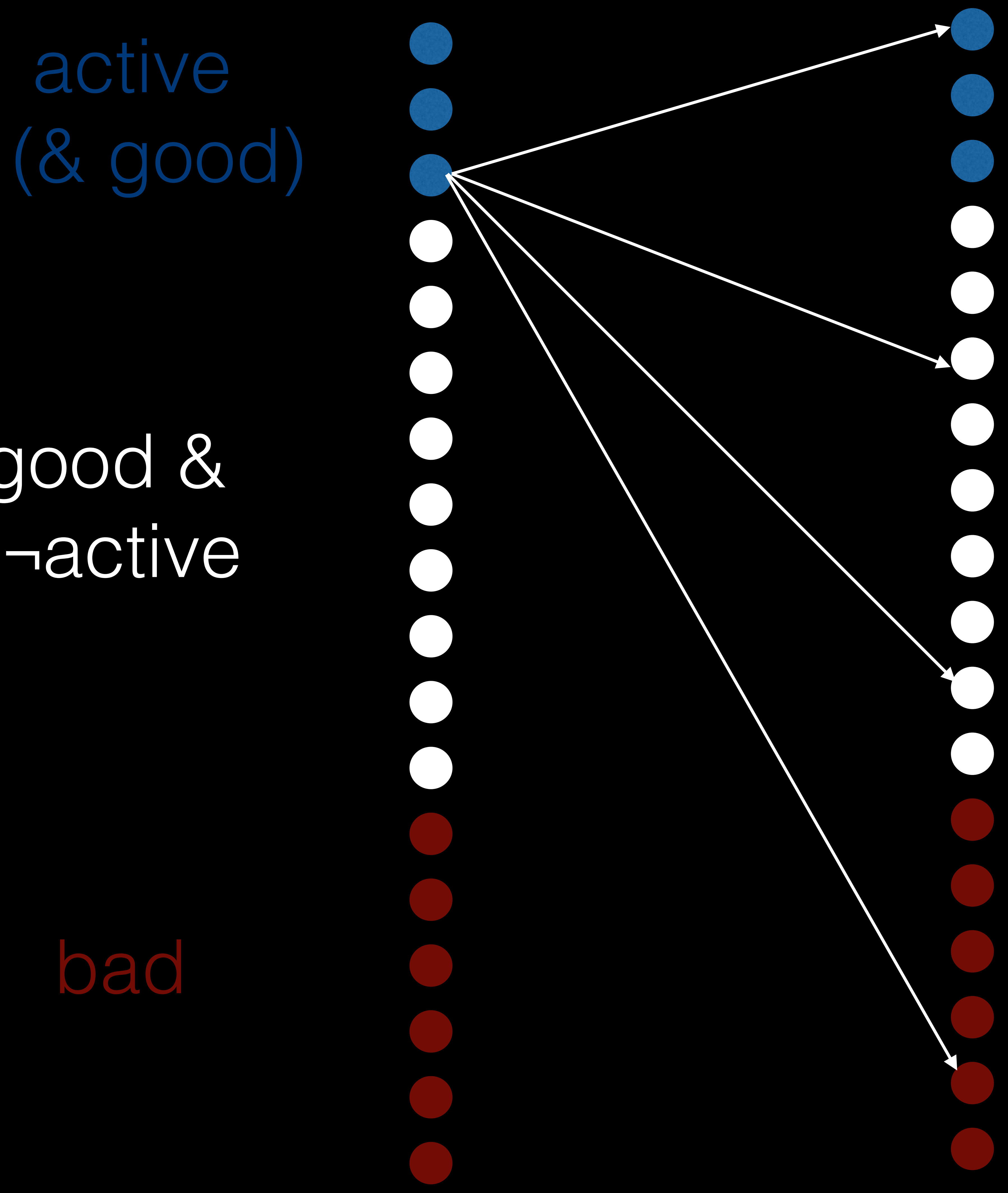

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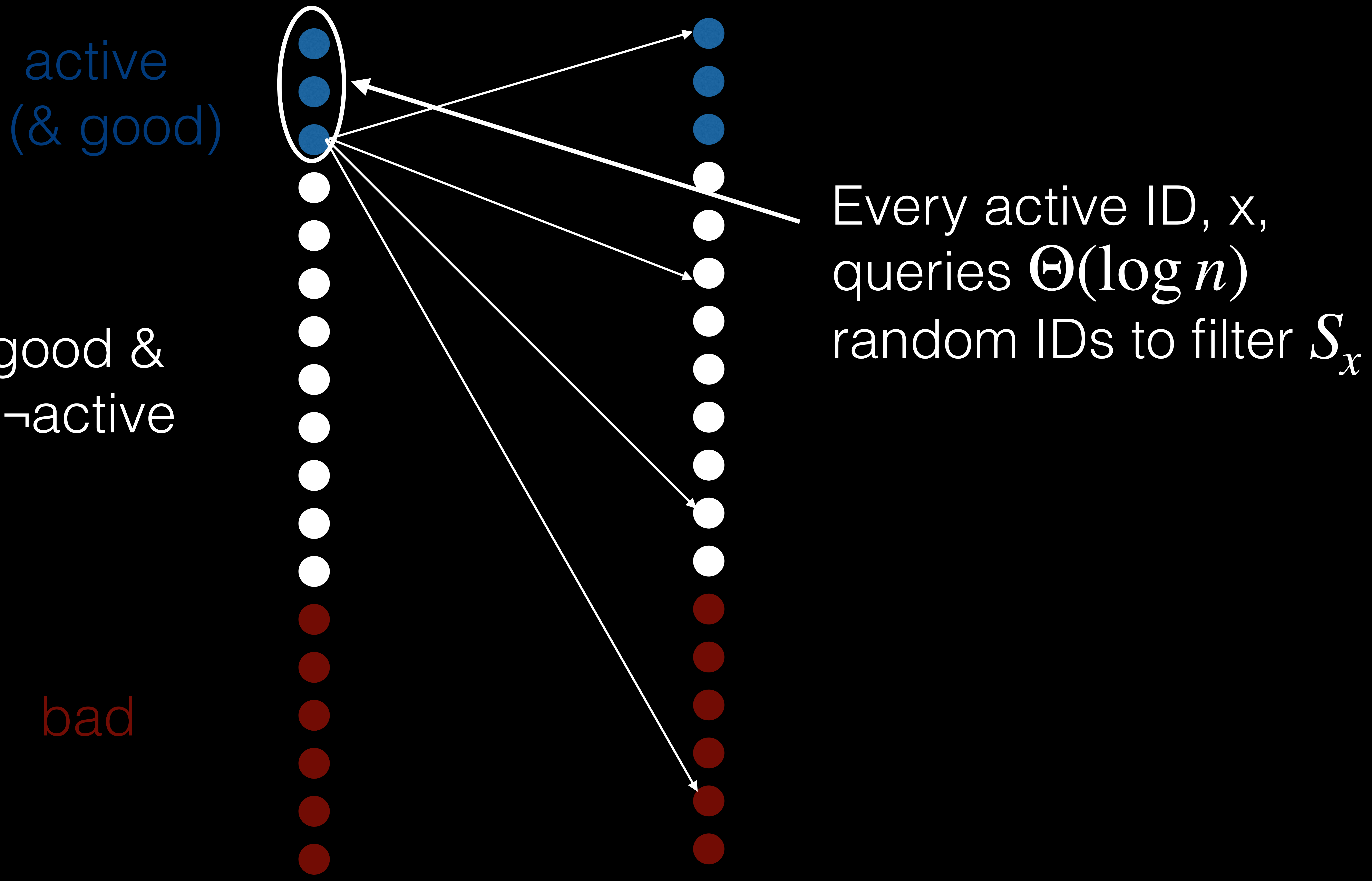

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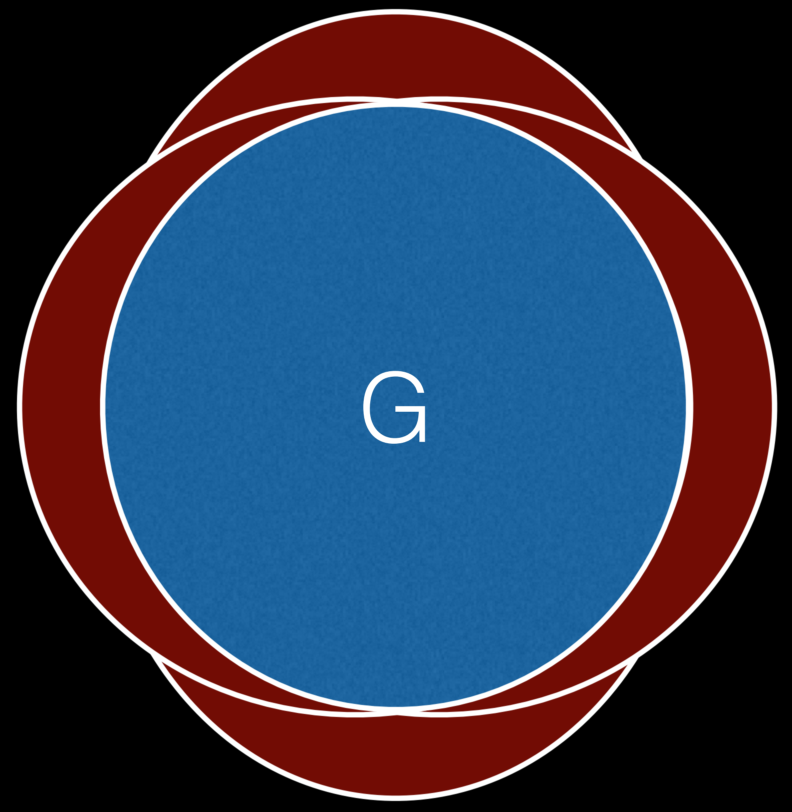

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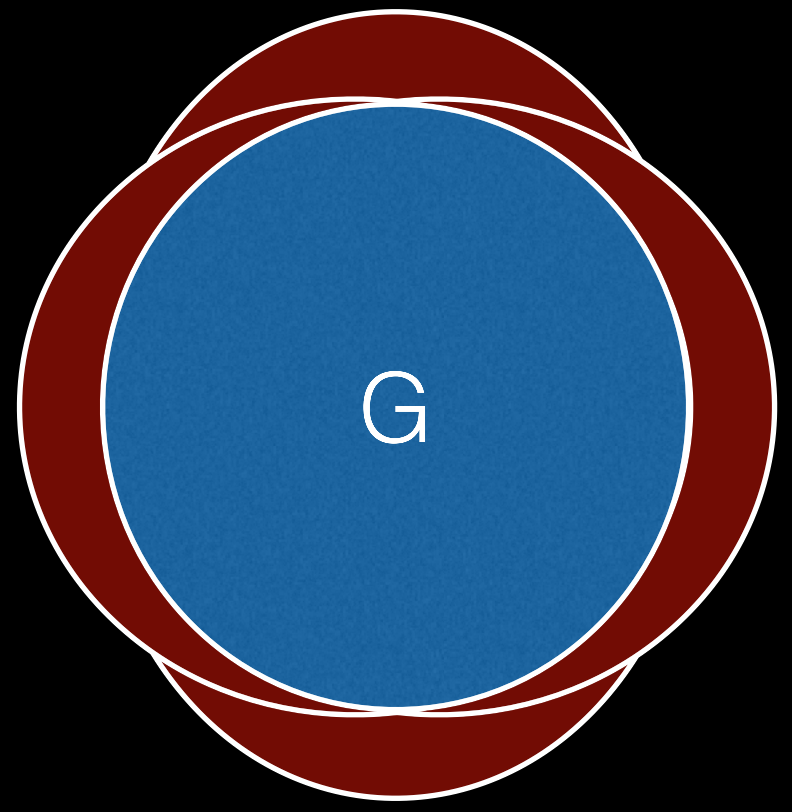

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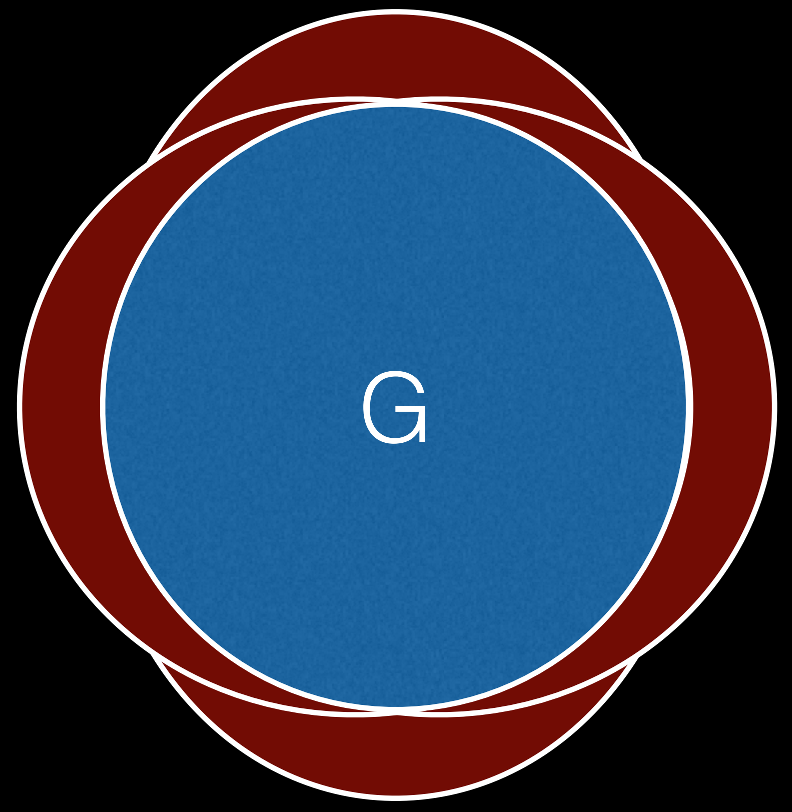

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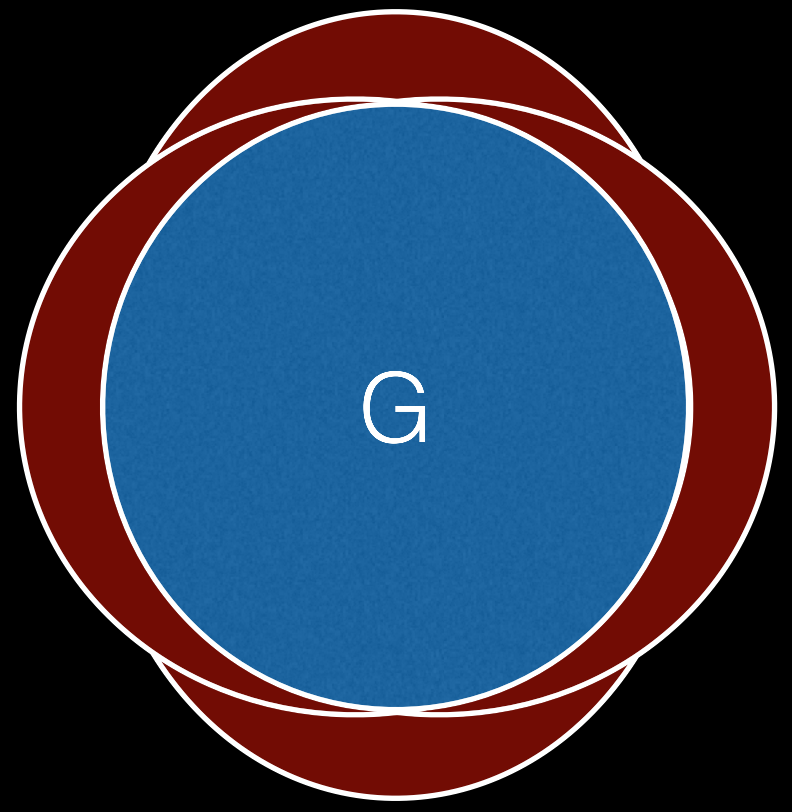

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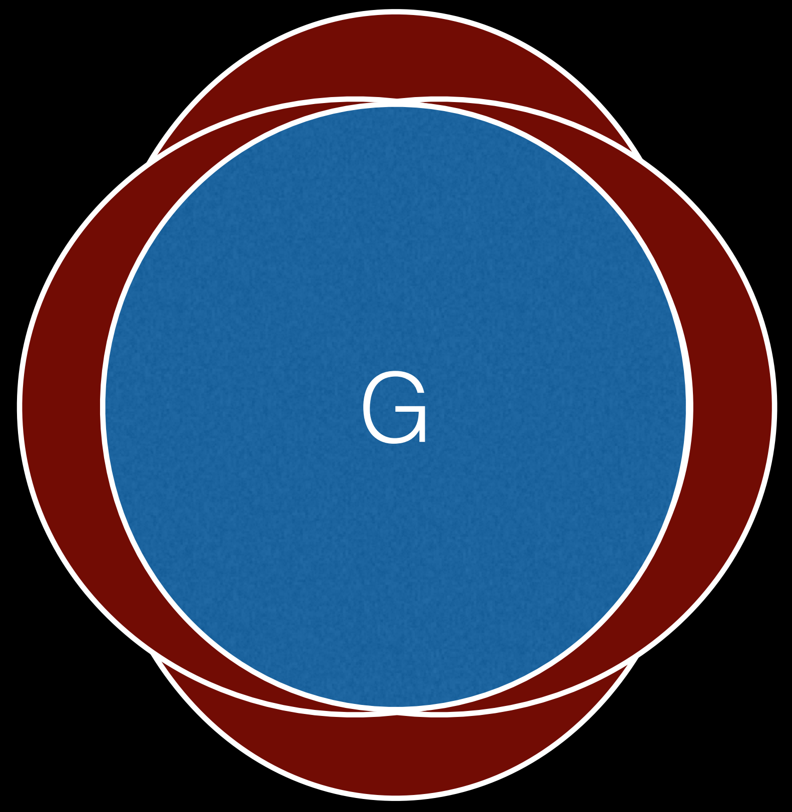

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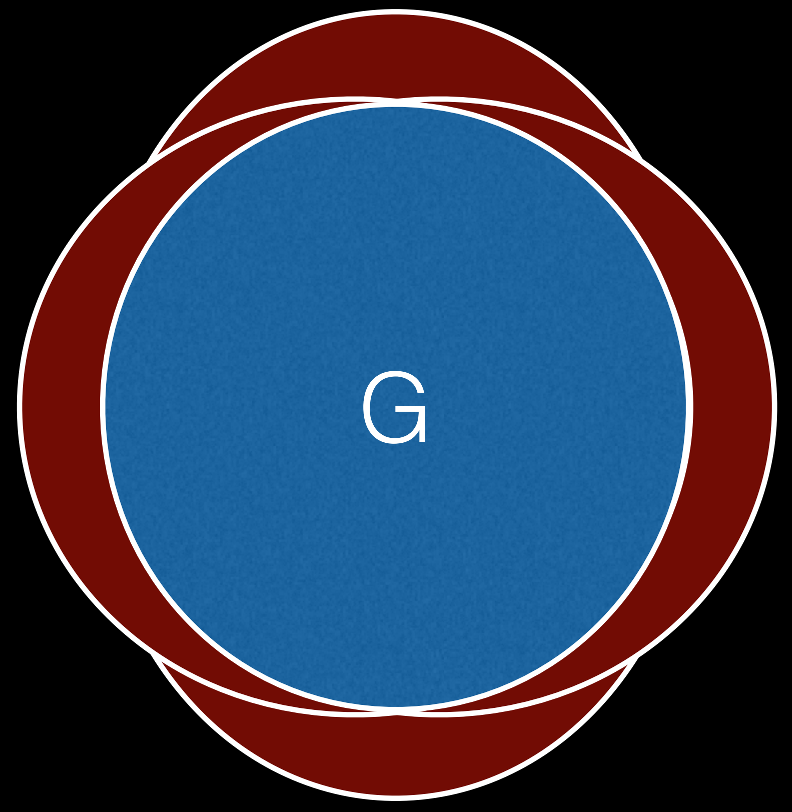

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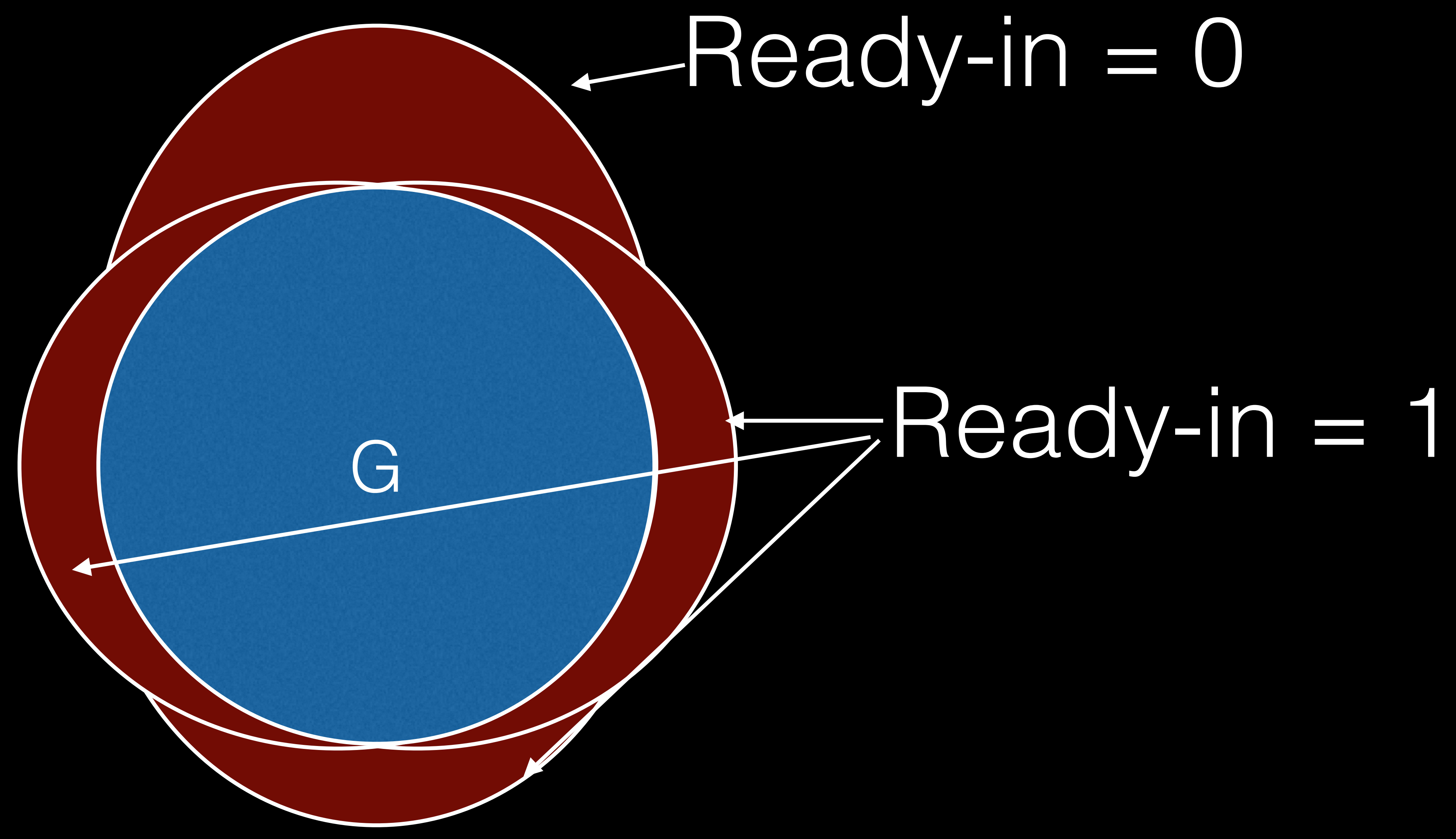
If "Ready?" output = yes, IDs run LCBA again for agreement

All active IDs then broadcast Ready? bit and Agreement bit

LCBA for
“Ready-out” bit



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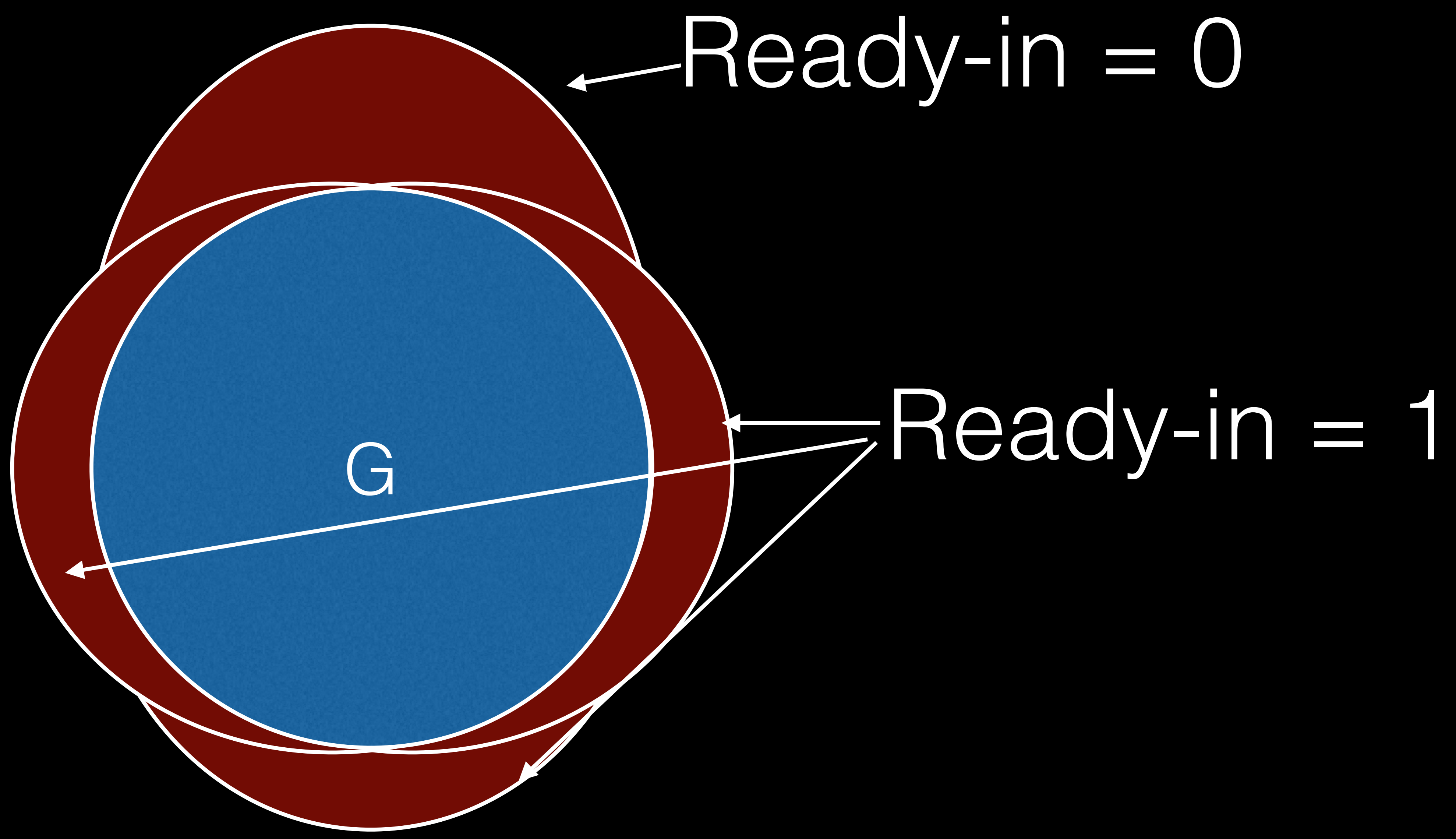
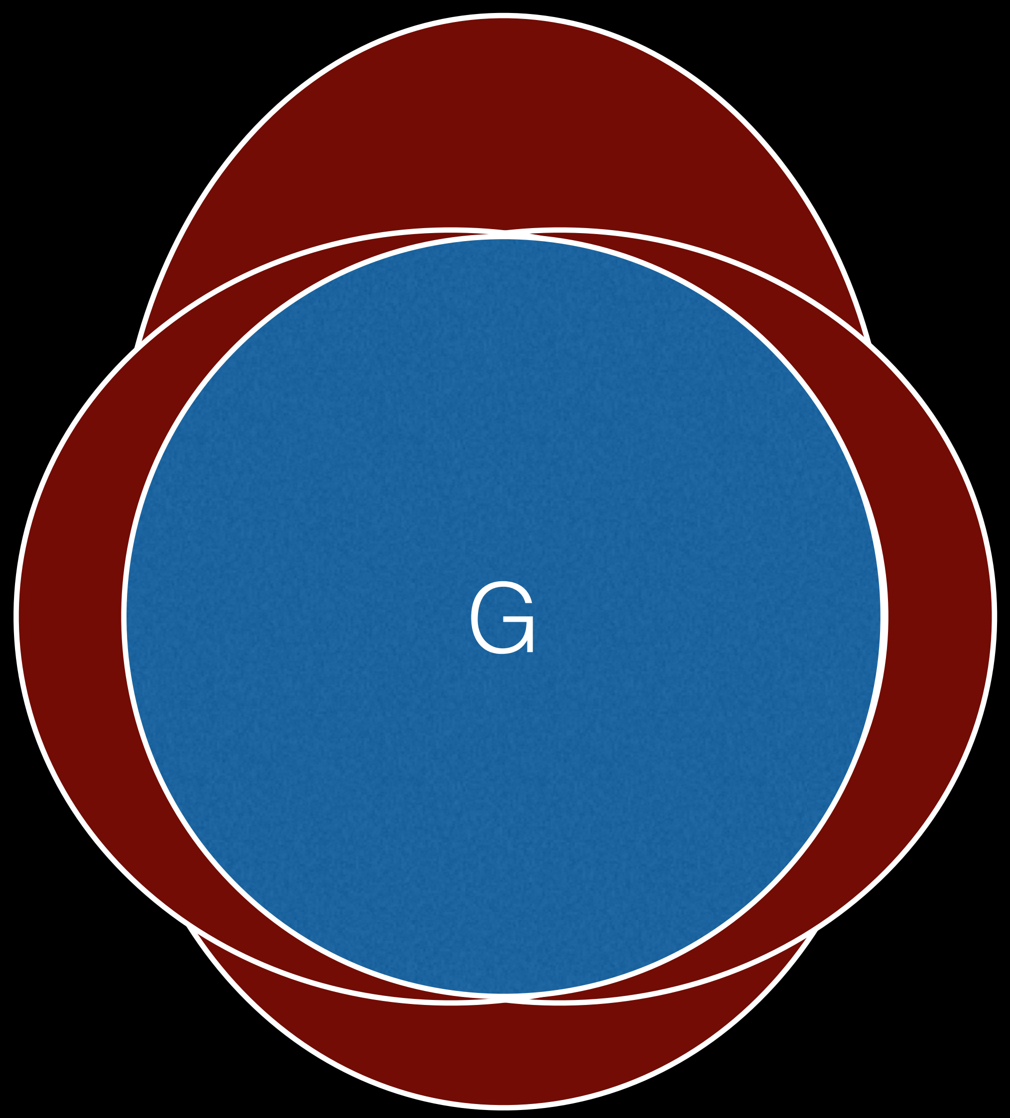


LCBA for agreement
“value” bit



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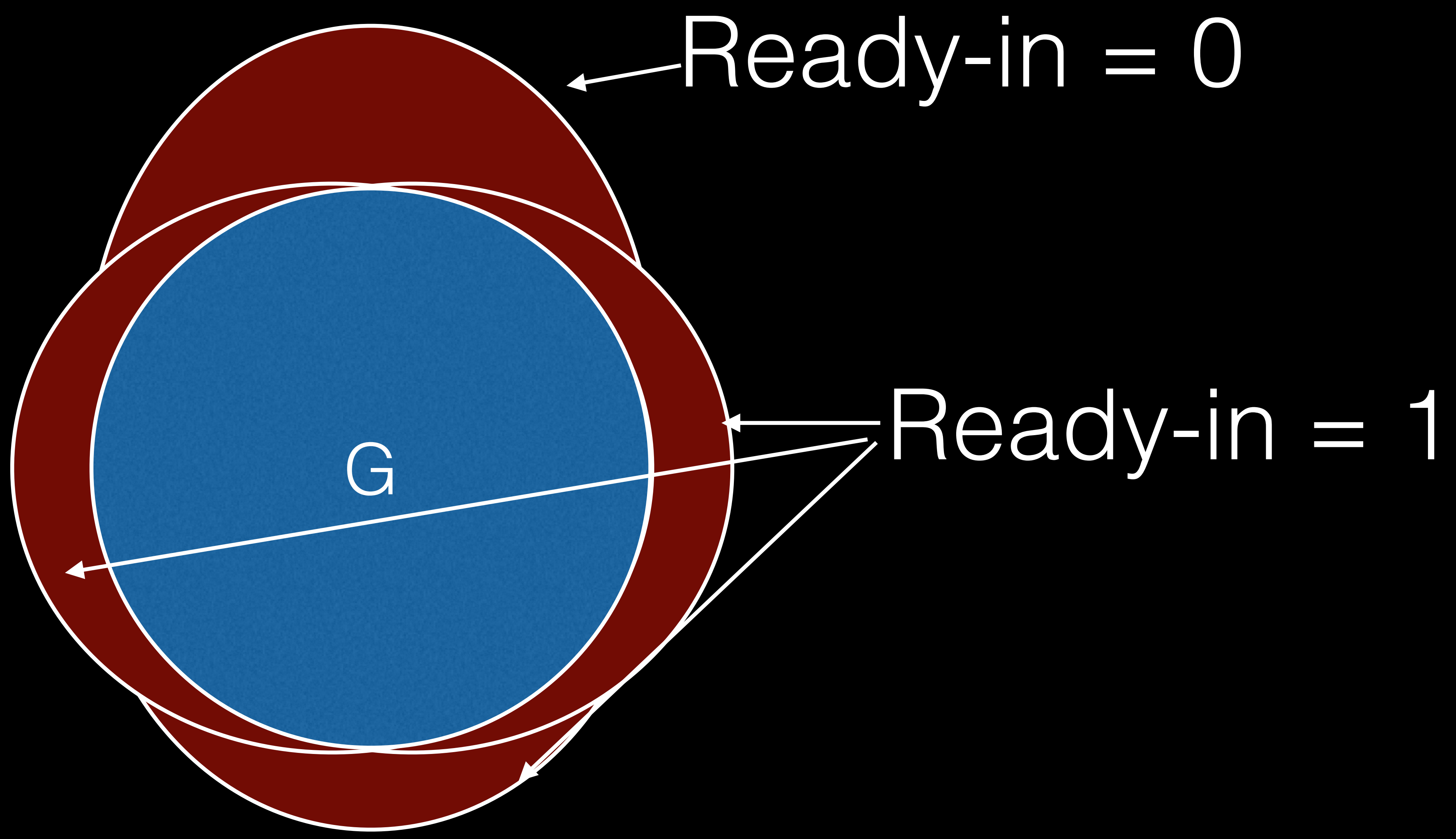

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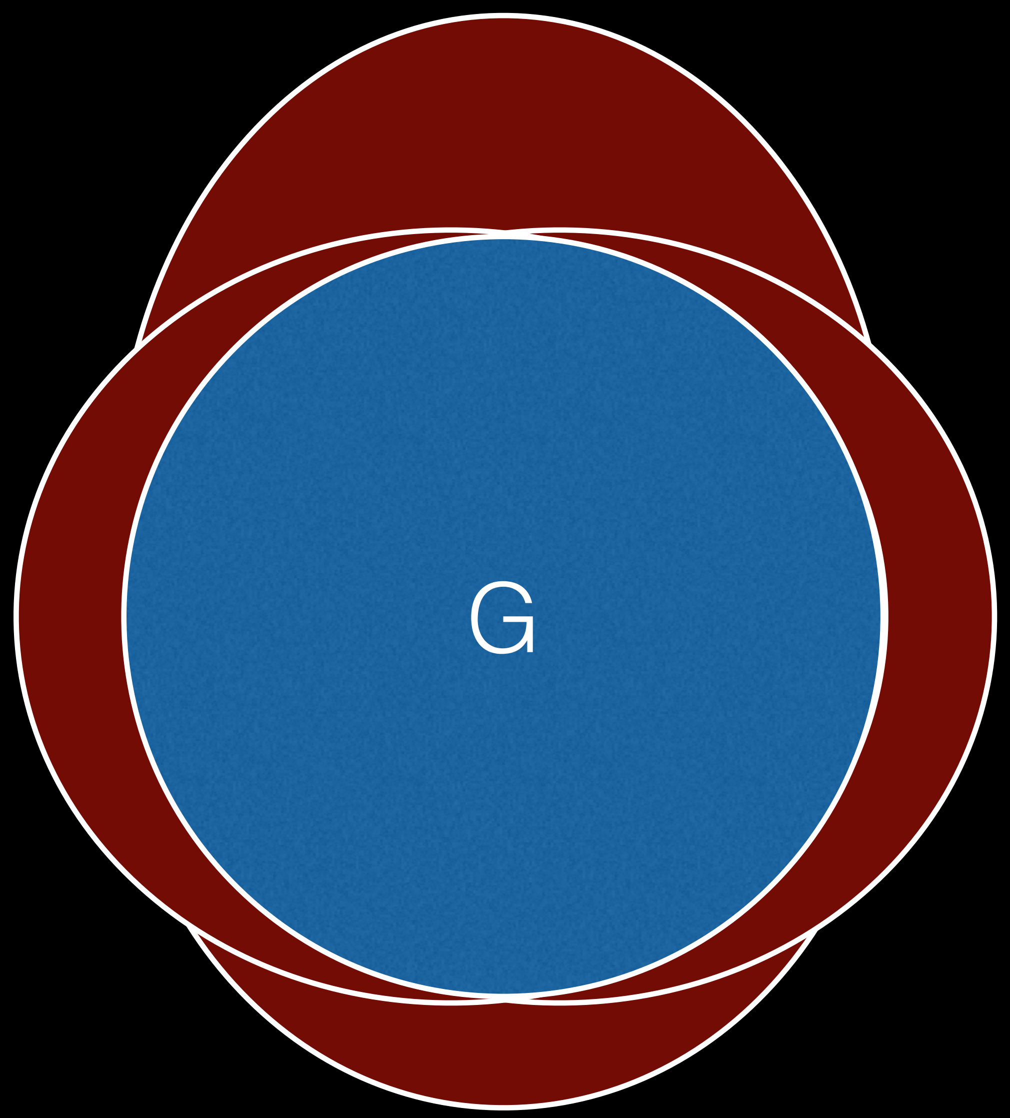
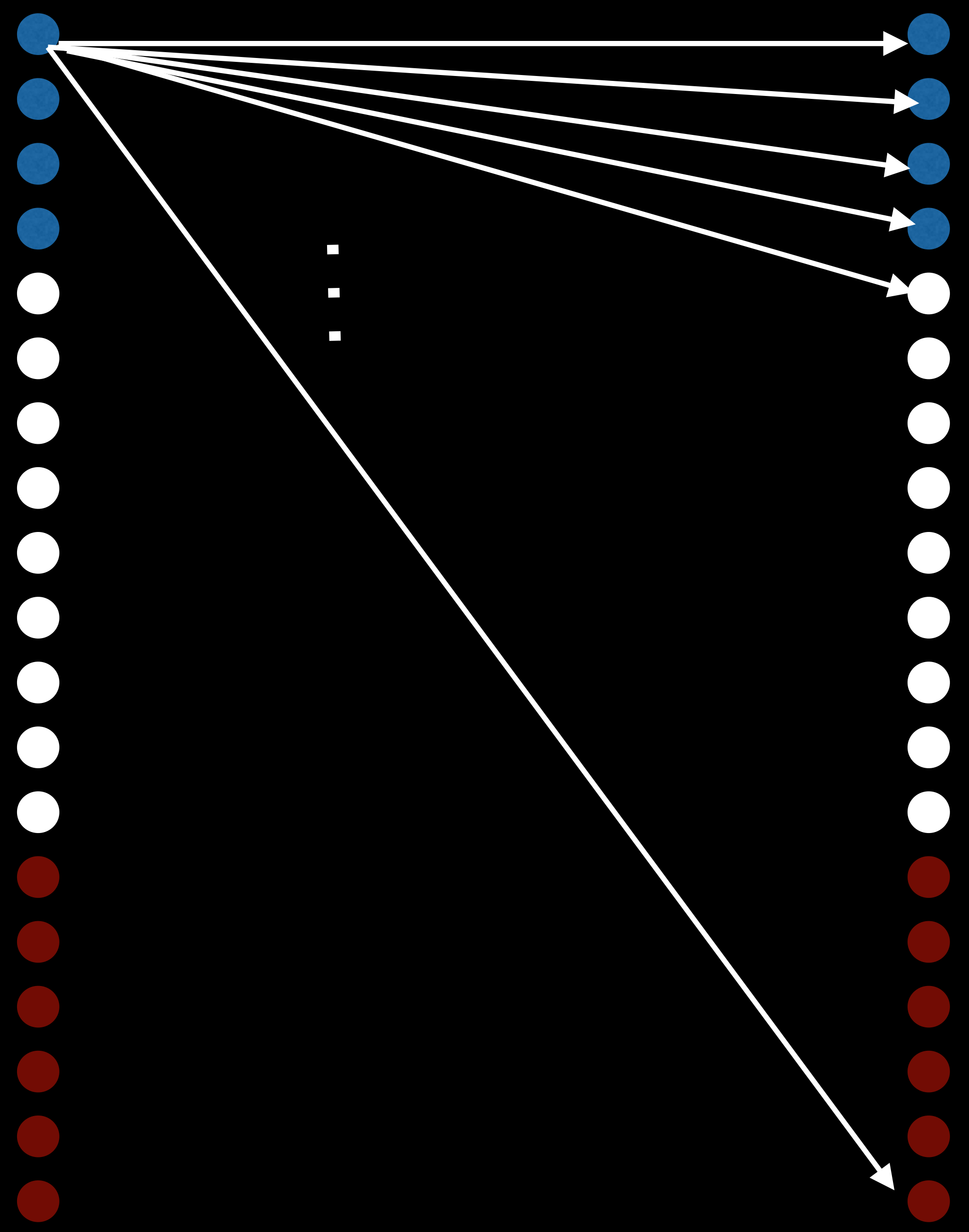


Every active ID
broadcasts its
(ready-out,value)
bits




Active IDs
sample $\Theta(\log n)$
to validate S_x

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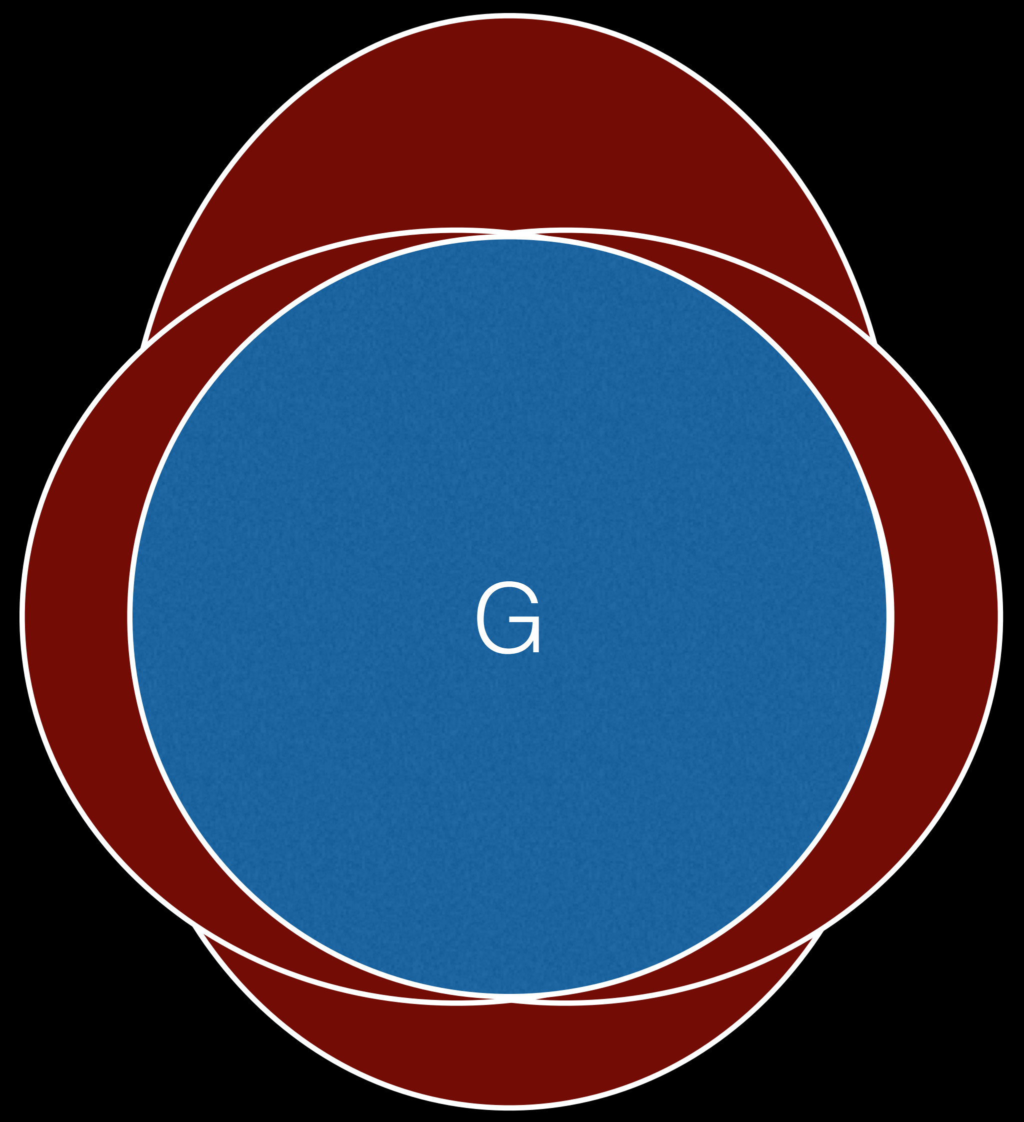

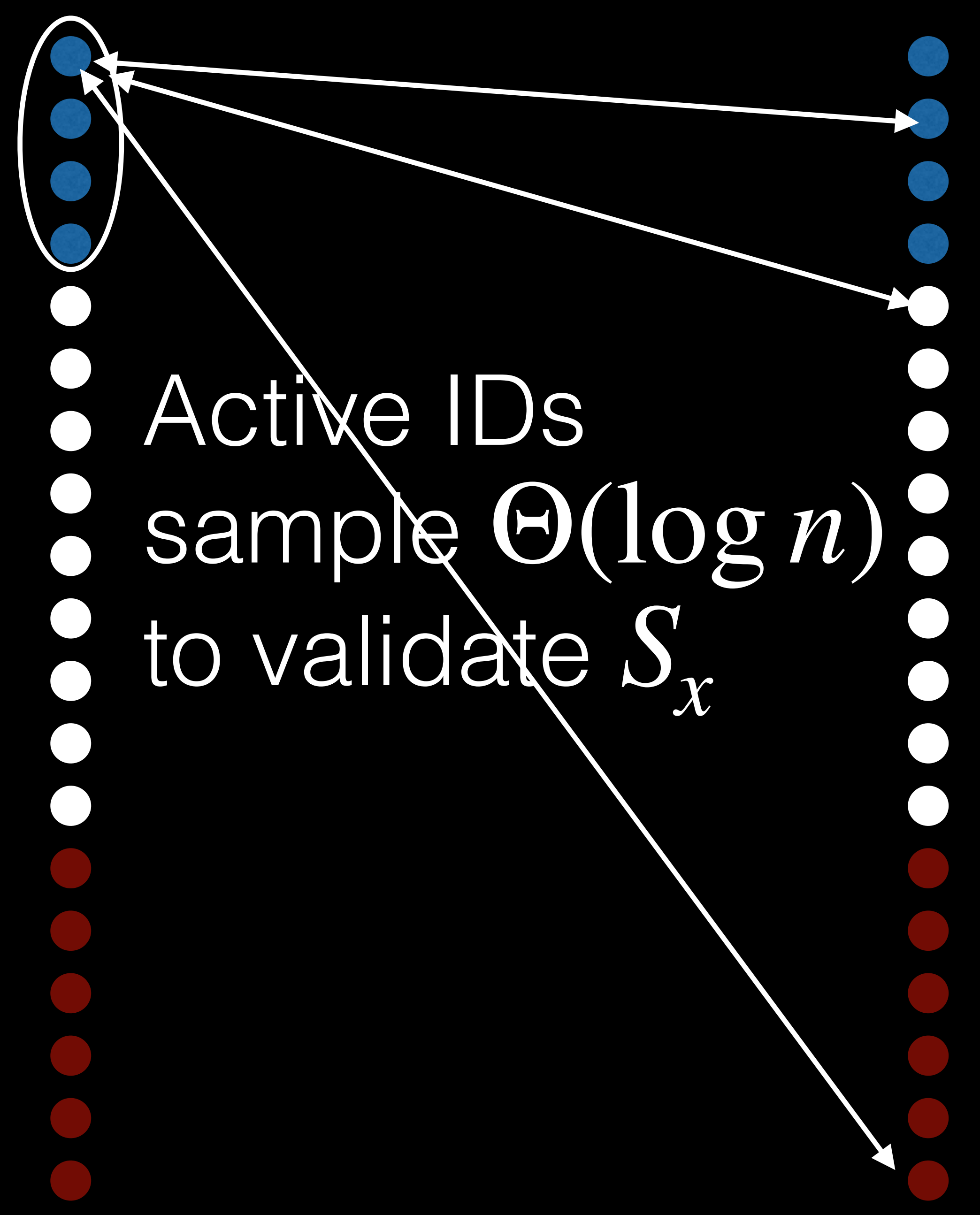

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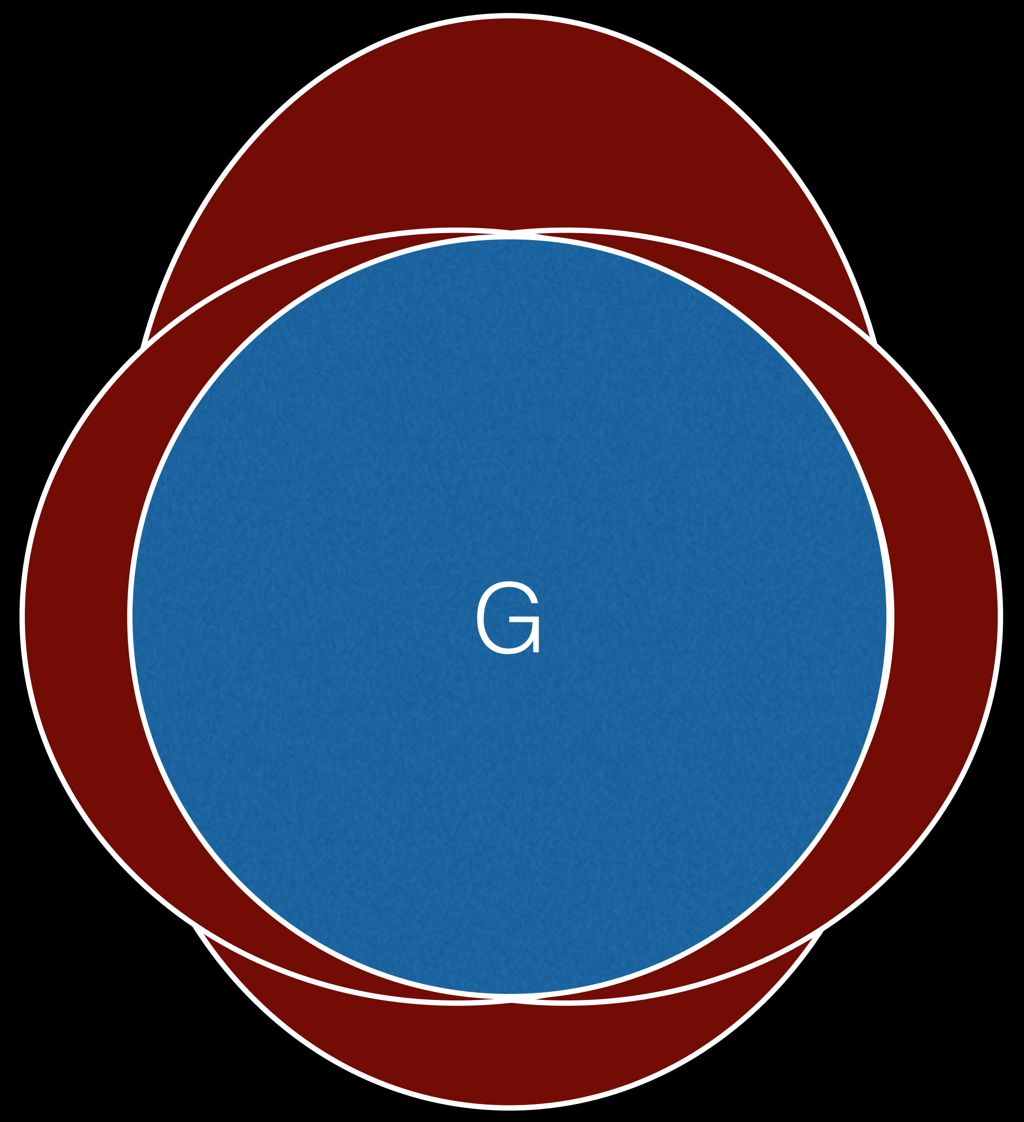

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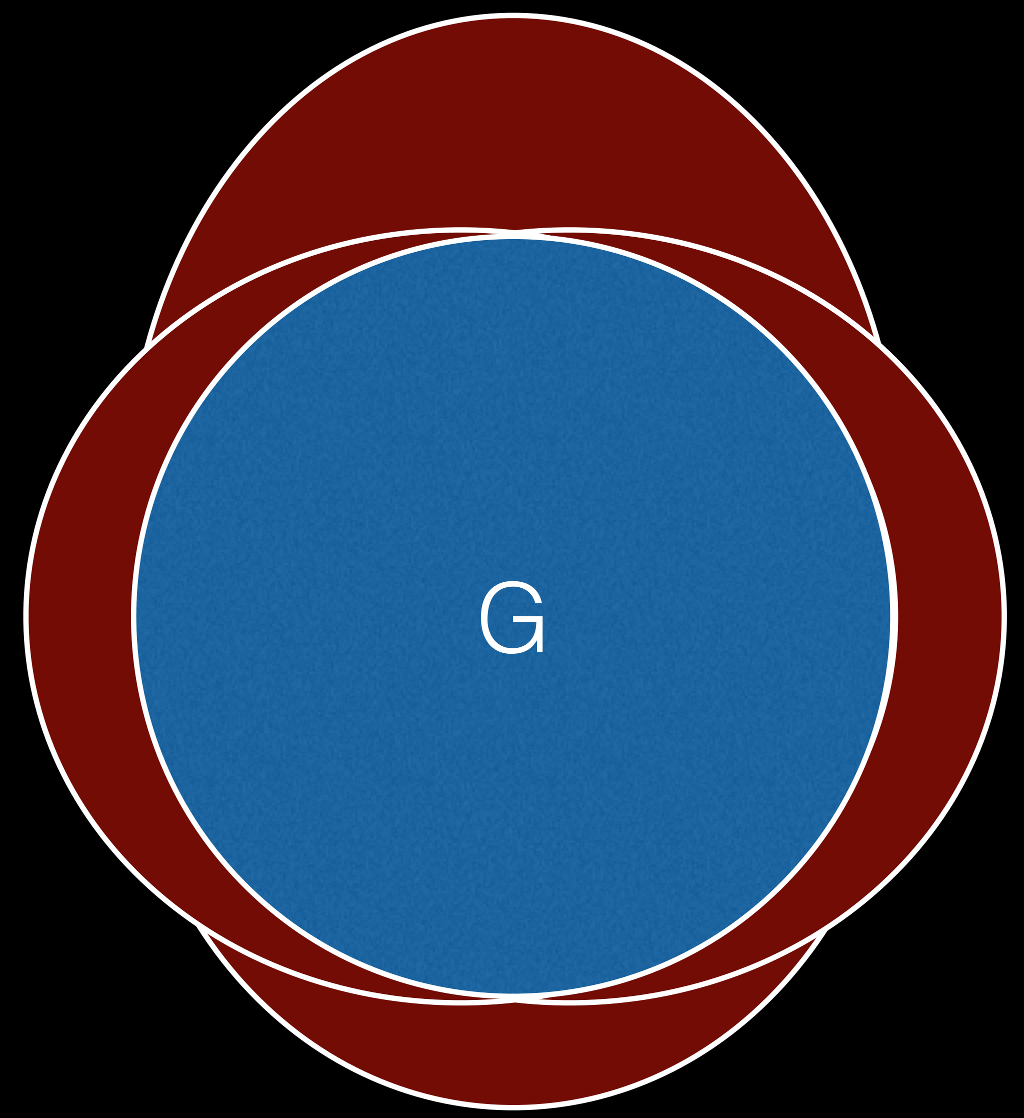

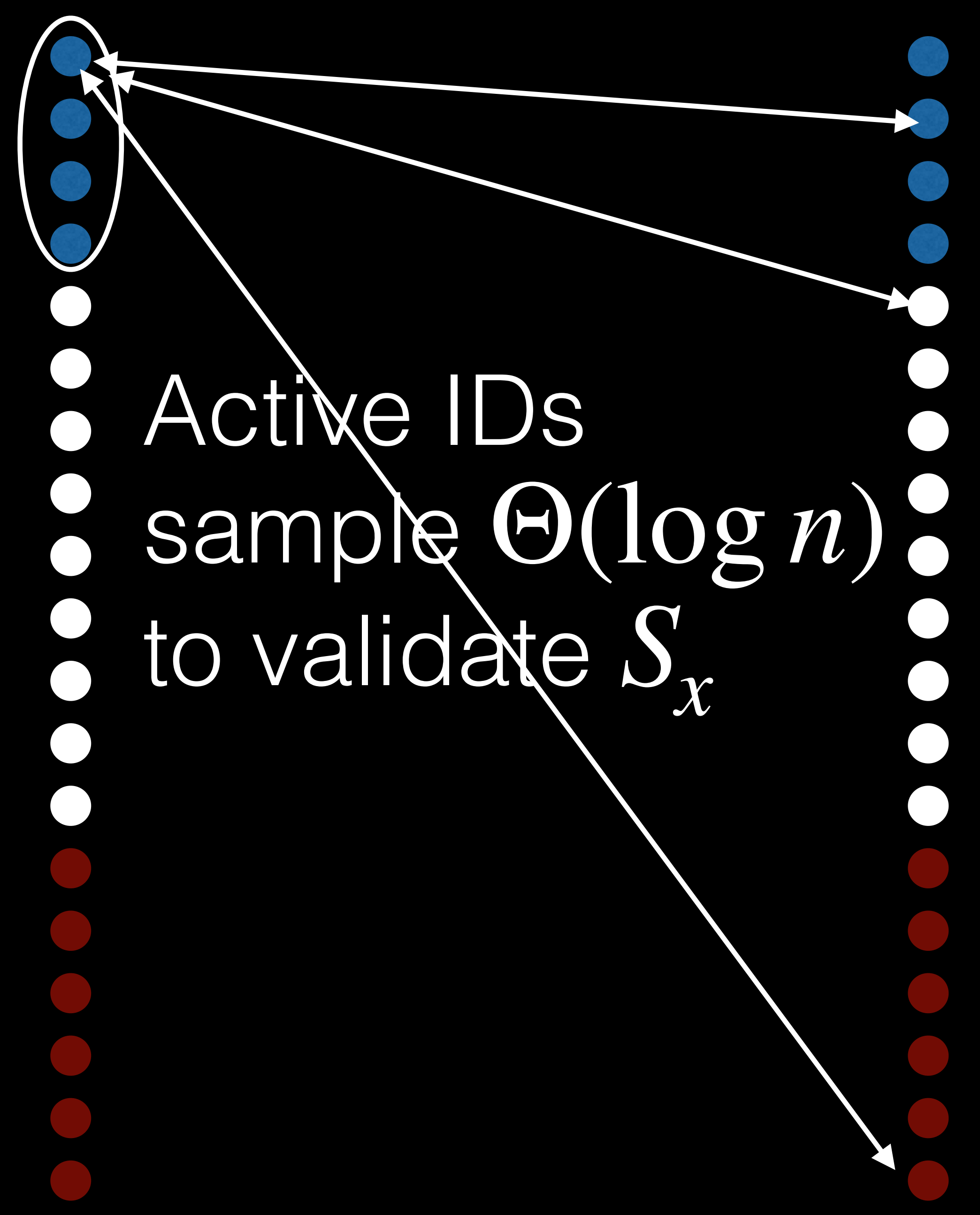

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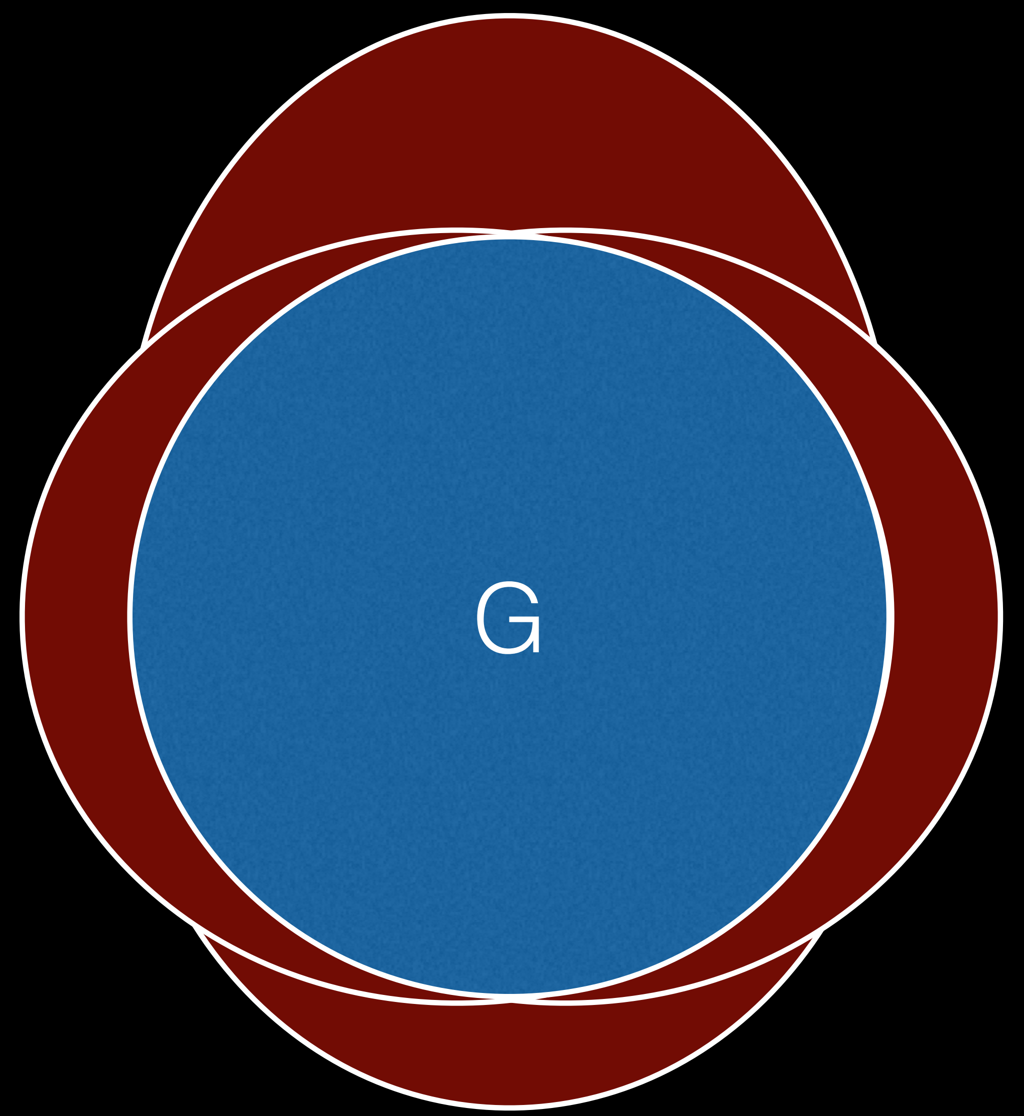

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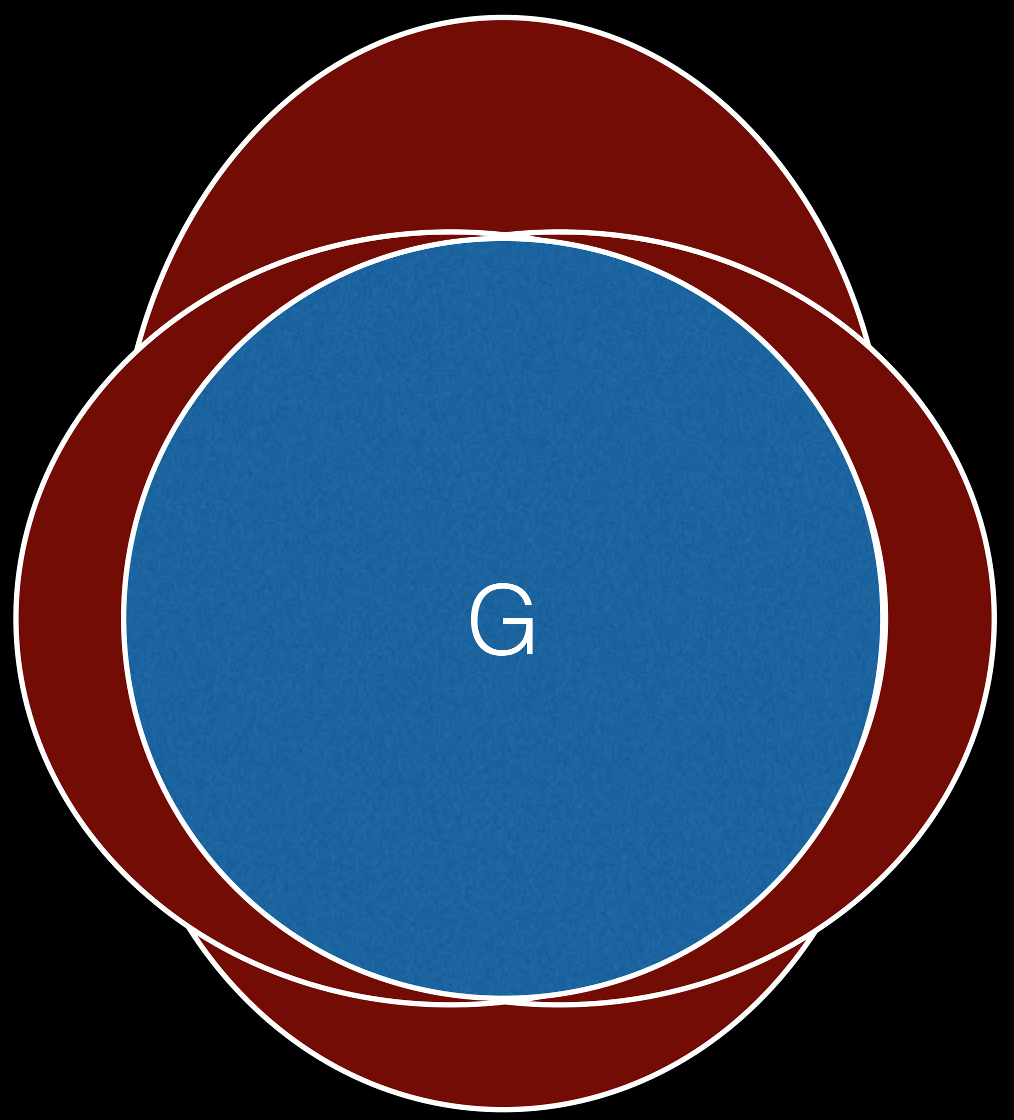
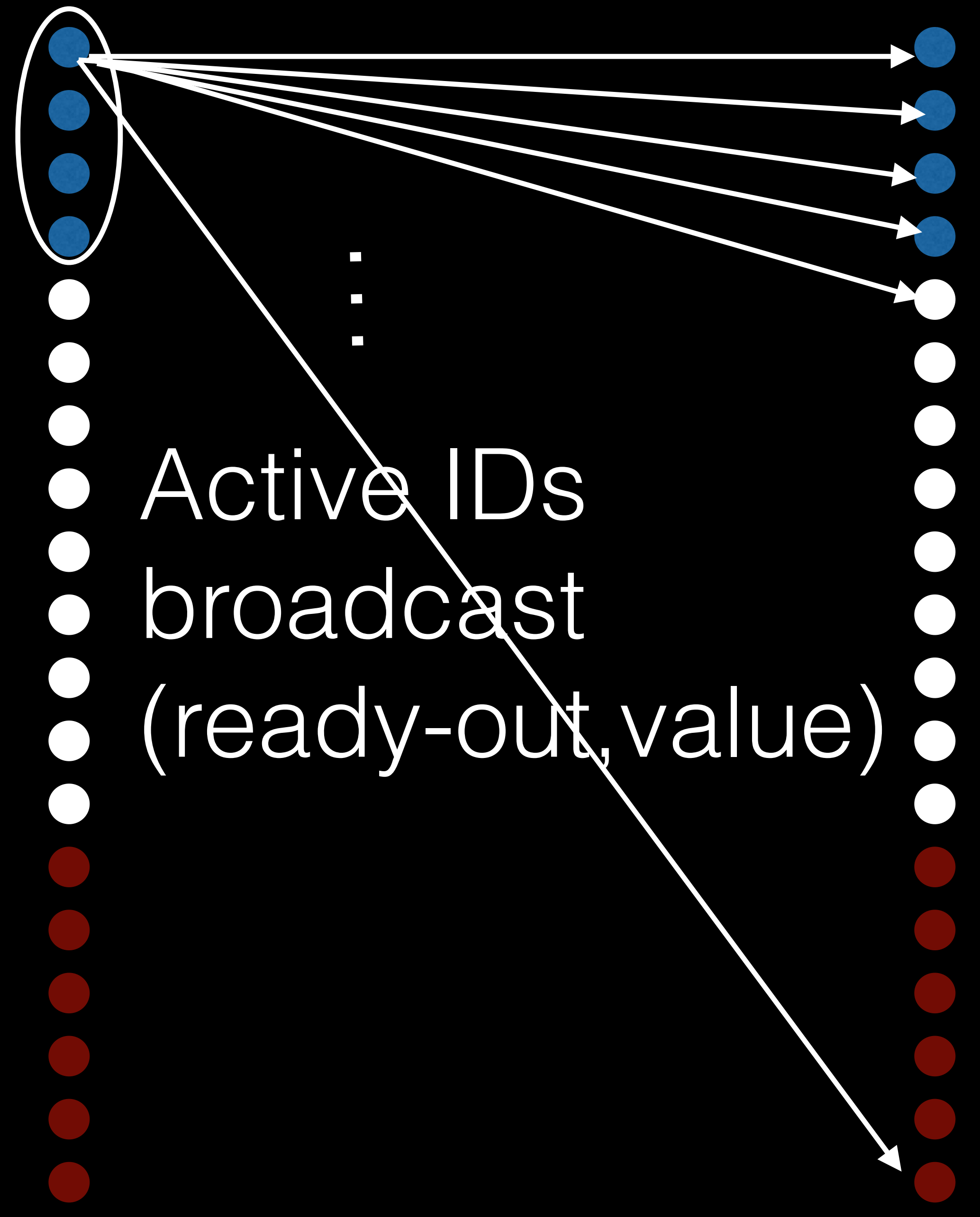
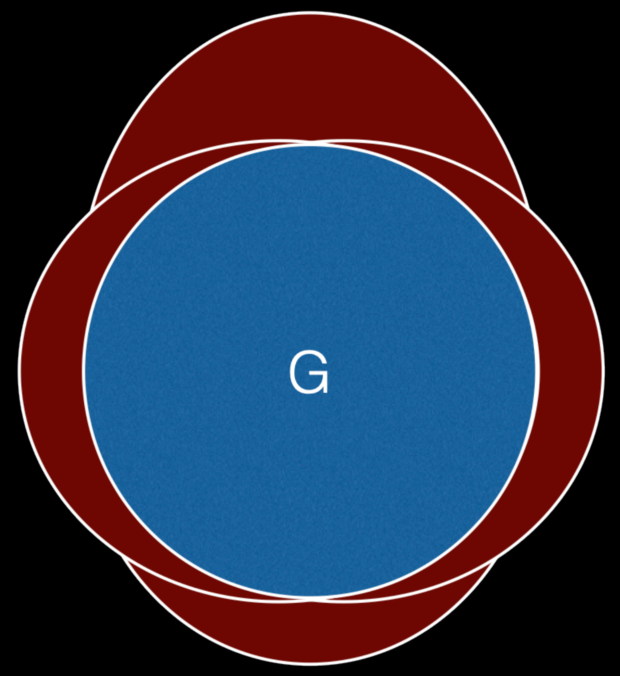


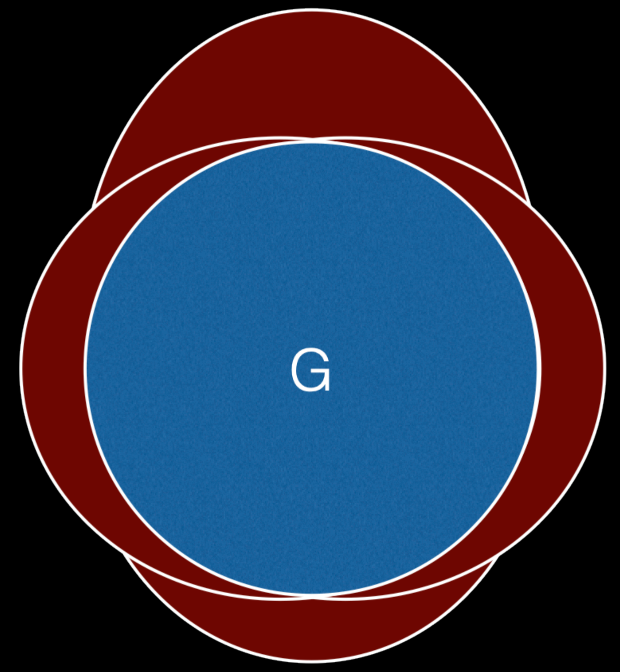


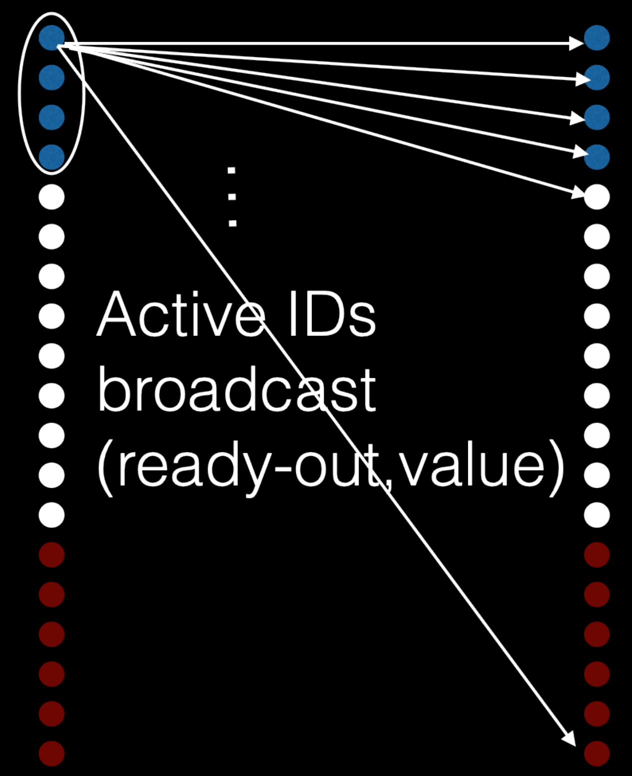
Implicit Agreement

LCBA for “Ready-out” bit



LCBA for “value” bit



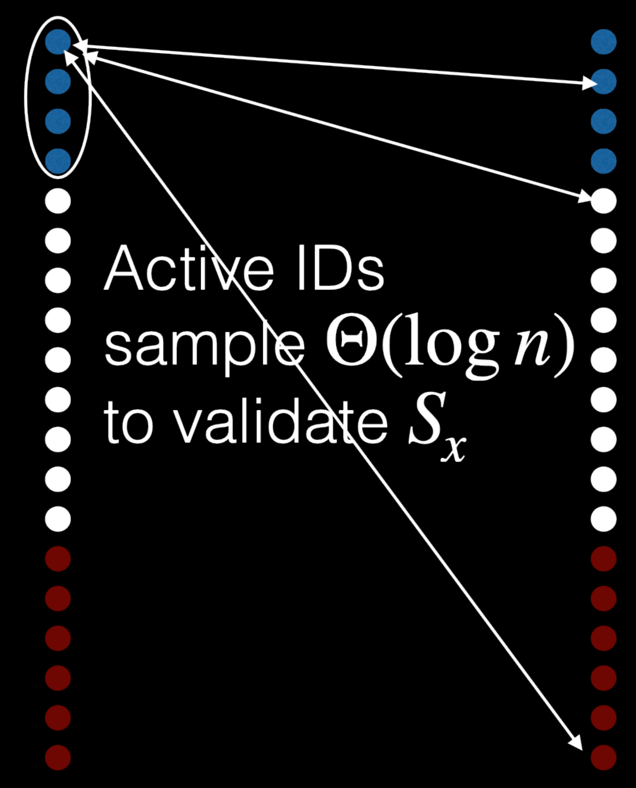


Either:

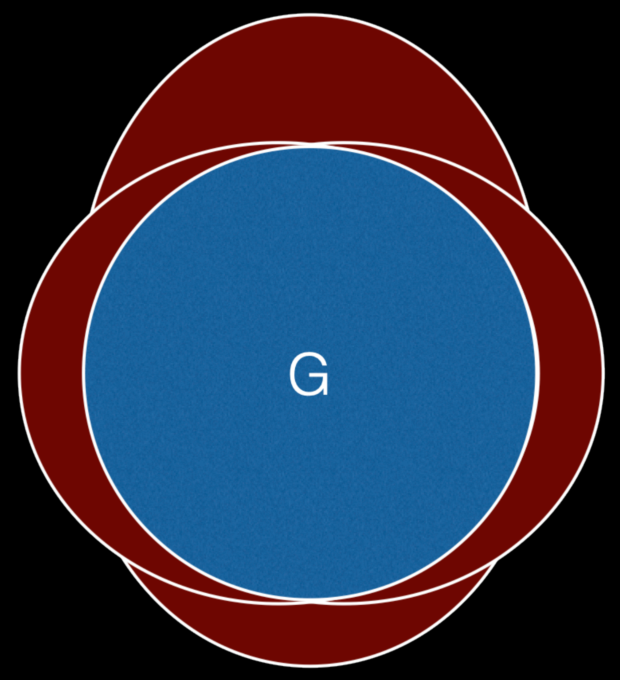
(1) > t/n good IDs decide; or

(2) no good IDs decide

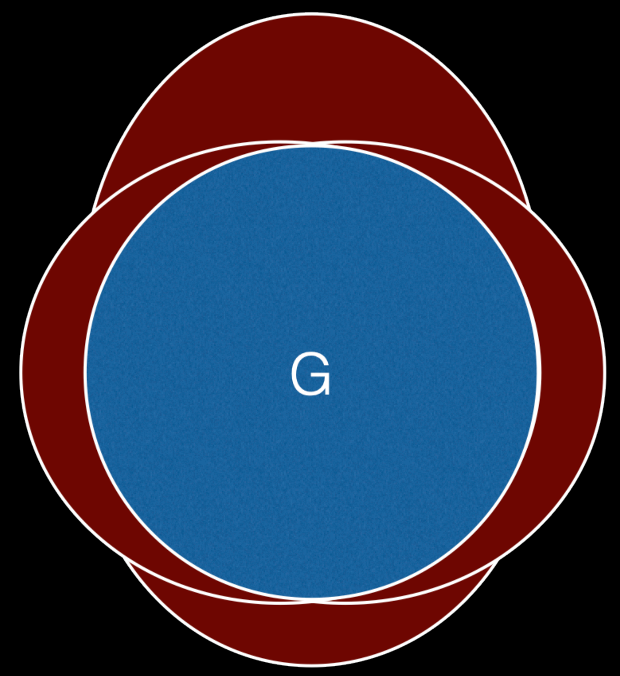
Implicit Agreement

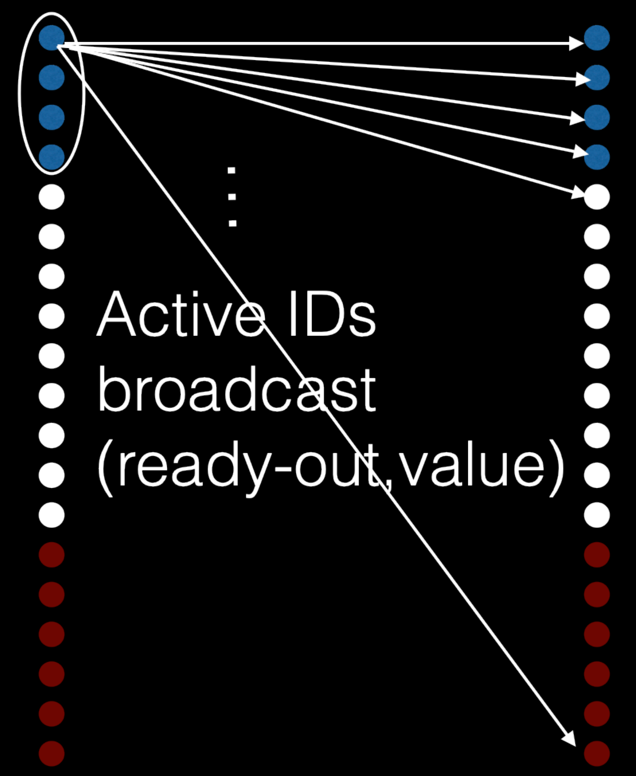


LCBA for “Ready-out” bit



LCBA for “value” bit





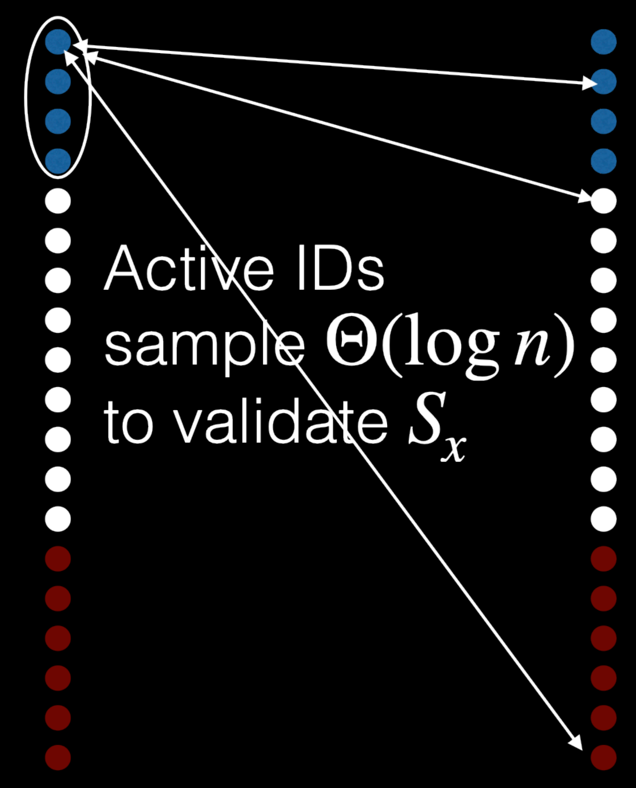
What next?

Either:

(1) > t/n good IDs decide; or

(2) no good IDs decide

Implicit Agreement



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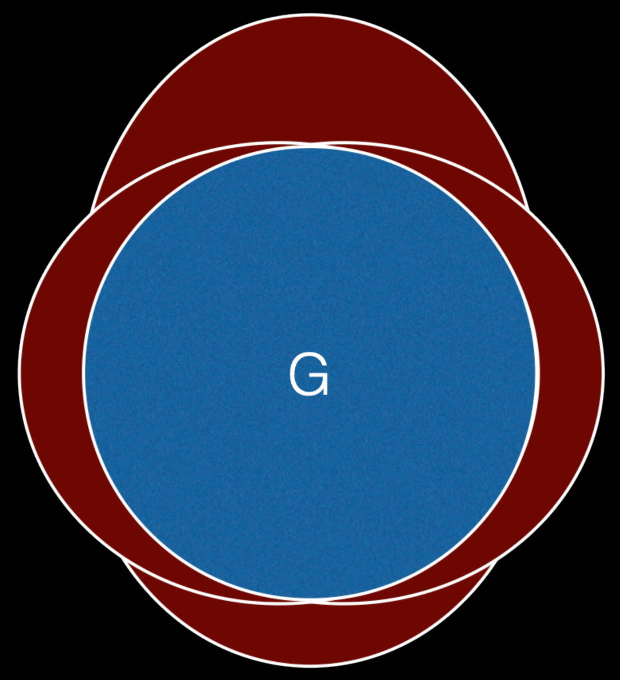

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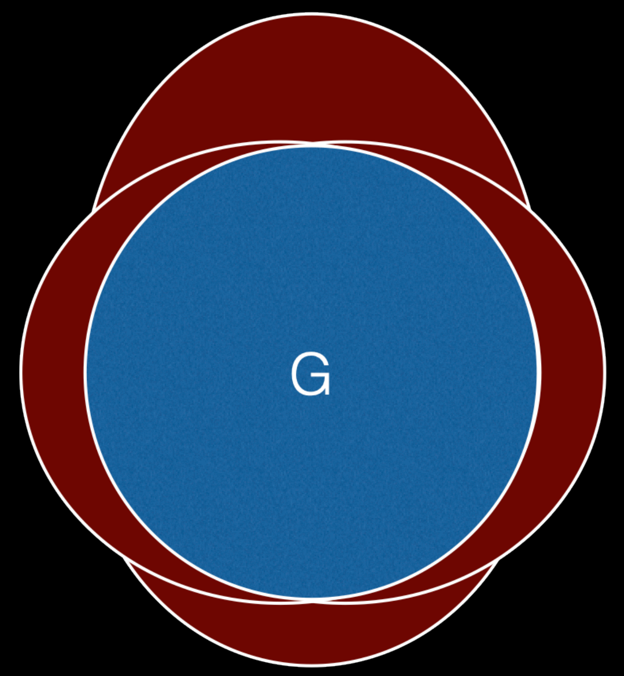

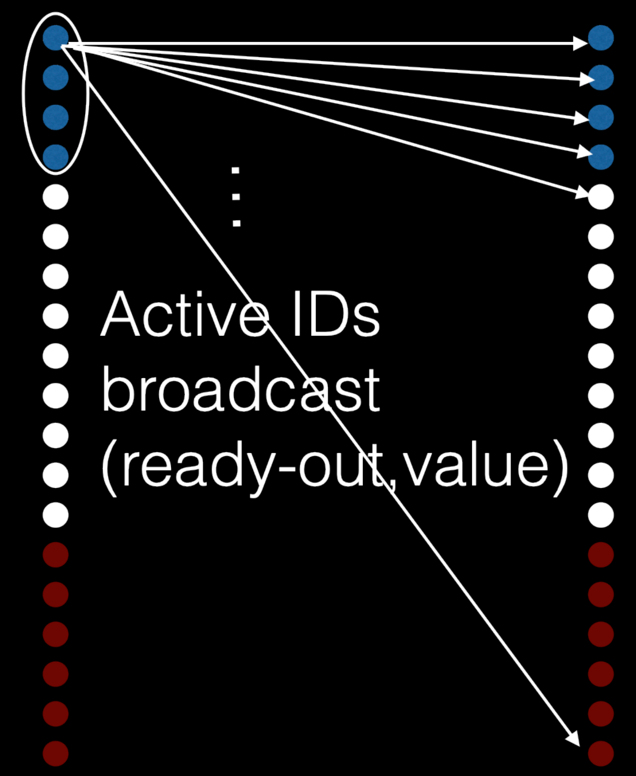

Either:

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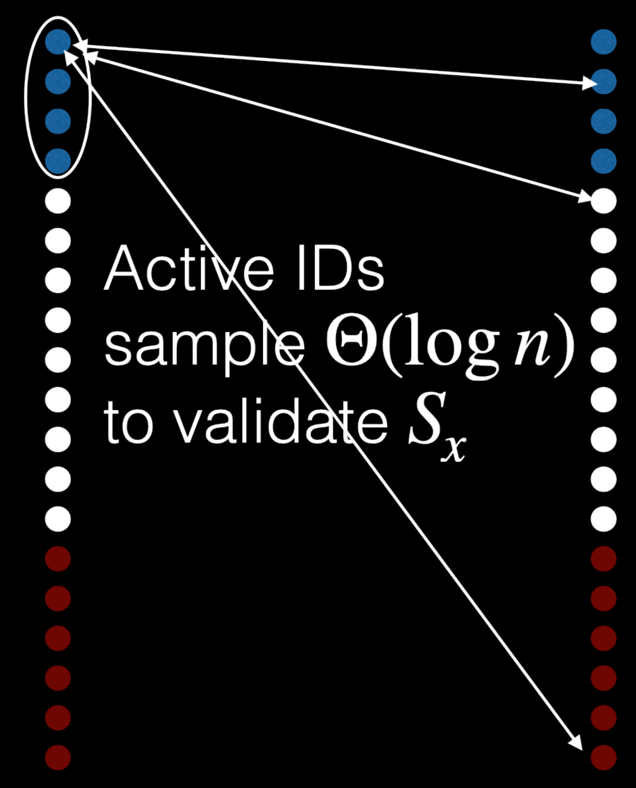
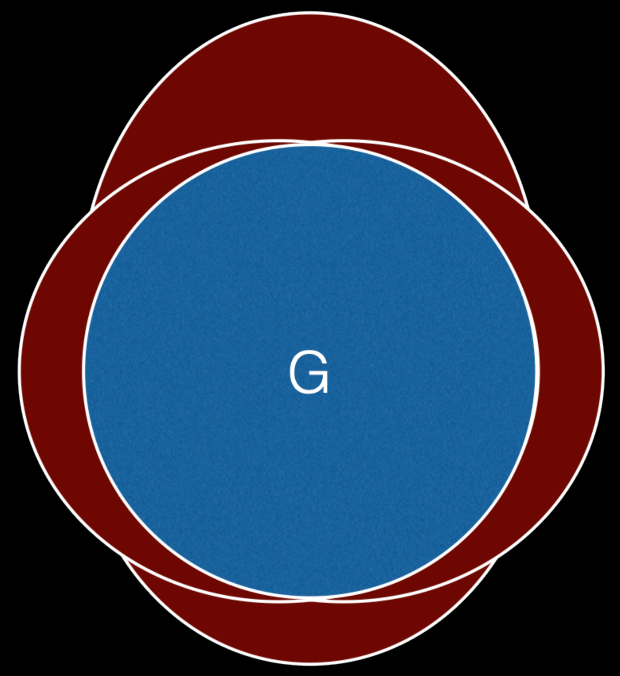
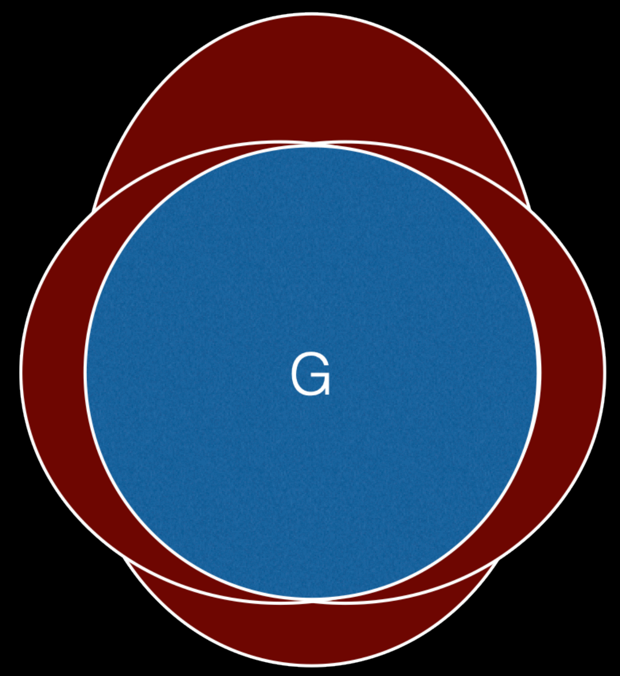
Implicit Agreement

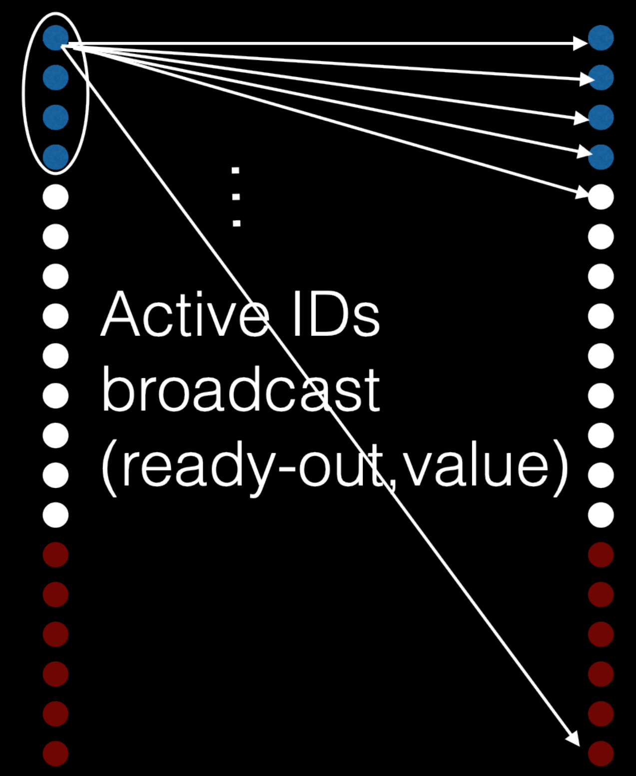


LCBA for "Ready-out" bit



LCBA for "value" bit





Either:

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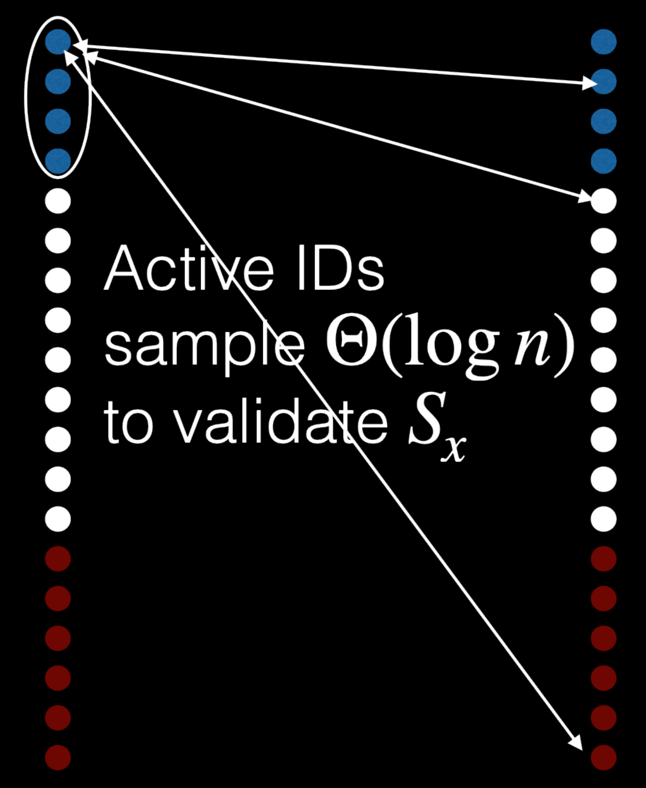
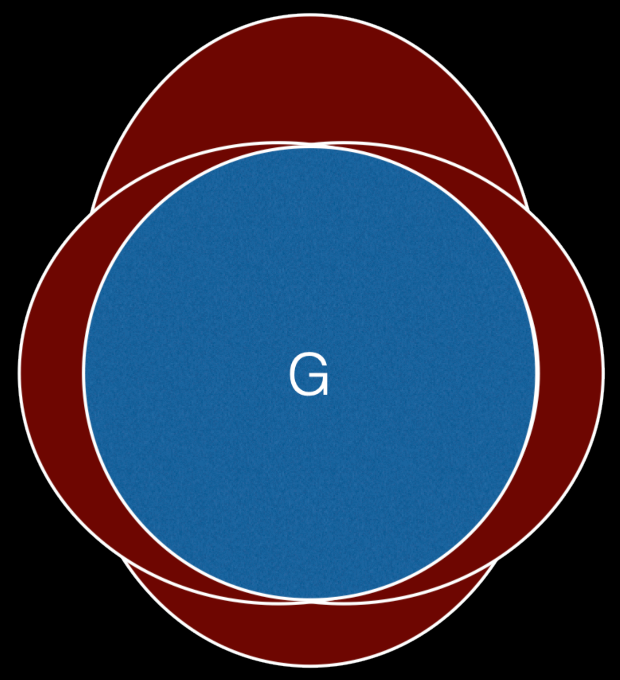
Promise Agreement

Implicit Agreement



LCBA for “Ready-out” bit



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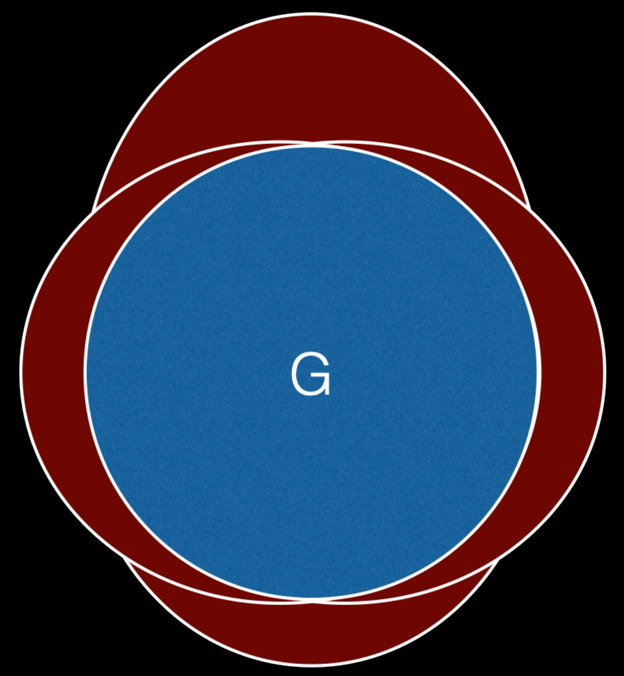

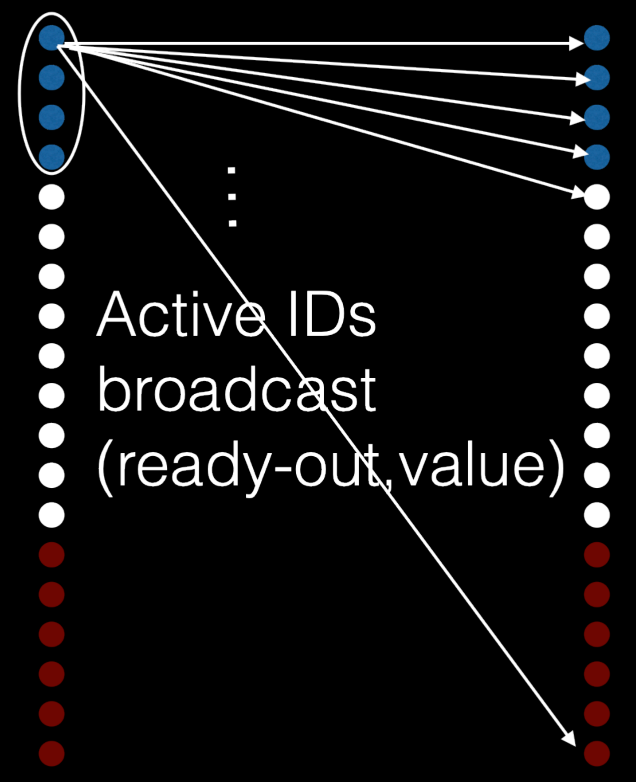

Either:

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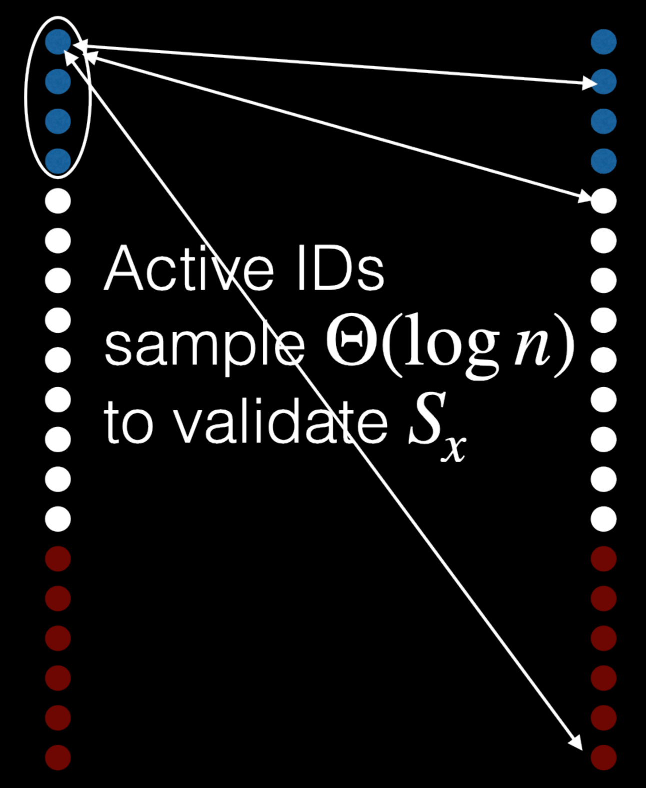
Promise Agreement

Everyone samples

Implicit Agreement



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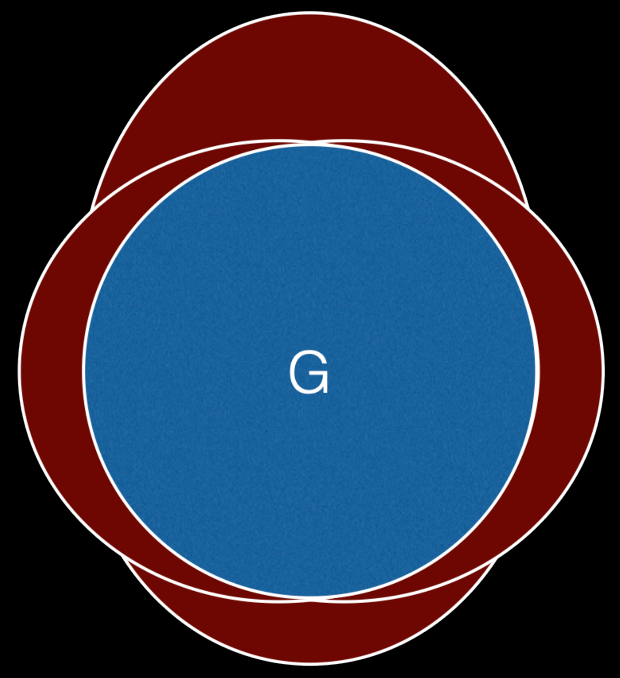
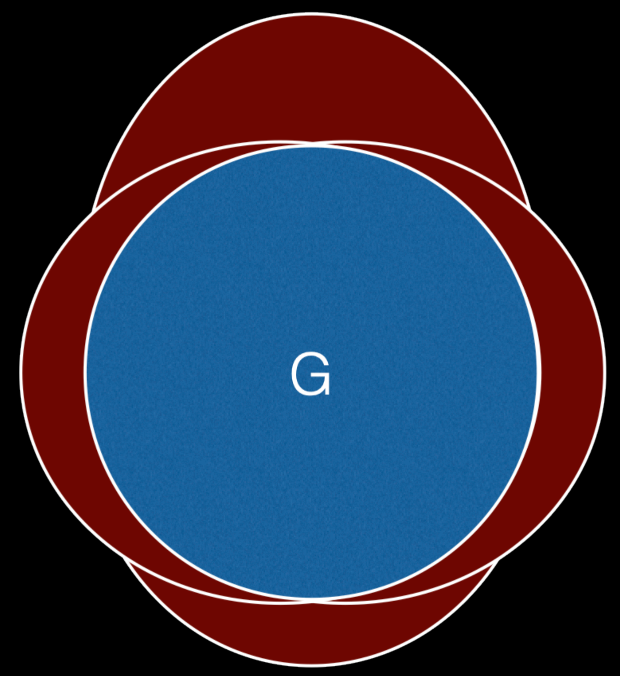
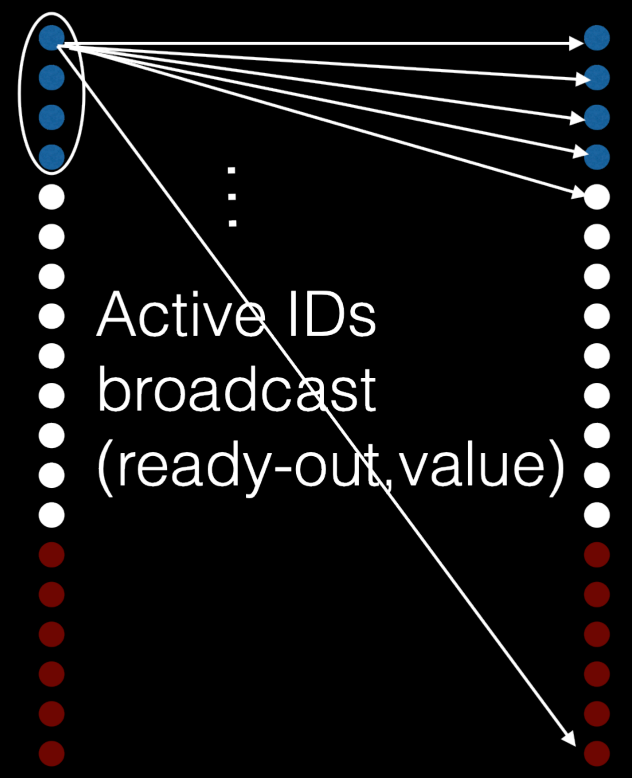
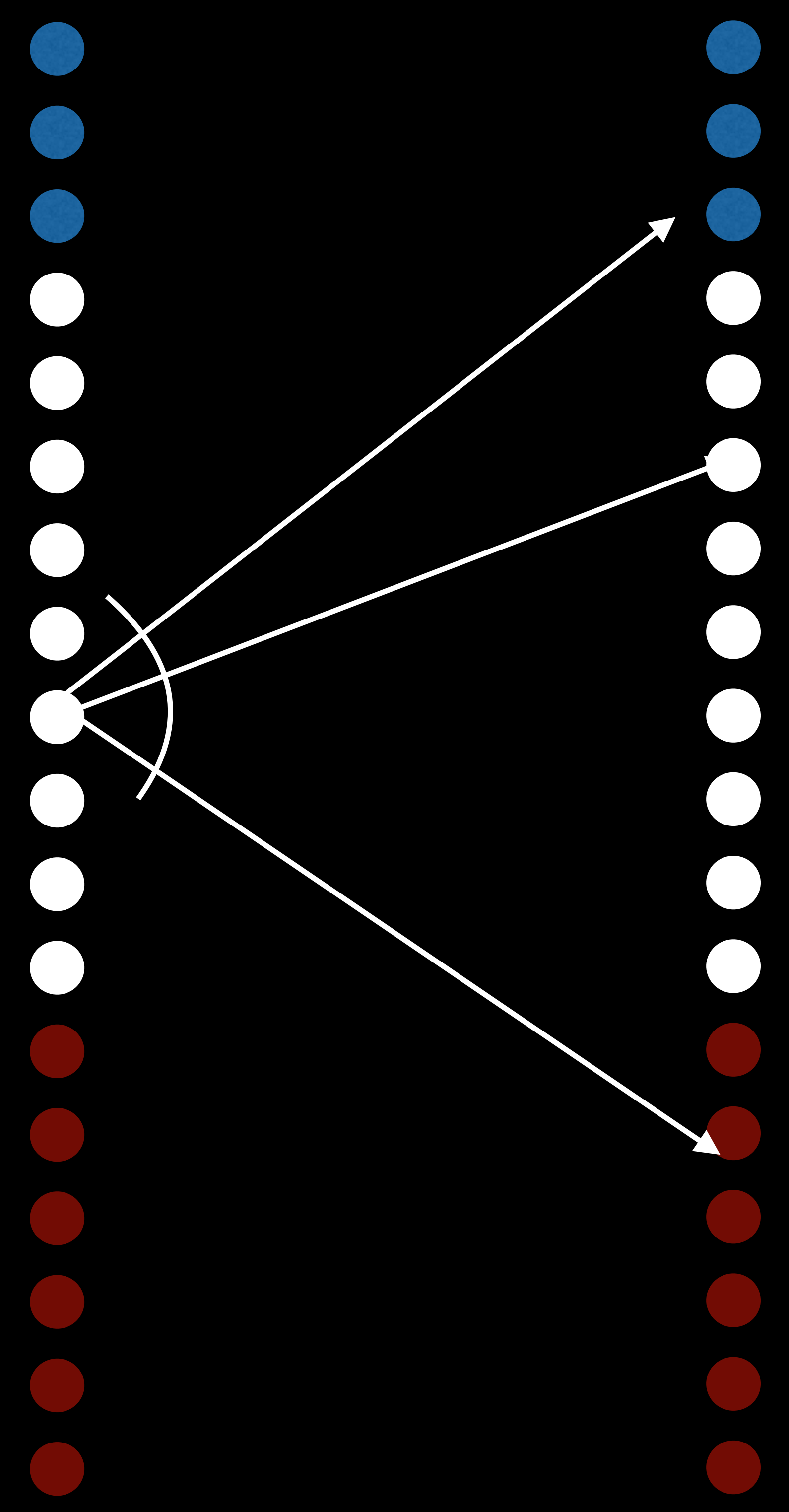


LCBA for "value" bit



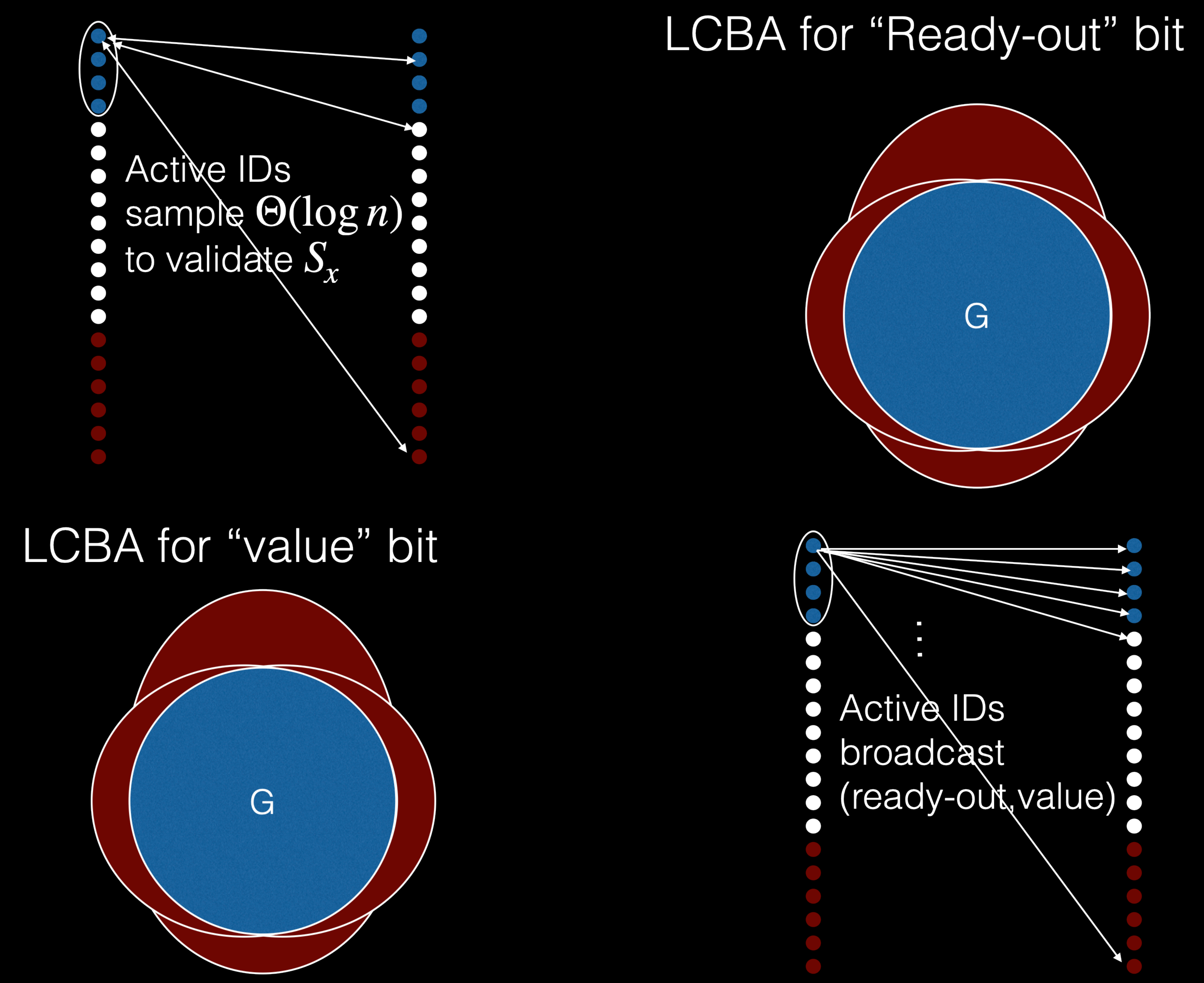




Either:
(1) > t/n good IDs decide; or
(2) no good IDs decide

Every good ID samples $\Theta(\log n)$ IDs for their (ready-out, value) bits

Implicit Agreement



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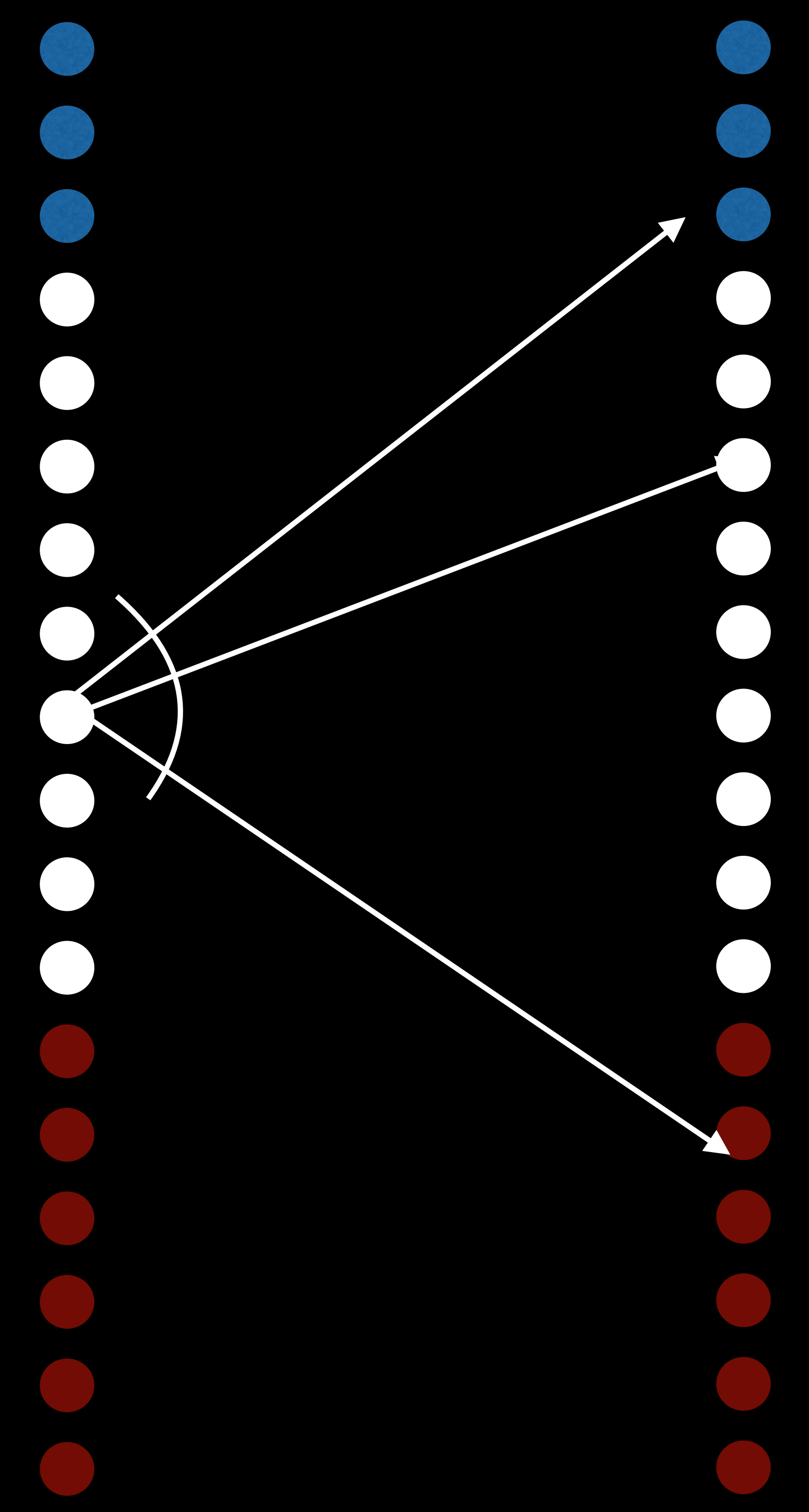
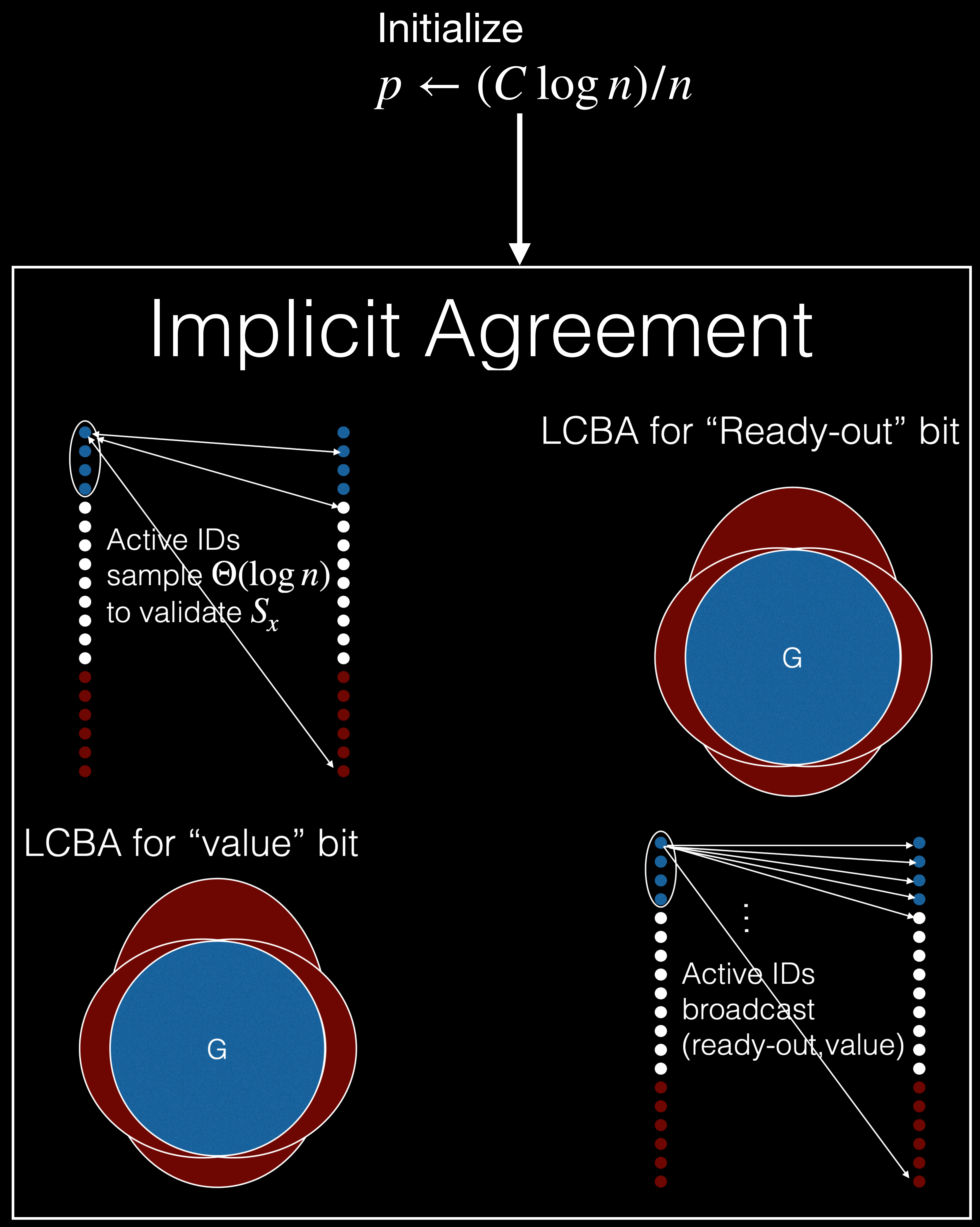
Promise Agreement



Every good ID samples $\Theta(\log n)$ IDs for their (ready-out, value) bits

Entire Algorithm



Initialize
$p \leftarrow (C \log n)/n$
Implicit Agreement
Active IDs
sample $\Theta(\log n)$
to validate S_x
LCBA for "Ready-out" bit
G
LCBA for "value" bit
G
Active IDs
broadcast
(ready-out,value)

Initialize
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LCBA for “value” bit
G
Active IDs
broadcast
(ready-out,value)
Promise Agreement
Sample $\Theta(\log n)$
for (ready-out, value)
If fail:
$p \leftarrow 2p$
If success:
DONE!

Initialize
$p \leftarrow (C \log n)/n$
Implicit Agreement
Active IDs
sample $\Theta(\log n)$
to validate S_x
LCBA for "Ready-out" bit
G
LCBA for "value" bit
G
Active IDs
broadcast
(ready-out,value)
Promise Agreement
Sample $\Theta(\log n)$
for (ready-out, value)
If fail:
$p \leftarrow 2p$
$p < \frac{1}{C \log n}$?
Y
N
Heavy-weight
Byzantine agreement
If success:
DONE!

Conclusion

Can solve Byzantine agreement in KT_0 with:

$O(\text{polylog}(n))$ latency

$O((T + n)\log n)$ expected messages

$T = \min(n^2,$ # bits sent by adversary$)$

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(1) broadcast to all strangers; (2) writing to random stranger

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Communication with strangers only occurs via:

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Almost matching lower bounds for polylog(n) round algs

Non-trivial lower-bound for all Las Vegas algorithms

Future Work

(1) Closing gap between upper and lower bounds for randomized algorithms:

Know: If $T = n^{1+\alpha}$ for $\alpha \in (0,1]$, then any Las Vegas algorithm sends $\Omega(n^{1+\alpha/2})$ bits in expectation

But, our algorithm sends $O(n^{1+\alpha})$ bits in this case

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Know: If $T = n^{1+\alpha}$ for $\alpha \in (0,1]$, then any Las Vegas algorithm sends $\Omega(n^{1+\alpha/2})$ bits in expectation

But, our algorithm sends $O(n^{1+\alpha})$ bits in this case

(2) Can we adapt our algorithm to better handle churn in permissionless networks?

Need a good model of churn

Thanks!