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VeRSA

Verifiable Registries with Efficient Client Audits from RSA Authenticated Dictionaries

Nirvan Tyagi Ben Fisch Andrew Zitek

Joseph Bonneau Stefano Tessaro

Setting: Verifiable registries

Applications: certificate transparency, key transparency, binary transparency, etc.

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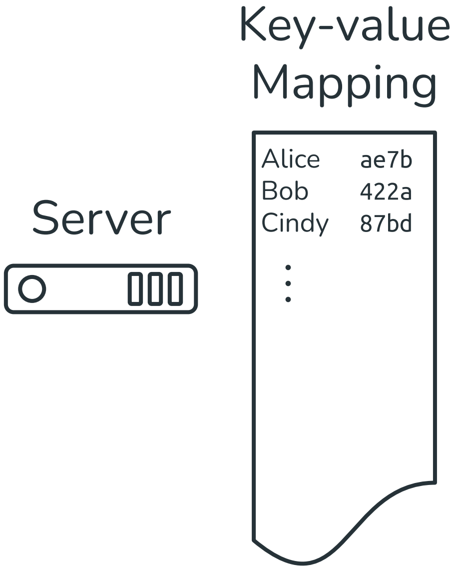

e.g. public key identities
software binary checksums
domain name routing info

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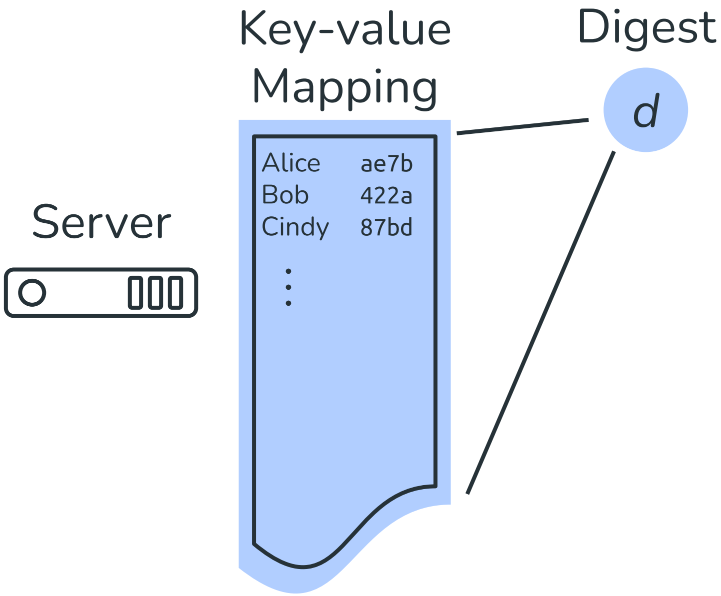

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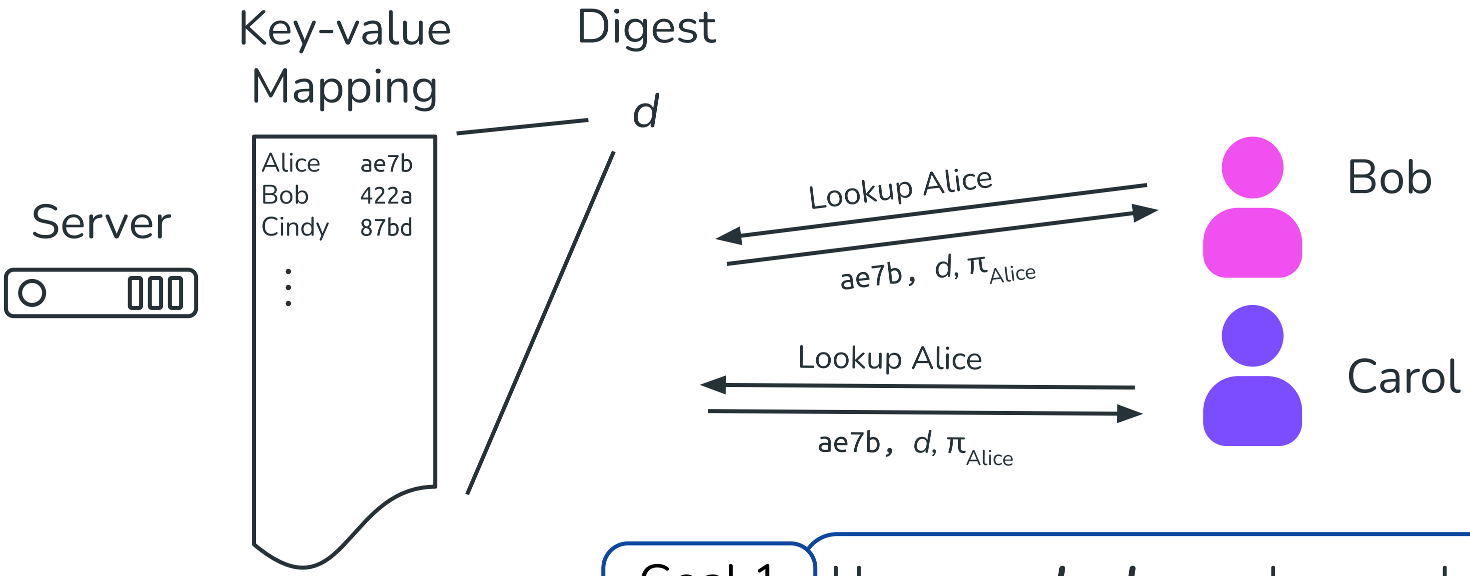
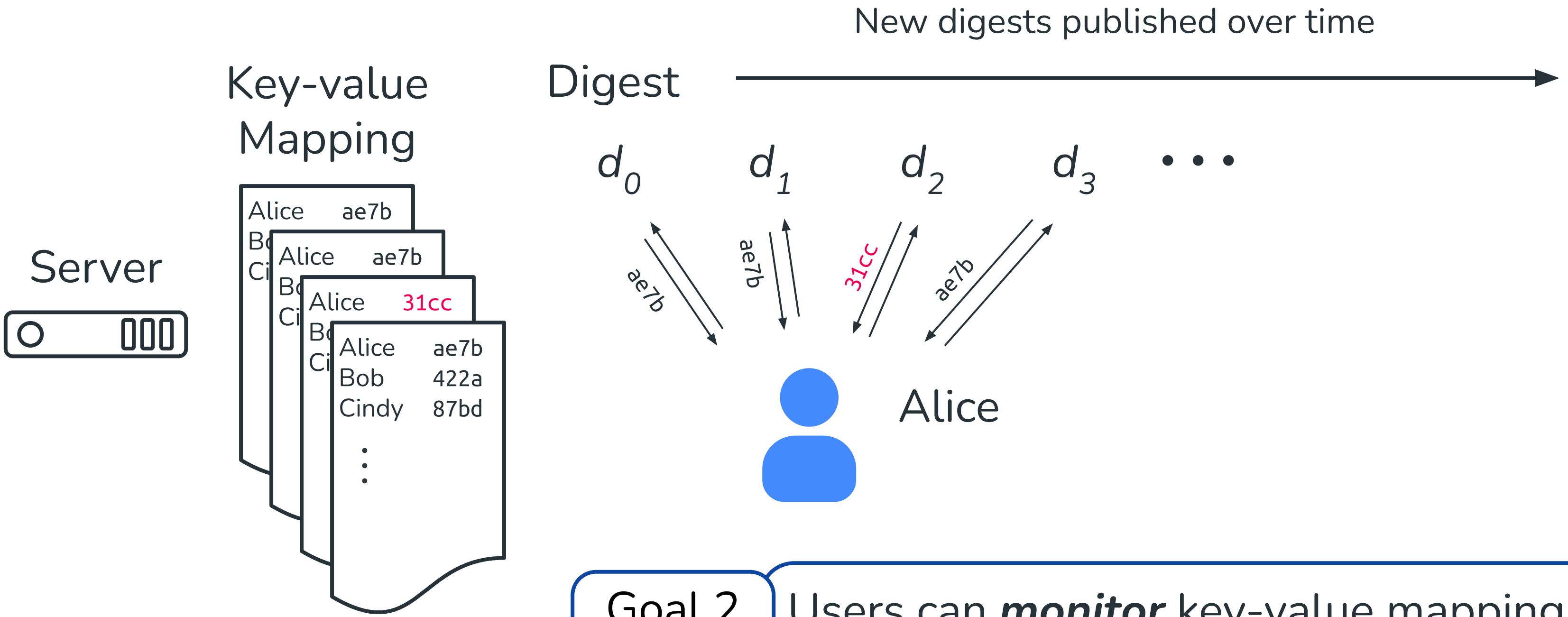


Goal 1 Users can ***lookup*** values and verify they are consistent with what other users receive.

e.g. public key identities
software binary checksums
domain name routing info

Setting: Verifiable registries



Goal 2 Users can ***monitor*** key-value mappings to detect unexpected modifications.

e.g. public key identities
software binary checksums
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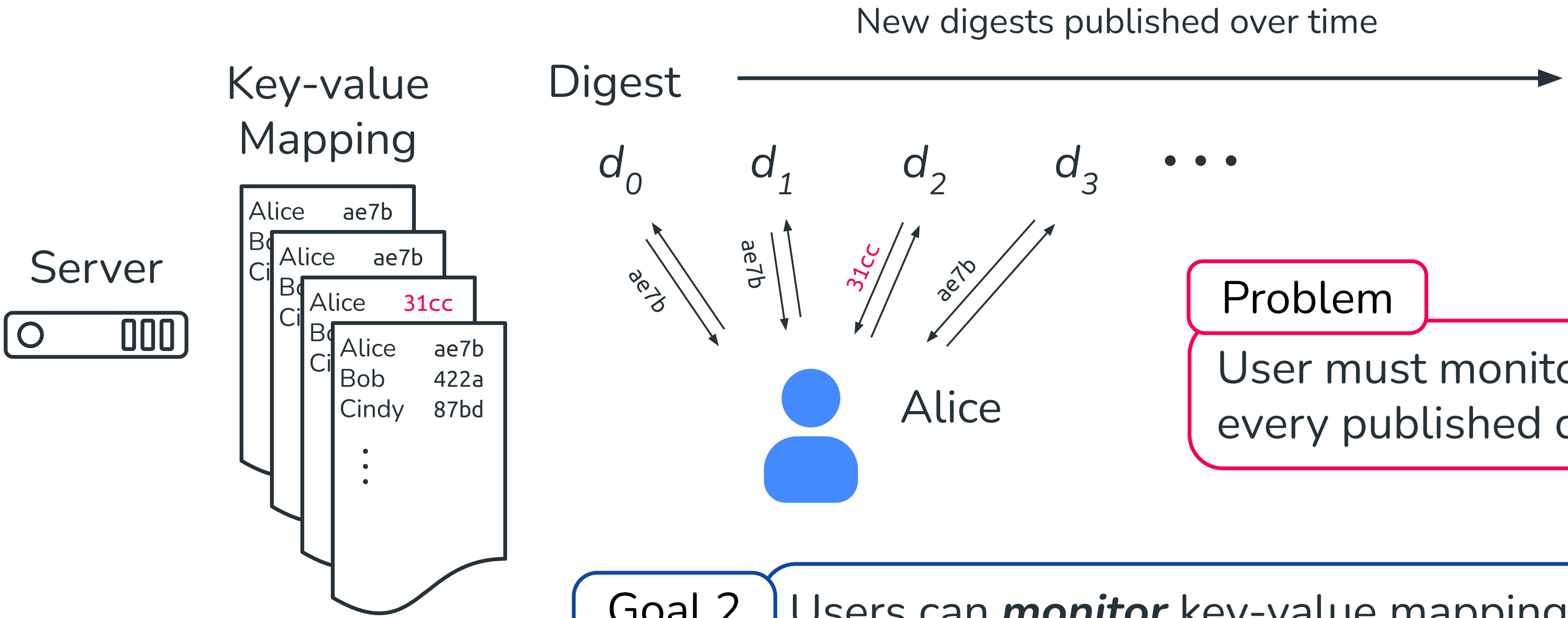


Problem

User must monitor every published digest.

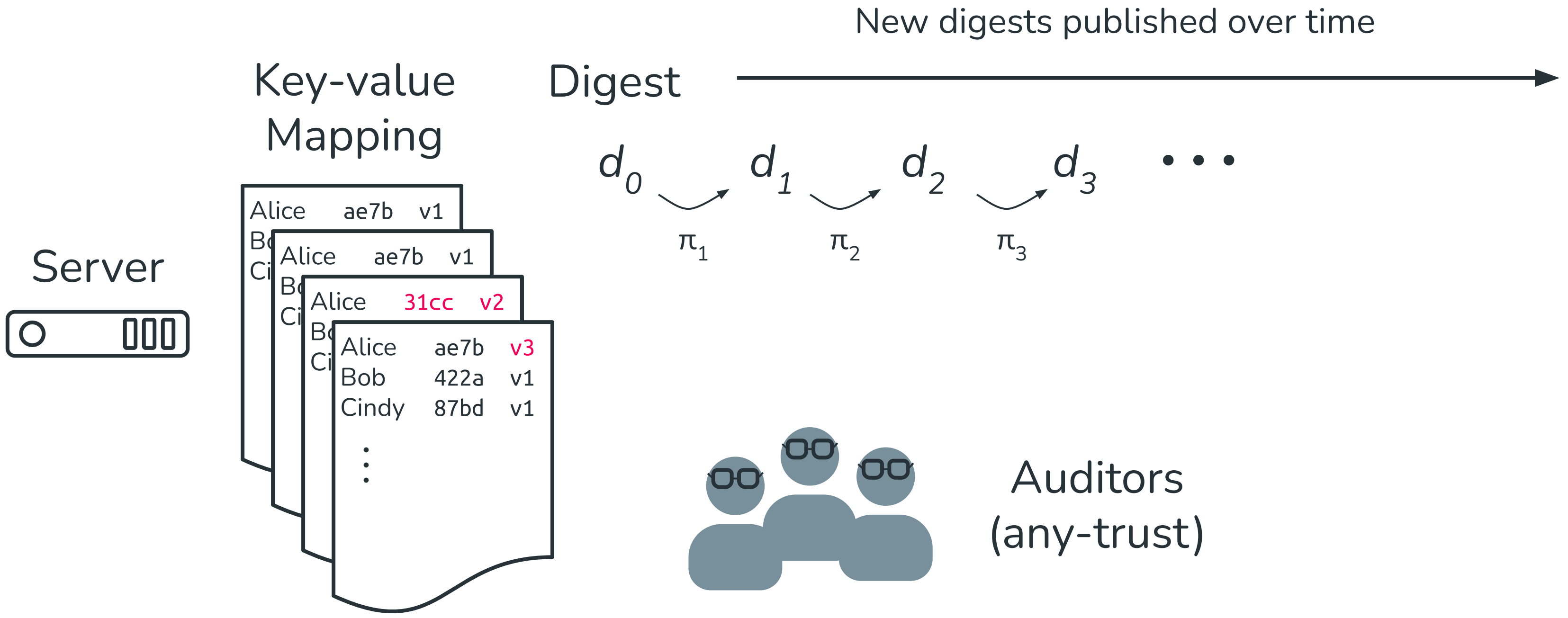
Goal 2

Users can ***monitor*** key-value mappings to detect unexpected modifications.

e.g. public key identities
software binary checksums
domain name routing info

Previous approaches: Trusted third-party auditors

[CONIKS'15, SEEMless'19, Mog'20]



Trusted third-party auditors verify ***version-only*** invariant is preserved between digests. Invariant allows efficient detection of unexpected changes by user.

Previous approaches: Trusted third-party auditors

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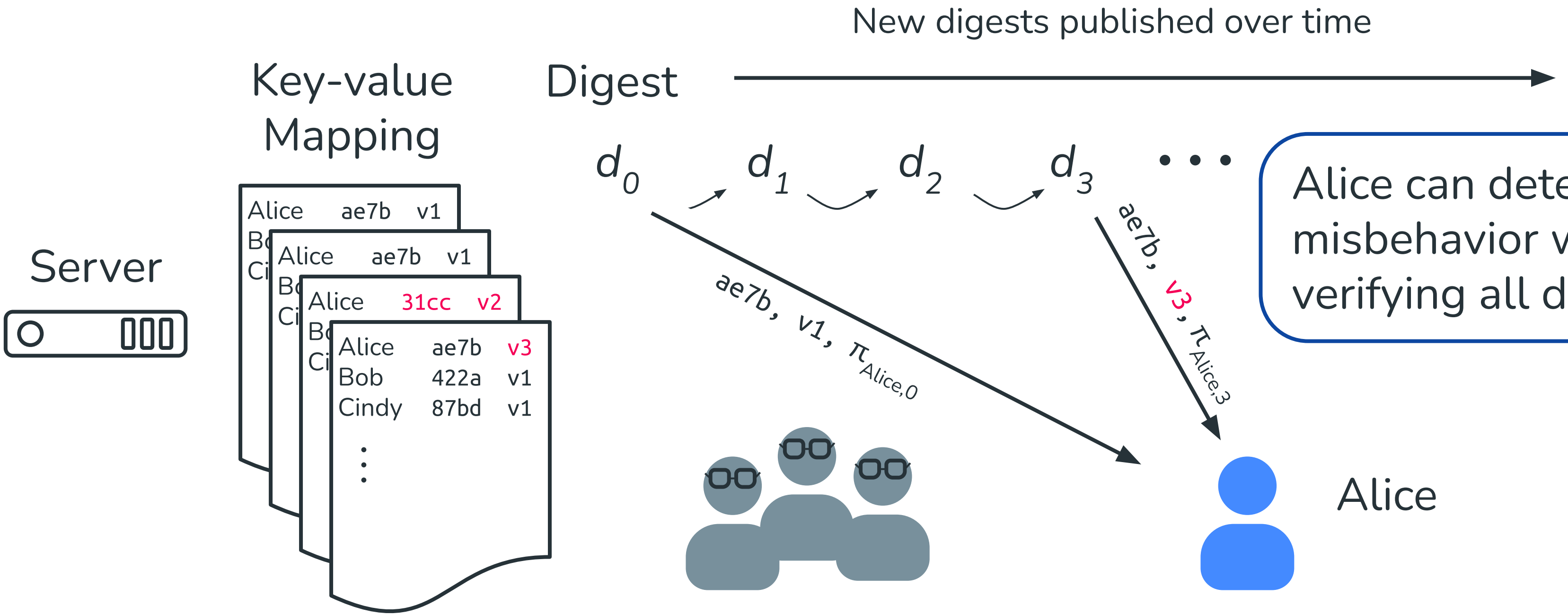

Alice can detect misbehavior without verifying all digests!

Trusted third-party auditors verify ***version-only*** invariant is preserved between digests. Invariant allows efficient detection of unexpected changes by user.

This work: Enabling efficient client auditability

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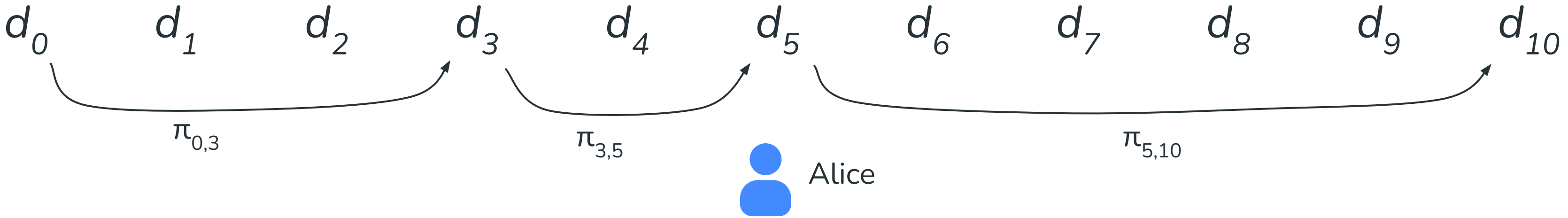
Contribution 1

New RSA key-value commitment with succinct proofs that invariant is preserved over ranges of digests



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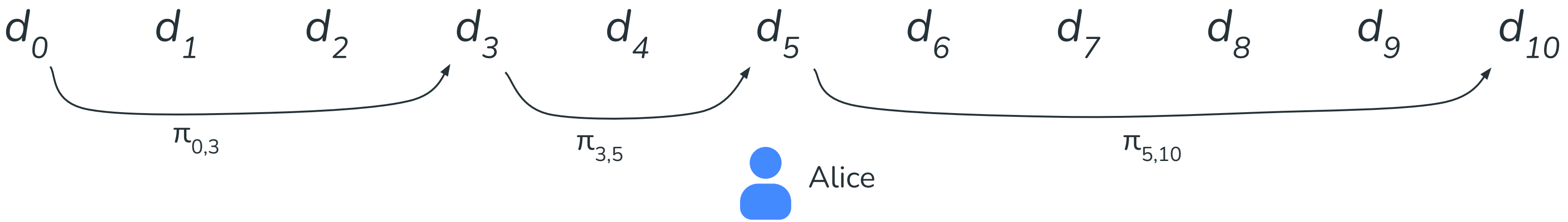
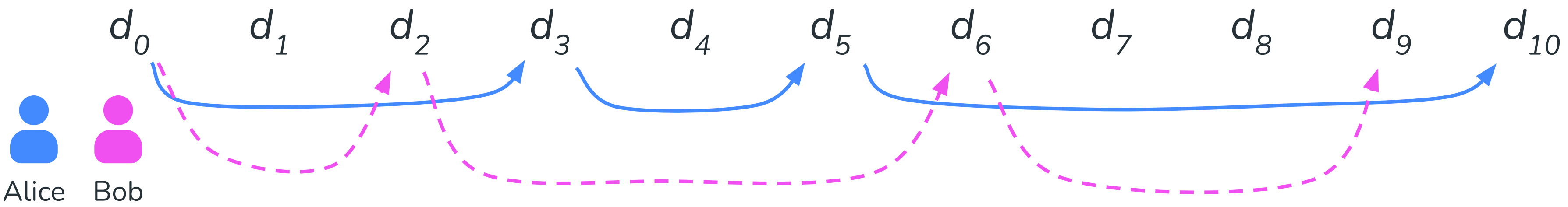


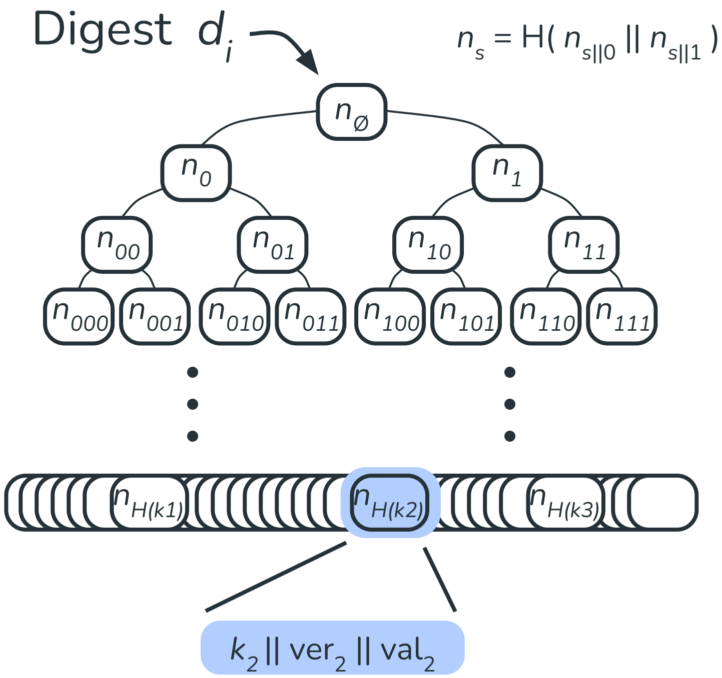
Contribution 2

Checkpointing technique to ensure user views remain eventually consistent even when auditing distinct ranges of digests



Prior work: Invariant proofs for Merkle trees

[CONIKS ‘15, SEEMless ‘19, Mog ‘20, Verdict ‘21]



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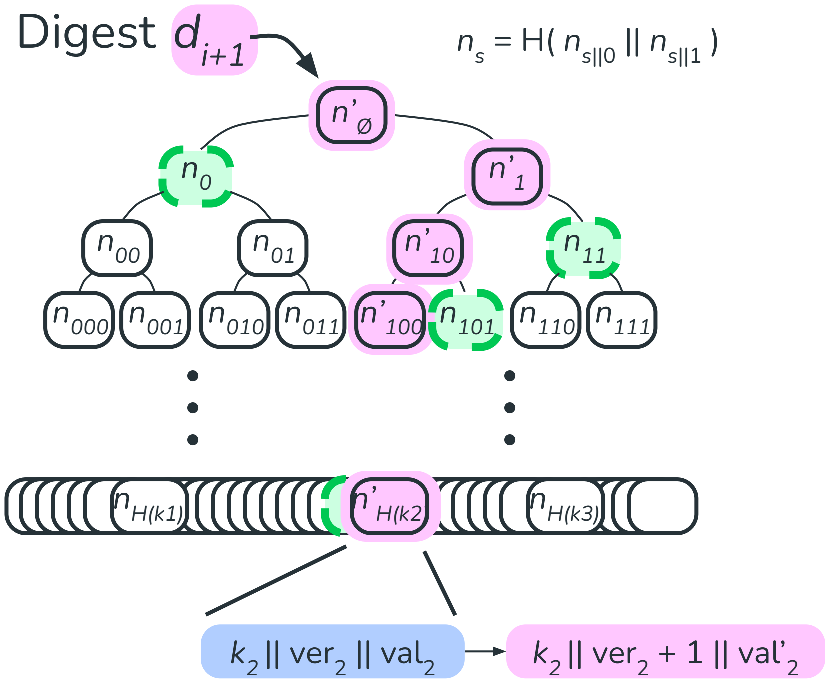

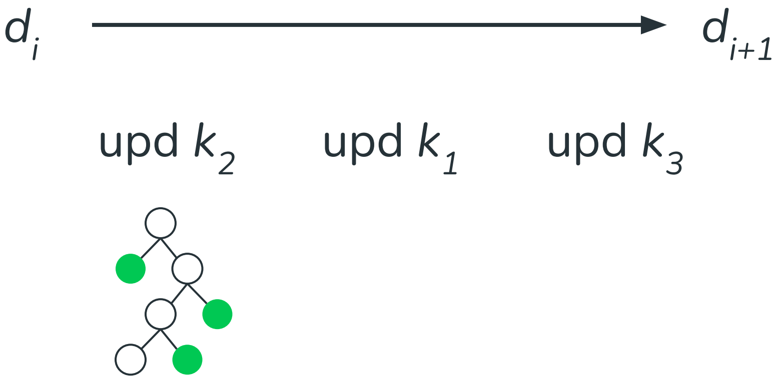

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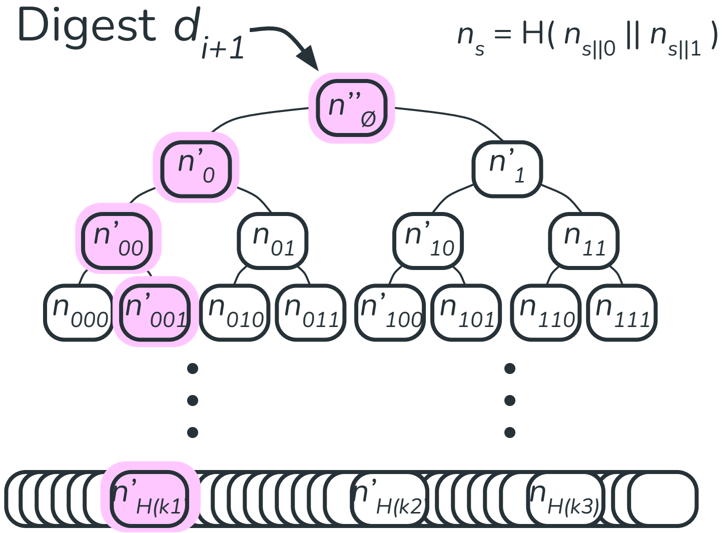

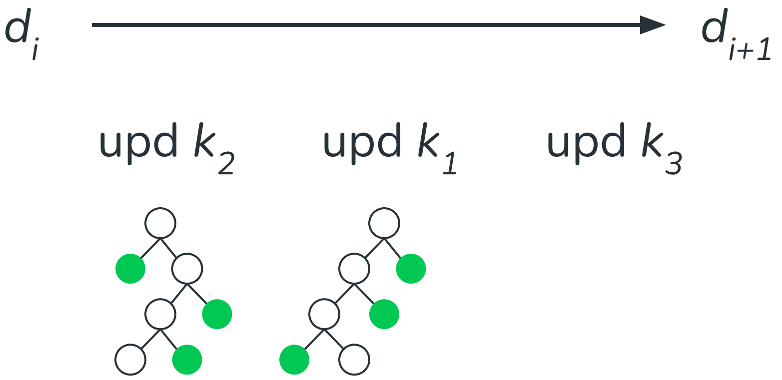

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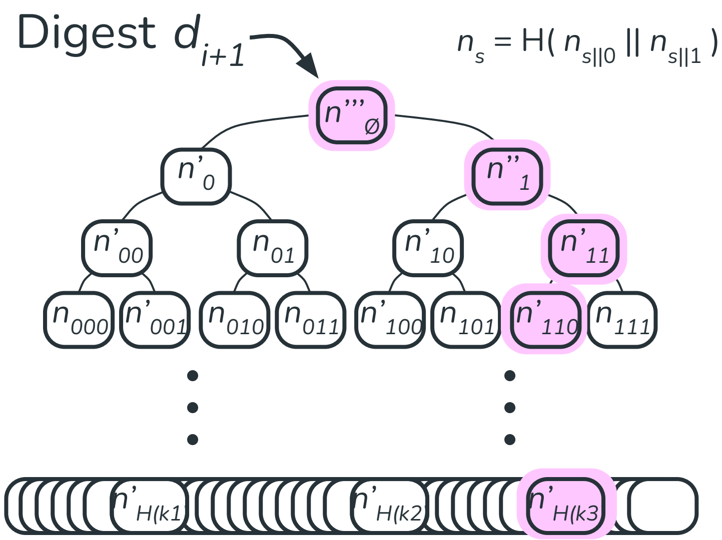

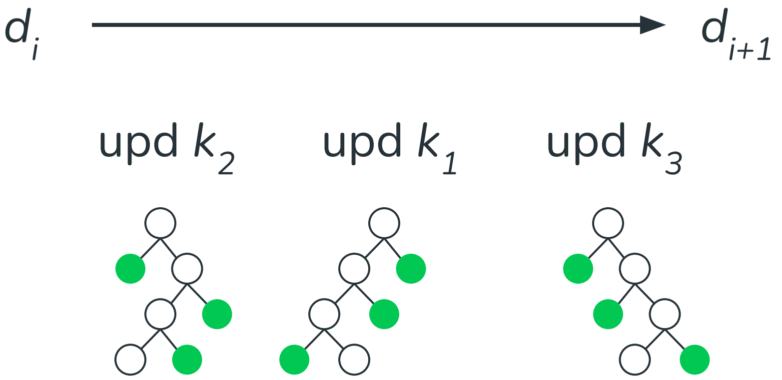

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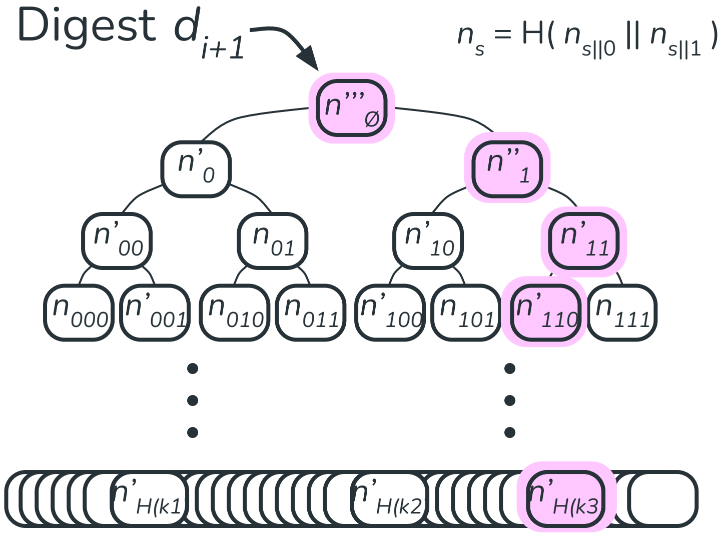

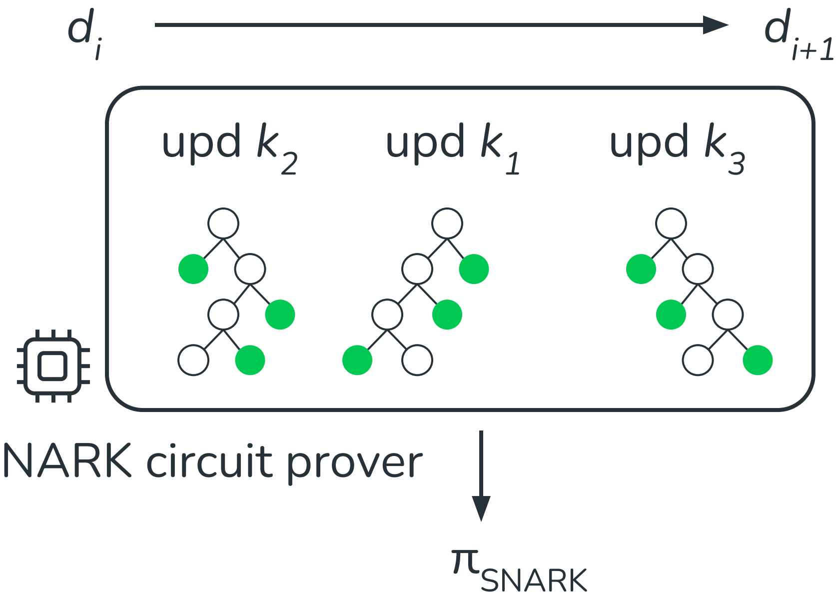

To obtain succinct invariant proofs over a range of digests, we compress the Merkle paths proof into a generic-circuit SNARK, which enables SNARK recursion/aggregation.

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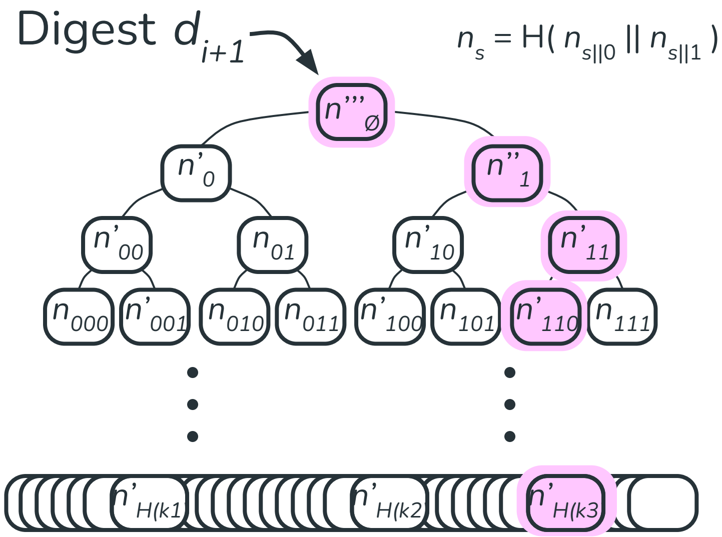

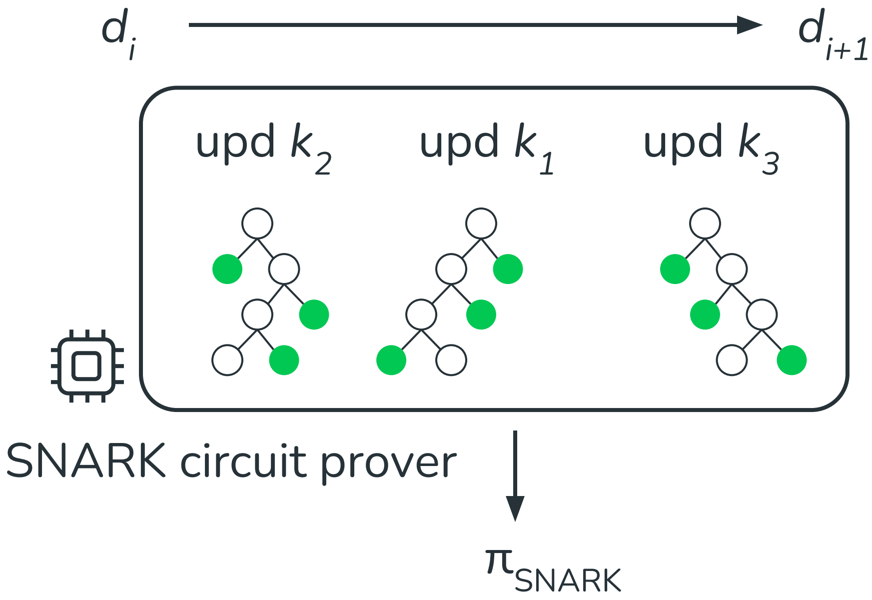

To obtain succinct invariant proofs over a range of digests, we compress the Merkle paths proof into a generic-circuit SNARK, which enables SNARK recursion/aggregation.

Problem

SNARK provers are concretely expensive, and every Merkle path must be included.

Our work: Invariant proofs for RSA KV commitments

[AR Asiacrypt '20]

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$d_i \longrightarrow d_{i+1}$

upd k_2 upd k_1 upd k_3

$\downarrow$

π_{RSA}

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π_{RSA}

Constant-size and constant-verif invariant proof!
Using variant of proof of knowledge of integer exponentiation [Wesolowski ‘19][BBF ‘19]

Our work: Invariant proofs for RSA KV commitments

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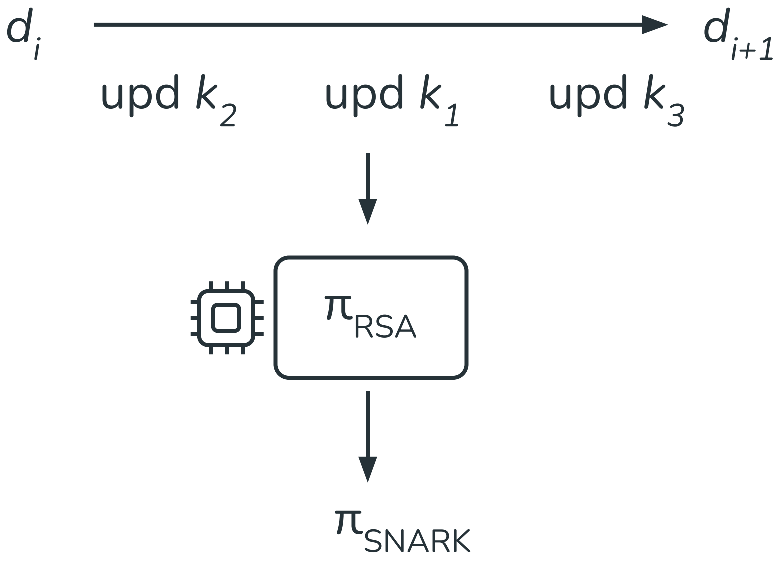

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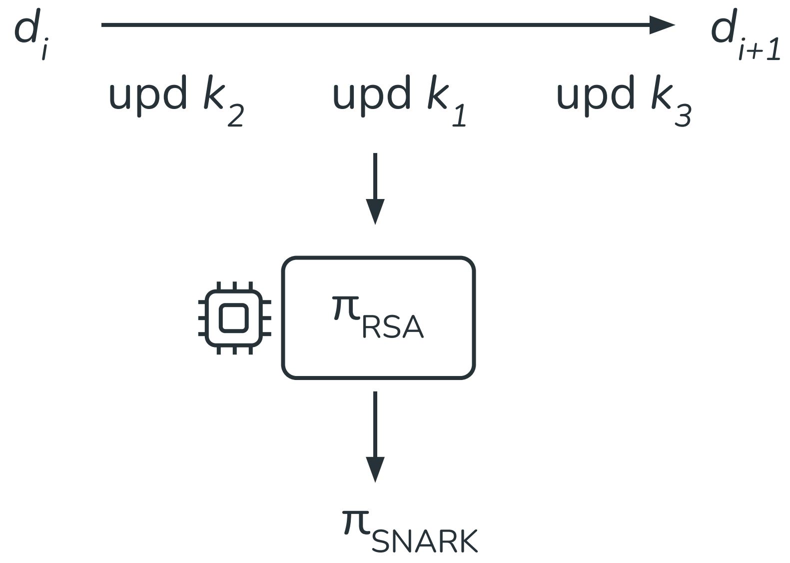

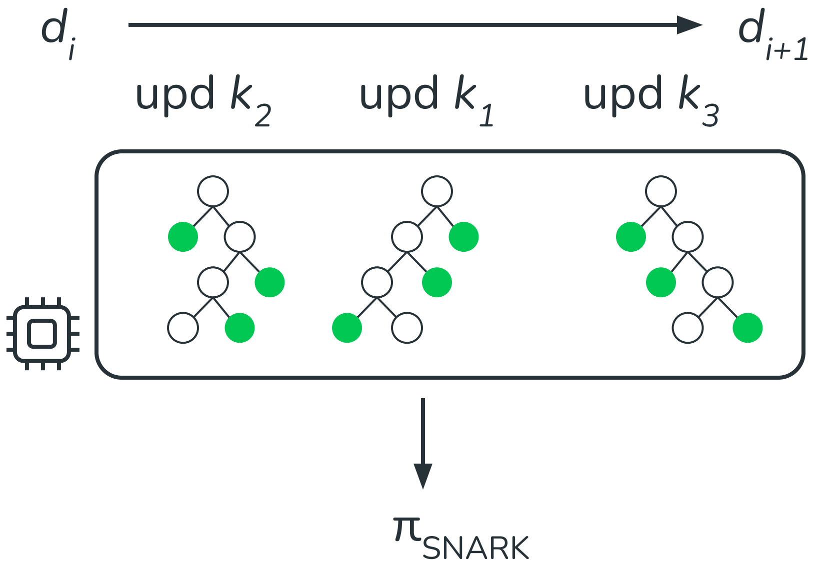

Constant circuit size independent of number of key updates.

Circuit size linearly dependent on number of key updates.

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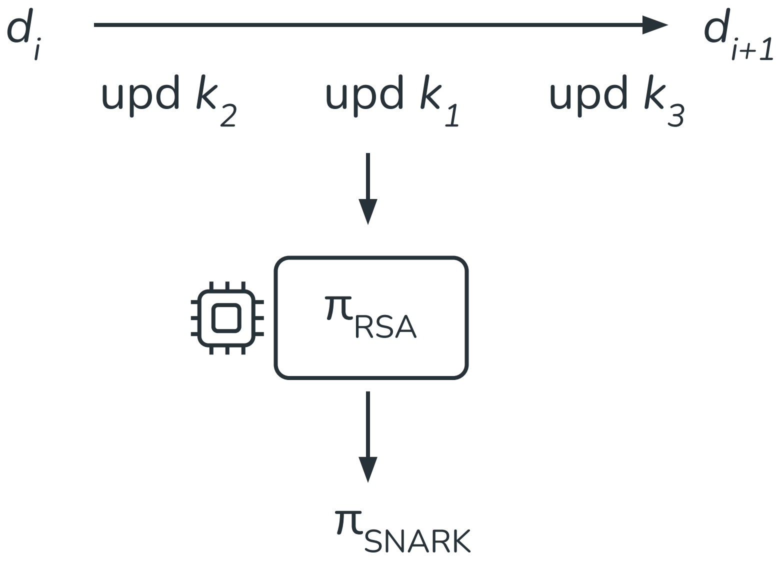


Constant circuit size independent of number of key updates.

✓ Small circuit translates to high update throughput for invariant proofs.

! Lookup proofs for RSA key-value commitment are expensive to compute on demand.

This work: Enabling efficient client auditability

Contribution 1

New RSA key-value commitment with succinct proofs that invariant is preserved over ranges of digests

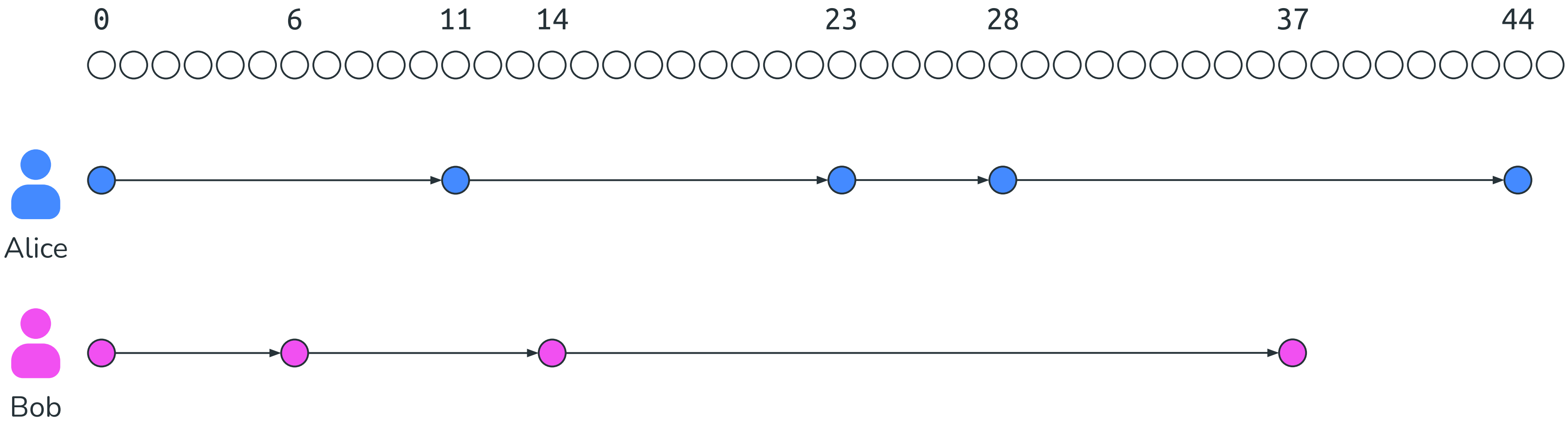
Contribution 2

Checkpointing technique to ensure user views remain eventually consistent even when auditing distinct ranges of digests

- When auditing a range, users additionally audit logarithmic checkpoints within range
- Two users are guaranteed to eventually share checkpoints and will be able to detect inconsistencies if they exist

Inconsistent user views: Oscillation attacks

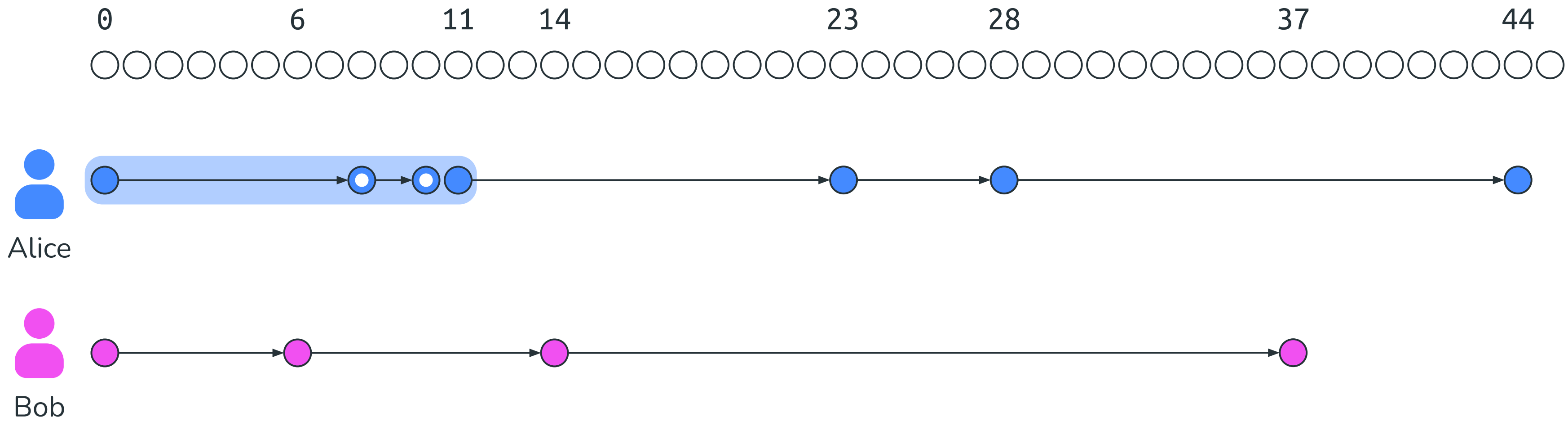
[Mog'20]



Problem

Since users are not guaranteed to see the same digests, a malicious platform may "oscillate", publishing digests for two different valid data structures at different time steps.

Eventual inconsistency detection via checkpointing



- An invariant proof is verified for a sequence of “checkpoints”. The number of checkpoints between two digests is logarithmic in the size of the range.

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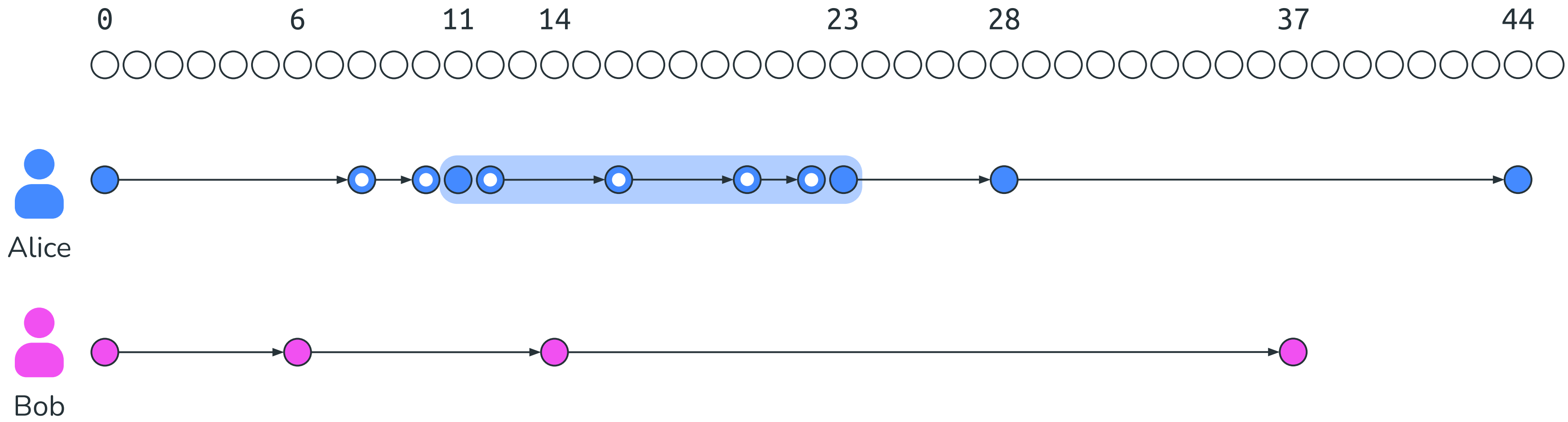

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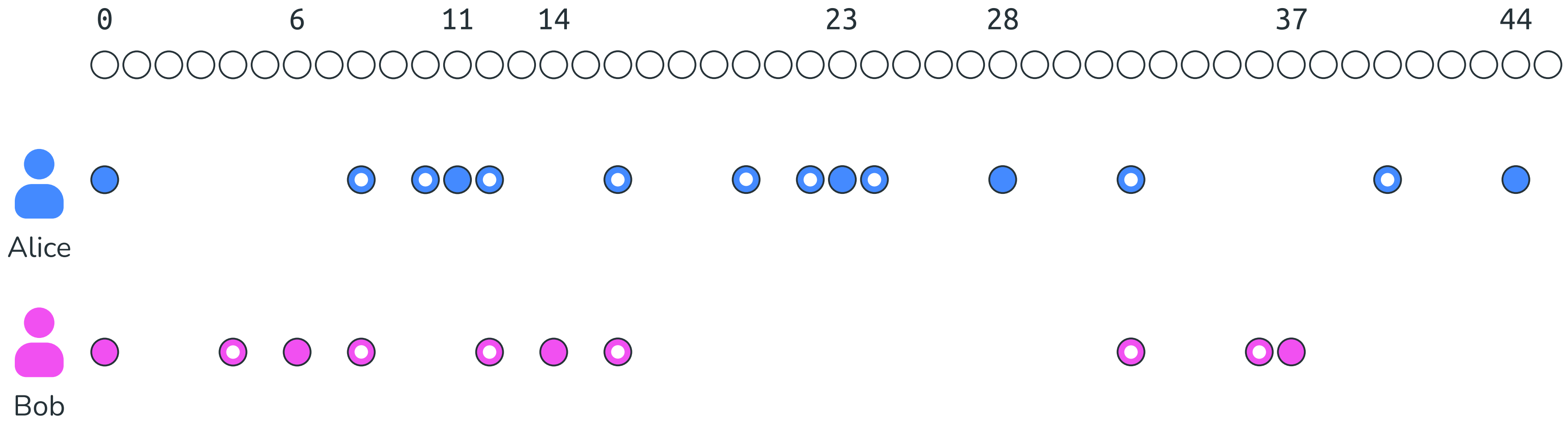

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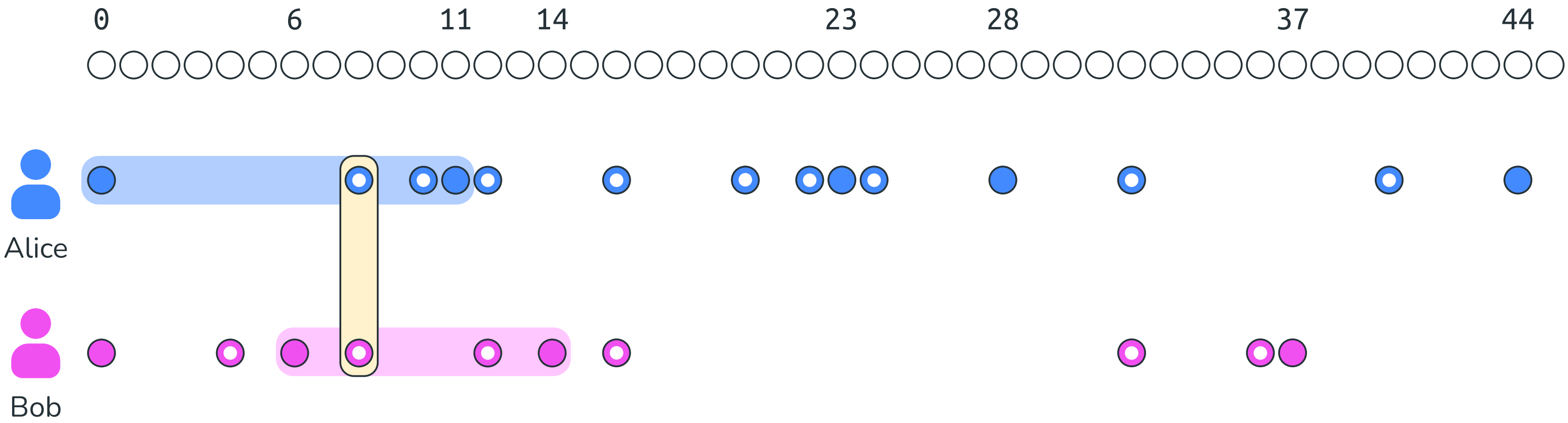

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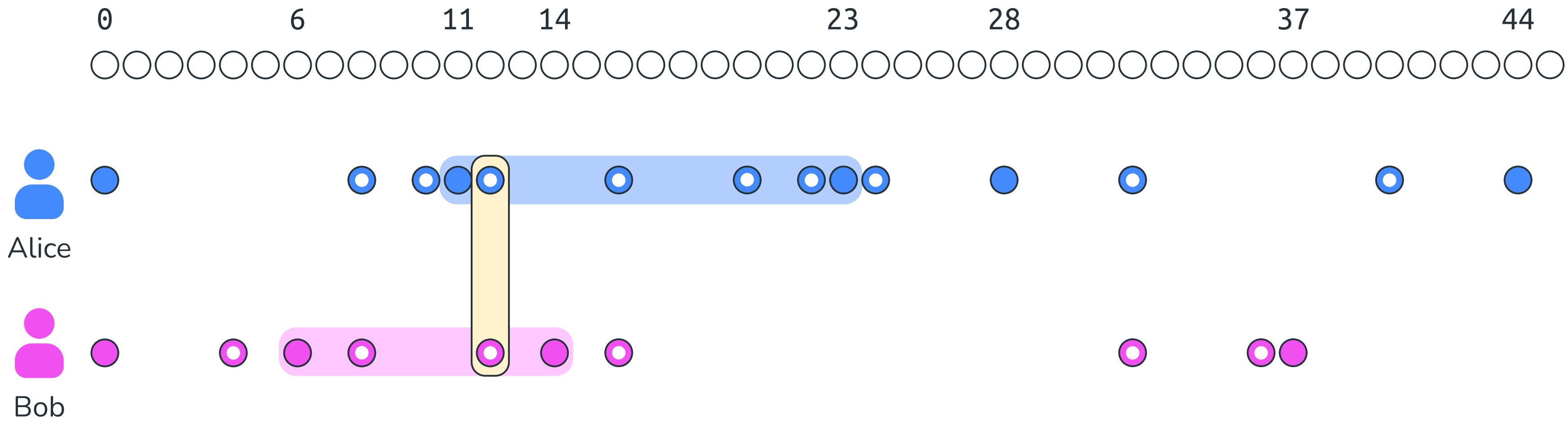

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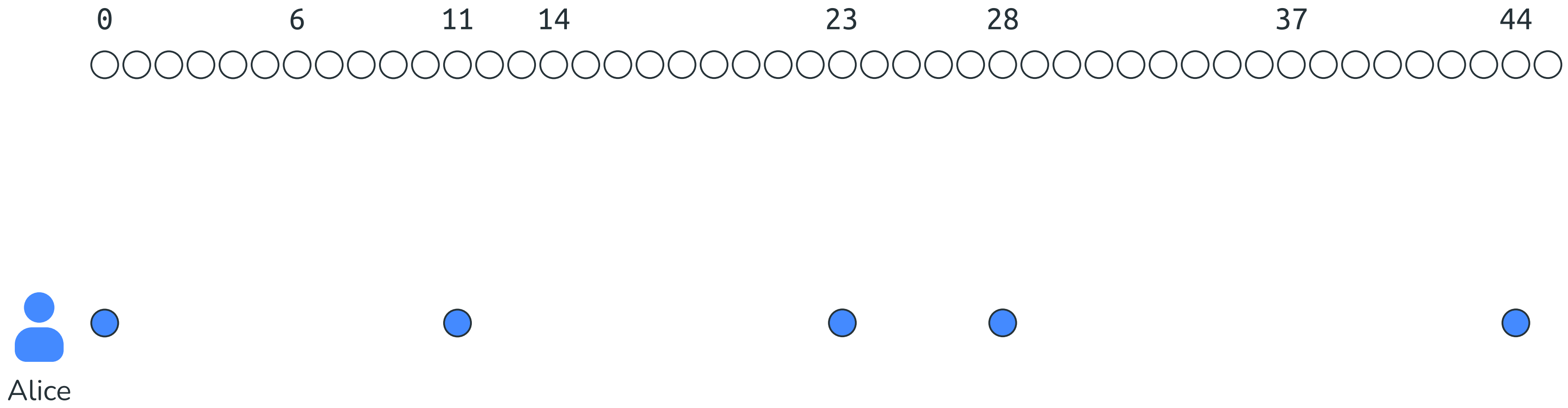

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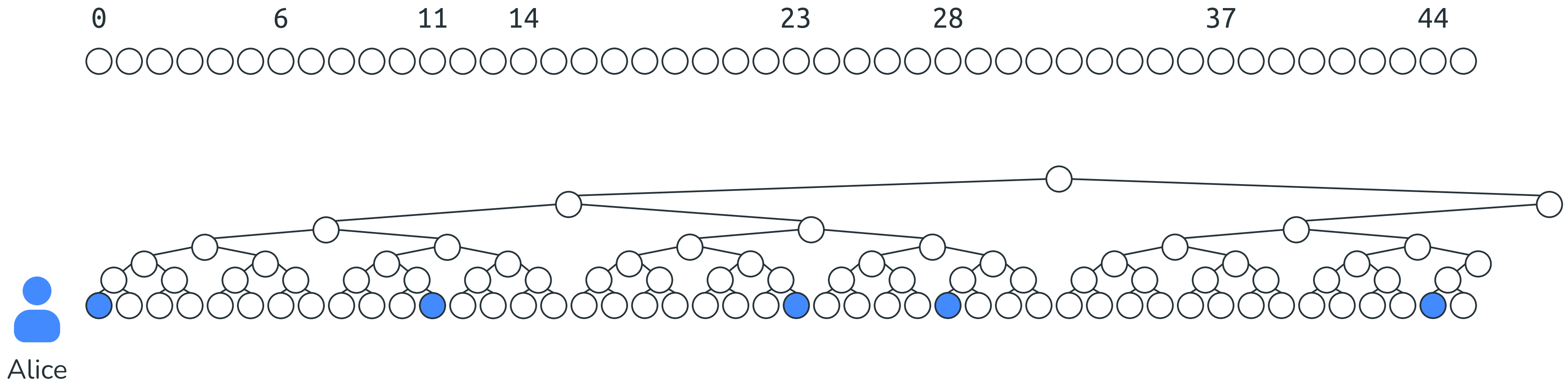

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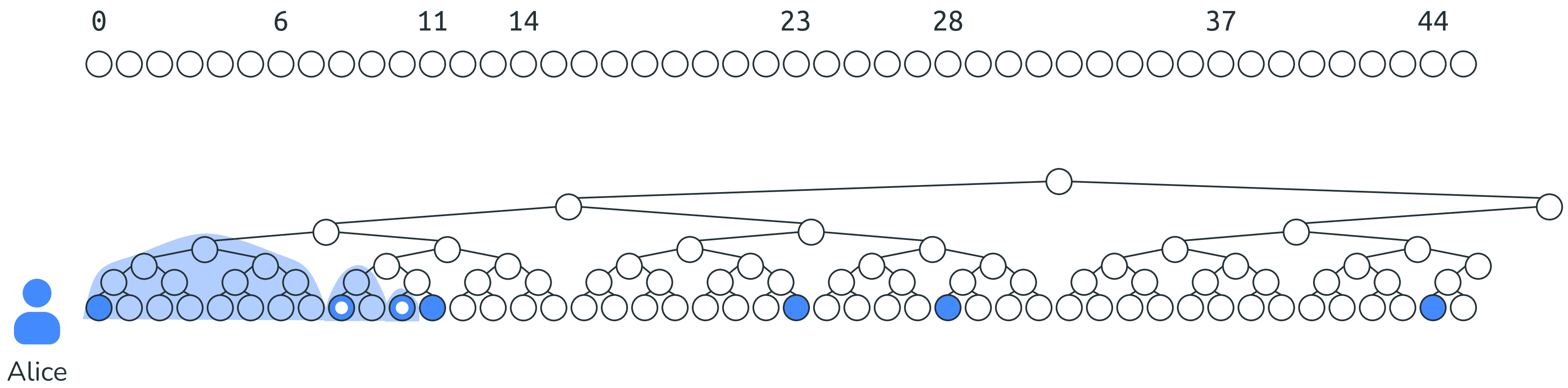

Checkpoints determined by compact subtree representation of range. The number of checkpoints will be logarithmic in the size of the range.

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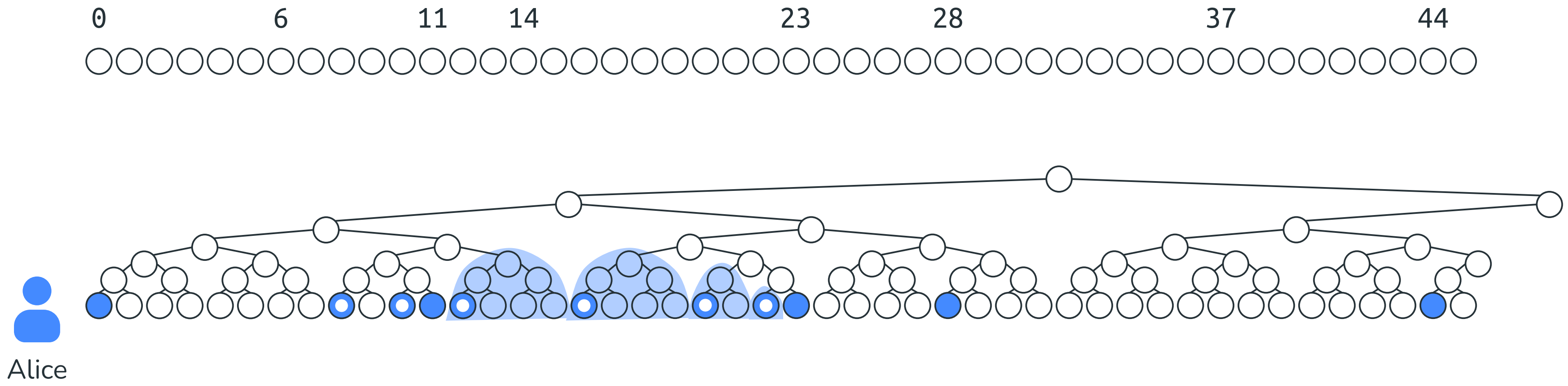

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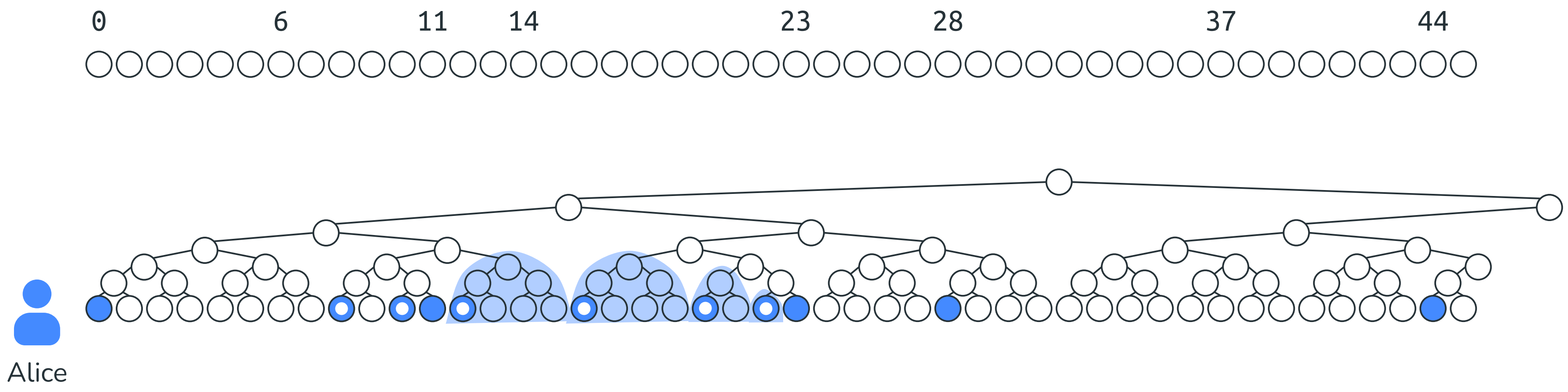

Checkpoints determined by compact subtree representation of range. The number of checkpoints will be logarithmic in the size of the range.

Shared checkpoints between overlapping ranges guaranteed to exist – see paper!

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Implementation and performance evaluation

- RSA key-value commitment and invariant proofs
- R1CS constraints for RSA algorithms in `arkworks` ecosystem for zkSNARKs
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Comparison to Merkle Tree baseline: Server with 32 CPU cores + 512 GB memory

- **Client verification costs:** similar
  - Proofs < 20kB, verify in < 100ms

- **Update proof throughput:** 10x-400x higher
  - Prototype achieves 60-90 updates/second on a single server

- **Lookup proof costs:** substantially worse
  - VeRSA limited to registries of ~millions of entries due to $O(n^2)$ costs
  - Millions of entries can be handled with O(nlogn) batch computation costs

Potential application: *binary transparency*

Characteristics:

- Medium overall registry size
- Relatively high update frequency
- Moderate latency is acceptable (~30 minutes)

Examples:

- Ubuntu package repo: 106k packages, mean 3.4 versions/year
- Apple iOS app store: 2.1M apps, mean 52.5 versions/year

Conclusion

- **VeRSA:** New design for verifiable registry enabling efficient client-auditing
  - New RSA key-value commitments and constant-size invariant proofs
  - New client auditing approach that maintains eventual consistency
- Suitable for binary transparency applications with medium-size registries
  - Bottleneck: RSA lookup proof computation
- Open source: `github.com/nirvantyagi/versa`

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Backup slides

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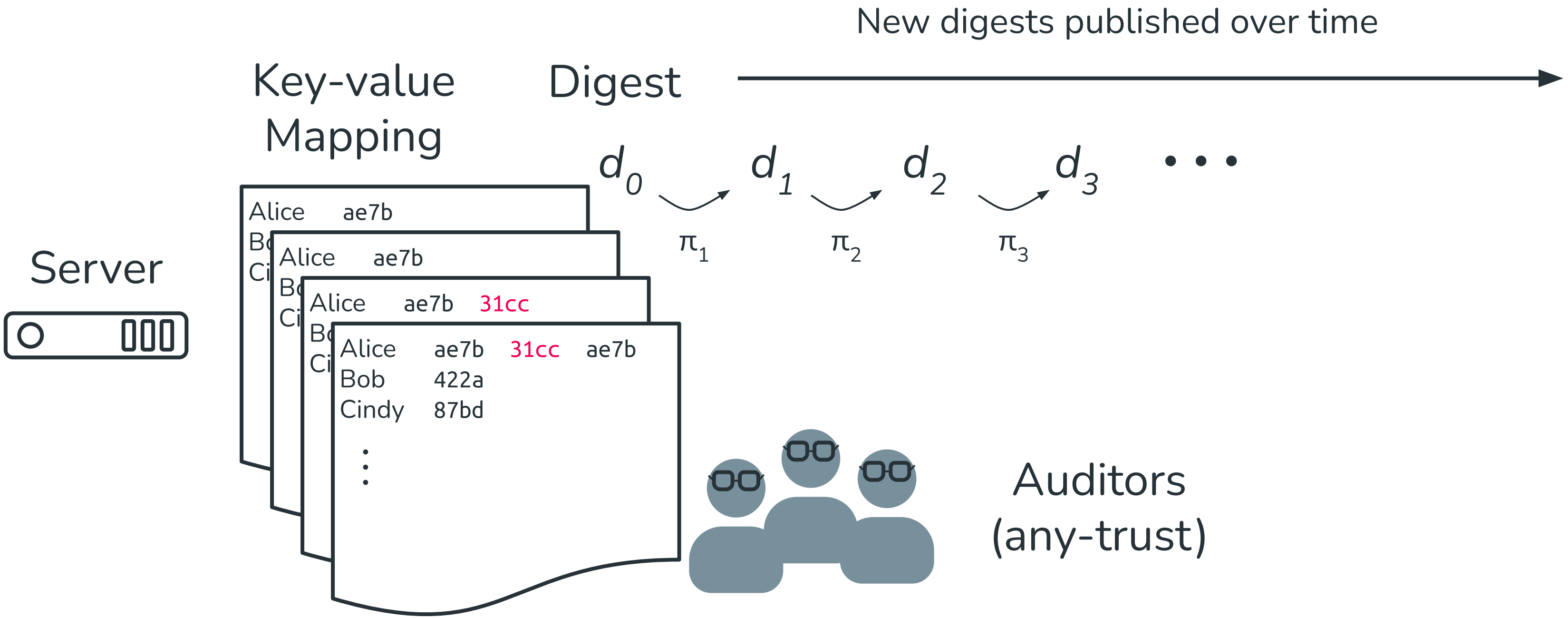

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Invariant proofs: RSA key-value commitments

[AR'20]

Digest $d_i = (d_{i,1} , d_{i,2}) = \left(g^{(\prod_j H(k_j)^{ver_j})\cdot(\sum_j val_j / H(k_j))},\ g^{\prod_j H(k_j)^{ver_j}}\right)$

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where $\delta = val'_2 - val_2$

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$Z = \prod_j H(k_j)$ for $j \in \{1, 2, 3\}$

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Algebraic invariant proof (constant-size!)

[Wes'19, BBF'19]

Statement $\left\{(\alpha, \beta)\ :\ d_{i+1,1} = d_{i,1}^{\alpha} d_{i,2}^{\beta} \wedge d_{i+1,2} = d_{i,2}^{\alpha}\right\} \longrightarrow \pi_{\mathrm{RSA}}$

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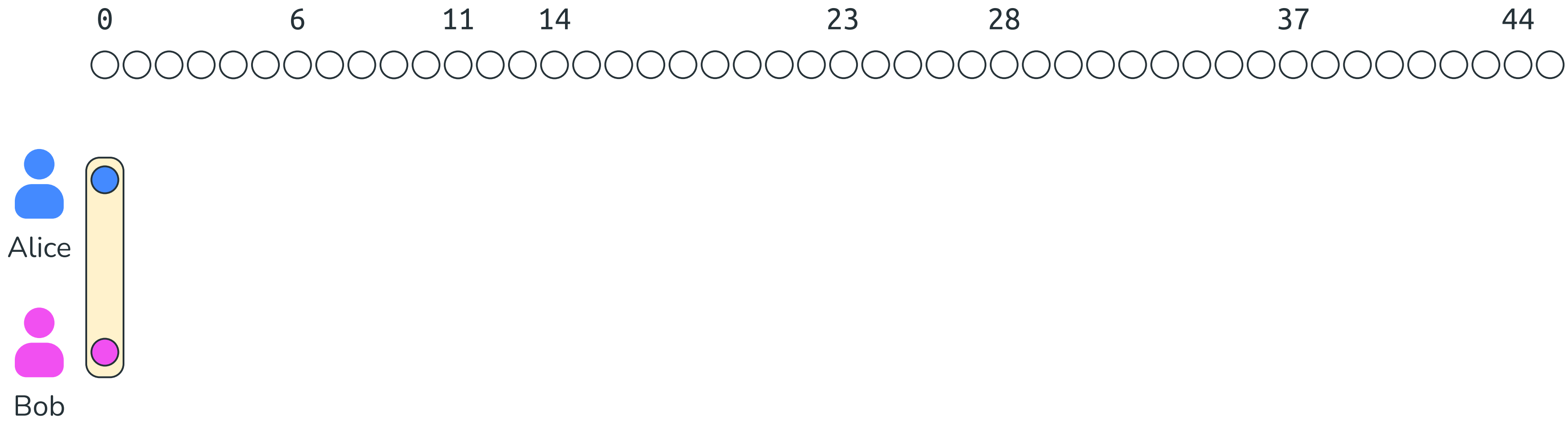
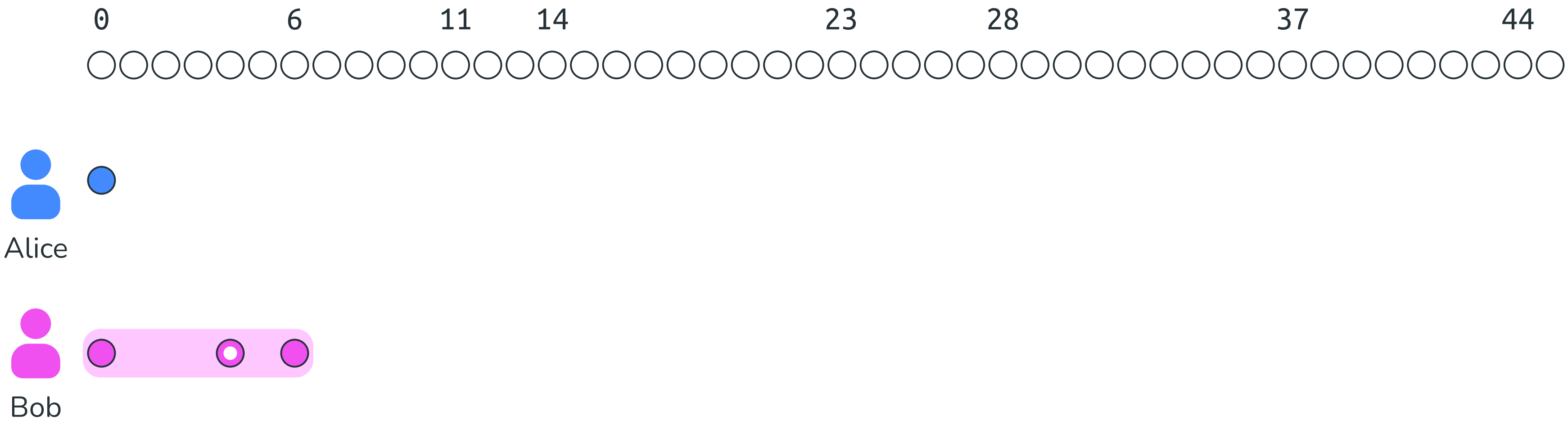


Committed joint view

Eventual inconsistency detection via checkpointing



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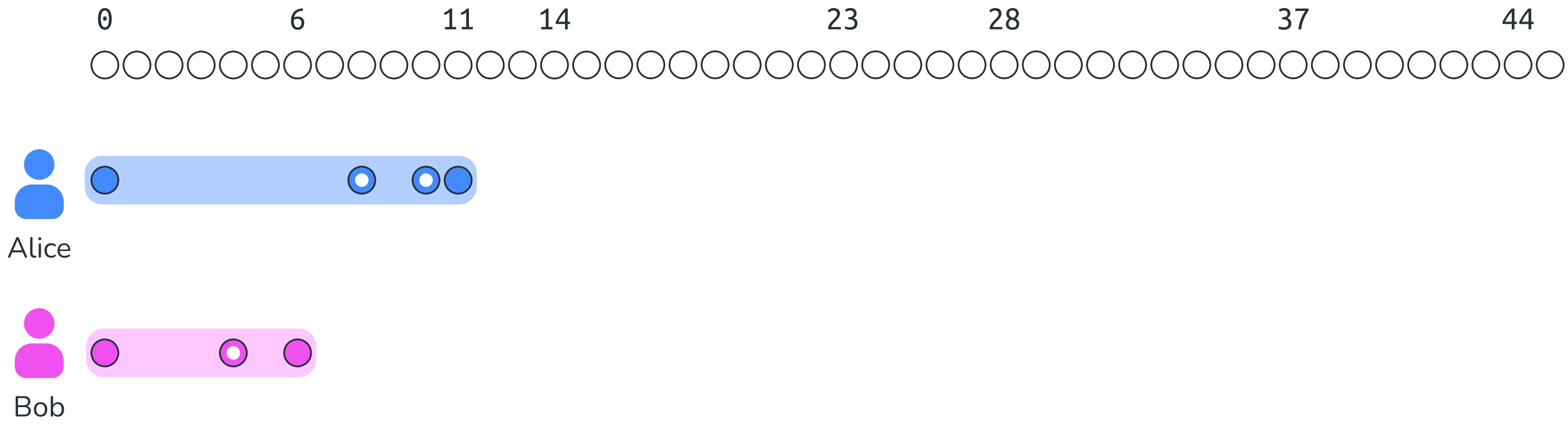

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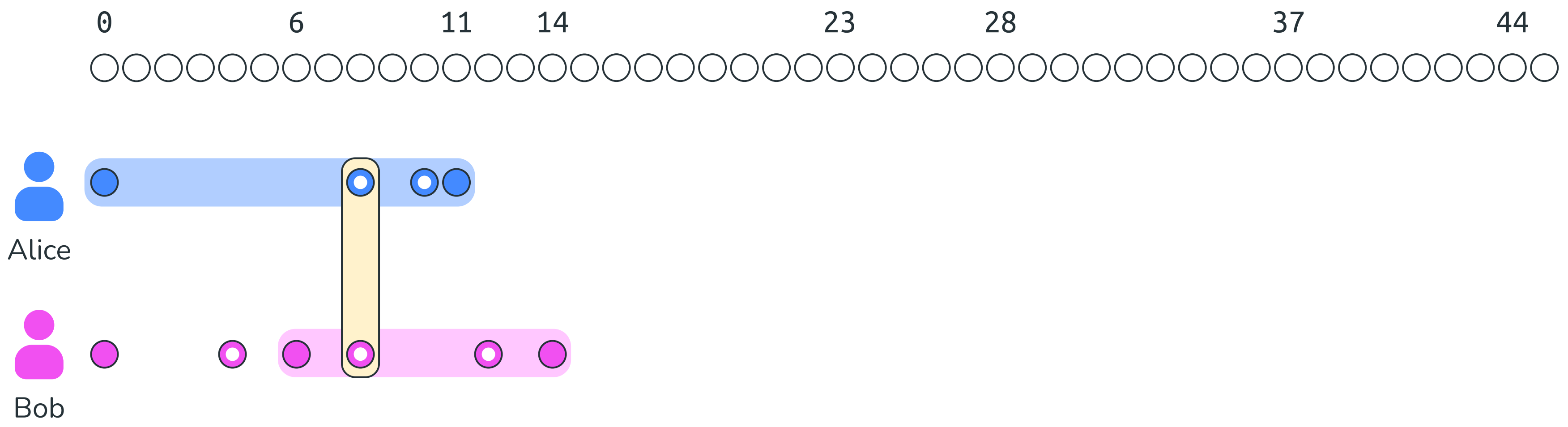
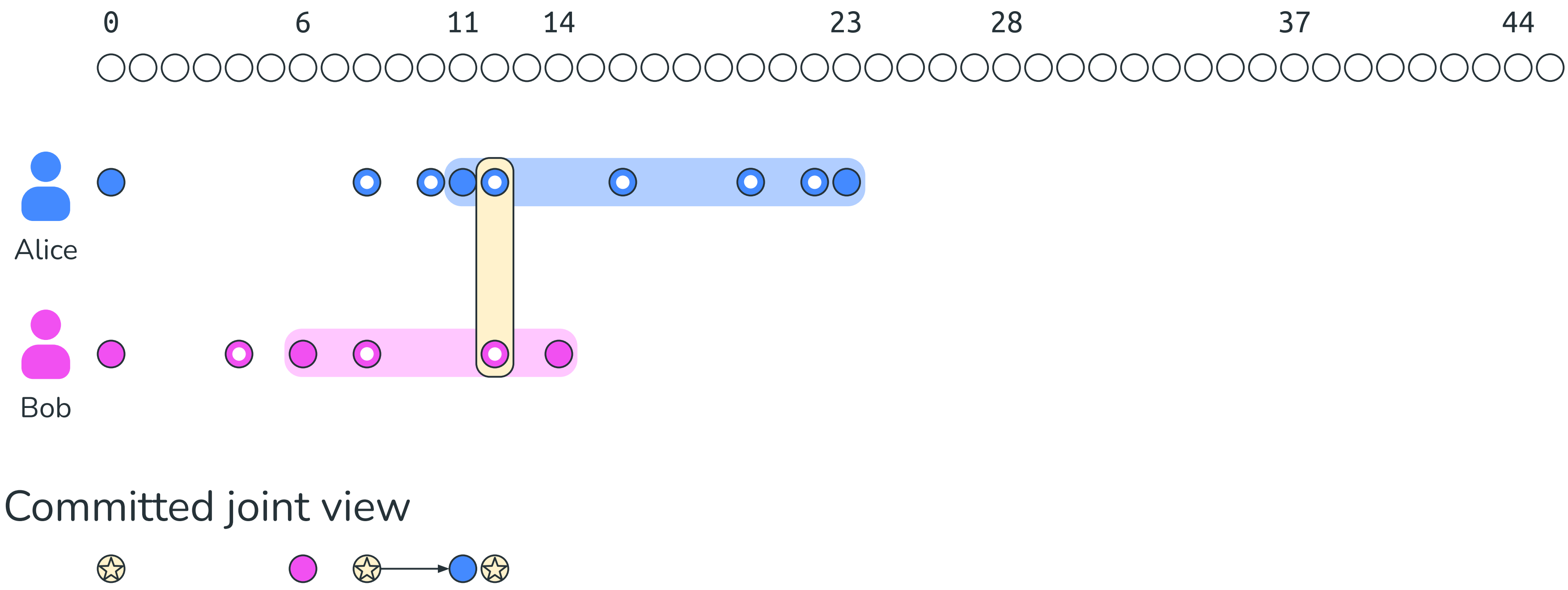
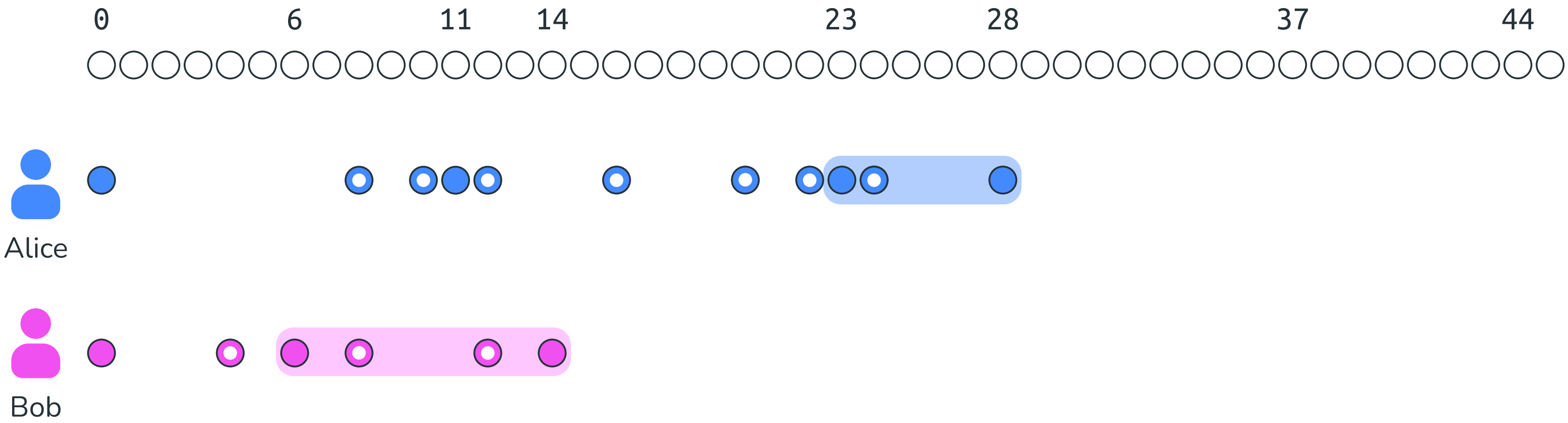


Committed joint view

Eventual inconsistency detection via checkpointing

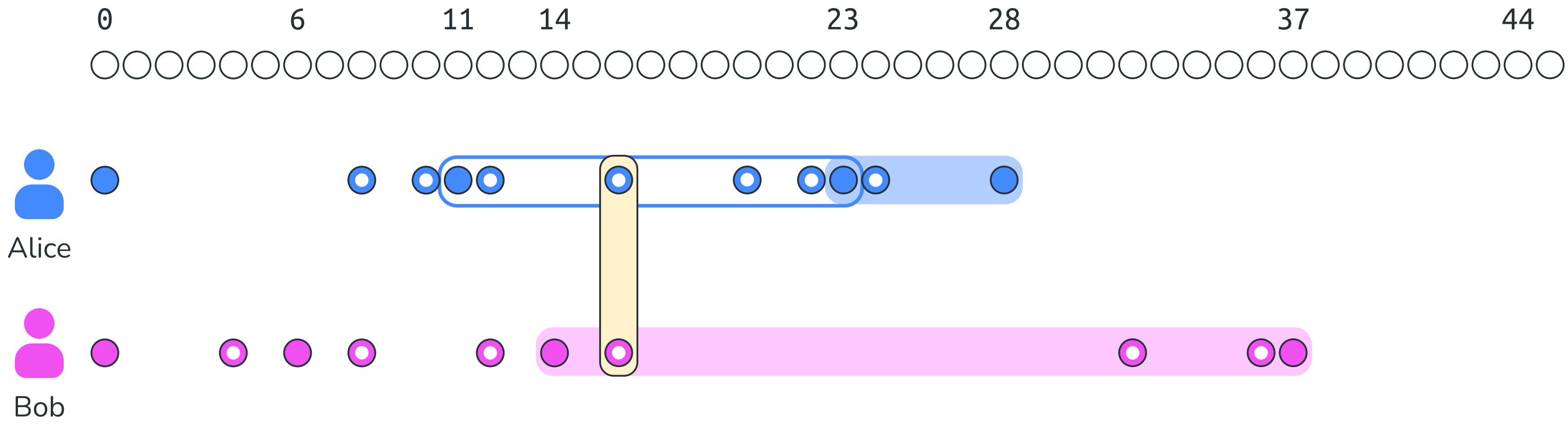


Eventual inconsistency detection via checkpointing



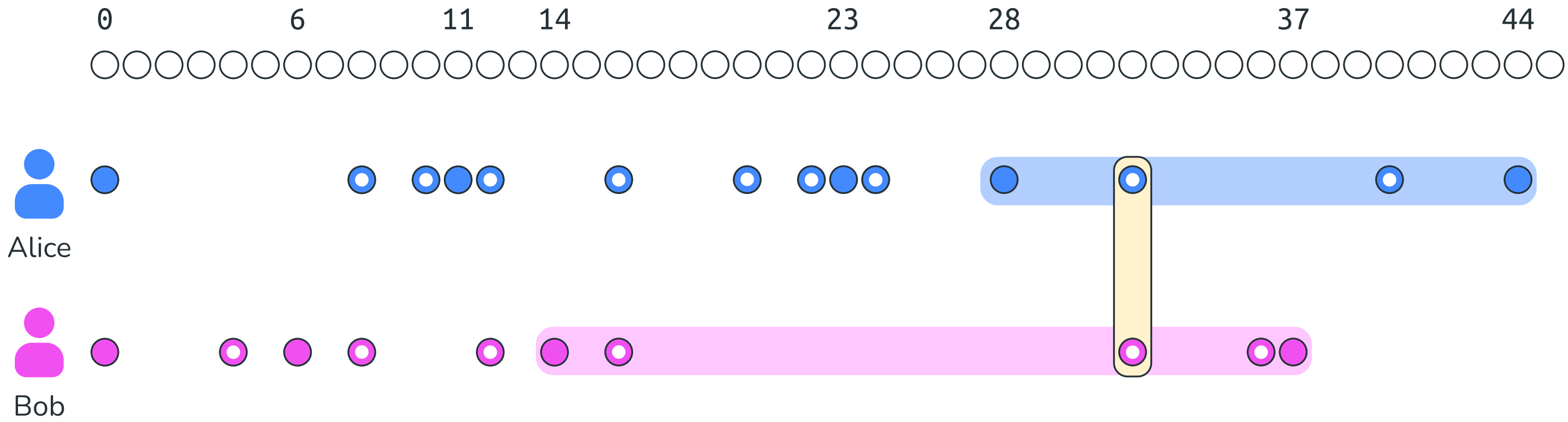
Committed joint view

Eventual inconsistency detection via checkpointing



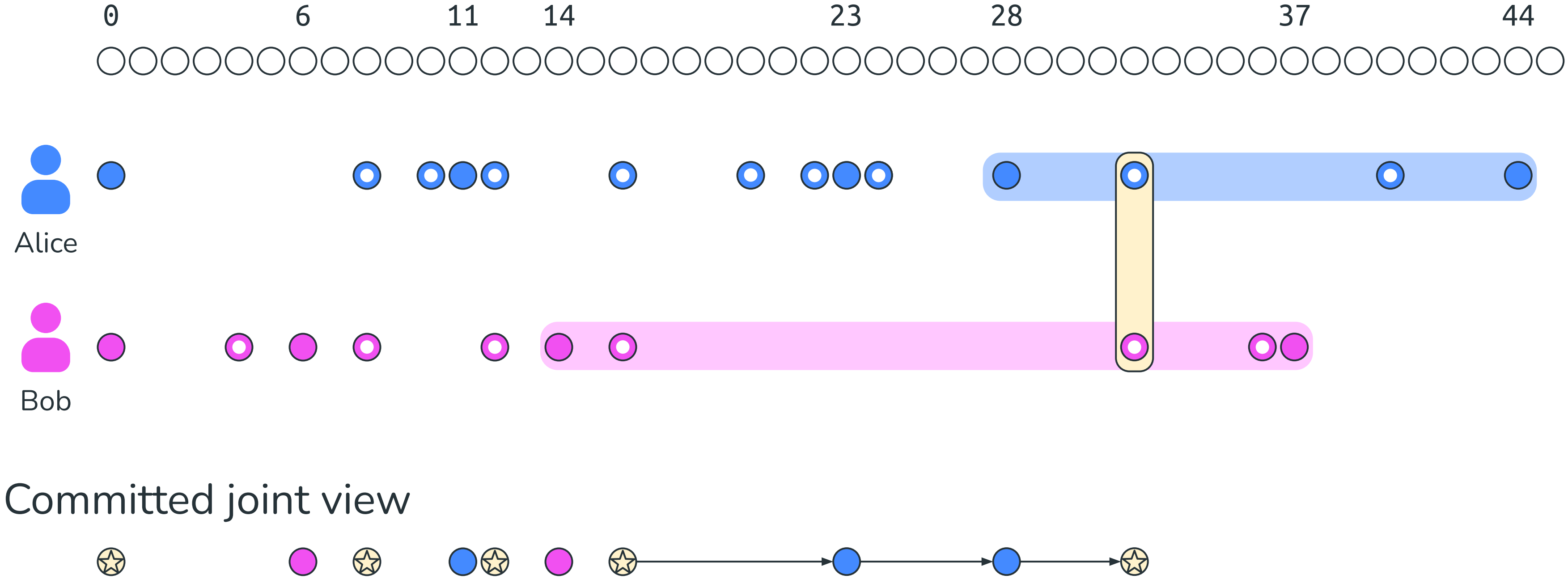
Committed joint view

Eventual inconsistency detection via checkpointing



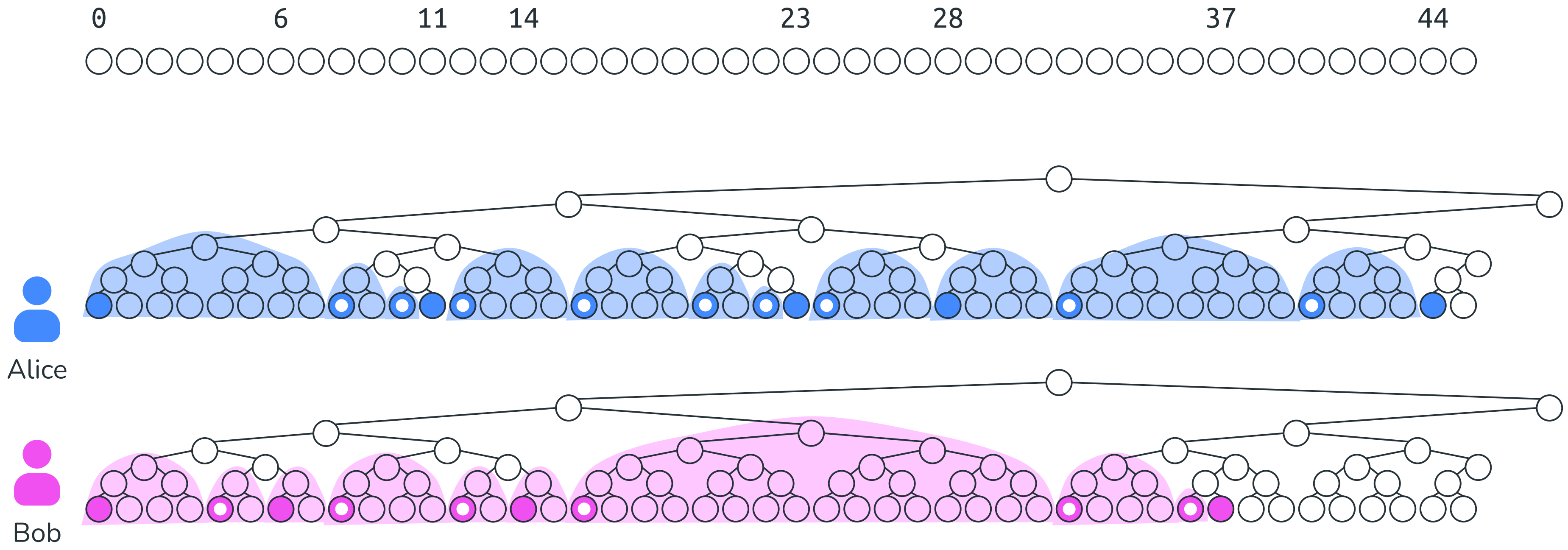
Committed joint view

Eventual inconsistency detection via checkpointing



Checkpointing allows users to implicitly create an ordered consistent view that trails the current time step.

Eventual inconsistency detection via checkpointing



Checkpoints are determined by the minimum number of subtrees that span the range in the superimposed binary tree -- guaranteed to be logarithmic in range size!