Hello from the Other Side: SSH over Robust Cache Covert Channels in the Cloud

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Outline

- cache covert channels
- how do we get a covert channel working in the cloud?
- how do we get a covert channel working in a noisy environment?
- what are the applications of such covert channel?

CPU cache

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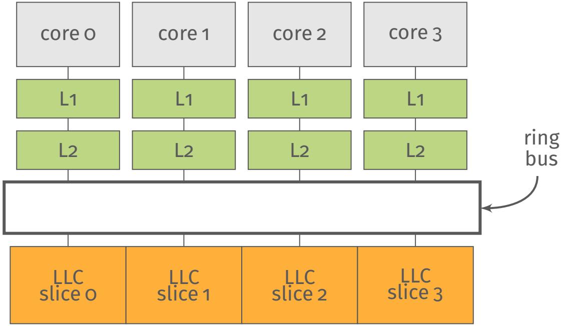
- every data access goes through the cache
- caches are transparent to the OS and the software

Caches on Intel CPUs



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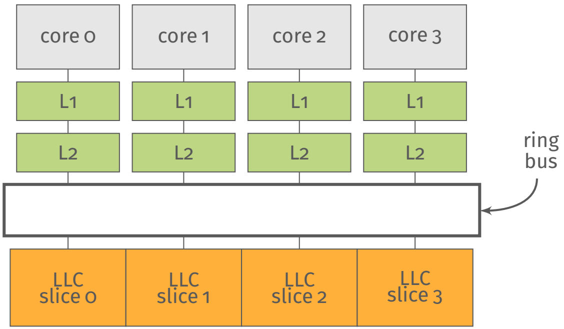

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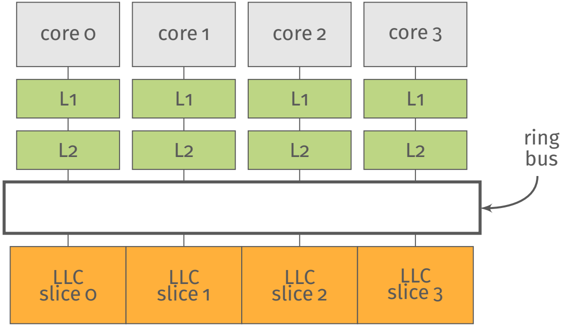

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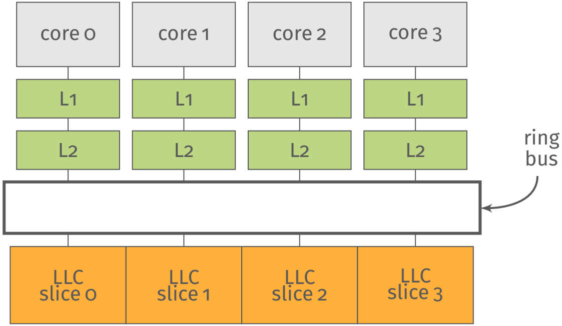

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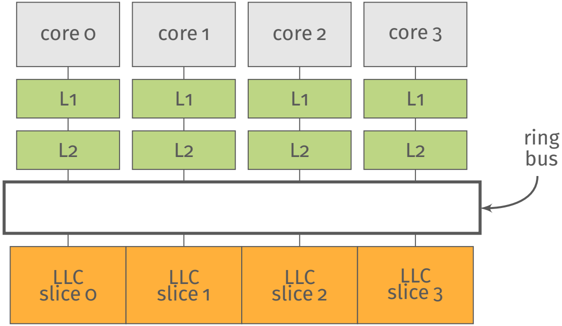

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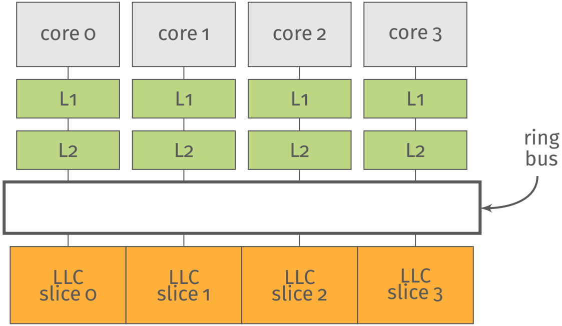

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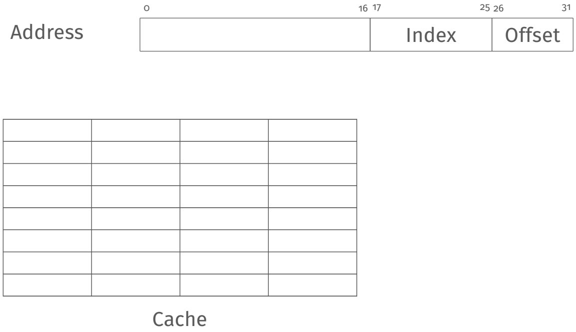
- last-level cache
  - divided in slices
  - shared across cores
  - inclusive
  - hash function maps a physical address to a slice

Set-associative caches



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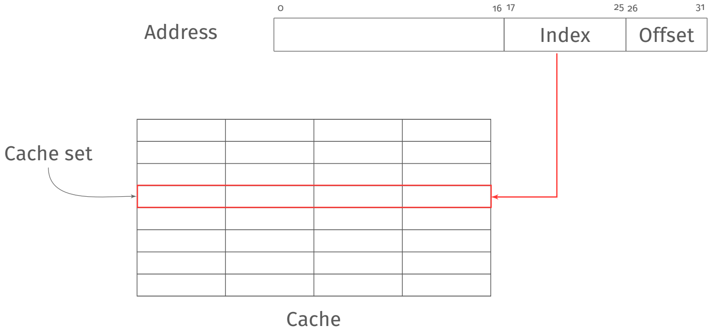

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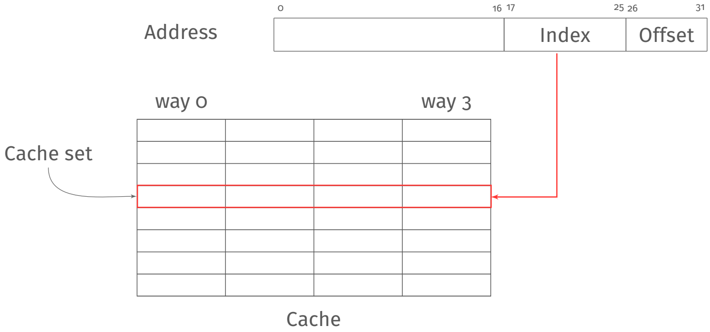

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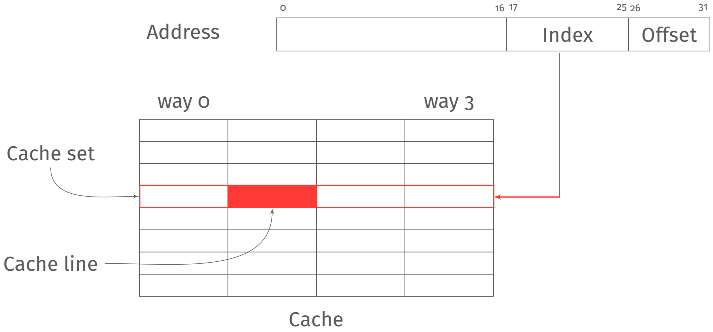
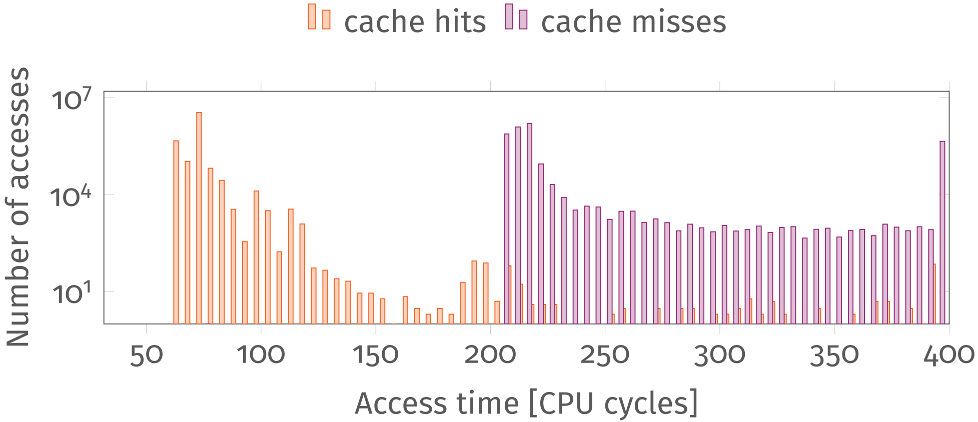


Data loaded in a specific set depending on its address

Several ways per set

Cache line loaded in a specific way depending on the replacement policy

Timing differences



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- literature: stops working with noise on the machine
- solution? “Just use error-correcting codes”

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→ works across VM in the cloud, e.g., on Amazon EC2

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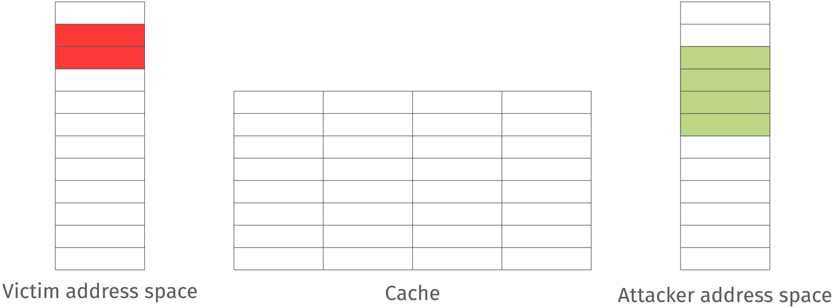

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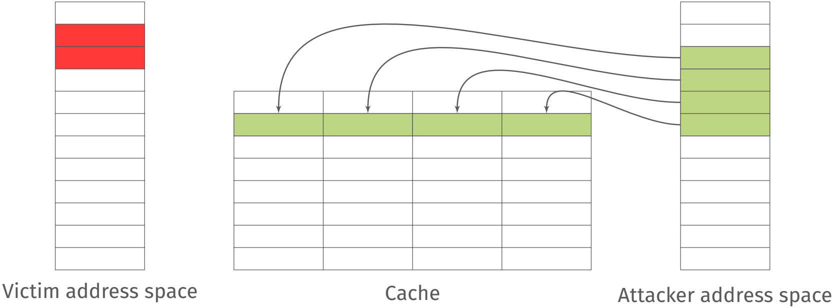

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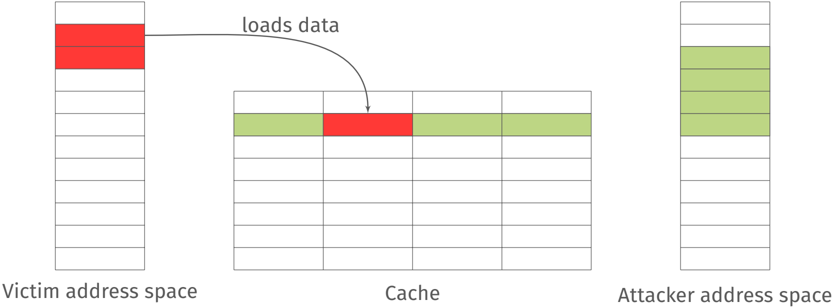

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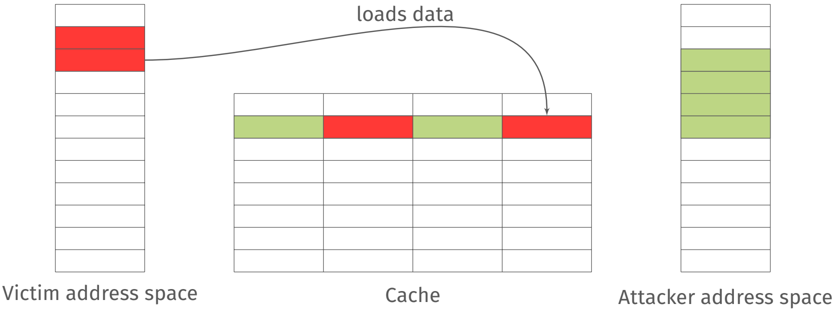

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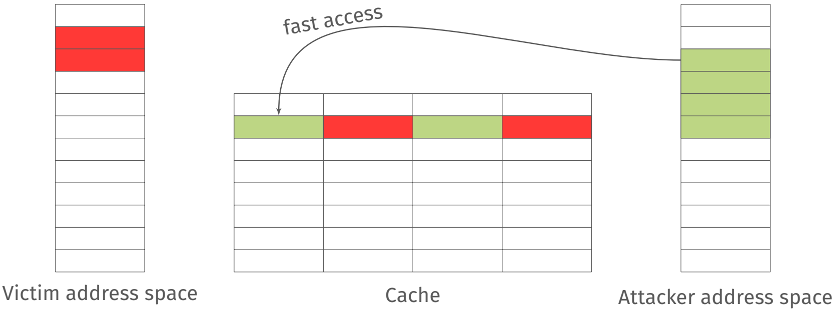

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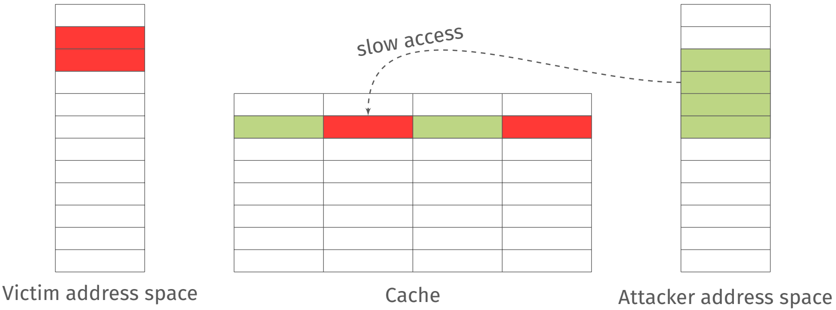

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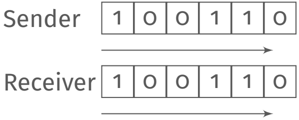

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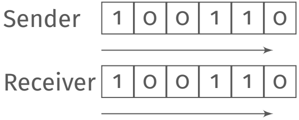

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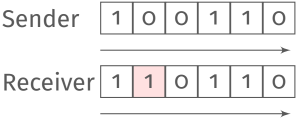

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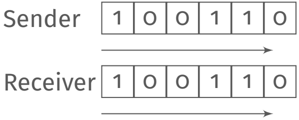

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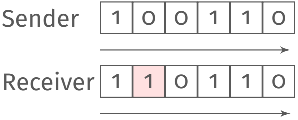

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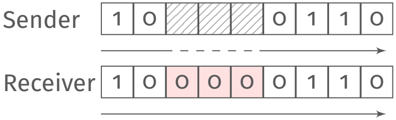

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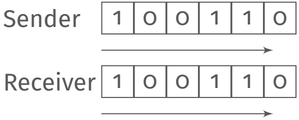

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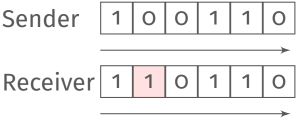

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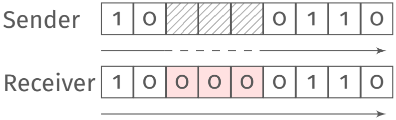

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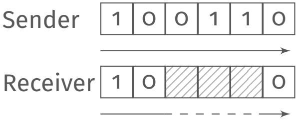

(d) Receiver descheduled: deletions

Our robust covert channel

- physical layer:
  - transmits words as a sequence of '0's and '1's
  - deals with synchronization errors
- data-link layer:
  - divides data to transmit into packets
  - corrects the remaining errors

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- sender and receiver agree on one set
- receiver probes the set continuously
- sender transmits ’0’ doing nothing
  - → lines of the receiver still in cache → fast access
- sender transmits ’1’ accessing addresses in the set
  - → evicts lines of the receiver → slow access

Eviction set generation

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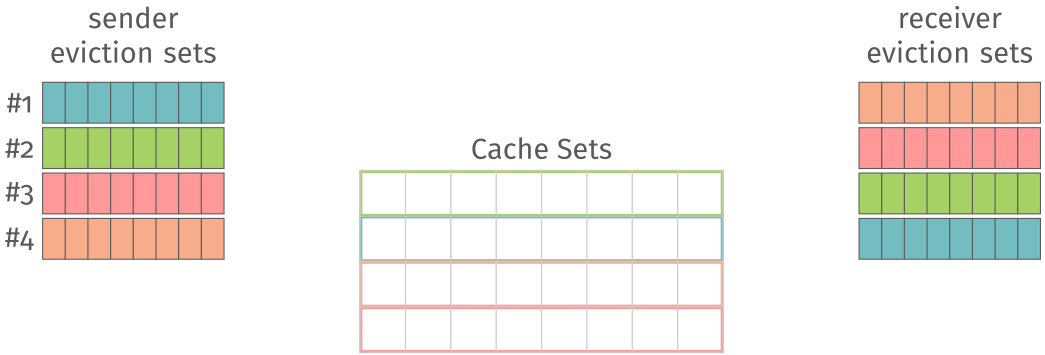
- we can build a set of addresses in the same cache set and same slice
- without knowing which slice

Jamming agreement



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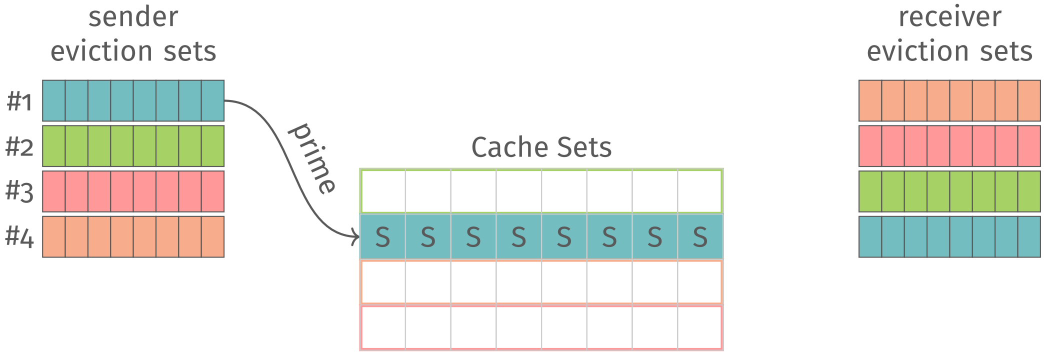

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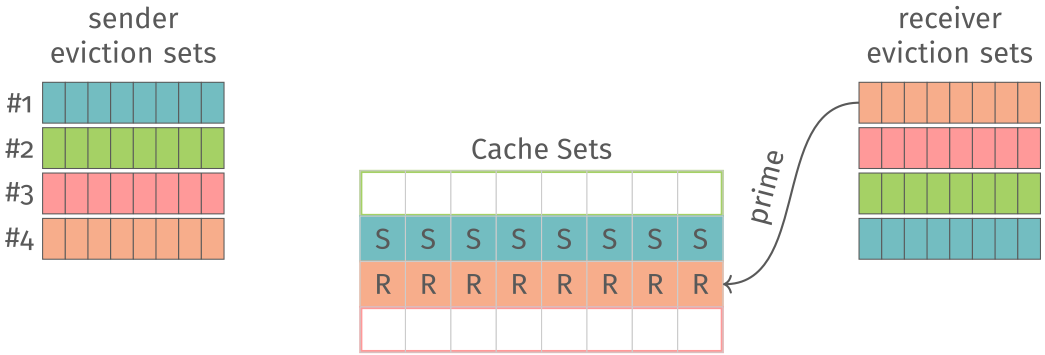

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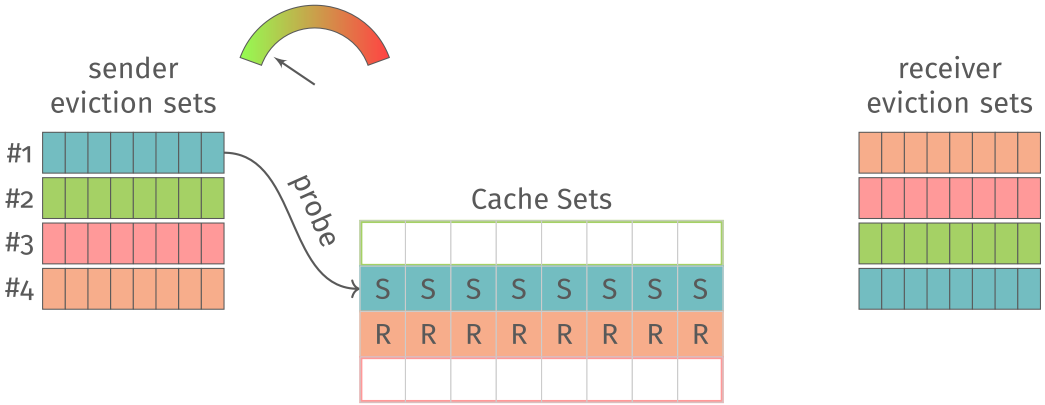

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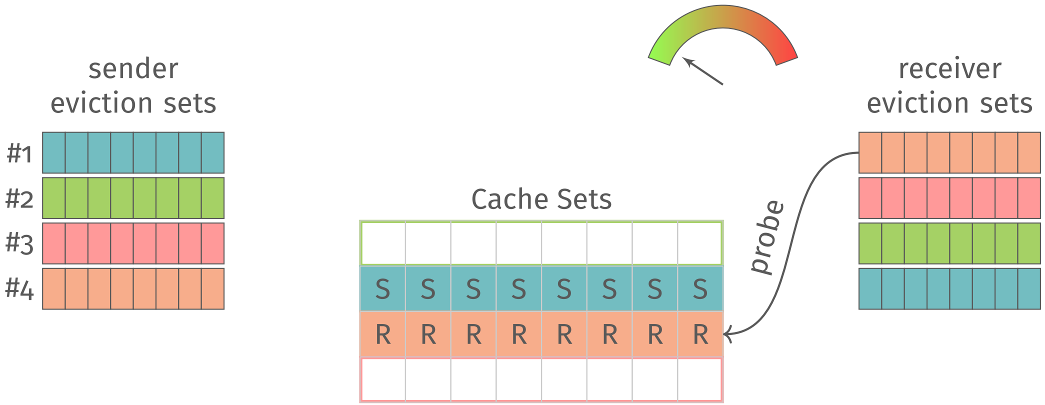

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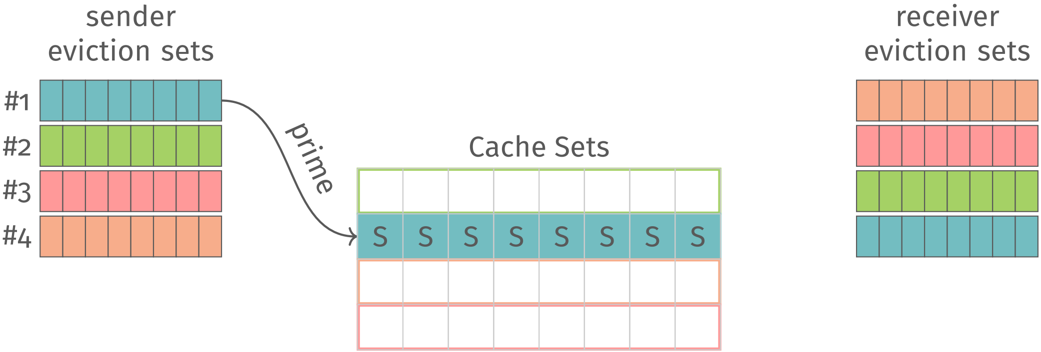

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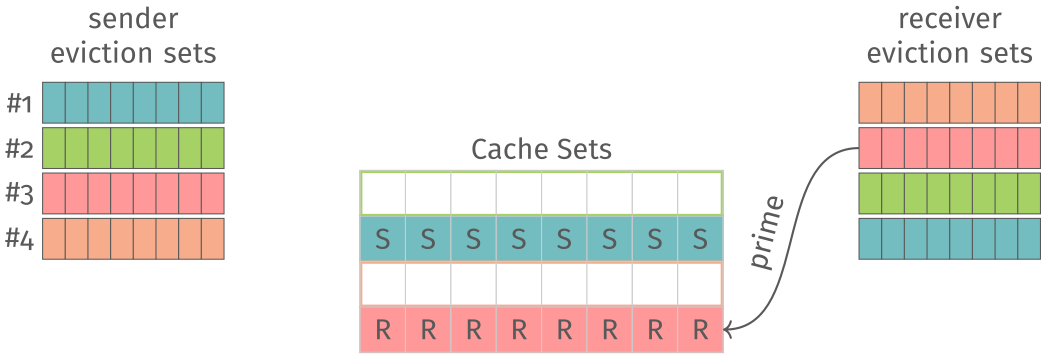

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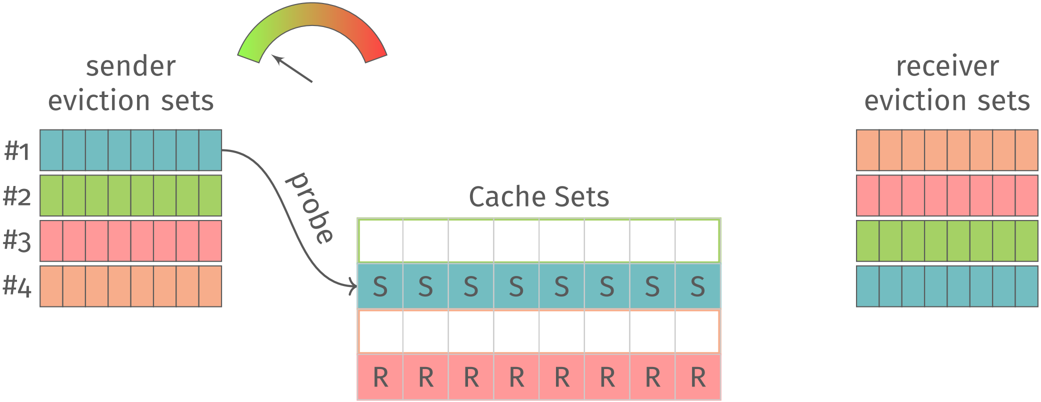

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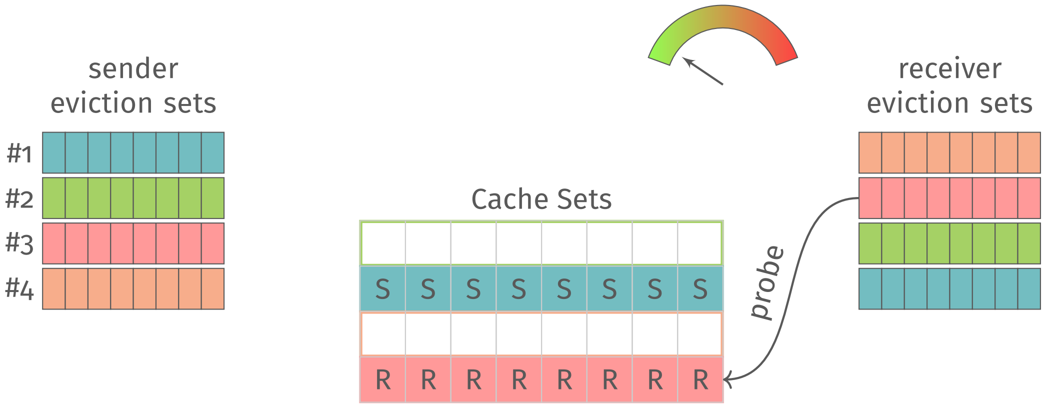

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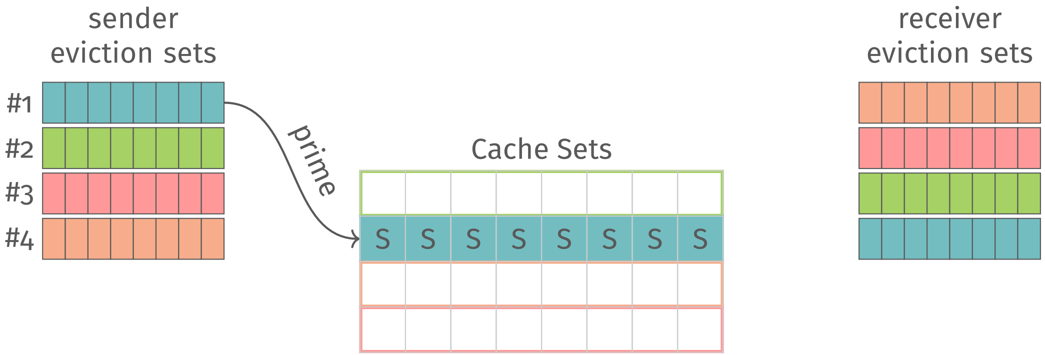

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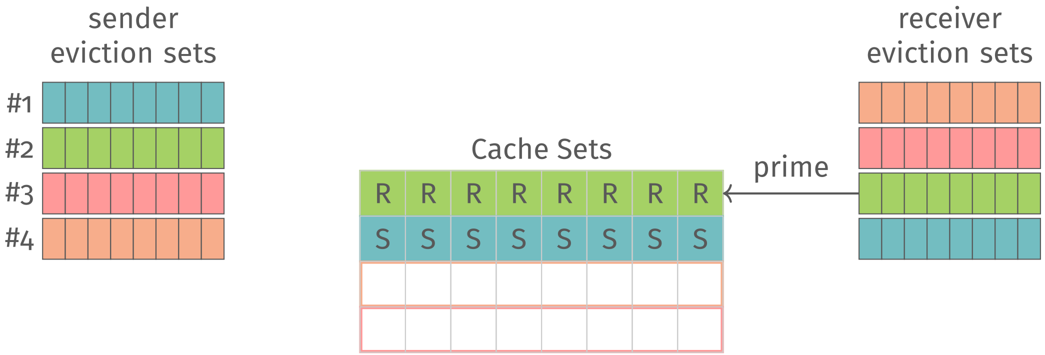

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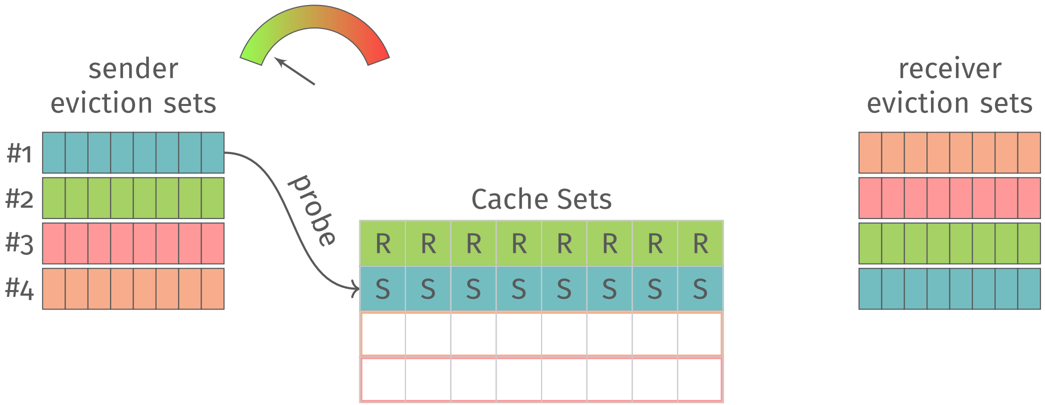

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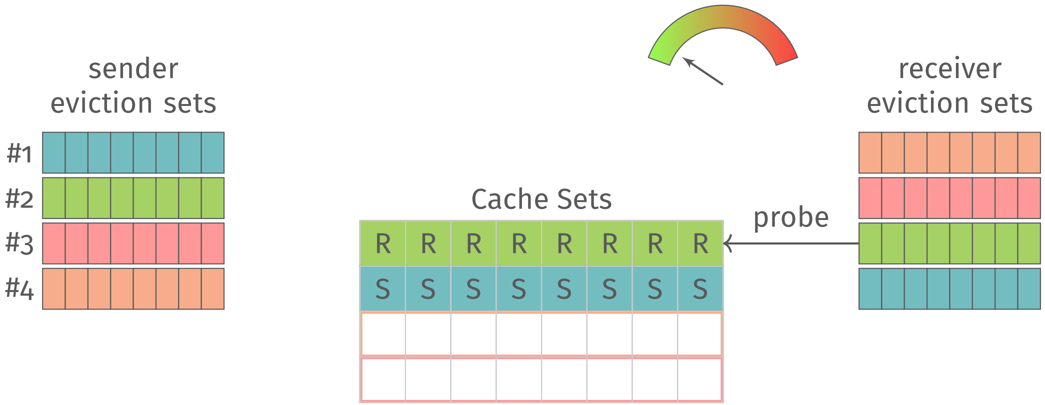

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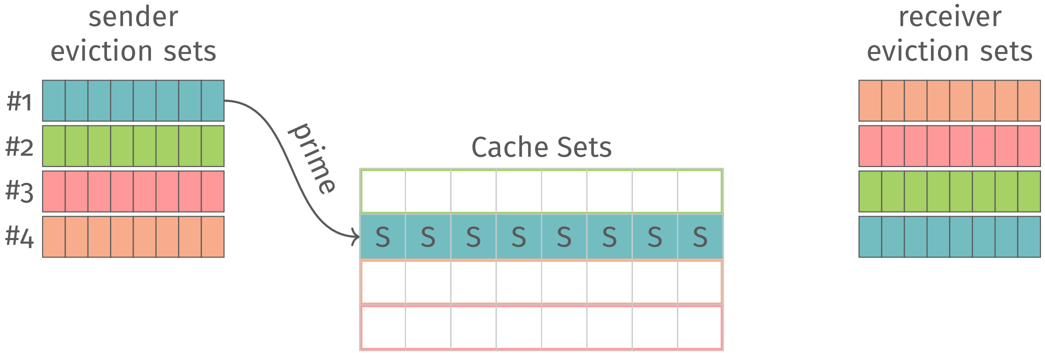

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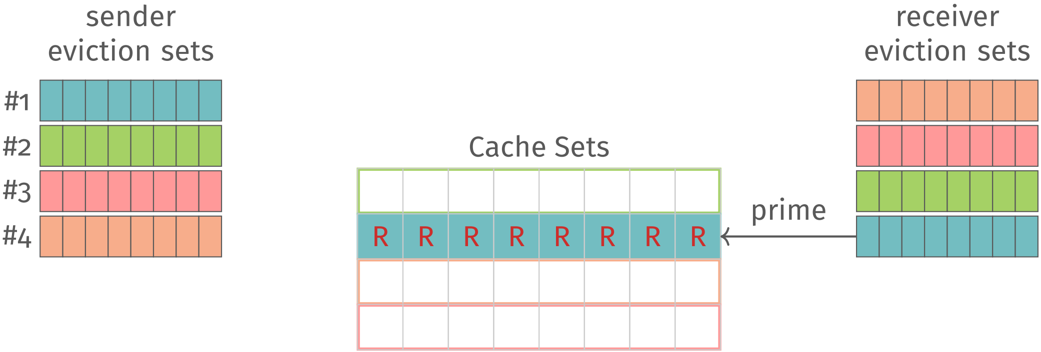

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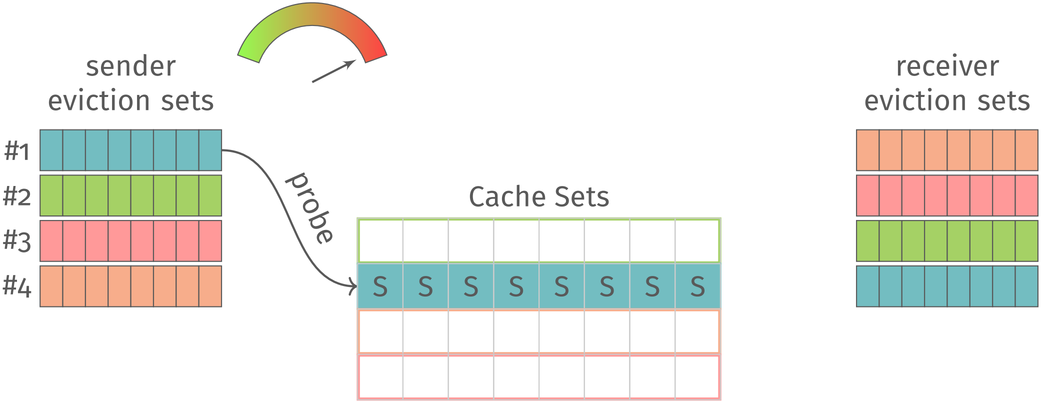

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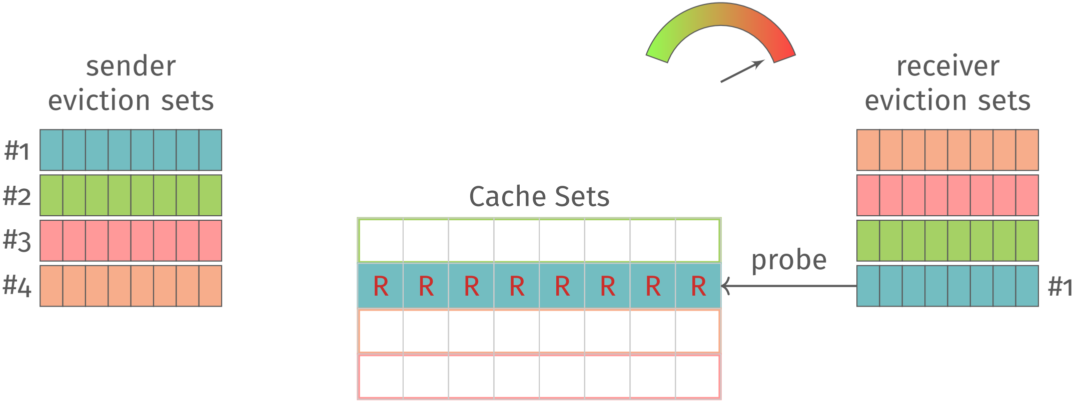

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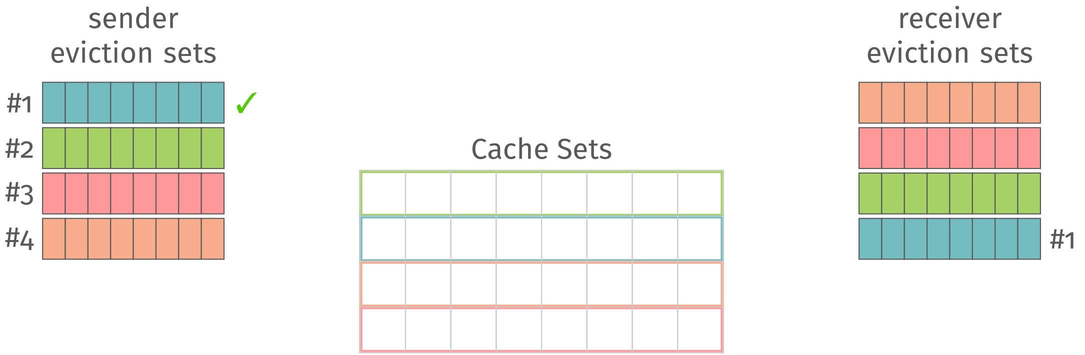

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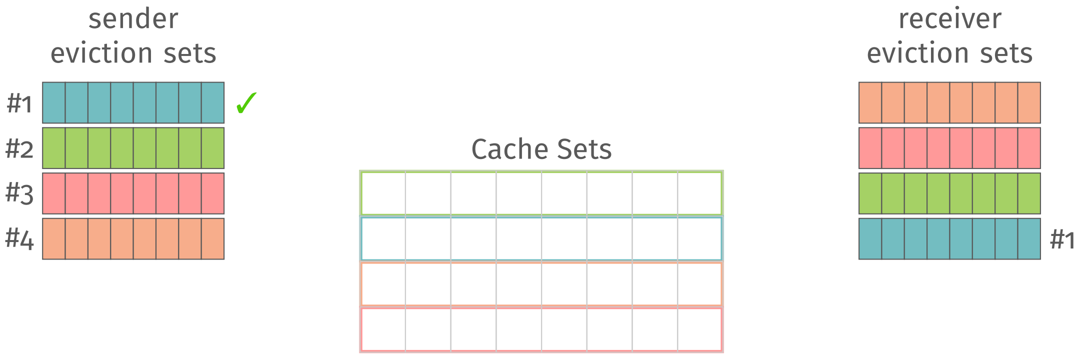

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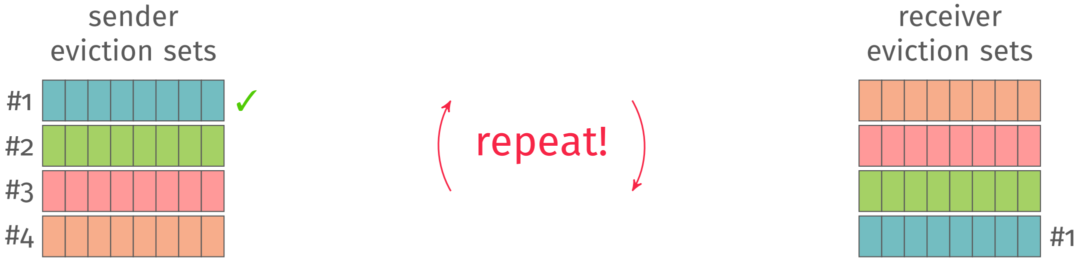

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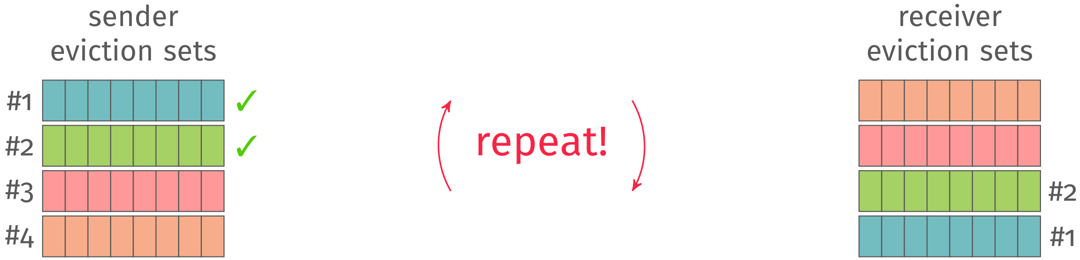

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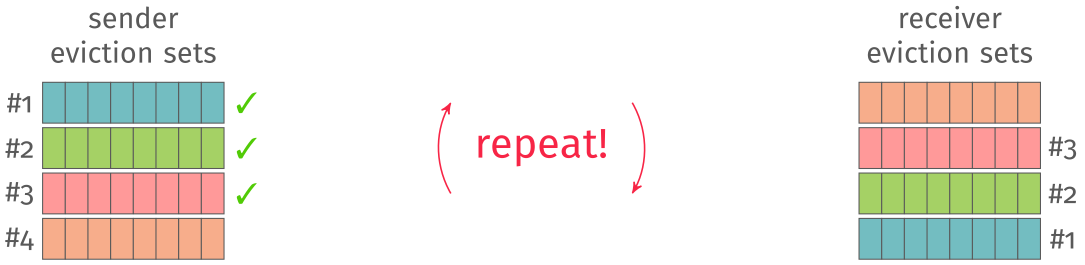

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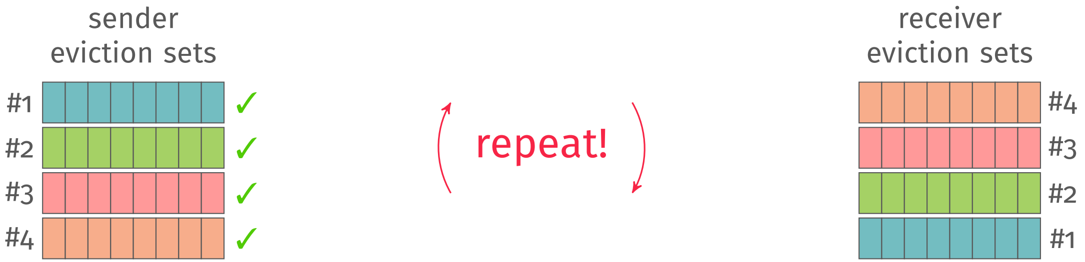
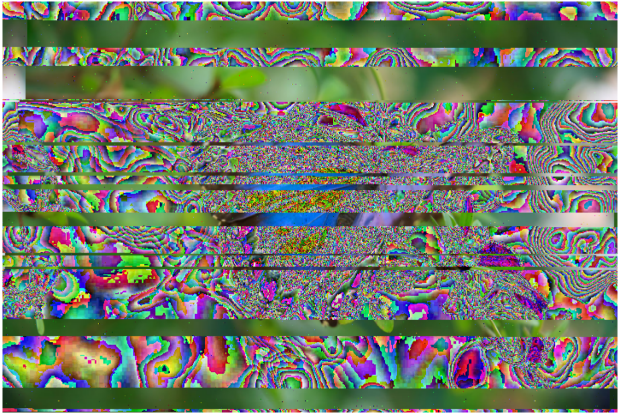


Sending the first image

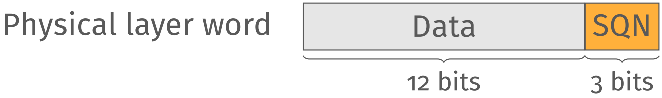


Handling synchronization errors

Physical layer word $\underbrace{\boxed{\text{Data}}}_{\text{12 bits}}$

Handling synchronization errors

- deletion errors: request-to-send scheme that also serves as ack
  - 3-bit sequence number
  - request: encoded sequence number (7 bits)

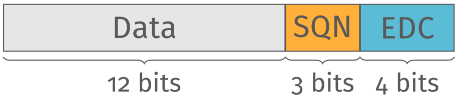


Handling synchronization errors

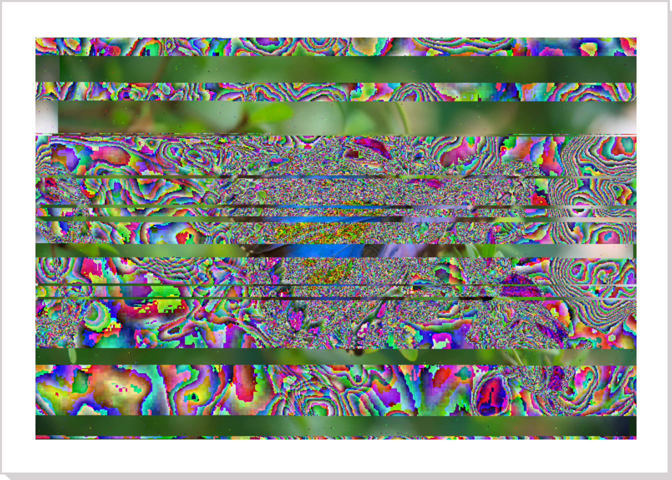
- deletion errors: request-to-send scheme that also serves as ack
  - 3-bit sequence number
  - request: encoded sequence number (7 bits)
- ’0’-insertion errors: error detection code → Berger codes
  - appending the number of ’0’s in the word to itself

  → property: a word cannot consist solely of ’0’s

Physical layer word



Synchronization (before)



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Data-link layer: Error correction

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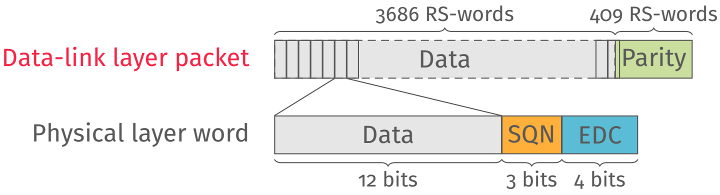
- RS word size = physical layer word size = 12 bits
- packet size = $2^{12} - 1$ = 4095 RS words
- 10% error-correcting code: 409 parity and 3686 data RS words



Error correction (after)

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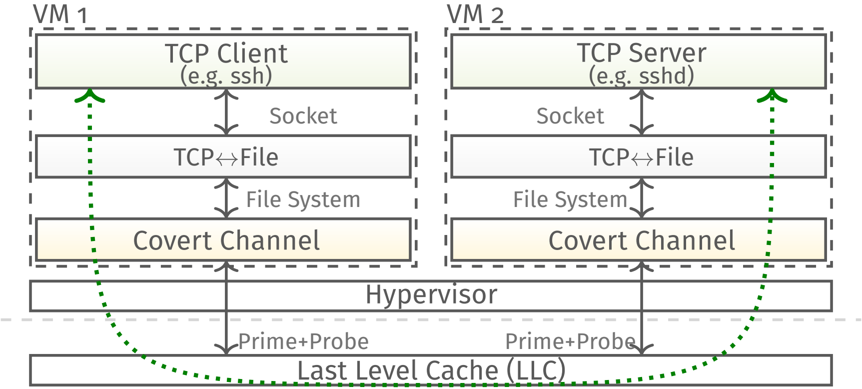
Amazon EC2	45.25 KBps	0.00%	–
Amazon EC2	45.09 KBps	0.00%	web server serving files on sender VM
Amazon EC2	42.96 KBps	0.00%	`stress -m 2` on sender VM
Amazon EC2	42.26 KBps	0.00%	`stress -m 1` on receiver VM
Amazon EC2	37.42 KBps	0.00%	web server on all 3 VMs, `stress -m 4` on 3rd VM, `stress -m 1` on sender and receiver VMs
Amazon EC2	34.27 KBps	0.00%	`stress -m 8` on third VM

Building an SSH connection



SSH evaluation

Between two instances on Amazon EC2

Noise	Connection
No noise	✓
`stress -m 8` on third VM	✓
Web server on third VM	✓
Web server on SSH server VM	✓
Web server on all VMs	✓
`stress -m 1` on server side	unstable

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Web server on SSH server VM	✓
Web server on all VMs	✓
`stress -m 1` on server side	unstable

Telnet also works with occasional corrupted bytes with `stress -m 1`

Conclusion

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Hello from the Other Side: SSH over Robust Cache Covert Channels in the Cloud

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