Hashing 3: Saving Space and Allowing Deletion with Cuckoo Filters

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SOLUTION ARCHITECT

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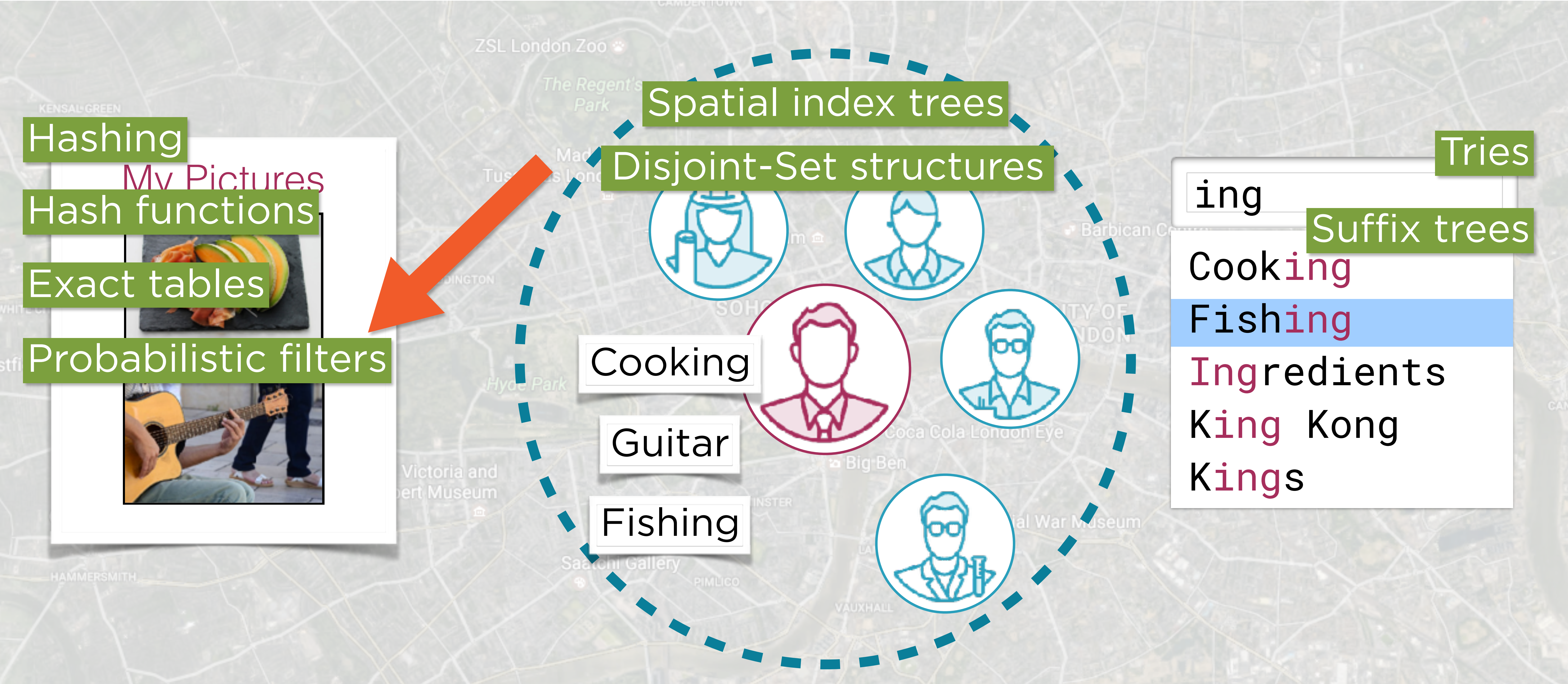
The Match Finder App



Hashing

My Pictures

Hash functions

Exact tables

Probabilistic filters

Spatial index trees

Disjoint-Set structures

Cooking

Guitar

Fishing

Tries

ing

Suffix trees

Cooking

Fishing

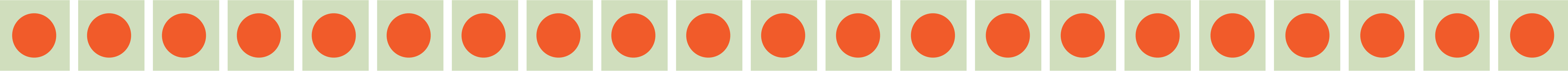
Ingredients

King Kong

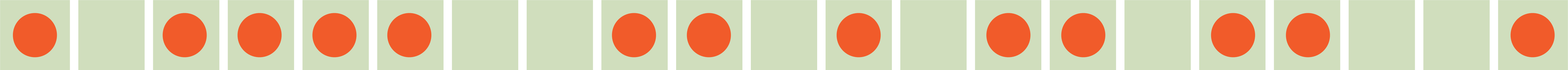
Kings

A Challenge with Bloom Filters

False positive risk increases



Lower false positive risk



Demo

Still wasting cache space

Cuckoo Filters

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
				15			32	64					15		
57		52		12							92		79		67
				49		47				82			26		
	29			33						19			74		31

Fingerprint (fp): $h_{\text{fp}}(\text{key})$

$p_1 = h_{\text{key}}(\text{key})$

XOR (eXclusive OR)

Bitwise operator

0 if bits are equal

1 if bits are different

$$\begin{array}{rr} & 1010 \\ \oplus & 0110 \\ \hline & 1100 \end{array} \qquad \begin{array}{rr} & 1100 \\ \oplus & 0110 \\ \hline & 1010 \end{array}$$

Cuckoo Filters

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
				15			32	64					15		
57		52		12		5					92		10 79		67
				49		47				82			26		
	29			33						19			74		31

Stop after “enough” iterations

Fingerprint (fp): $h_{\text{fp}}(\text{key})$

$p_1 = h_{\text{key}}(\text{key})$

$p_2 = p_1 \oplus h_{\text{key}}(\text{fp})$

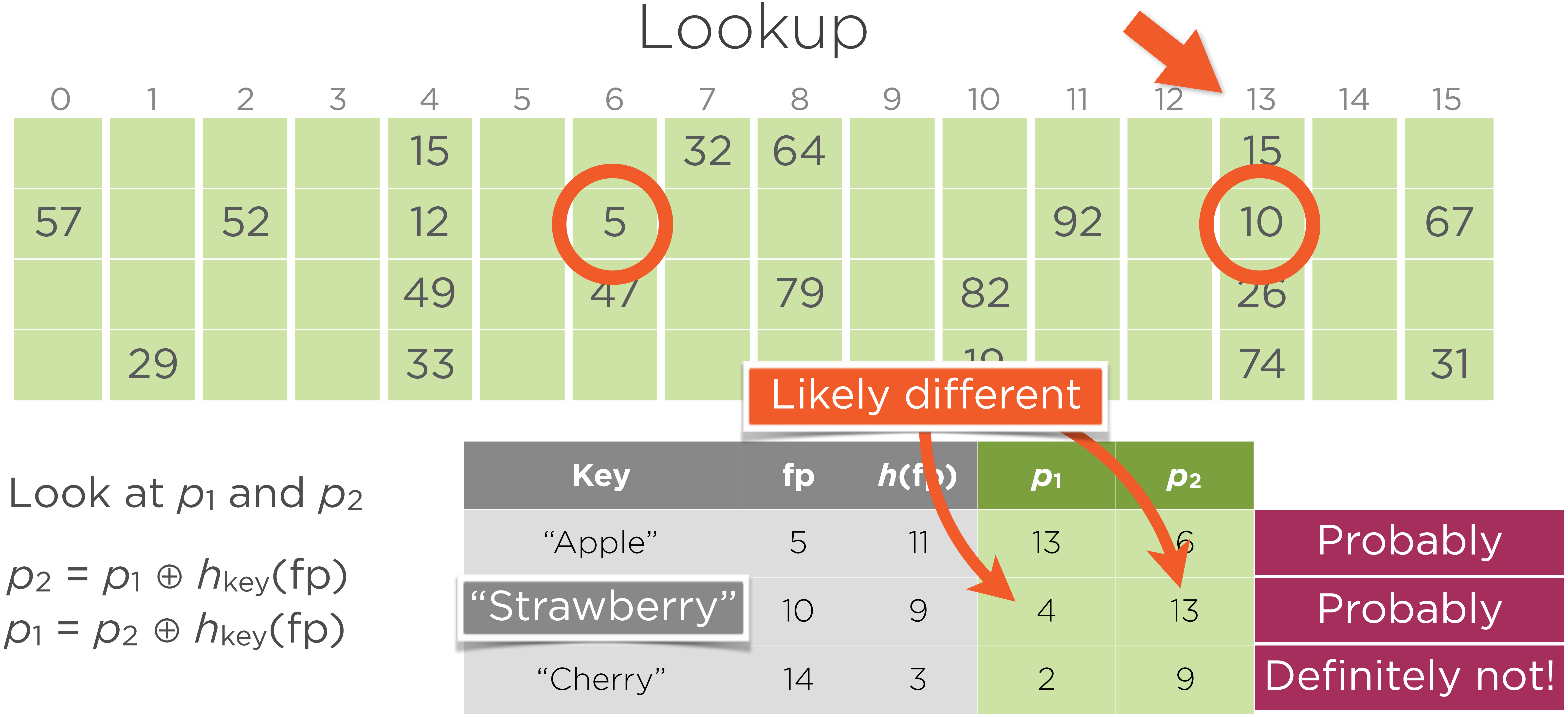
Insert fp at either p_1 or p_2

$p_1 = p_2 \oplus h_{\text{key}}(\text{fp})$

ey	fp	h(fp)	p_1	p_2
“Apple”	5	11	13	6
“Orange”	10	9	4	13
$13 \oplus 5 = 8$	79	5	13	8

Expected $O(1)$ time for insertion

Lookup



0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
				15			32	64					15		
57		52		12		5					92		10		67
				49		47		79		82			26		
	29			33						19			74		31

Likely different

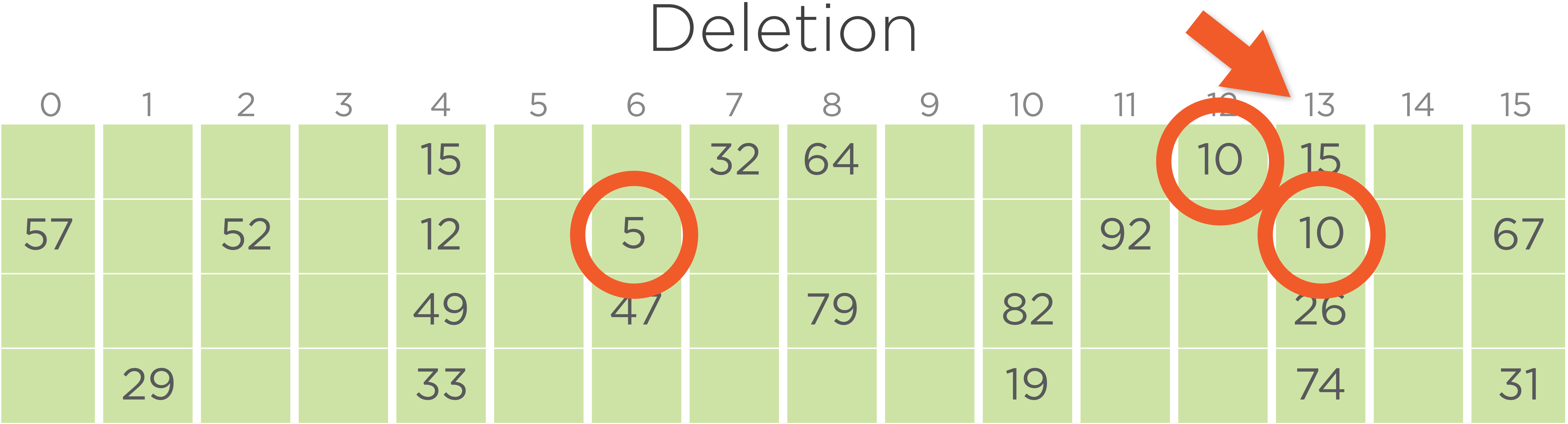
Key	fp	h(fp)	p_1	p_2	
"Apple"	5	11	13	6	Probably
"Strawberry"	10	9	4	13	Probably
"Cherry"	14	3	2	9	Definitely not!

Look at p_1 and p_2

$p_2 = p_1 \oplus h_{\text{key}}(\text{fp})$
$p_1 = p_2 \oplus h_{\text{key}}(\text{fp})$

Worst-case O(1) time for lookup

Deletion



0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
				15			32	64				10	15		
57		52		12		5					92		10		67
				49		47		79		82			26		
	29			33						19			74		31

Look at p_1 and p_2

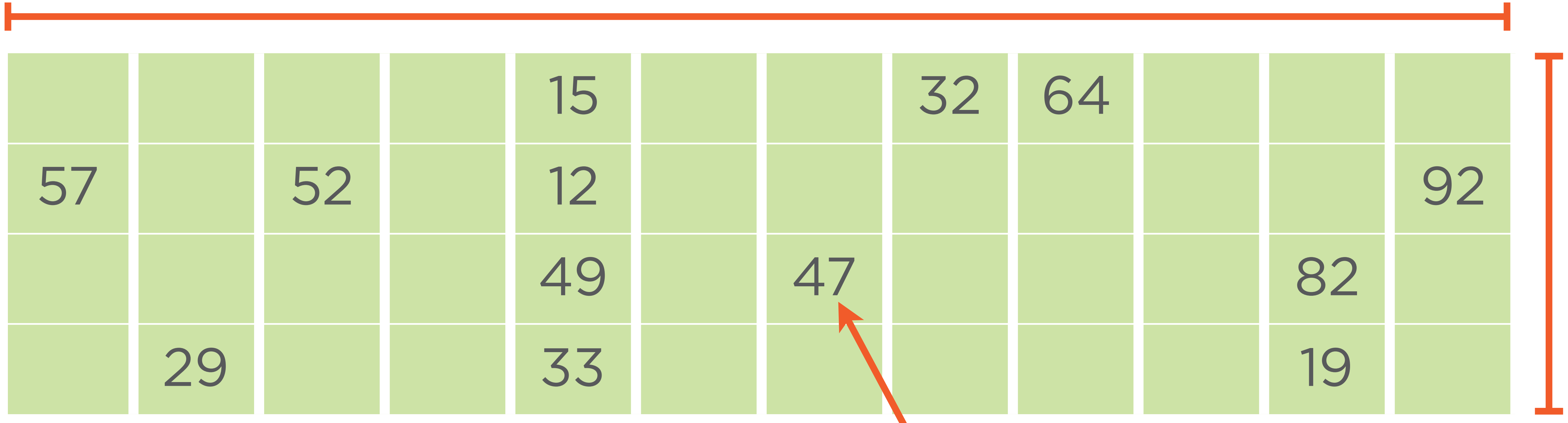
Delete matching fingerprint

(Other matches will remain)

Key	fp	*h*(fp)	p_1	p_2
"Apple"	5	11	13	6
"Orange"	10	9	4	13
"Cherry"	10	9	12	5

Worst-case O(1) time for deletion

Sizing



Around nearest power of 2 above number of items

				15			32	64			
57		52		12							92
				49		47				82	
	29			33						19	

Around 4
slots per
bucket

Around 6 bits per fingerprint
(supporting a few billion items)

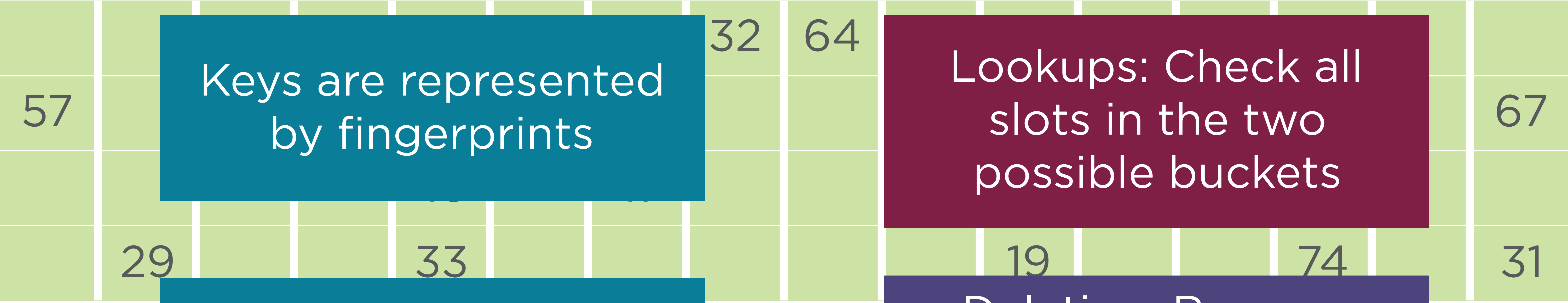
In-depth details: `tinyurl.com/cuckoobloom`

Bloom filter by example: `tinyurl.com/cuckooByExample`

Demo

Saving the cache (again)

Lessons Learned



Keys are represented by fingerprints

Two possible positions

Both can be deduced from the other using the fingerprint

Lookups: Check all slots in the two possible buckets

Deletion: Remove fingerprint

False positives

No false negatives