Karlsruhe Institute of Technology

High Performance Construction of RecSplit Based Minimal Perfect Hash Functions

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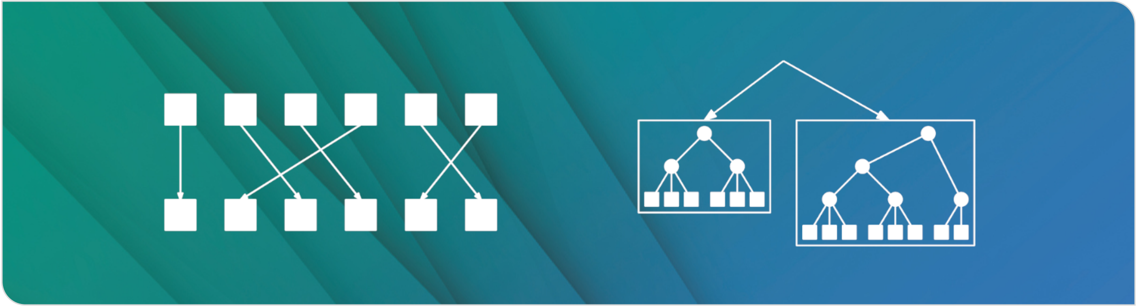
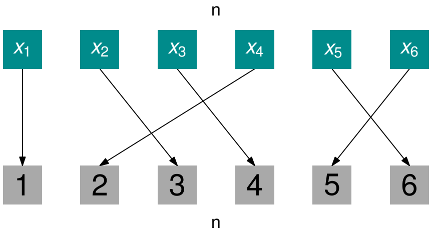
Dominik Bez, Florian Kurpicz, Hans-Peter Lehmann, Peter Sanders | September 4, 2023



Minimal Perfect Hashing

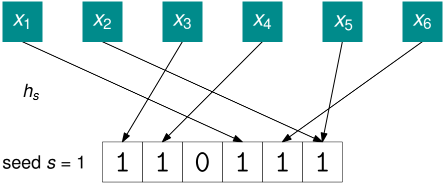
- Static set of *n* keys
- Bijectively map keys to the first *n* integers

- Recent idea: RecSplit [EGV20] (Esposito, Mueller Graf, Vigna)
- Push the boundaries of practical space usage
- Utilize modern processors and GPU



Bijections: RecSplit [EGV20]

- Brute-force
- Bit pattern indicates used hash values (single machine word)
- Store successful seed s



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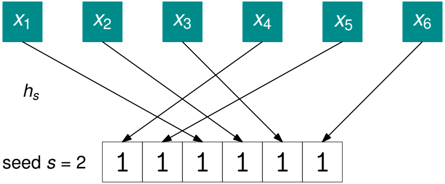
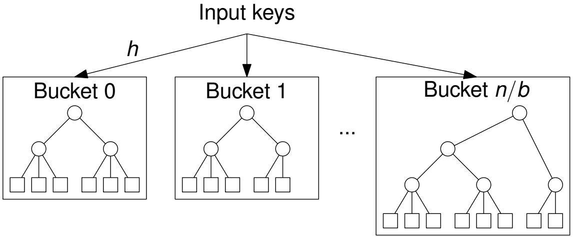


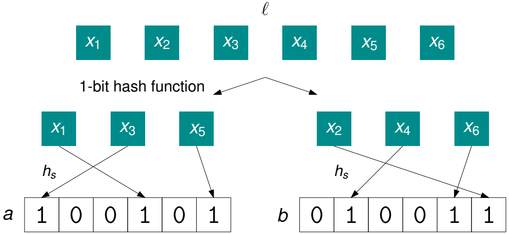
RecSplit [EGV20]

- Hash keys to buckets
- Tree structure within buckets
  - Brute-force search for splitting hash function
  - Specific shape depending only on bucket size
- Small leaves of size $\ell \leq 16$
  - Brute-force search for bijection hash function



Bijections: Rotation Fitting

- Split keys into two subsets
- Determine function values independently
- Cyclically “rotate” word b
- Store seed and rotation $s \cdot \ell + r$
- Test $\approx \ell$ times fewer seeds



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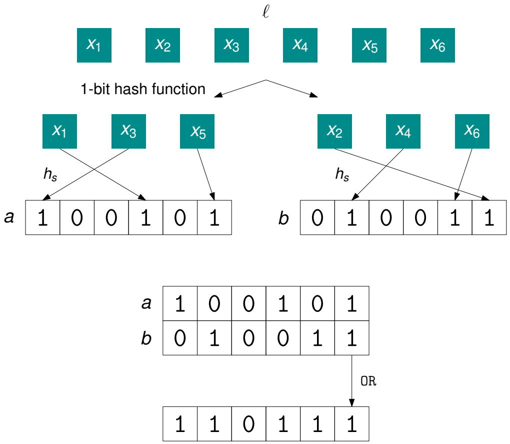

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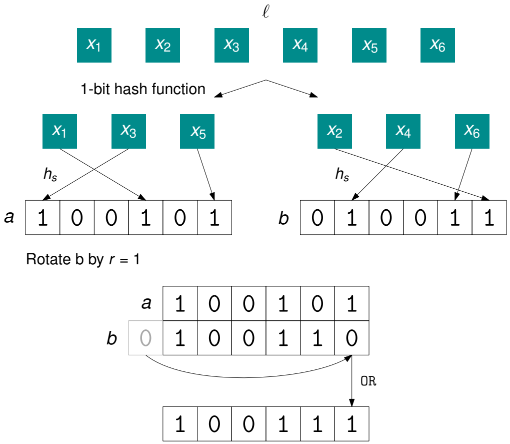

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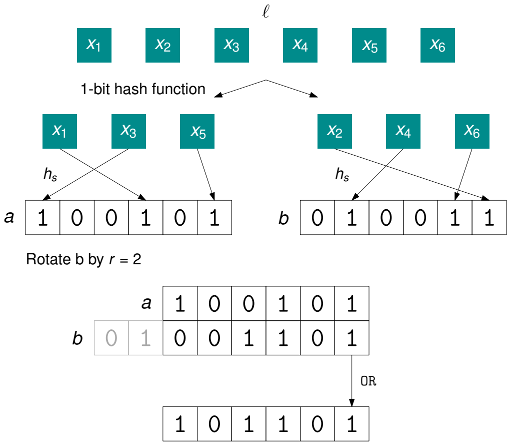

ℓ

x_1 x_2 x_3 x_4 x_5 x_6

1-bit hash function

x_1 x_3 x_5 x_2 x_4 x_6

h_s h_s

a 1 0 0 1 0 1 b 0 1 0 0 1 1

Rotate b by $r = 2$

a 1 0 0 1 0 1

b 0 1 0 0 1 1 0 1

OR

1 0 1 1 0 1

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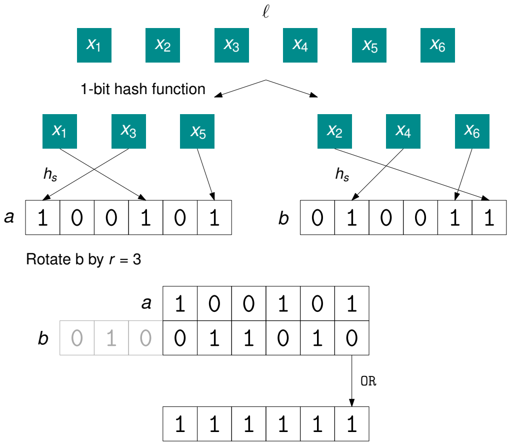
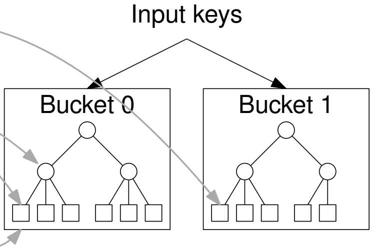


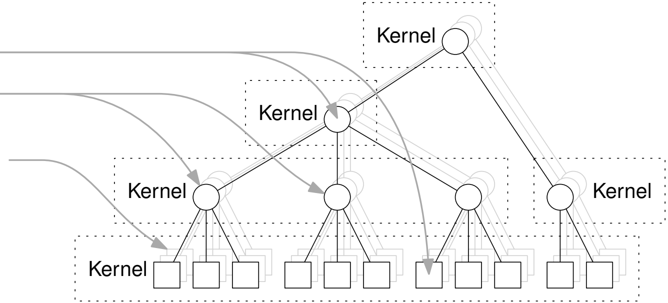
CPU Parallelization

- Bit parallelism
  - Bit operations rotate all keys of a leaf
- SIMD parallelism
  - Each lane tries a different hash function seed
- Multi-Threaded parallelism
  - Calculate different buckets in parallel

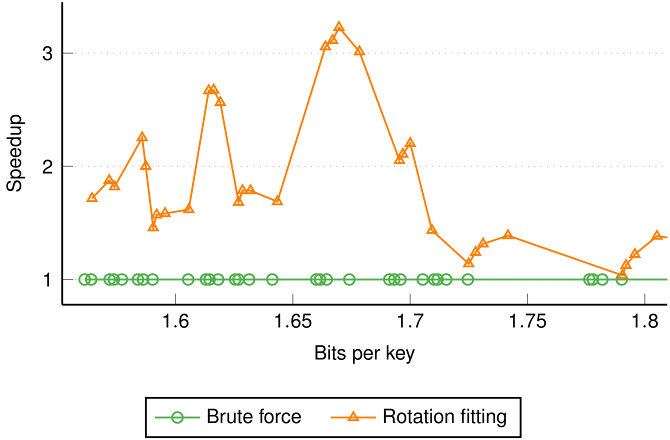


GPU Parallelization

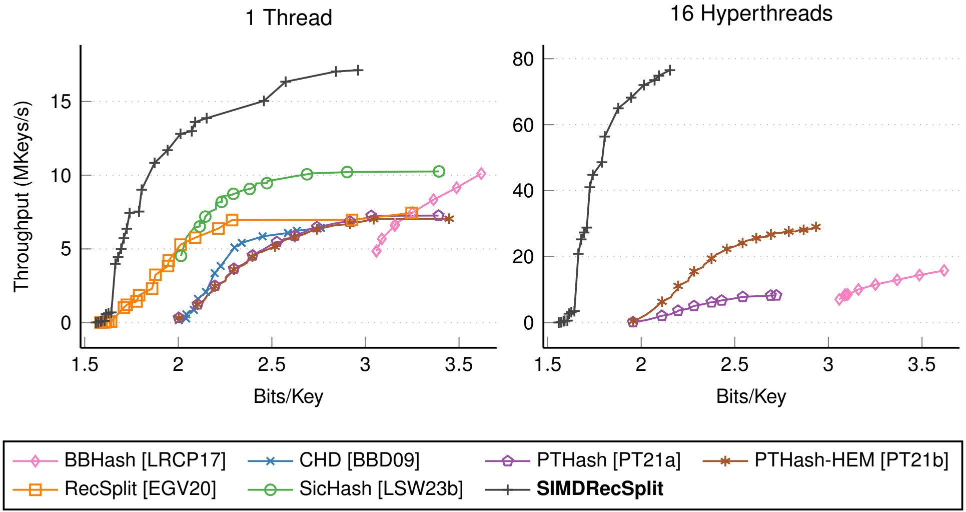
- Threads try different seeds
- Groups of threads work on different tree nodes
- 2D grid of groups to calculate all trees with same shape
- Streams to calculate different tree shapes in parallel



Construction with Rotation Fitting



Multi-Threaded Construction



GPU Construction

Configuration	Method	Threads	Bits/key	Construction	Speedup
$\ell = 16, b = 2000$	RecSplit [EGV20]	1	1.560	1175.4 μs/key	1×
	SIMDRecSplit	16	1.560	27.9 μs/key	42×
	GPURecSplit	GPU	1.560	1.0 μs/key	1175×
$\ell = 18, b = 50$	RecSplit [EGV20]	1	1.707	2942.9 μs/key	1×
	SIMDRecSplit	16	1.708	12.3 μs/key	239×
	GPURecSplit	GPU	1.709	0.5 μs/key	5438×
$\ell = 24, b = 2000$	GPURecSplit	GPU	1.496	467.9 μs/key	—

Conclusion

- New technique Rotation Fitting
- Heavy parallelization
  - Bits, Vectors, Cores, GPU
- Up to 5438 times faster construction
- First to achieve 1.4x bits per key
- /ByteHamster/GpuRecSplit

- Future work: Improve query performance
- New: ShockHash [LSW23a] for bijections

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