Karlsruher Institut für Technologie

PaCHash: Packed and Compressed Hash Tables

Vorlesung Algorithm Engineering

Hans-Peter Lehmann | 14. Juni 2022

Bitvektoren

- $rank_1(x)$: Anzahl der 1en bis zur Position x
- $select_1(x)$: Position der x-ten 1
- Query-Zeit $O(1)$ mit Platzverbrauch $o(n)$
- Implementierungen mit nur 3% Overhead [8]

0 1 1 0 1 1 1 0 0 1

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$$rank_1(4) = 3$$

0 1 1 0 1 1 1 0 0 1

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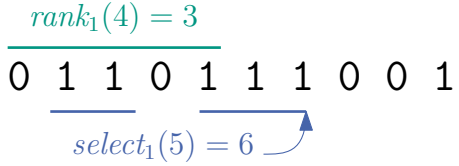

Elias-Fano Coding [3, 6]

- Kompakte Repräsentation einer monoton wachsenden Folge von n Ganzzahlen $\leq U$

i	$\texttt{arr}[i]$						L[i]	H
0	1	0	0	0	0	1		
1	4	0	0	1	0	0		
2	9	0	1	0	0	1		
3	9	0	1	0	0	1		
4	11	0	1	0	1	1		
...								

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i	$\texttt{arr}[i]$		L[i]	H
0	1	0 0 0 0 1	0 1	
1	4	0 0 1 0 0	0 0	
2	9	0 1 0 0 1	0 1	
3	9	0 1 0 0 1	0 1	
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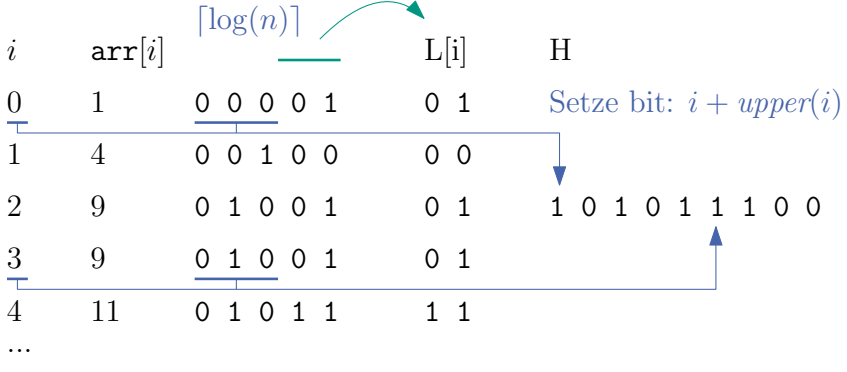


Elias-Fano Coding: Zugriff

- Zugriff in $O(1)$ mit $select_1$

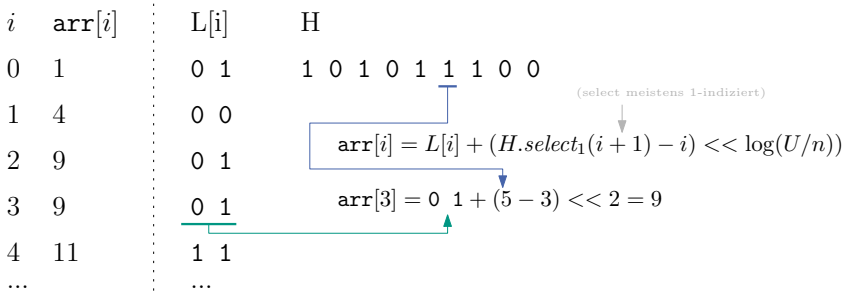
i	$\texttt{arr}[i]$	L[i]	H
0	1	0 1	1 0 1 0 1 1 1 0 0
1	4	0 0	
2	9	0 1	
3	9	0 1	
4	11	1 1	
...		...	

(select meistens 1-indiziert)

$$\texttt{arr}[i] = L[i] + (H.select_1(i+1) - i) << \log(U/n))$$

Elias-Fano Coding: Zugriff

- Zugriff in $O(1)$ mit $select_1$



Elias-Fano Coding: Predecessor Query

- *predecessor*$(x) = \max y \in \texttt{arr} : y \leq x$ in erwarteter Zeit $O(\log(U/n))$

i	$\texttt{arr}[i]$	L[i]	H
0	1	0 1	1 0 1 0 1 1 1 0 0
1	4	0 0	
2	9	0 1	
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...		...	

$predecessor(x)$: binäre Suche zwischen
$select_0(upper(x))..select_0(upper(x)+1)$

Elias-Fano Coding: Predecessor Query

- *predecessor*$(x) = \max y \in \texttt{arr} : y \leq x$ in erwarteter Zeit $O(\log(U/n))$

i	arr$[i]$	L[i]
0	1	0 1
1	4	0 0
2	9	0 1
3	9	0 1
4	11	1 1
...		...

H: 1 0 1 0 1 1 1 0 0

predecessor(x) : binäre Suche zwischen $select_0(upper(x))..select_0(upper(x)+1)$

$upper(10) =$ 0 1 0

$predecessor(10) \in select_0(2)..select_0(3)$

Elias-Fano Coding: Speicherplatz

Naiv:

- $n \cdot \log(U)$

Elias-Fano:

- Array L: $n \cdot \log(U/n)$
- Bitvektor H: $2n + 1$
- Select-Datenstruktur: $o(2n + 1)$
- $\rightarrow n \cdot (2 + \log(U/n) + o(1))$

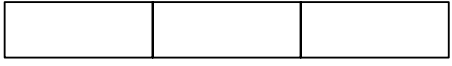
PaCHash: Motivation

	Cuckoo [13]	Interne HT mit Pointern	Separator Hashing [10]	Chaining [2]
Zugriff in 1 I/O	✗	✓	✓	✗
Objekte variabler Größe	✗	✓	✗	✓
Platzeffizient extern	✗	✓	✗	✓
Platzeffizient intern	✓	✗	✓	✓

PaCHash: Motivation

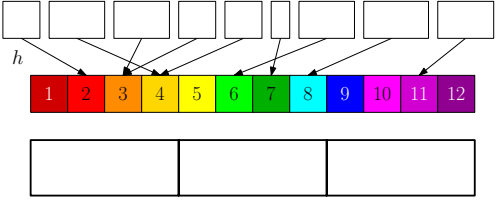
	Cuckoo [13]	Interne HT mit Pointern	Separator Hashing [10]	Chaining [2]	**PaCHash** [9]
Zugriff in 1 I/O	✗	✓	✓	✗	✓*
Objekte variabler Größe	✗	✓	✗	✓	✓
Platzeffizient extern	✗	✓	✗	✓	✓
Platzeffizient intern	✓	✗	✓	✓	✓

PaCHash [9]



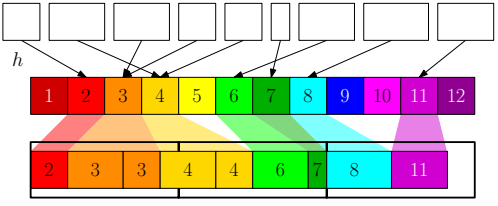
PaCHash [9]

- Objekte in *a* Bins/Block hashen



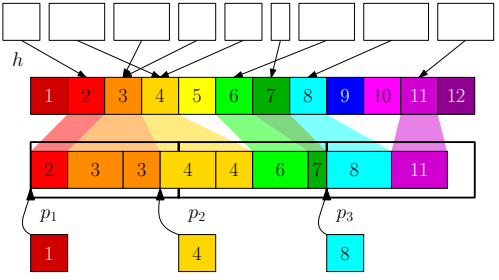
PaCHash [9]

- Objekte in *a* Bins/Block hashen
- Extern: Objekte gepackt, sortiert nach Bins



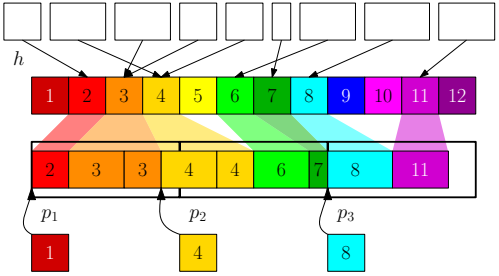
PaCHash [9]

- Objekte in *a* Bins/Block hashen
- Extern: Objekte gepackt, sortiert nach Bins
- Intern: Index speichert ersten Bin pro Block



PaCHash: Analyse

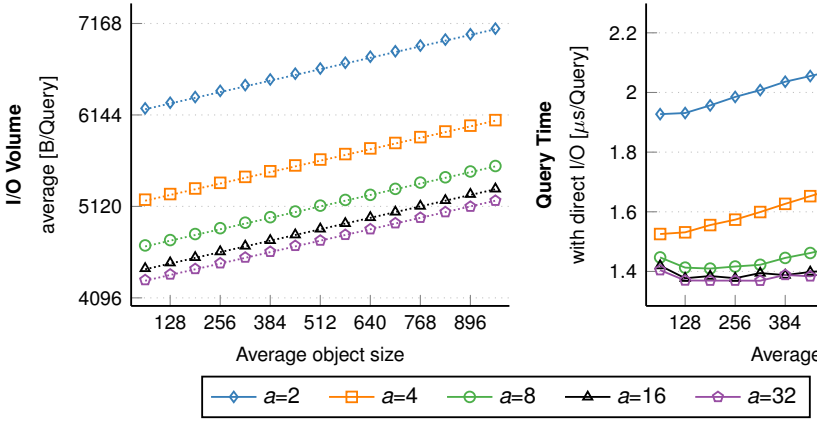
- Array p mit Elias-Fano codiert
  - m Blöcke, am Bins
  - $\log(a)$ bit direkt in L, Rest in H
  - $\rightarrow 2 + \log(a) + o(1)$ bit/Block
- Abrufen von Objekt x
  - Konstanter Lookup in Elias-Fano (Predecessor Query)
  - 1 I/O Operation mit $1 + |x|/B + 1/a$ konsekutiven Blöcken
- Extern fast 100% platzeffizient
  - Je nach Codierung der Objekte vielleicht zusätzlich $\log(B)$ bit Offset pro Block



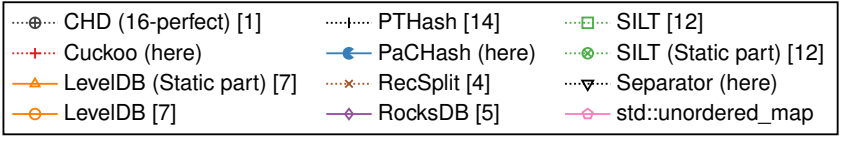
PaCHash: Engineering

- I/O
  - `io_uring` aus Linux 5.1
  - Queue depth: Latenz vs Throughput
- Block-Layout mit Tabelle
  - Schneller zu scannen als Objekte selbst
  - Offsets als Tabellen-Eintrag statt Größe
  - Tabelle am Ende des Blocks für lineares Schreiben
- Hashing: fastrange [11] statt Modulo
  - `r % am` vs `(uint64_t)(((__uint128_t)r * (__uint128_t)am) >> 64)`

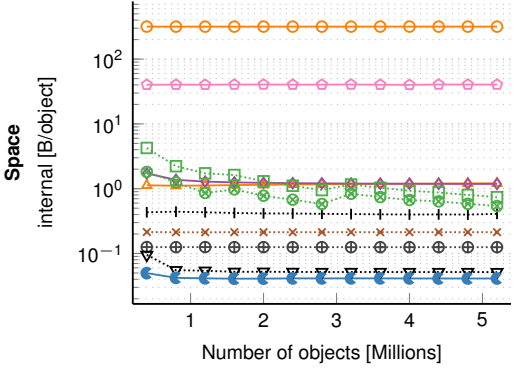
Evaluation: Parameter *a*

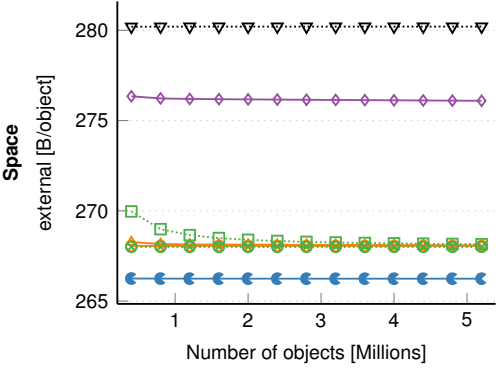


Evaluation: Competitors



Evaluation: Competitors





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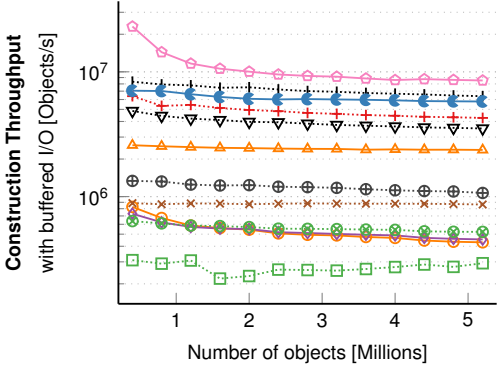

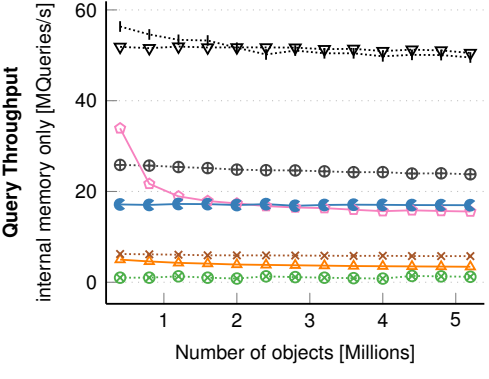

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