Database System Internals

Lecture 28

Column-store DBMSs

References

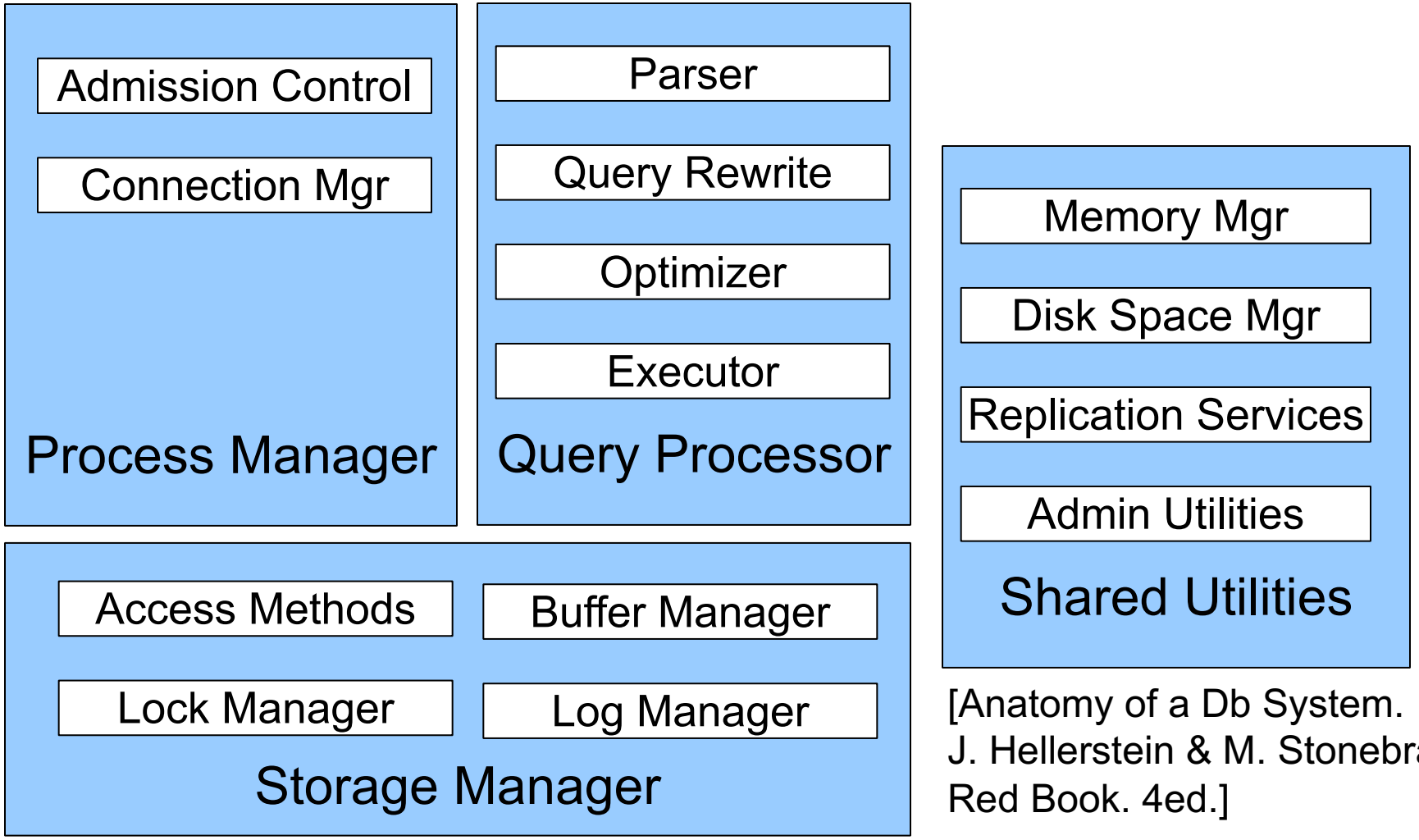
- Ailamaki et al. *Weaving Relations for Cache Performance,* VLDB'2001

- Daniel Abadi, Peter Boncz, Stavros Harizopoulos, Stratos Idreos, Samuel Madden. *The Design and Implementation of Modern Column-Oriented Database Systems* Foundations and Trends® in Databases 2012

Column Store Popularity Gain

- C-store ideas and research since 1970's
- **2004**: C-store research prototype at MIT
  - Started by Mike Stonebraker
  - Lead graduate student Daniel Abadi
- **2005**: Vertica founded by M. Stonebraker & A. Palmer
- **2011**: Vertica acquired by HP
- **2012**: As of VLDB'12 paper, 500 production deployments of Vertica, three over a PB in size
- **2013**: All major DB vendors include some column-store implementation

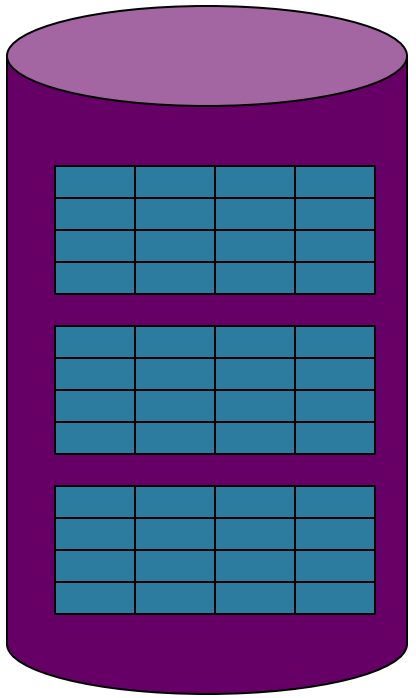
DBMS Architecture



[Anatomy of a Db System.
J. Hellerstein & M. Stonebraker.
Red Book. 4ed.]

Working with Pages

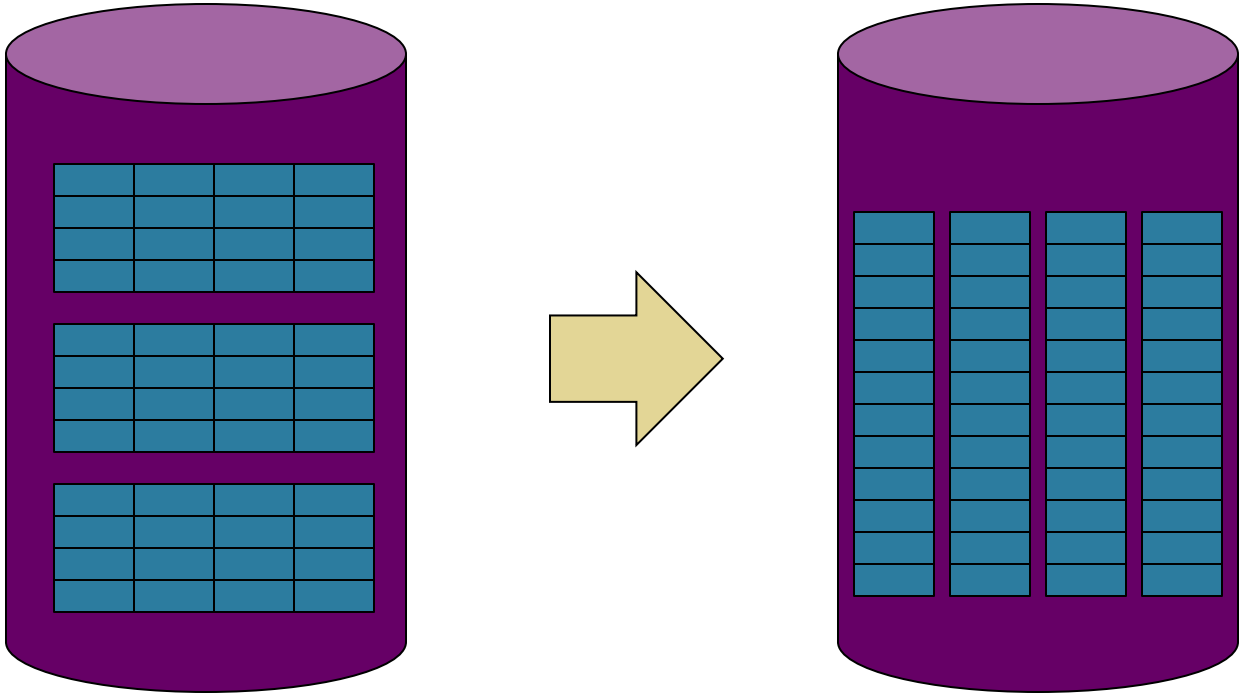
- Reading/writing to/from disk
  - Seeking takes a long time!
  - Reading sequentially is fast



- To simplify buffer manager, want to cache a collection of same-sized objects

- Solution: Read/write **pages** of data
  - A page should correspond to a disk block

From Row-Store to Column-Store



Rows stored
contiguously on disk
(+ tuple headers)

Columns stored
contiguously on disk
(no headers needed)

C-Store Illustration

Row-based
(4 pages)

Page

A	1
A	2

A	2
A	2

B	2
B	4

C	4
C	4

Column-based
(4 pages)

A	1
A	2
A	2
A	2

B	2
B	4
C	4
C	4

Page

C-Store also avoids large tuple headers

Column-Oriented Databases

- Main idea:
  - Physical storage: complete vertical partition; each column stored separately: R.A, R.B, R.A
  - Logical schema: remains the same R(A,B,C)

- Main advantage:
  - Improved transfer rate: disk to memory, memory to CPU, better cache locality

Basic Trade-Off

- Row stores
  - Quick to update entire tuple (1 page IO)
  - Quick to access a single tuple
- Column stores
  - Avoid reading unnecessary columns
  - Better compression
- Entire system needs a different design
  - Not only storage manager
  - To achieve high performance

An Intermediate Format: PAX

- PAX = Partition Attributes Across
- Addresses memory access bottleneck (not the disk bottleneck)

From Row to Column Storage (Initial Designs - 1985)

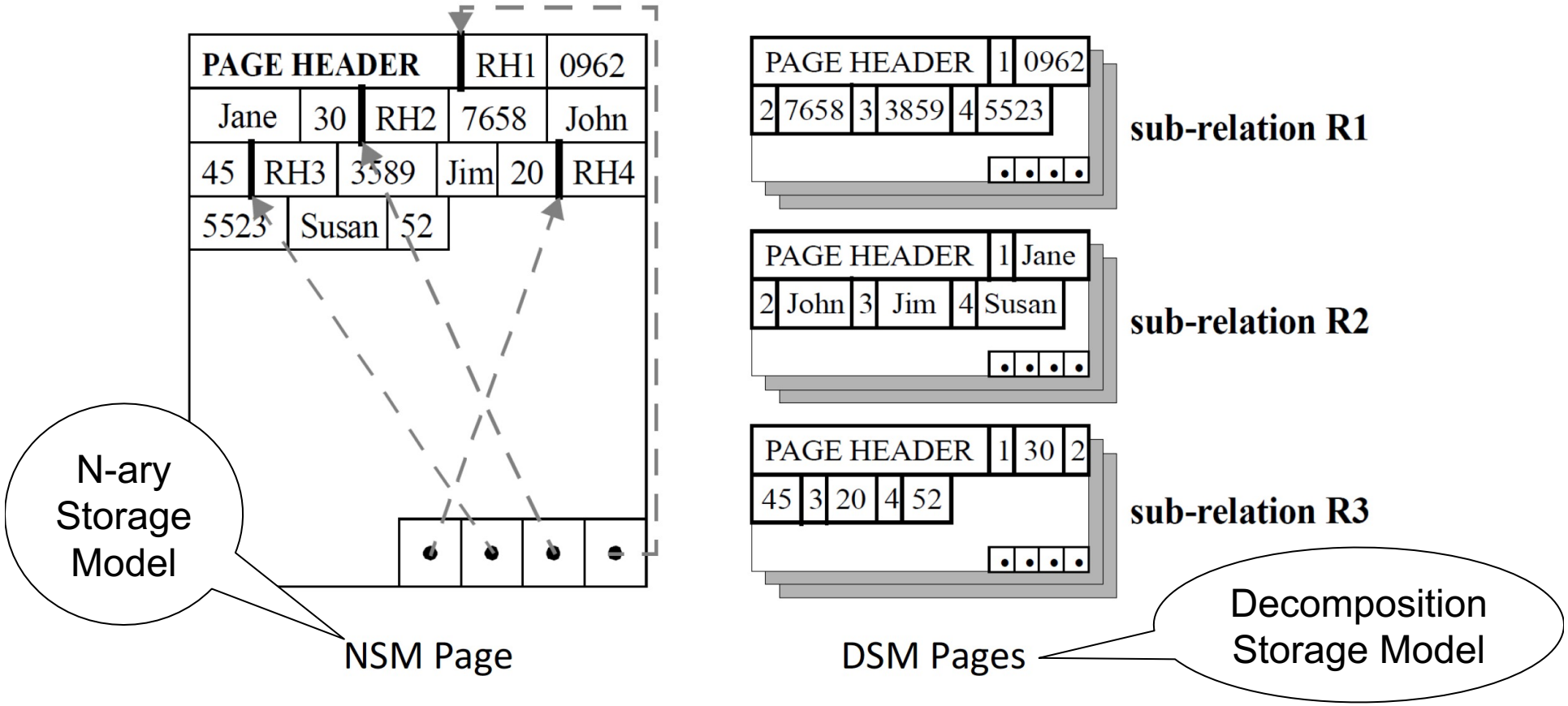


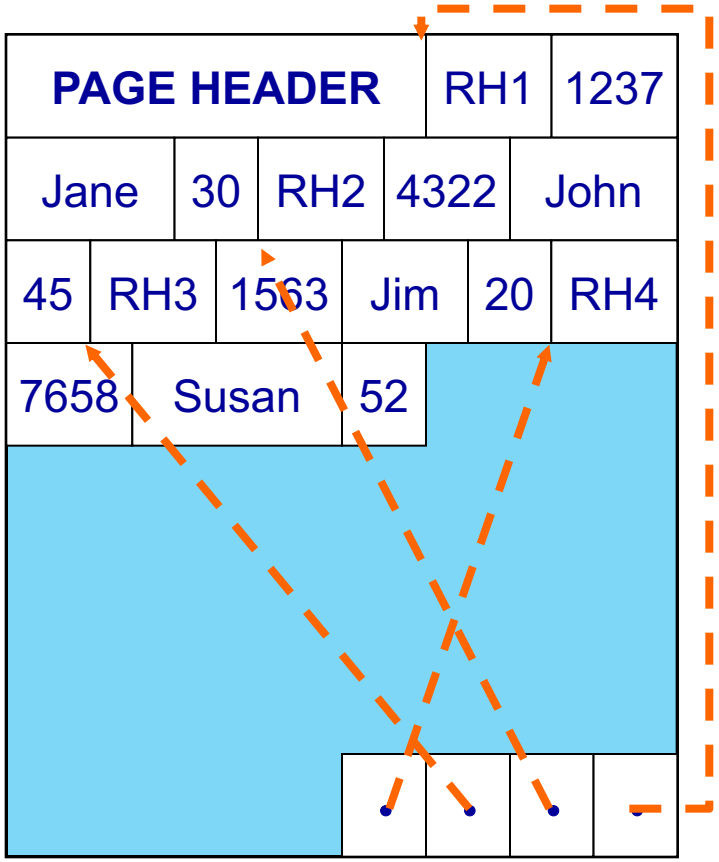
Figure 2.1: Storage models for storing database records inside disk pages: NSM (row-store) and DSM (a predecessor to column-stores). Figure taken from [5].

Current Scheme: Slotted Pages

Formal name: NSM (N-ary Storage Model)

R

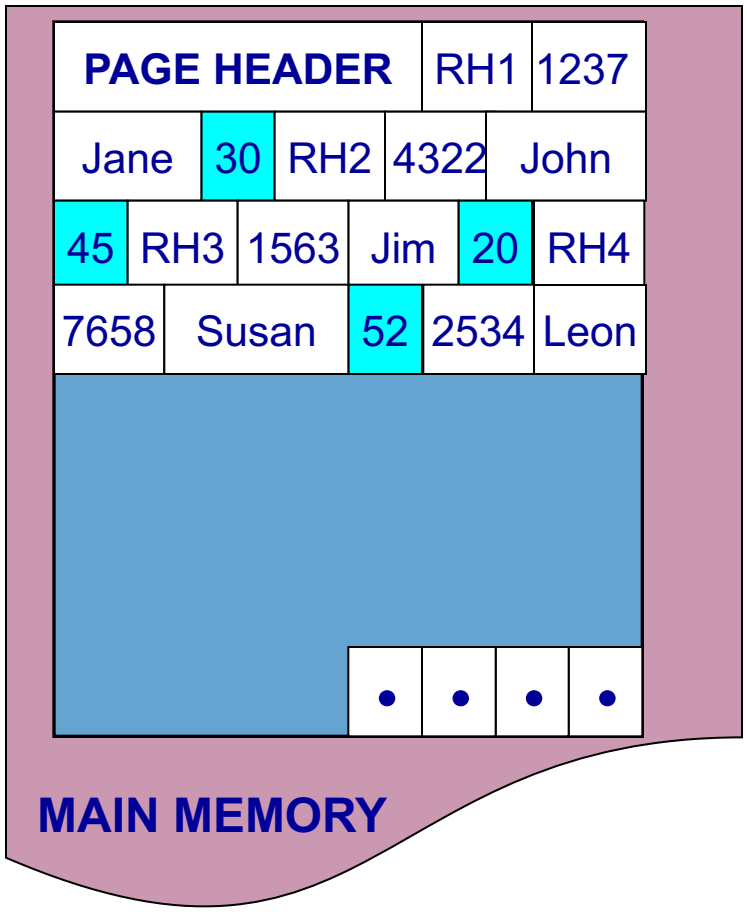
RID	SSN	Name	Age
1	1237	Jane	30
2	4322	John	45
3	1563	Jim	20
4	7658	Susan	52
5	2534	Leon	43
6	8791	Dan	37

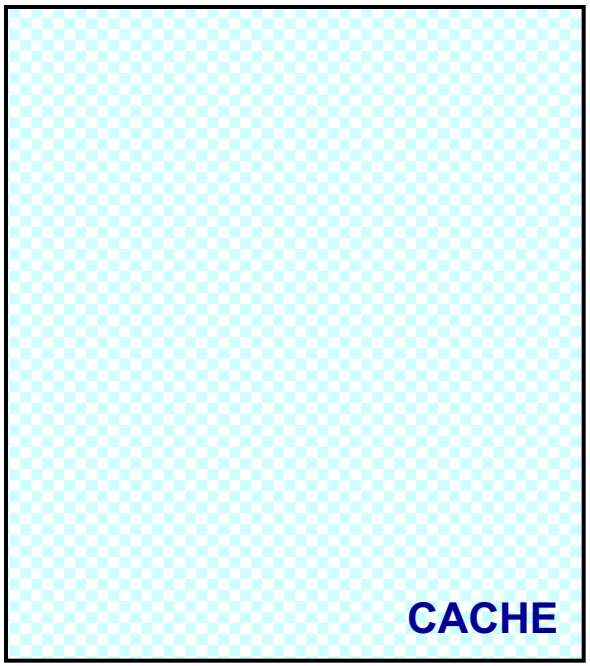


- Records are stored sequentially
- Offsets to start of each record at end of page

Ailamaki VLDB'01 http://research.cs.wisc.edu/multifacet/papers/vldb01_pax_talk.ppt

Predicate Evaluation using NSM



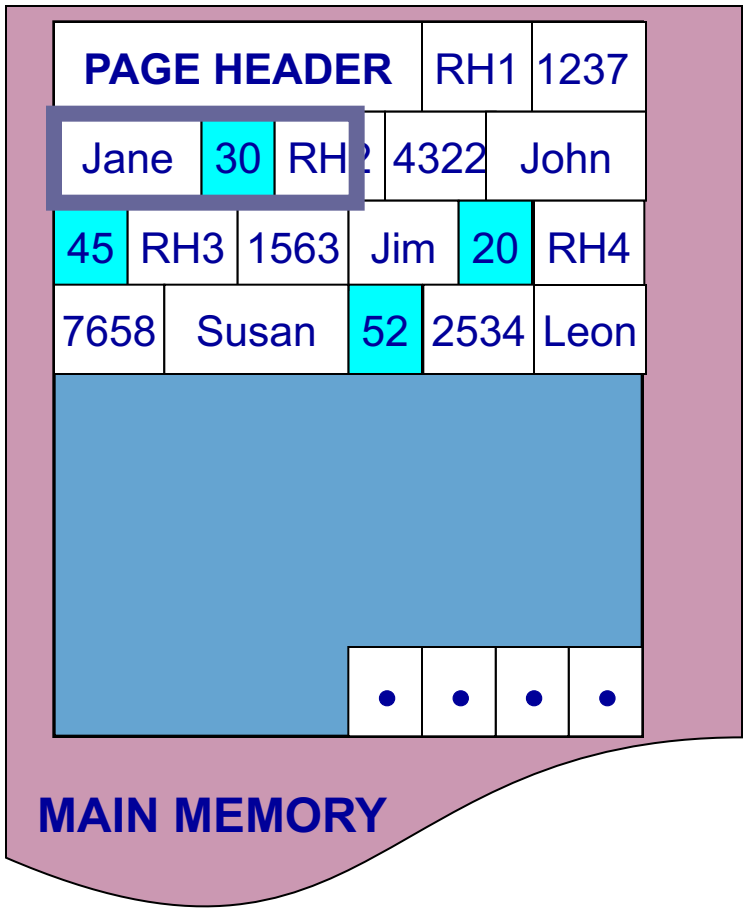


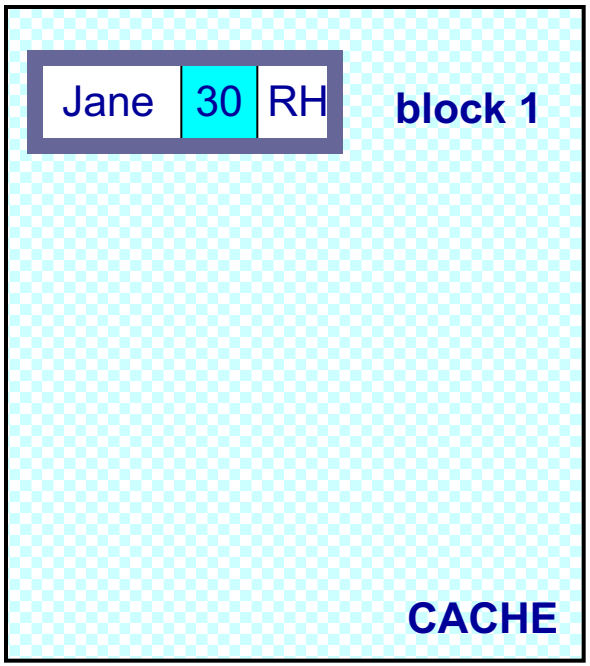

```
select name
from  R
where age > 50
```

NSM pushes non-referenced data to the cache

Ailamaki VLDB'01 http://research.cs.wisc.edu/multifacet/papers/vldb01_pax_talk.ppt

Predicate Evaluation using NSM



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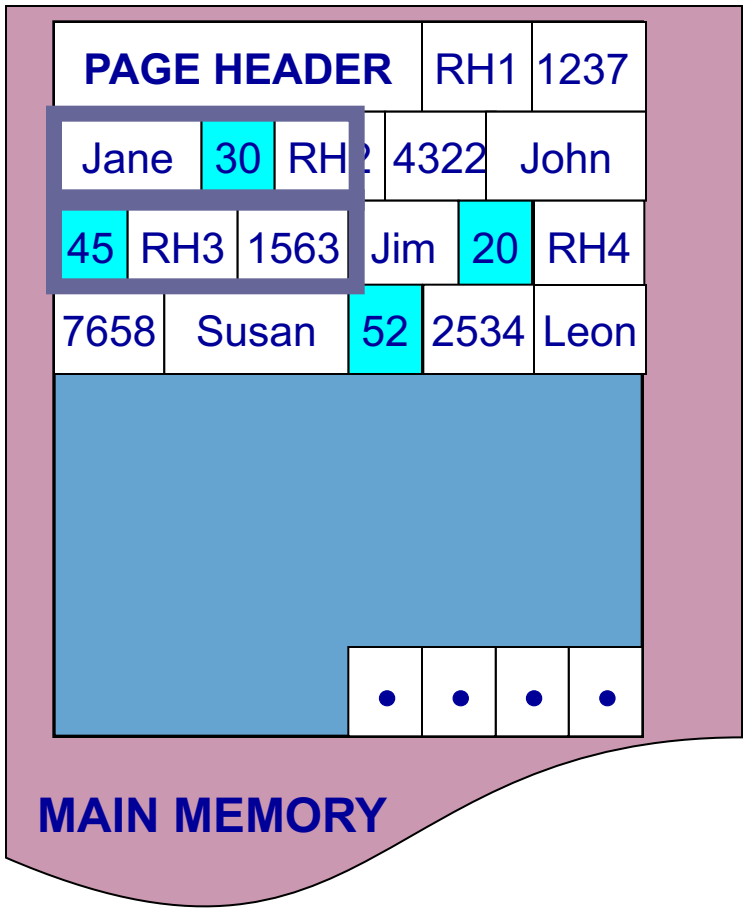

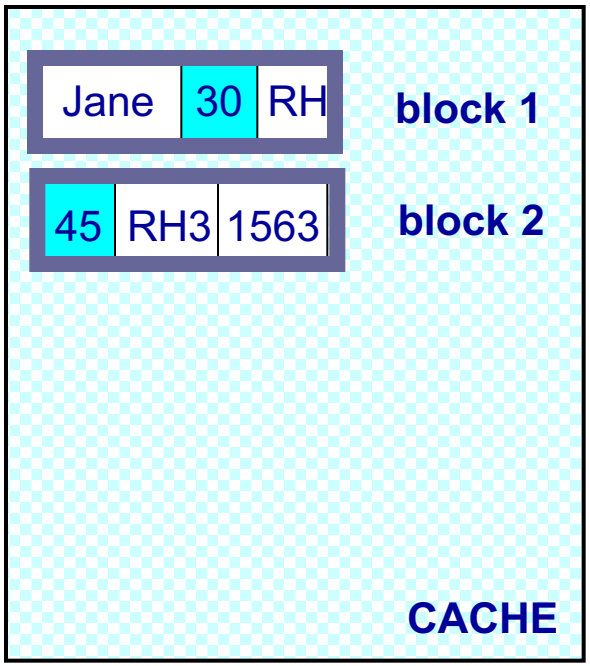


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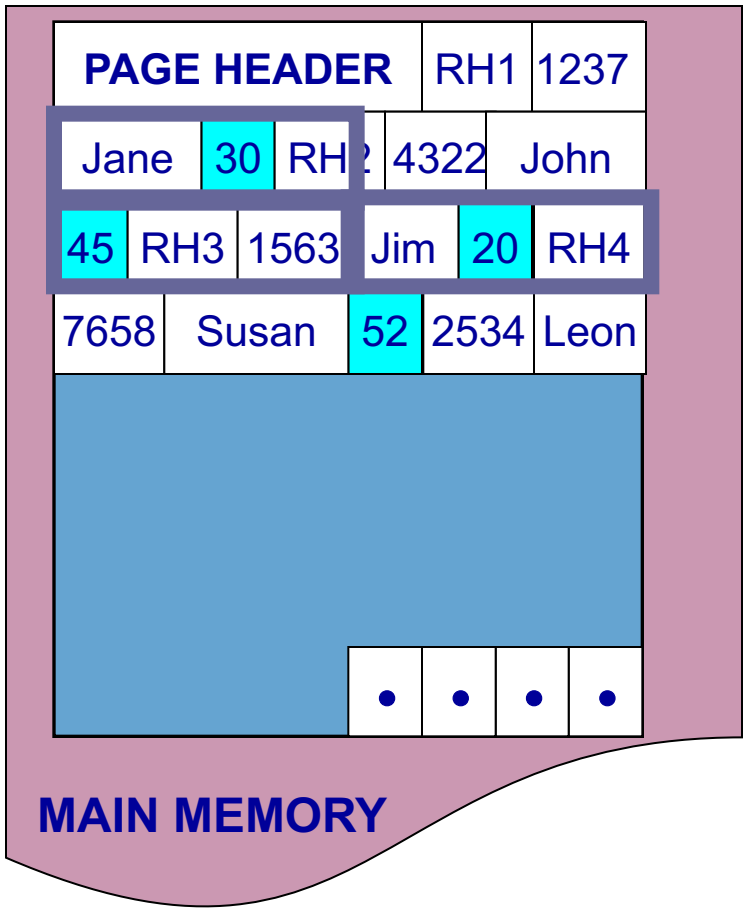

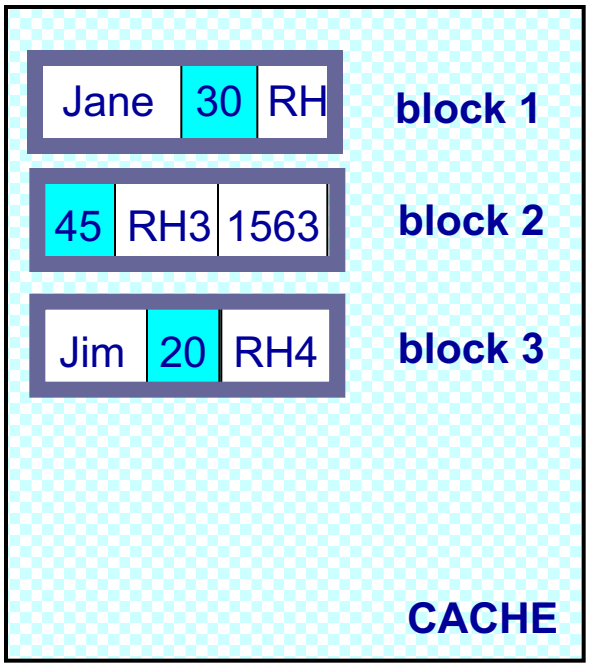


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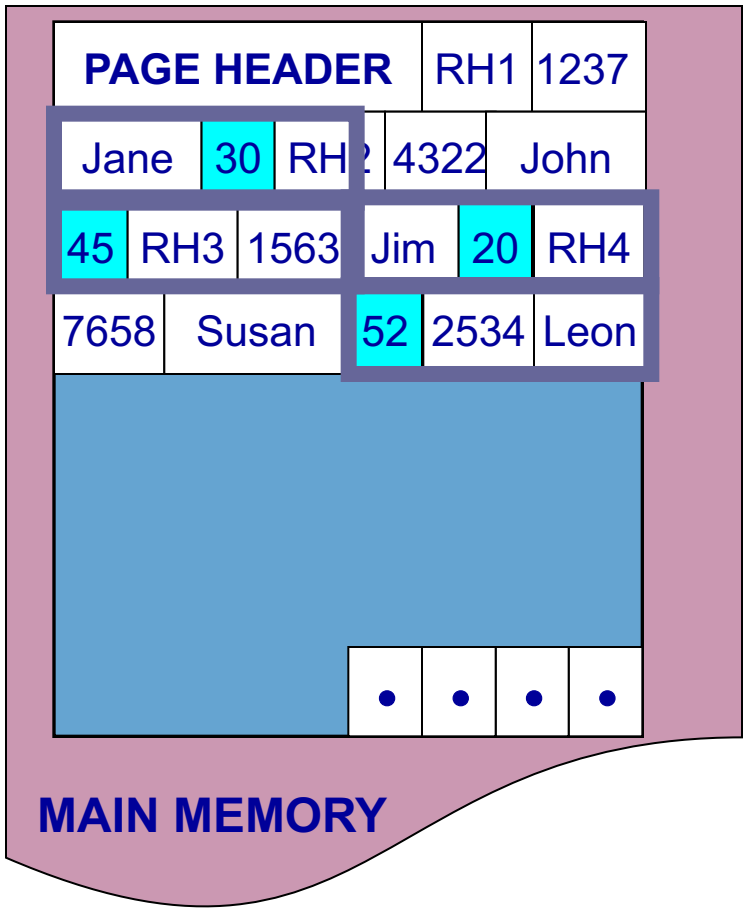

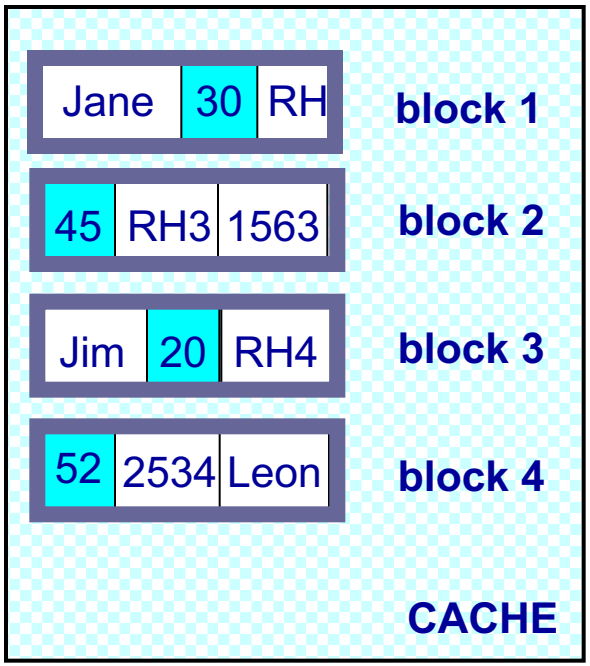


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Need New Data Page Layout

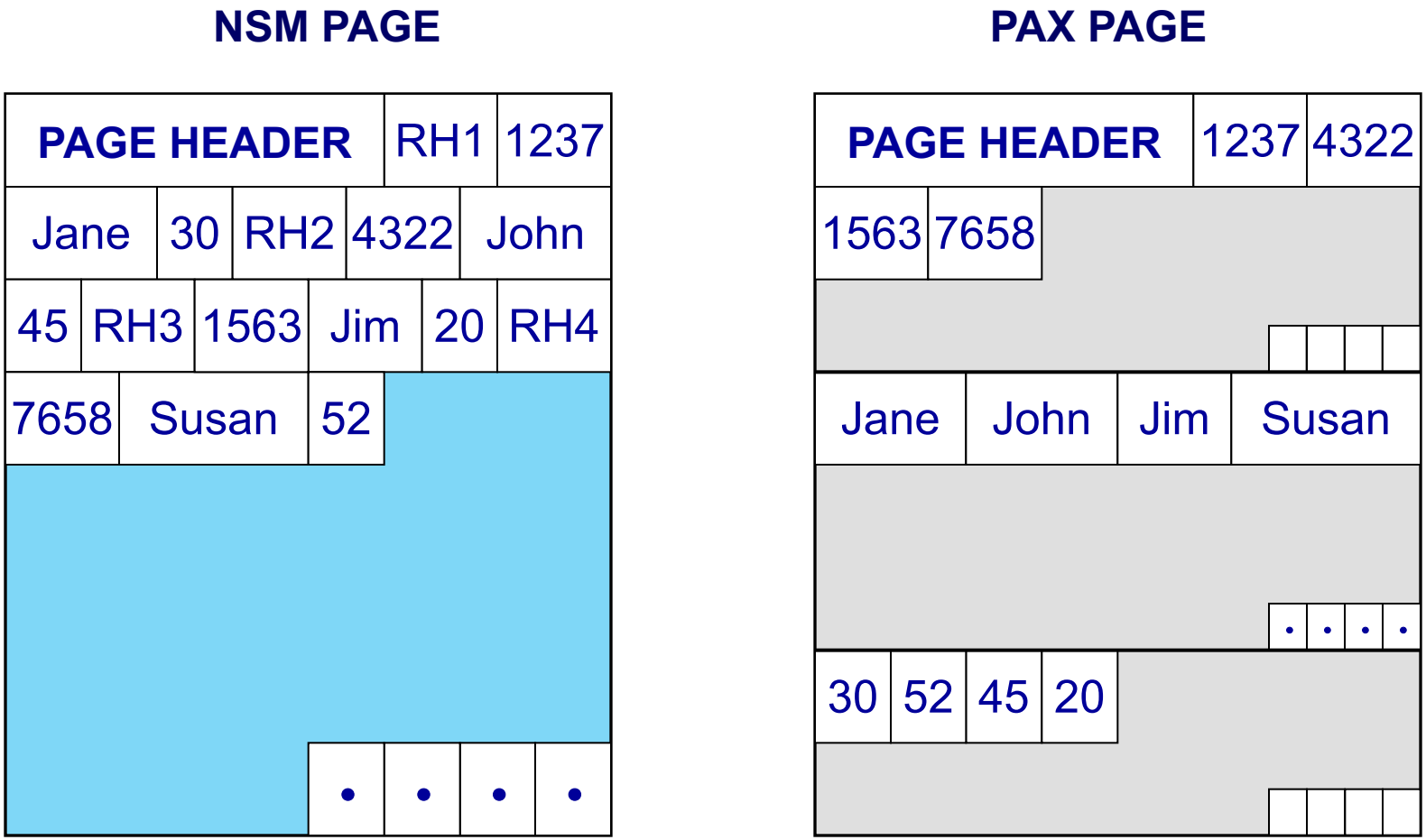
- Eliminates unnecessary memory accesses
- Improves inter-record locality
- Keeps a record's fields together
- Does not affect I/O performance

and, most importantly, is…

low-implementation-cost, high-impact

Ailamaki VLDB'01 http://research.cs.wisc.edu/multifacet/papers/vldb01_pax_talk.ppt

Partition Attributes Across (PAX)



Partition data *within* the page for spatial locality

Ailamaki VLDB'01 http://research.cs.wisc.edu/multifacet/papers/vldb01_pax_talk.ppt

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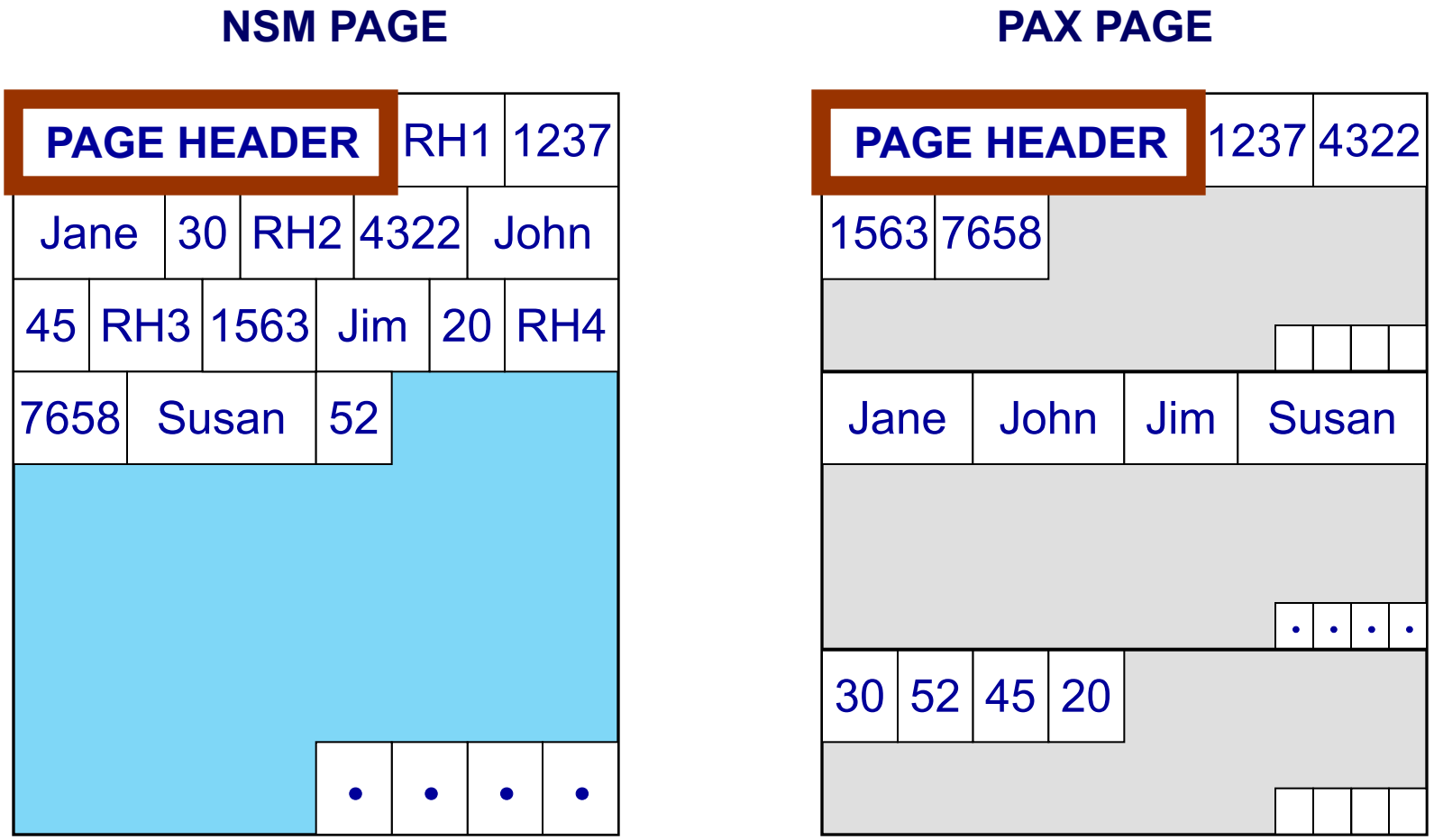

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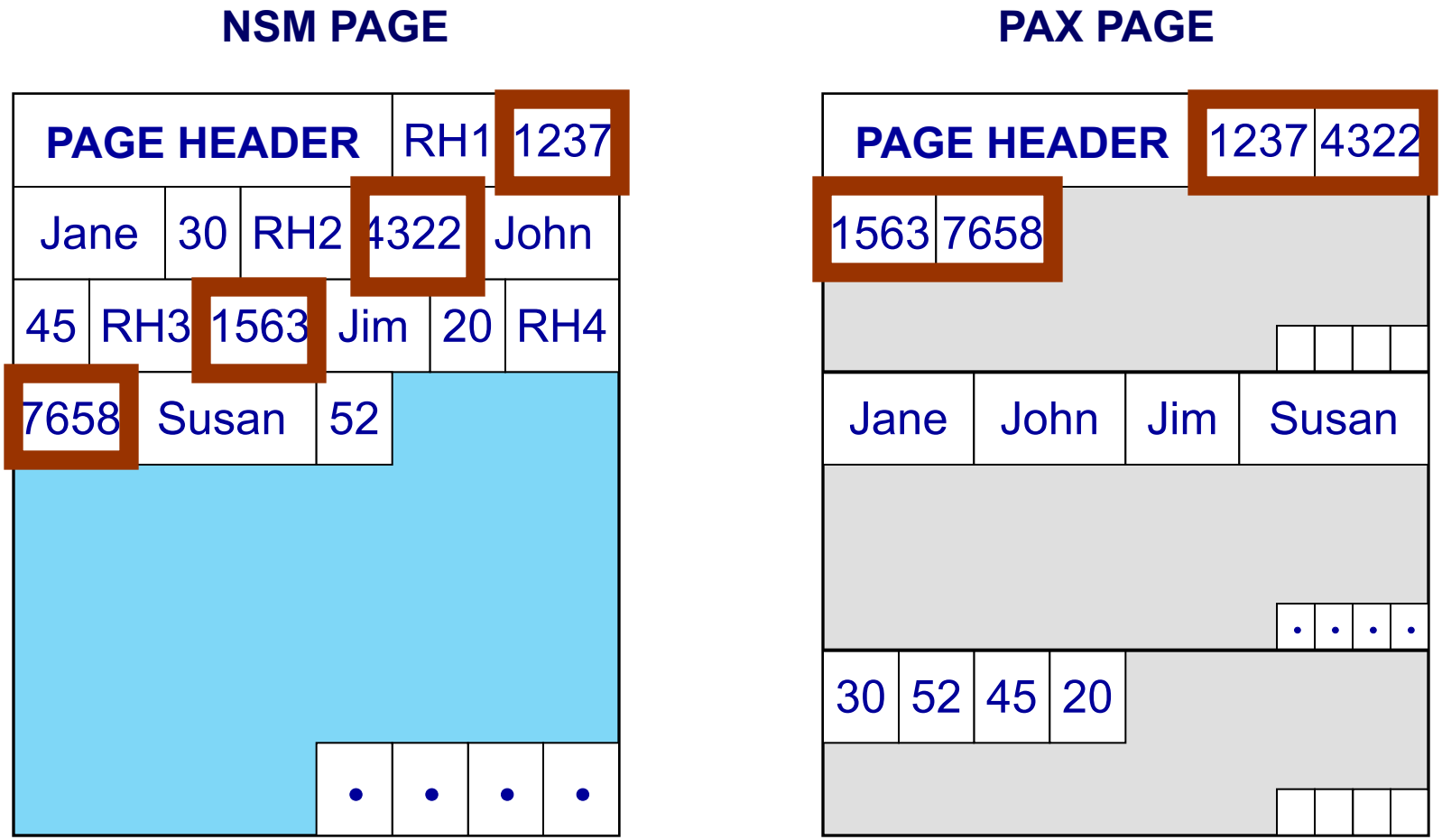

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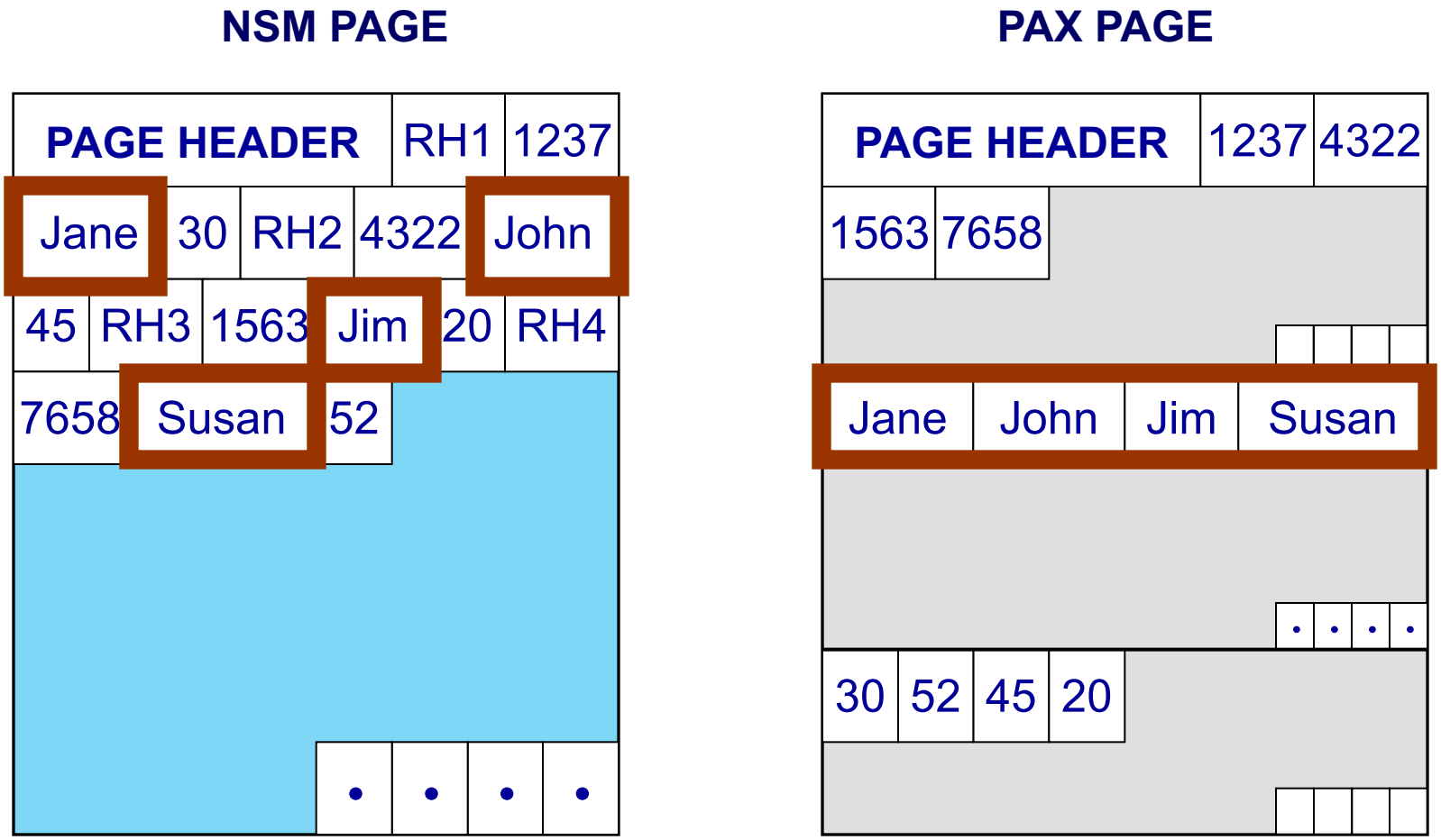

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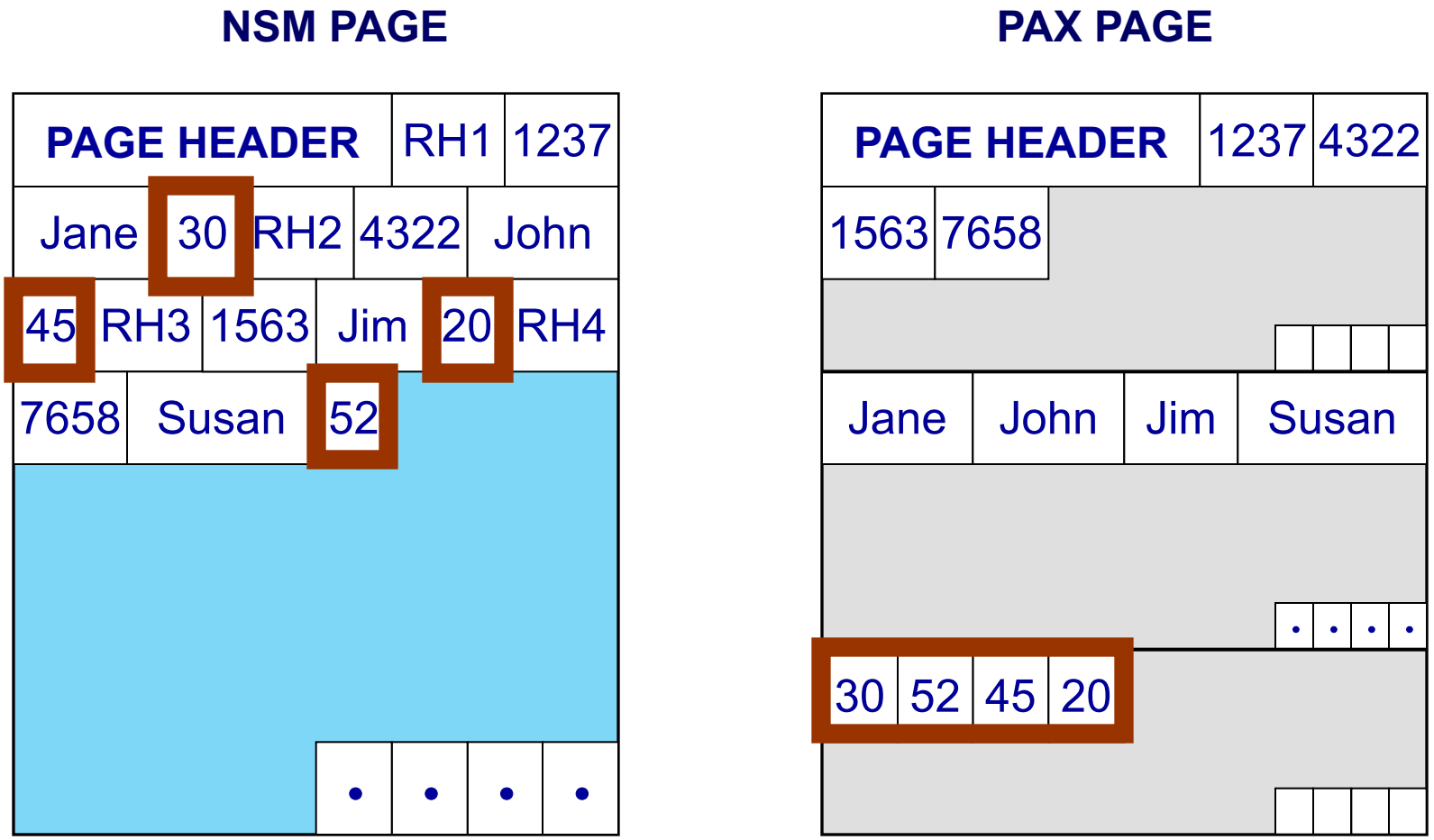

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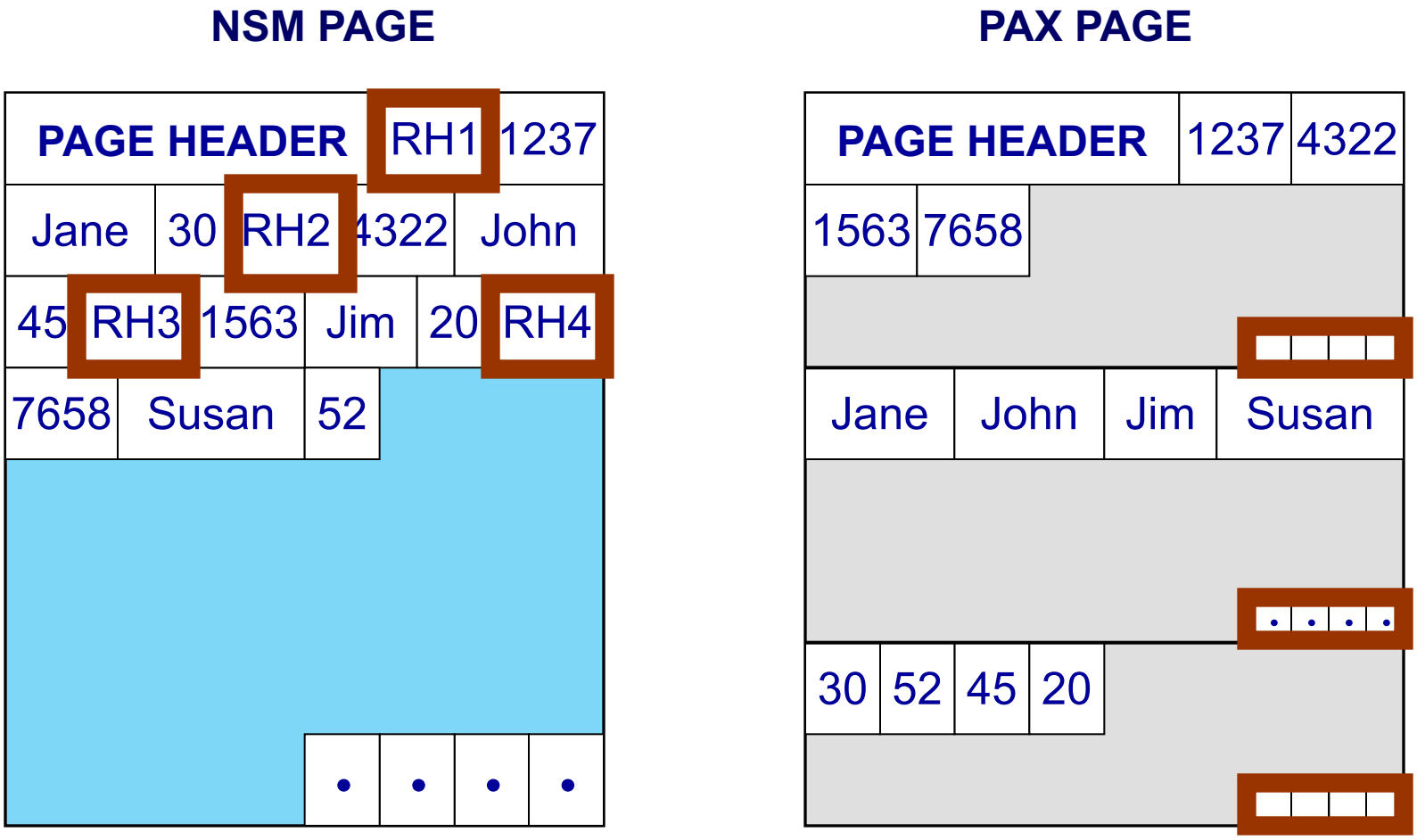

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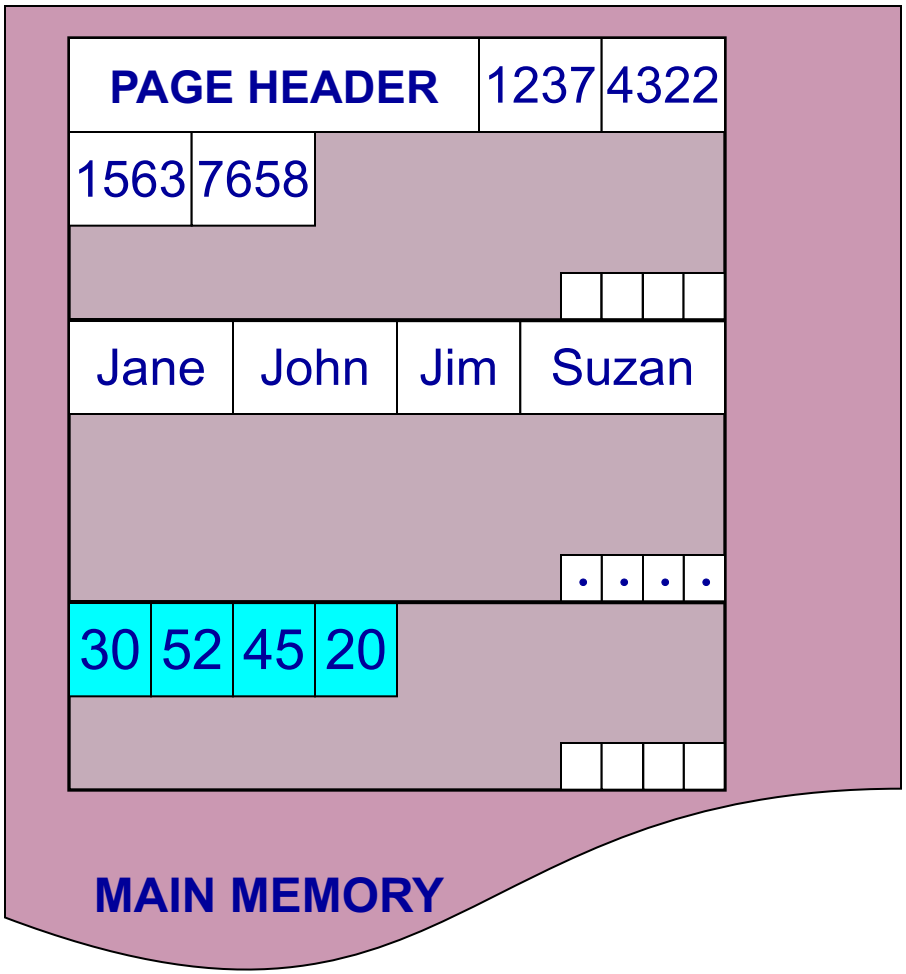

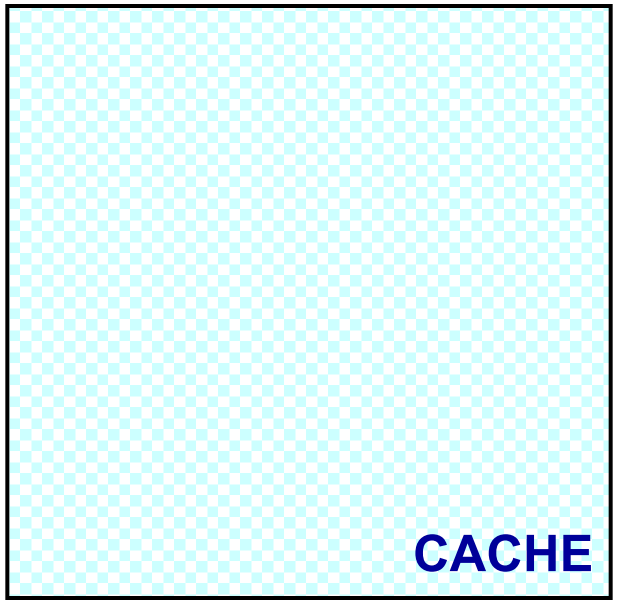


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Fewer cache misses, low reconstruction cost

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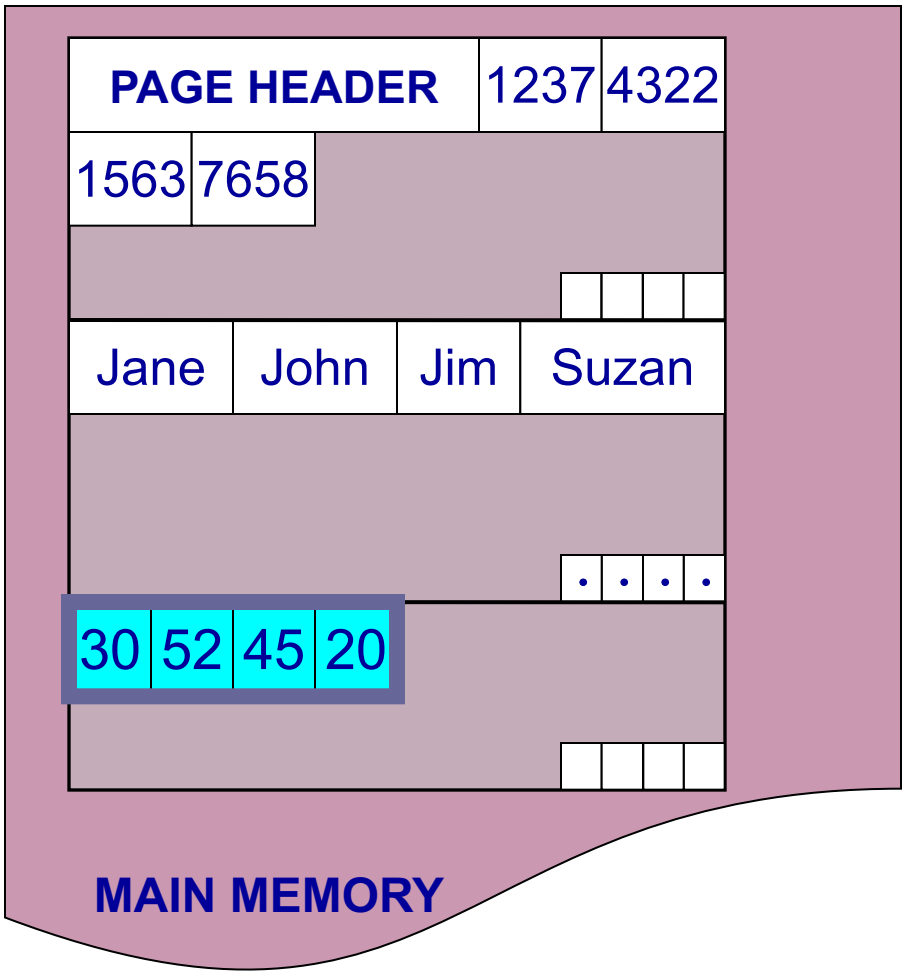

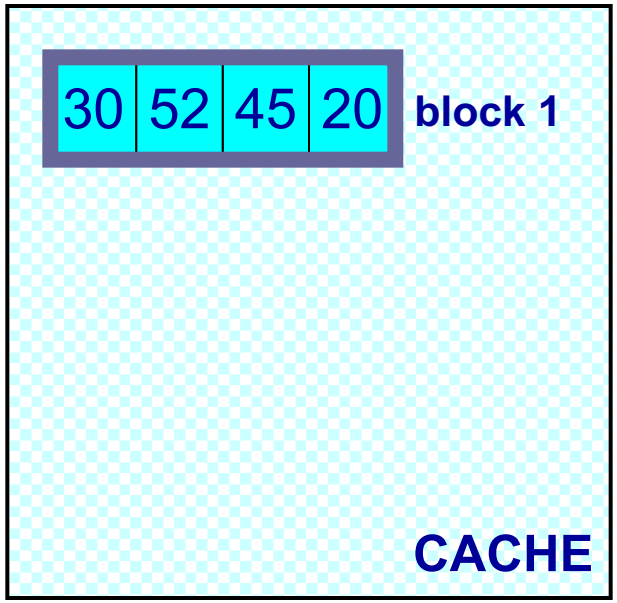


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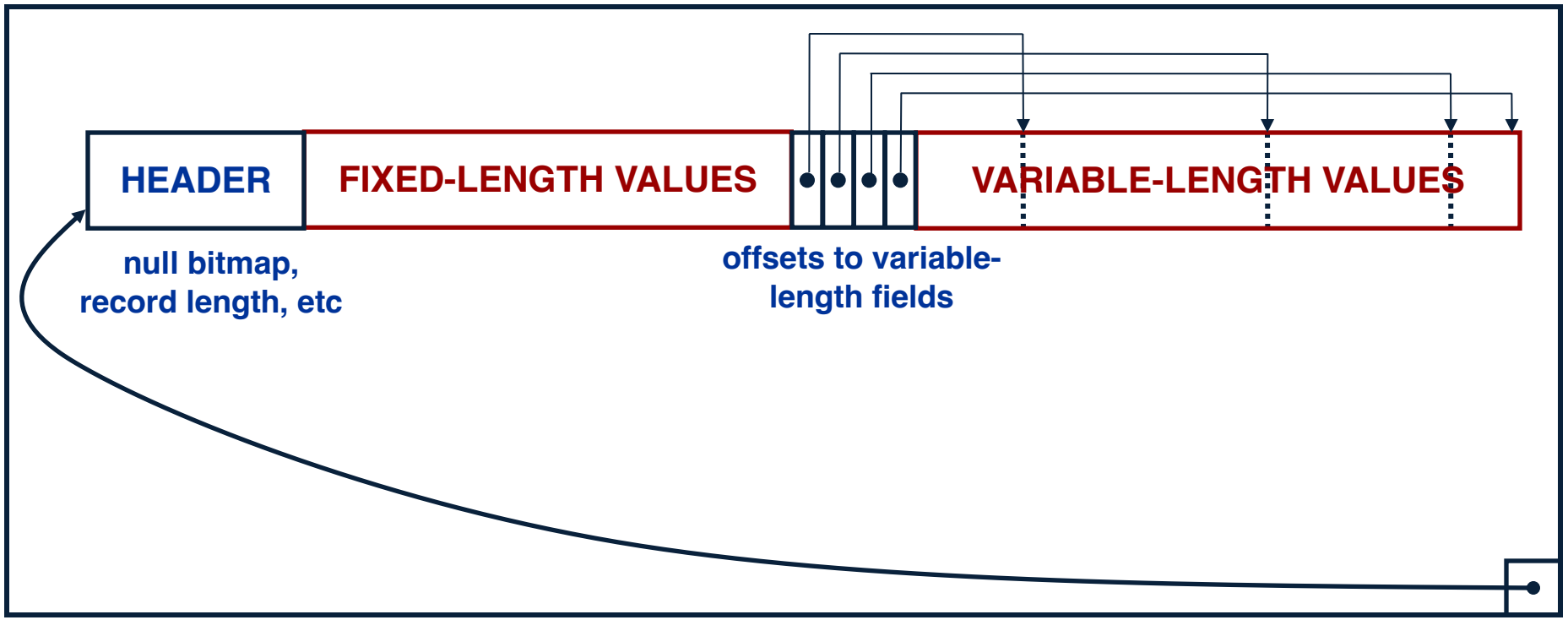
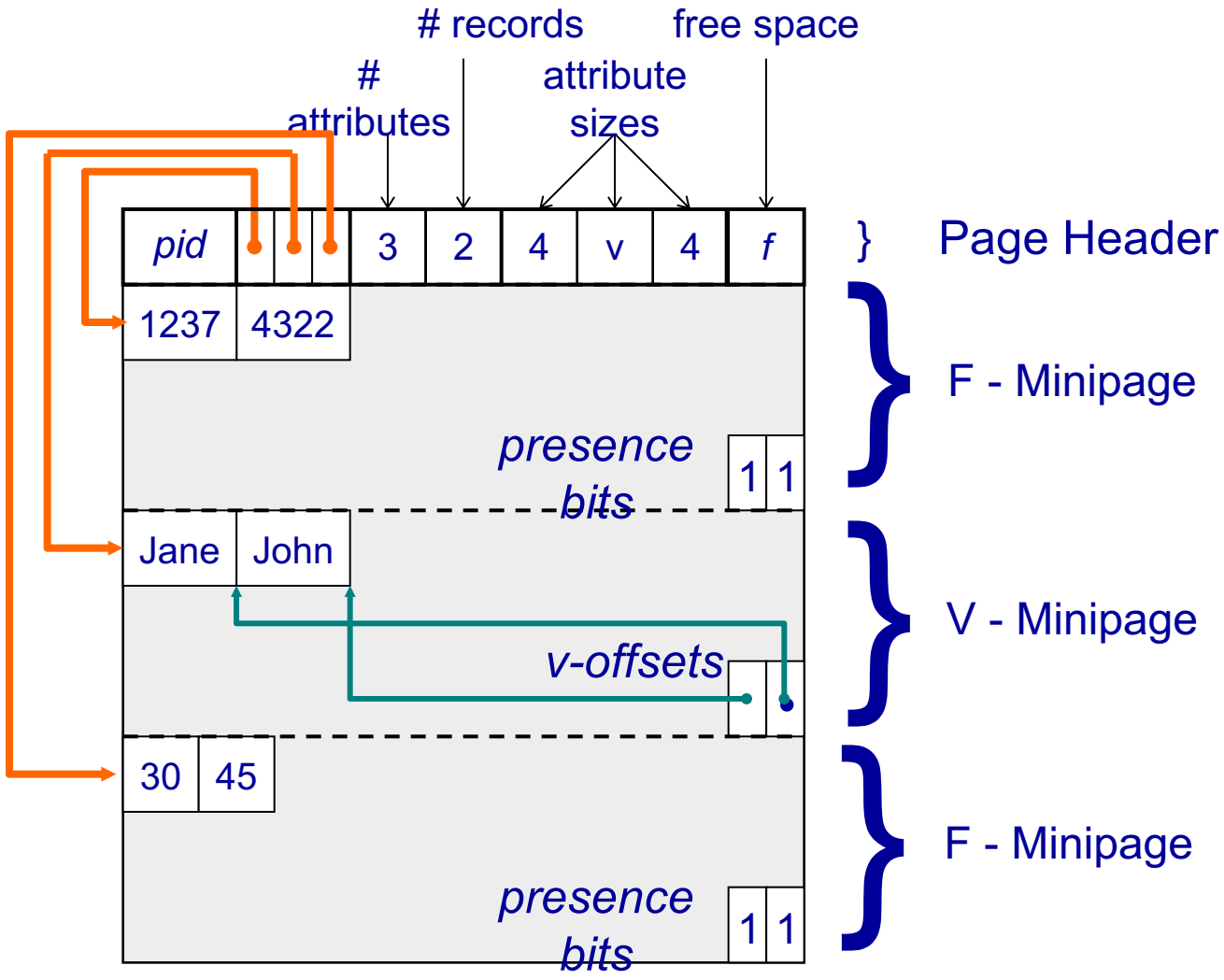
A Real NSM Record



NSM: All fields of record stored together + slots

Ailamaki VLDB'01 http://research.cs.wisc.edu/multifacet/papers/vldb01_pax_talk.ppt

PAX: Detailed Design



PAX: Group fields + amortizes record headers

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From Row to Column Storage (Modern Designs)

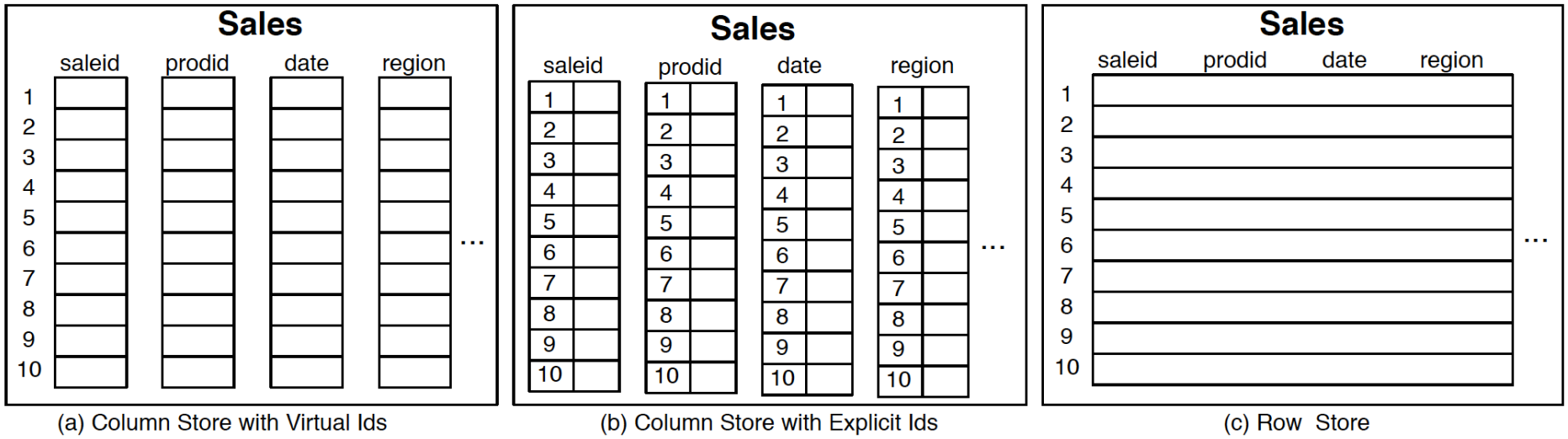

Figure 1.1: Physical layout of column-oriented vs row-oriented databases.

Basic tradeoffs:

- Reading all attributes of one records, v.s.
- Reading some attributes of many records

PAX - Conclusion

- Improves processor cache locality
- Does not affect I/O behavior
  - Same disk accesses for NSM or PAX storage
  - No need to change the buffer manager

- Column stores:
  - Store each attribute in a different file

Congratulations and thank you for a great quarter!