CS150A Database

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Today:

- Disk Representations:
  - Files, Pages and Records

Readings:

- Database Management Systems (DBMS), Chapter 8
- Lecture note Disk Files

Acknowledgement: Joe Hellerstein@UCBerkeley’s scourse notes

STORING DATA: FILES

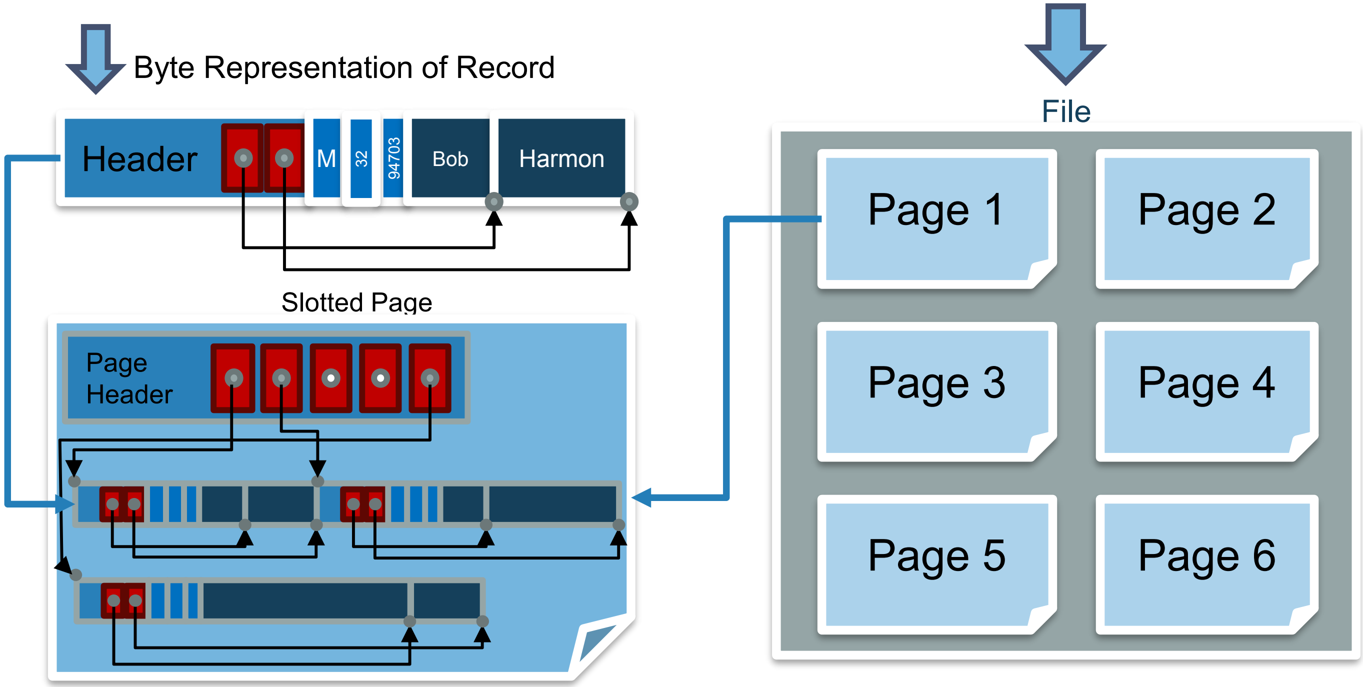
FILE REPRESENTATIONS

Overview: Representations

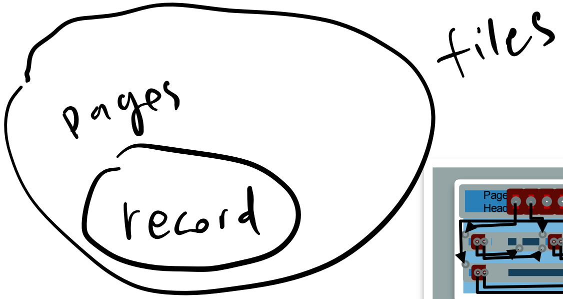
Record

Bob	Harmon	M	32	400
Varchar	Varchar	Char	Int	Int

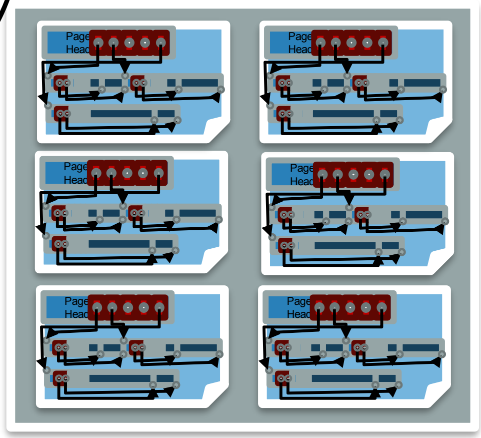
SSN	Last Name	First Name	Age	Salary
123	Adams	Elmo	31	$400
443	Grouch	Oscar	32	$300
244	Oz	Bert	55	$140
134	Sanders	Ernie	55	$400



Overview: Files of Pages of Records



- Tables stored as logical files
  - Consist of pages
    - Pages contain a collection of records
- Pages are managed
  - On disk by the disk space manager: pages read/written to physical disk/files
  - In memory by the buffer manager: higher levels of DBMS only operate in memory



DATABASE FILES

Files of Pages of Records

- **DB FILE:** A collection of pages, each containing a collection of records.
- API for higher layers of the DBMS:
  - Insert/delete/modify record
  - Fetch a particular record by ***record id*** …
    - Record id is a pointer encoding pair of (**pageID, location** on page)
  - Scan all records
    - Possibly with some conditions on the records to be retrieved
- Could span multiple OS files and even machines
  - Or "raw" disk devices

Many DB File Structures

- Unordered Heap Files
  - Records placed arbitrarily across pages
- Clustered Heap Files
  - Records and pages are grouped
- Sorted Files
  - Pages and records are in sorted order
- Index Files
  - B+ Trees, Linear Hashing, …
  - May contain records or point to records in other files

Unordered Heap Files

- Collection of records in no particular order
  - Not to be confused with "heap" data-structure

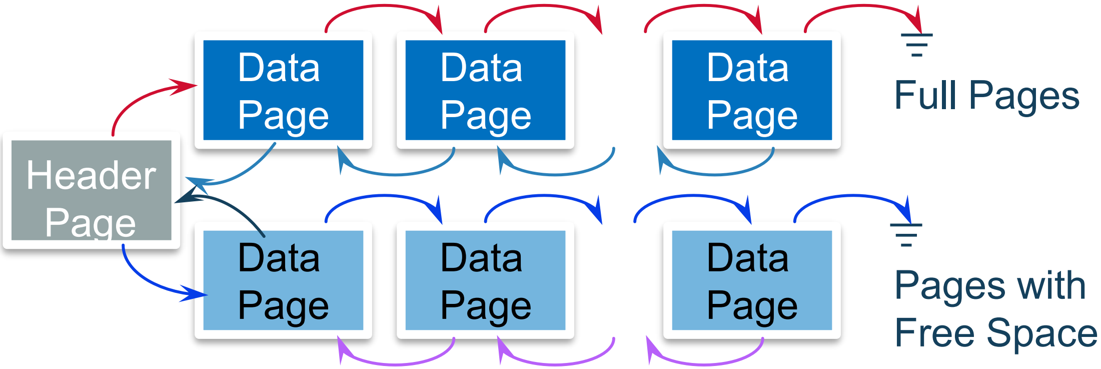
Not heap

- As file shrinks/grows, pages (de)allocated

- To support record level operations, we must
  - Keep track of the pages in a file
  - Keep track of free space on pages
  - Keep track of the records on a page

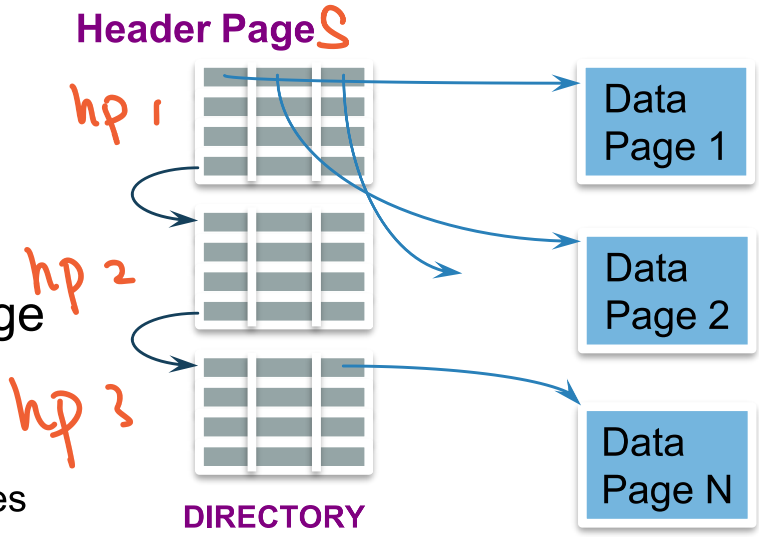
Heap File Implemented as List

- Header page ID and Heap file name stored elsewhere
  - Database catalog
- Each page contains 2 “pointers” plus **free space** and **data**
- What is wrong with this?
  - How do I find a page with enough space for a 20 byte records



Better: Use a Page Directory

- Directory entries include:
  - #free bytes on the referenced page and pointer
- Header pages accessed often → likely in cache
- Finding a page to fit a record required far fewer page loads than linked list
  - Why?
    - One header page load reveals free space of many pages
- You can imagine optimizing the page directory further
  - But diminishing returns?



Summary

- Table encoded as files which are collections of pages

SSNz	Last Name	First Name	Age	Salary
123	Adams	Elmo	31	$400
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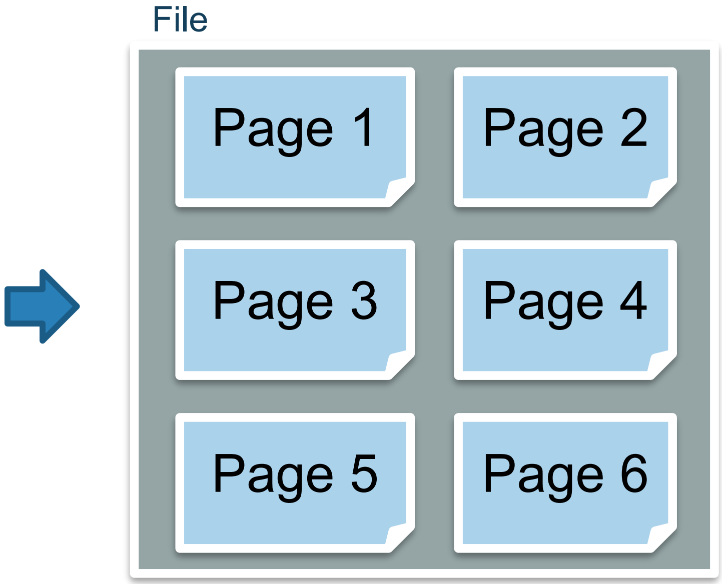


File

Page 1

Page 2

Page 3

Page 4

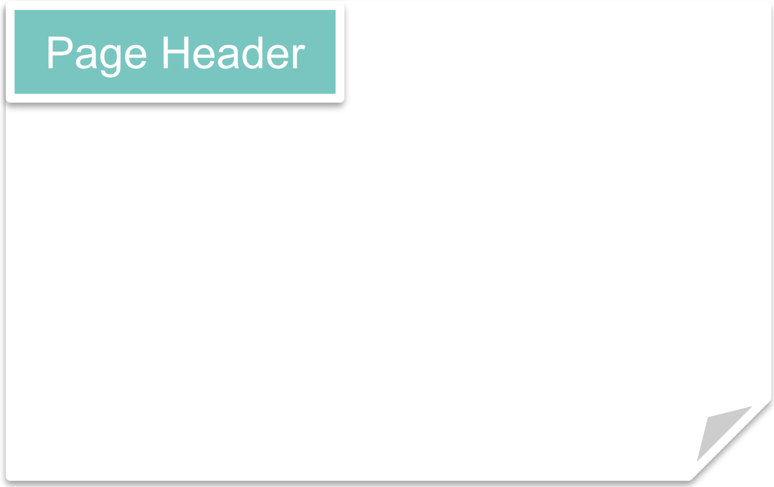
Page 5

Page 6

PAGE LAYOUT

Page Basics: The Header

- Header may contain:
  - Number of records
  - Free space (how much)
  - Maybe a next/last pointer
  - Bitmaps, Slot Table

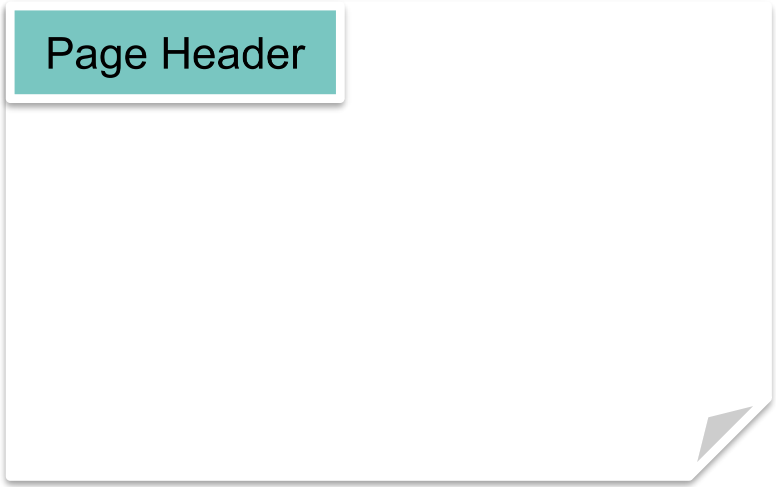


Page Header

Things to Address

"fixed length"

- Record length? Fixed or Variable
- Find records by record id?
  - Record id = (Page id, Location in Page)
- How do we add and delete records?

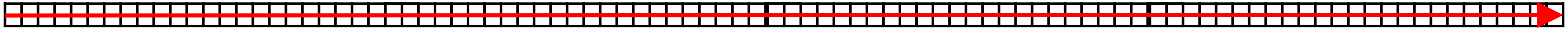


Options for Page Layouts

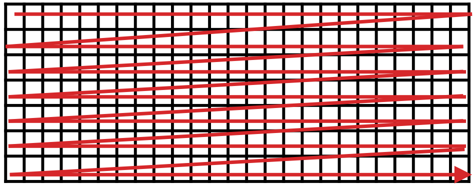
- Depends on
  - Record length (fixed or variable)
  - Page packing (packed or unpacked)

A Note On Imagery

- Data is stored in linear order
  - 1 byte per position
  - Memory addresses are ordered
  - Disk addresses are ordered

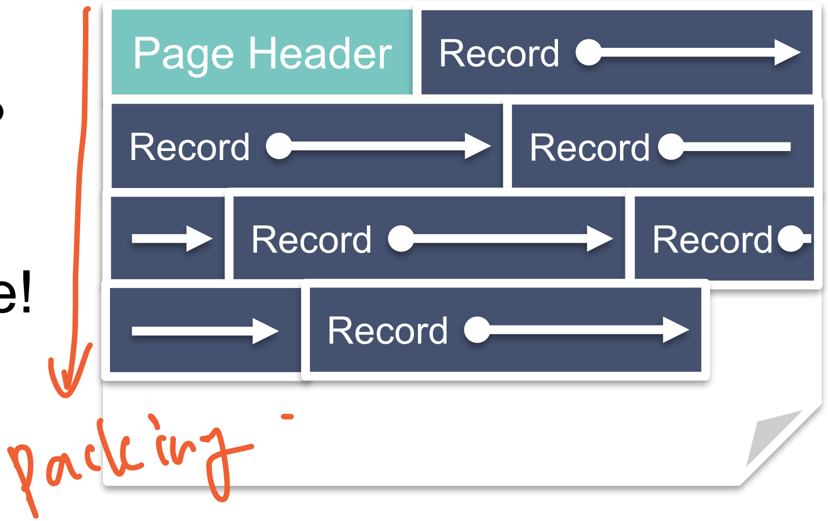


- This doesn’t fit nicely on screen
  - So we will “wrap around” the linear order into a rectangle



Fixed Length Records, Packed

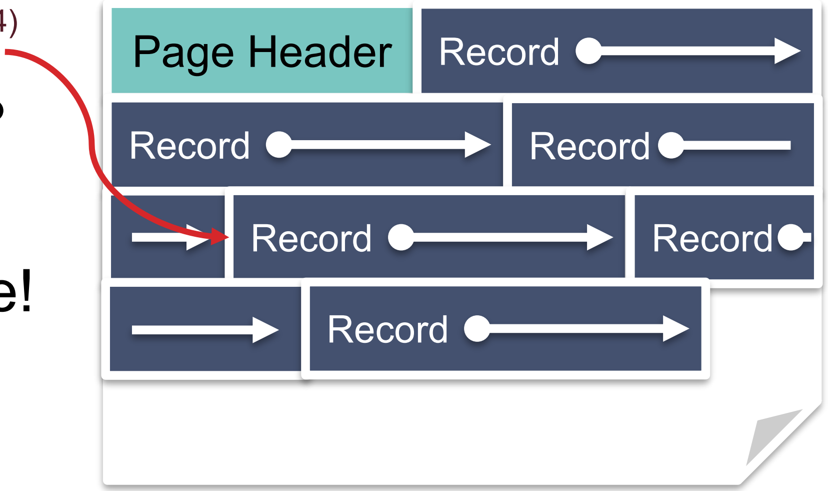
- Pack records densely
- Record id = (pageId, "location in page")?
    - (pageId, record number in page)!
    - We know the offset from start of page!
- Easy to add: just append
- Delete?



Fixed Length Records, Packed, Pt 2.

- Pack records densely
- Record id = (pageId, “location in page”)?
  - (pageId, record number in page)!
  - We know the offset from start of page!
- Easy to add: just append
- Delete?

Record id:
(Page 2, Record 4)



Fixed Length Records: Packed, Pt 3.

- Pack records densely
- Record id = (pageId, “location in page”)?
  - (pageId, record number in page)!
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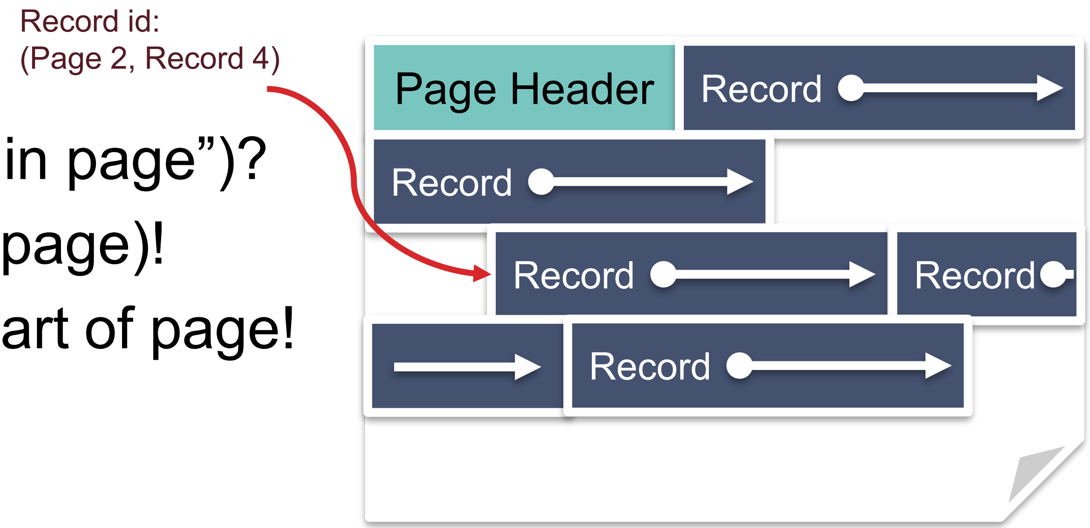
- Delete?

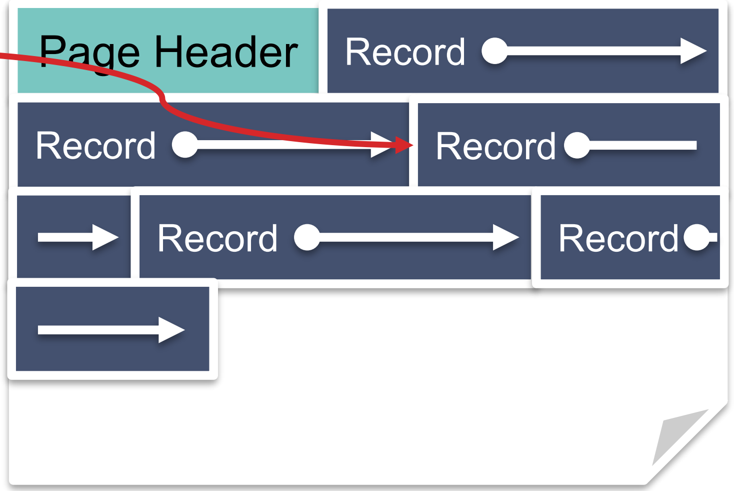


Fixed Length Records: Packed, Pt. 5

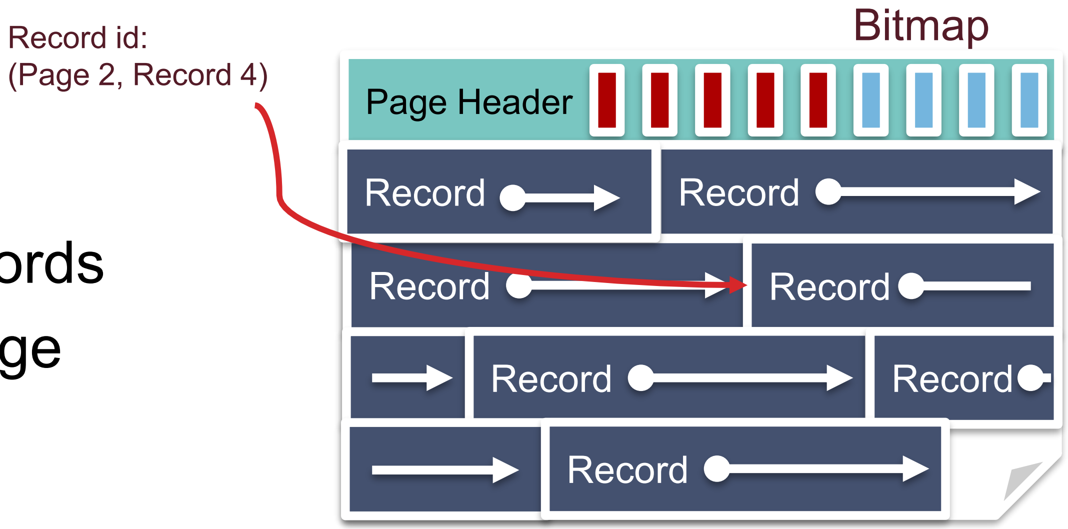
- Pack records densely
- Record id = (pageId, "location in page")?
  - (pageId, record number in page)!
  - We know the offset from start of page!
- Easy to add: just append
- Delete?
  - Packed implies re-arrange!
  - Record Id pointers need to be updated!
    - Could be expensive if they're in other files.

Record id:
(Page 2, Record 3)

change.

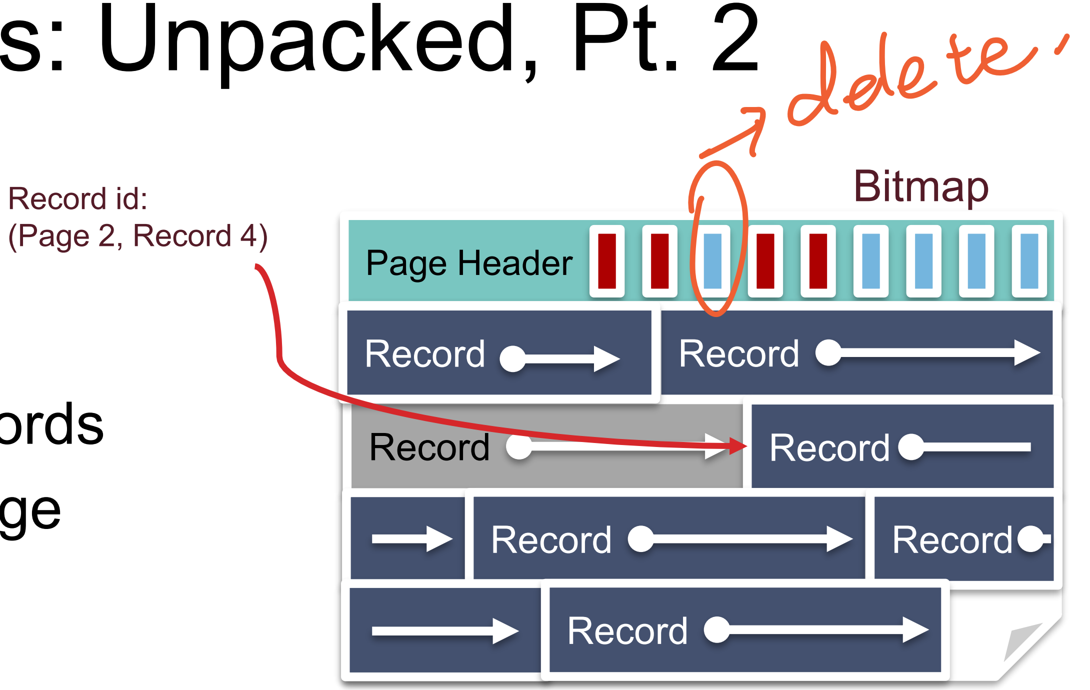


Fixed Length Records: Unpacked



- Bitmap denotes “slots” with records
- Record id: record number in page
- **Insert**: find first empty slot
- **Delete**: Clear bit

Fixed Length Records: Unpacked, Pt. 2



- Bitmap denotes “slots” with records
- Record id: record number in page
- **Insert**: find first empty slot
- **Delete**: Clear bit

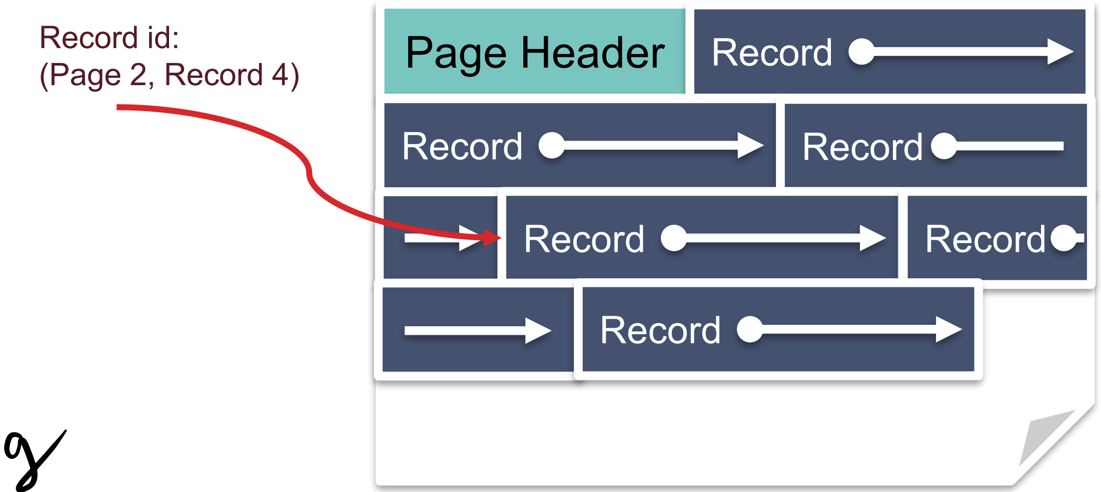
Variable Length Records

- How do we know where each record begins?
- What happens when we add and delete records?

delete small

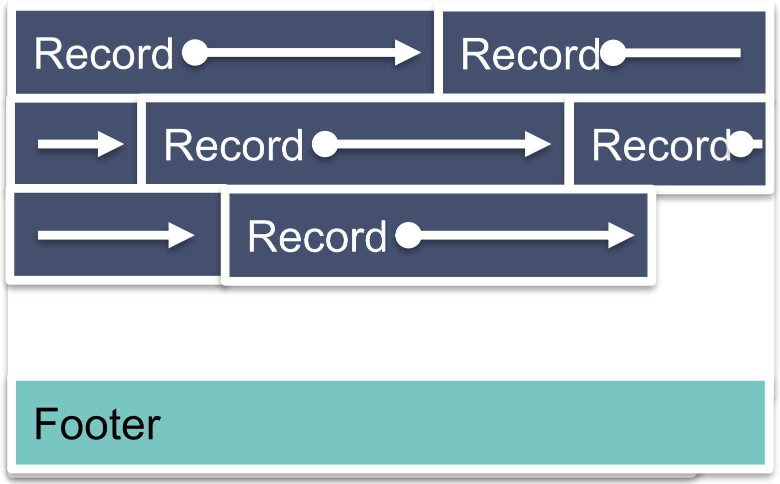
insert big

Record id:
(Page 2, Record 4)



First: Relocate metadata to footer

- We’ll see why this is handy shortly…



Slotted Page

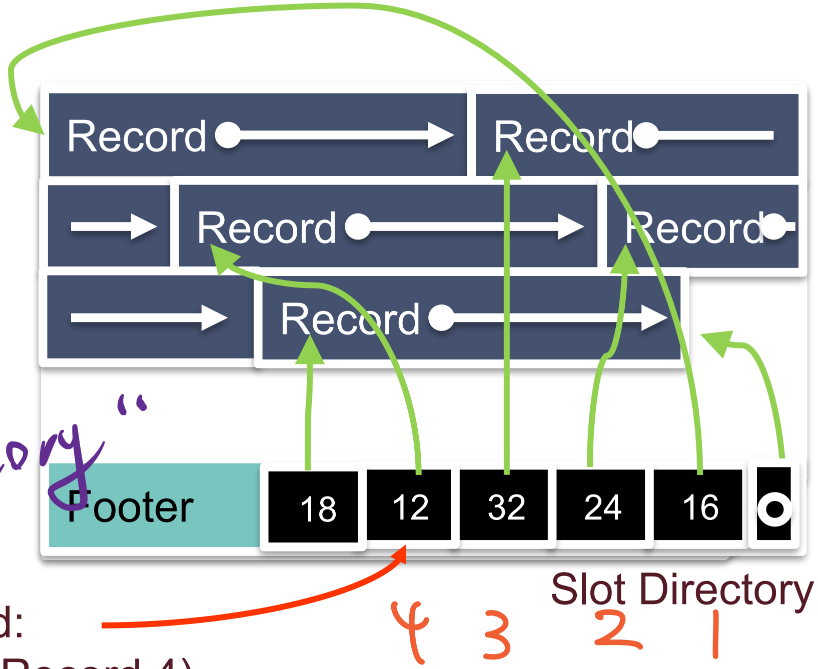
- Introduce slot directory in footer
  - Pointer to free space
  - Length + Pointer to beginning of record
    - reverse order

self length

" offset"

- Record ID = location in slot table
  - from right
- Delete?
  - e.g., 4th record on the page

" slot directory "



Record Id:
(Page 2, Record 4)

tail → head.

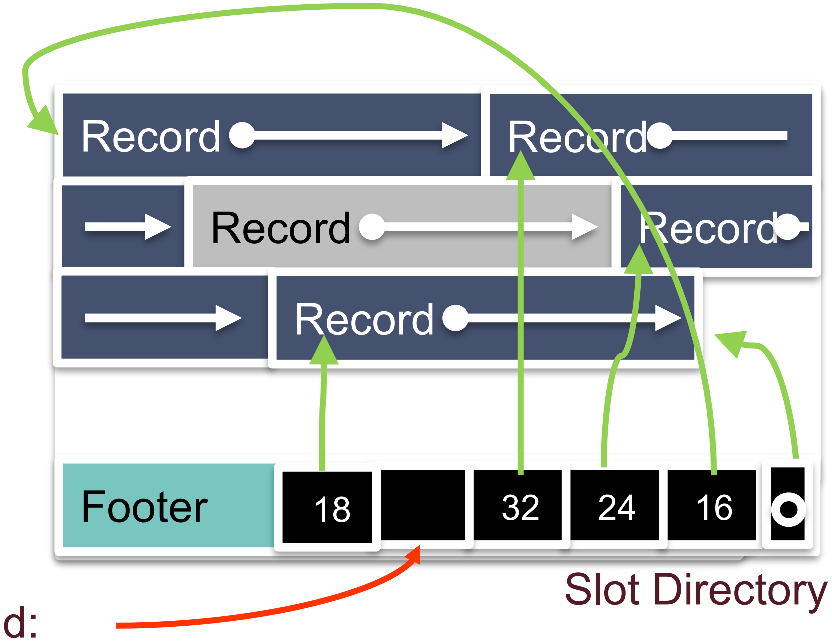
Slotted Page: Delete Record

- Delete record (Page 2, Record 4): Set 4th slot directory pointer to null
  - Doesn't affect pointers to other records

set record entry to NULL

other entry not changed

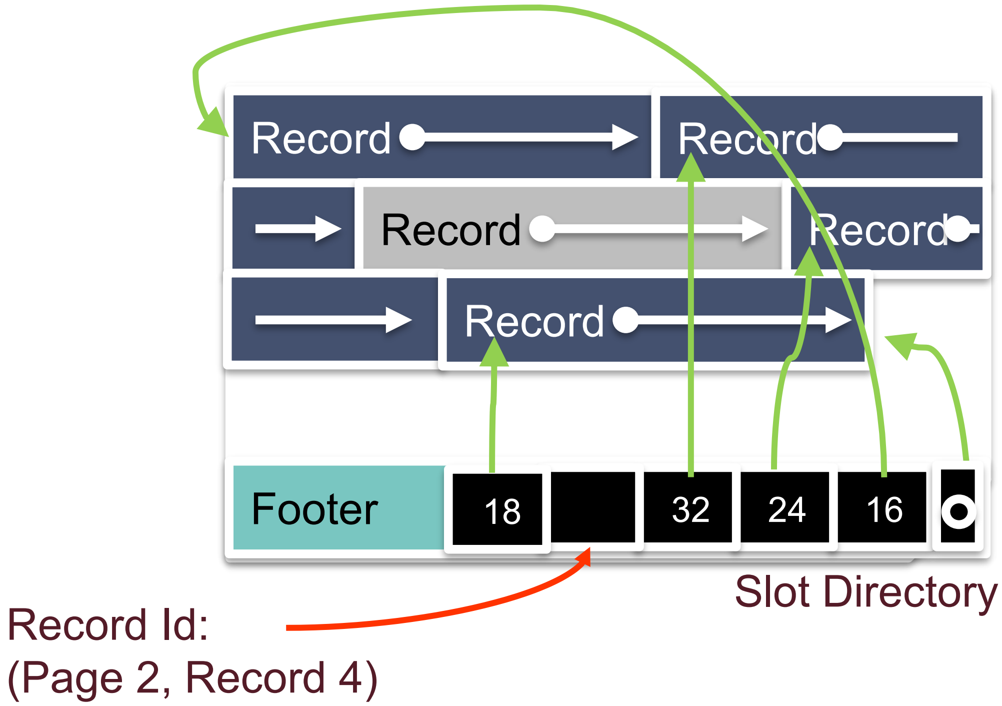
instead: unused in mid.



Record Id:
(Page 2, Record 4)

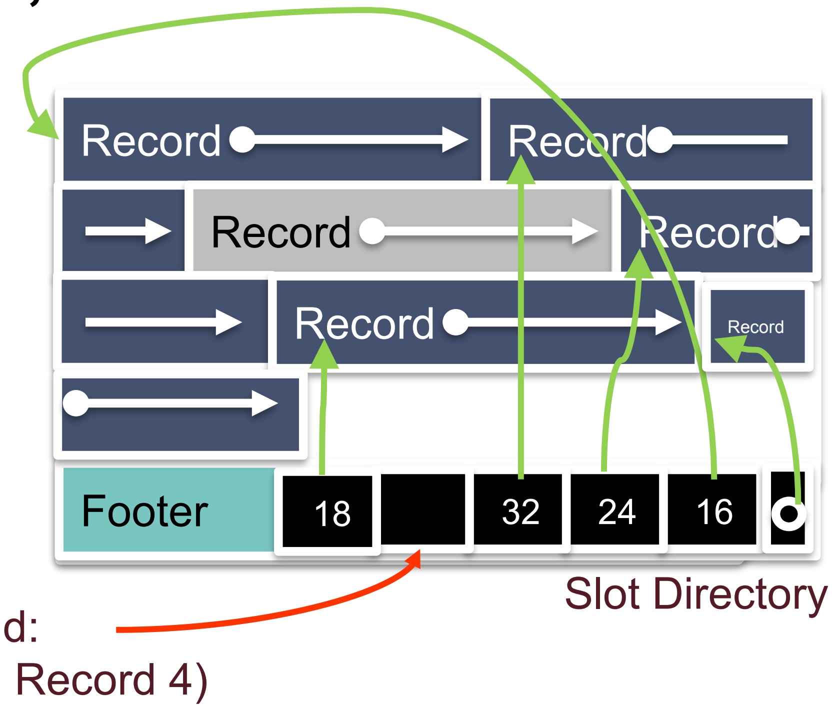
Slotted Page: Insert Record

- Insert:



Slotted Page: Insert Record, Pt 2.

- Insert:
  - Place record in free space on page

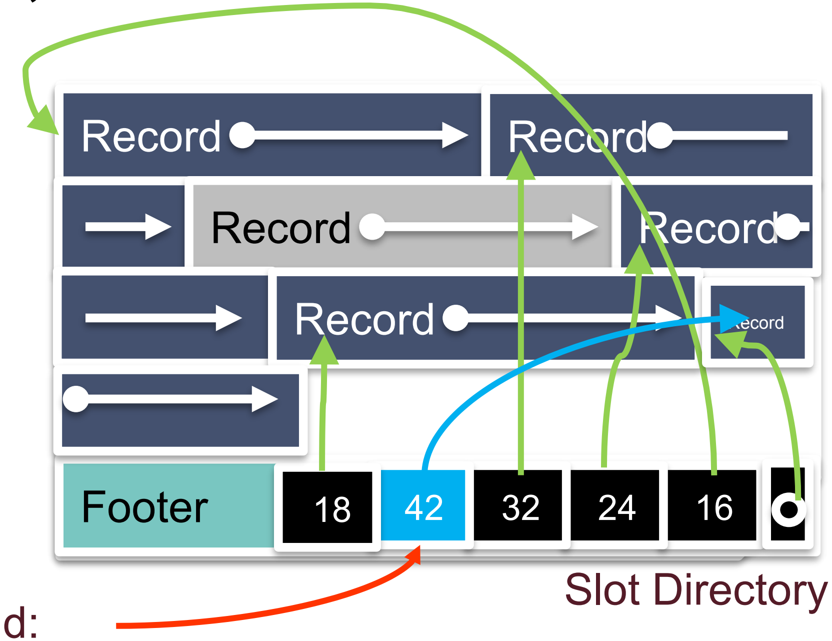


Slotted Page: Insert Record, Pt. 3

- Insert:
  - Place record in free space on page
  - Create pointer/length pair in next open slot in slot directory

Reuse the slot

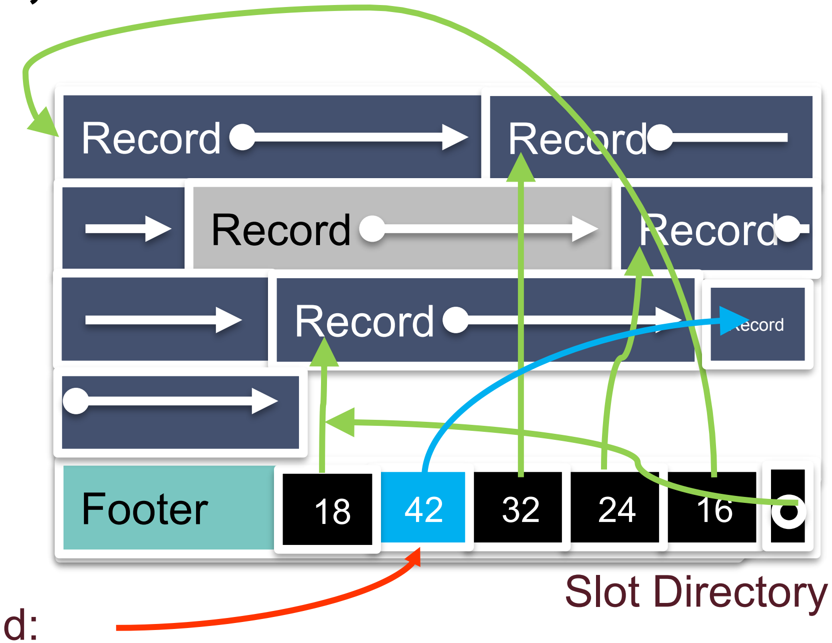
Not Reuse the space



Record Id:
(Page 2, Record 4)

Slotted Page: Insert Record, Pt. 4

- Insert:
  - Place record in free space on page
  - Create pointer/length pair in next open slot in slot directory
  - Update the free space pointer



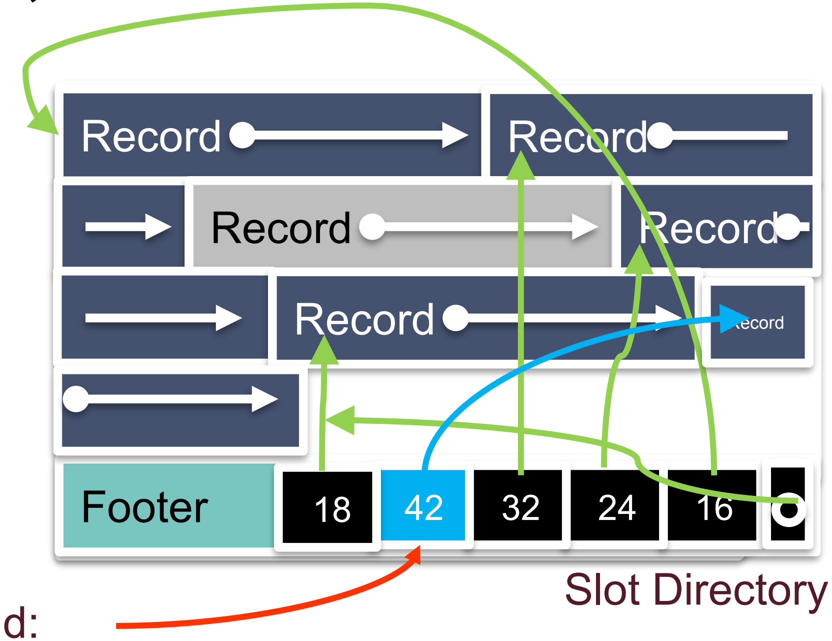
Record Id:
(Page 2, Record 4)

Slotted Page: Insert Record, Pt. 5

- Insert:
  - Place record in free space on page
  - Create pointer/length pair in next open slot in slot directory
  - Update the free space pointer
  - Fragmentation?

update

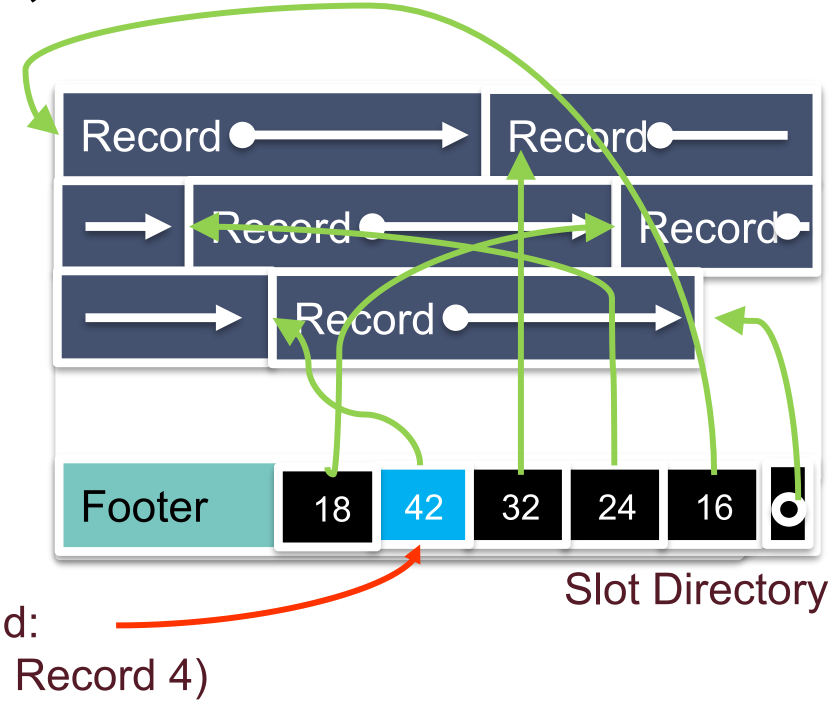
every time



Record Id:
(Page 2, Record 4)

Slotted Page: Insert Record, Pt. 6

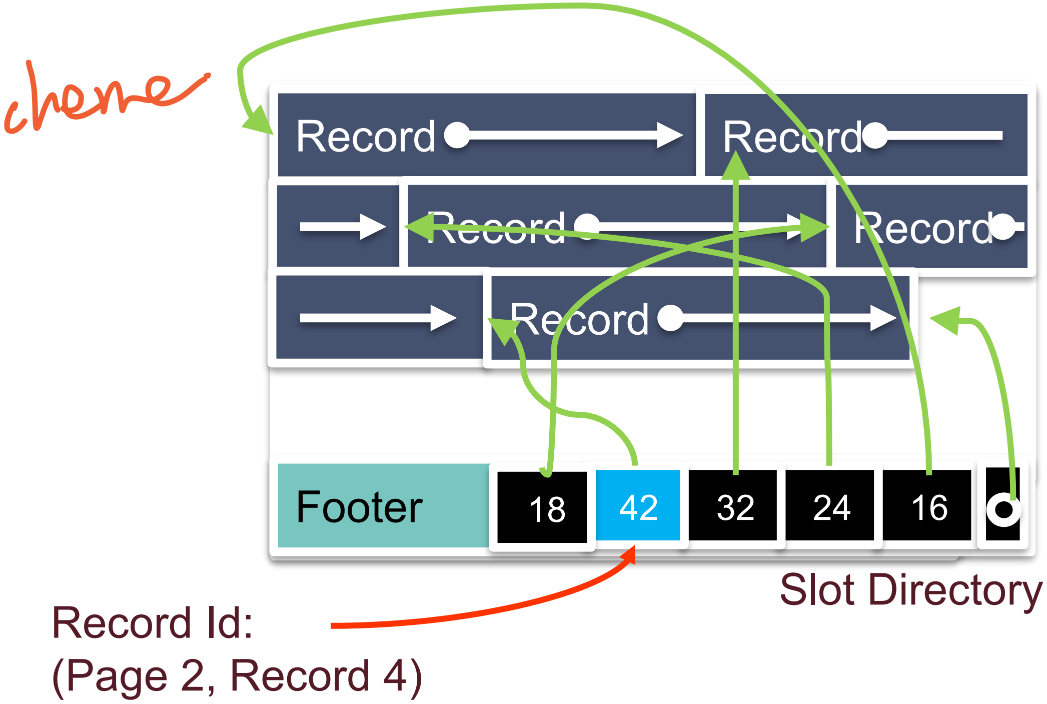
- Insert:
  - Place record in free space on page
  - Create pointer/length pair in next open slot in slot directory
  - Update the free space pointer
  - Fragmentation?
    - Reorganize data on page!



Slotted Page: Leading Questions

- Reorganize data on page lazy scheme
  - Is this safe?
    - Yes this is safe because records ids don’t change.
- When should I reorganize?
  - We could re-organize on delete
  - Or wait until fragmentation blocks record addition and then reorganize.
  - Often pays to be a little sloppy if page never gets more records.

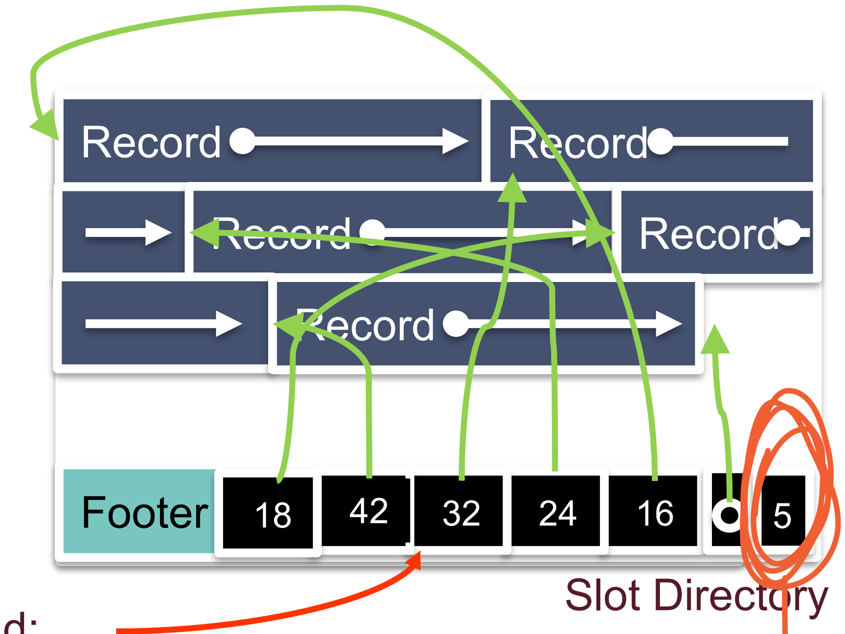
- What if we need more slots?
  - Let’s see…



Slotted Page: Growing Slots

- Tracking number of slots in slot directory
  - Empty or full

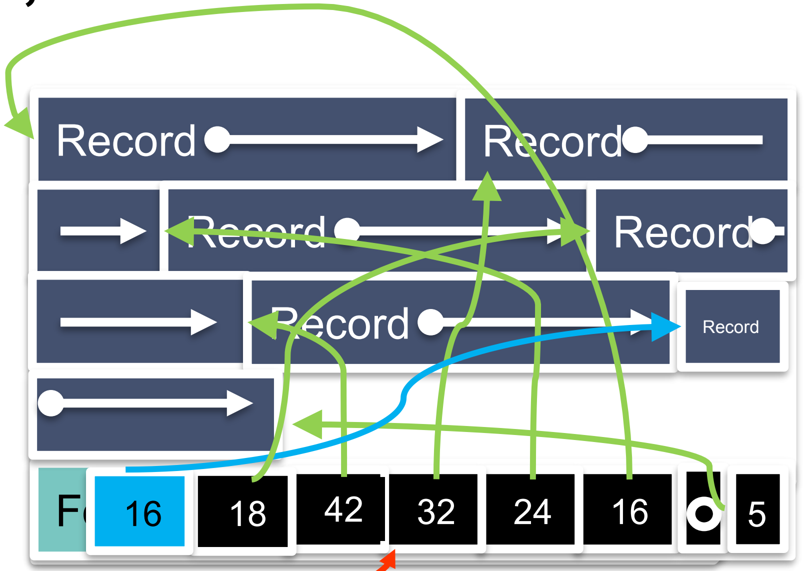
have to track # of slot in slot dict (Footer)



Record Id:
(Page 2, Record 4)

Slotted Page: Growing Slots, Pt. 2

- Tracking number of slots in slot directory
  - Empty or full
- Extend slot directory
  - Slots grow from end of page inward
  - Records grow from beginning of page inward.
  - Easy!

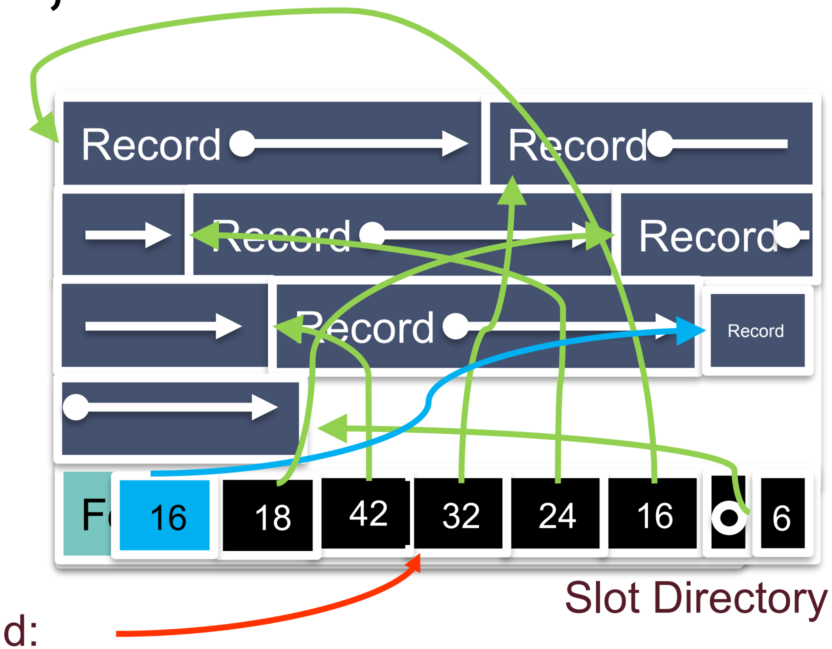


Slot Directory

Record Id:
(Page 2, Record 4)

Slotted Page: Growing Slots, Pt. 3

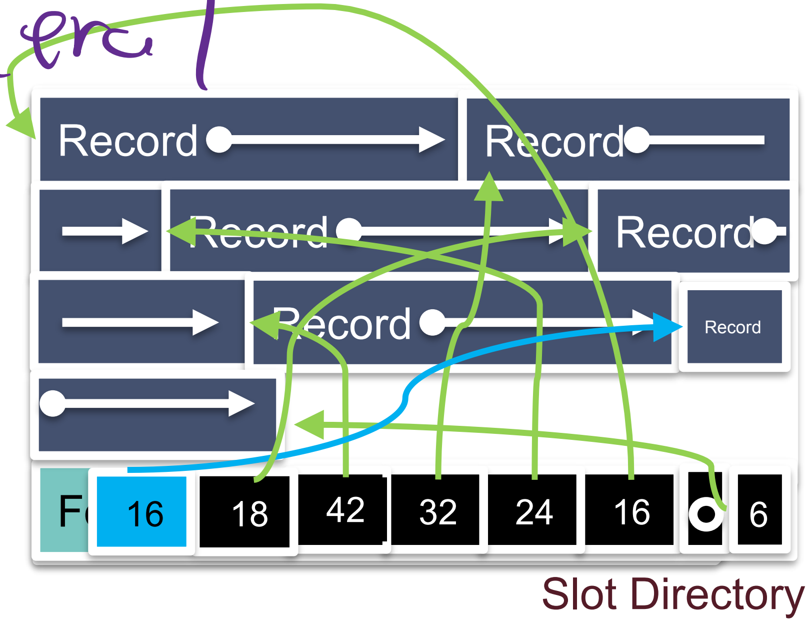
- Tracking number of slots in slot directory
  - Empty or full
- Extend slot directory
  - Slots grow from end of page inward
  - Records grow from beginning of page inward.
  - Easy!
- And update count



Record Id:
(Page 2, Record 4)

→ works for general

Slotted Page: Summary



- Typically use Slotted Page
  - Good for variable and fixed length records
- Not bad for fixed length records too.
  - Why?
  - Re-arrange (e.g., sort) and squash null fields
  - But for a whole table of fixed-length non-null records, can be worth the optimization of fixed-length format

RECORD LAYOUT

Record Formats

(SQL)

(type)

So no need store in record.

- Relational Model →
  - Each record in table has some fixed type
- Assume System Catalog stores the Schema
  - No need to store type information with records (save space!)
  - Catalog is just another table … (So same representation)
- Goals:

  袖珍

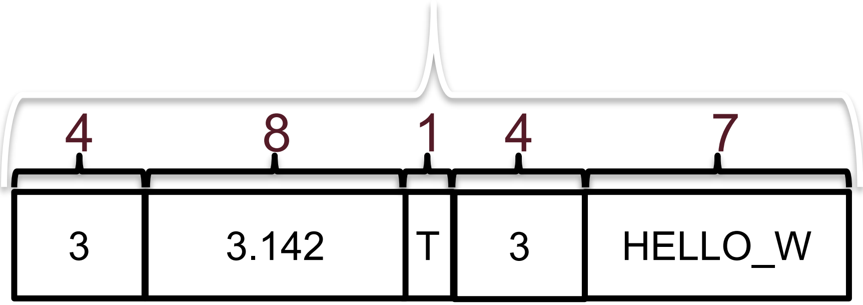
  - Records should be compact in memory & disk format
  - Fast access to fields (why?)

- Easy Case: Fixed Length Fields
- Interesting Case: Variable Length Fields

Record Formats: Fixed Length

- Field types same for all records in a file.
  - Type info stored separately in system catalog
- On disk byte representation same as in memory
- Finding i'th field?
  - done via arithmetic (fast)
- Compact? (Nulls?)

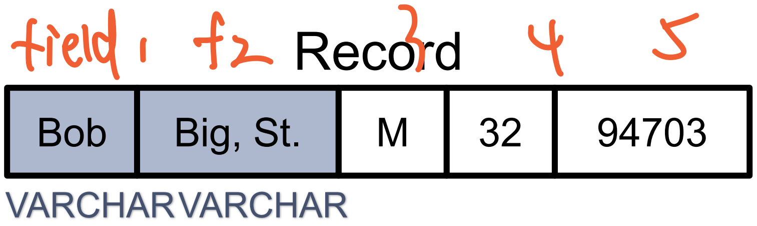
length of (i-1)
before
→ offset



4	8	1	4	7
3	3.142	T	3	HELLO_W

Record Formats: Variable Length

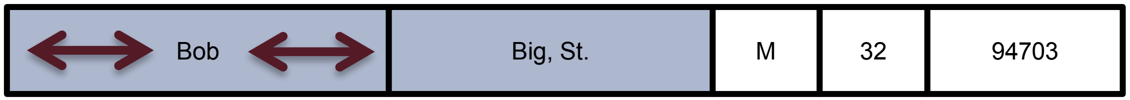
- What happens if fields are variable length?



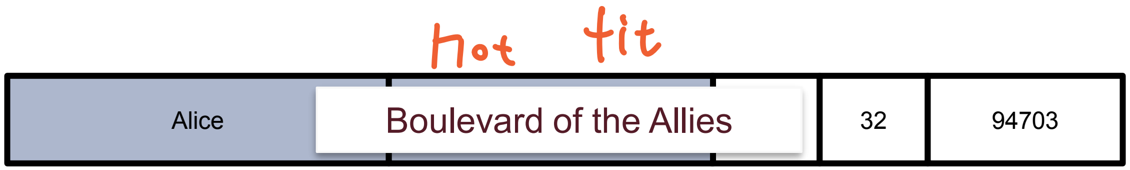
field 1 f2 Record 3 4 5

Bob	Big, St.	M	32	94703
VARCHAR	VARCHAR			

- Could store with padding? (Fixed Length)



Bob	Big, St.	M	32	94703



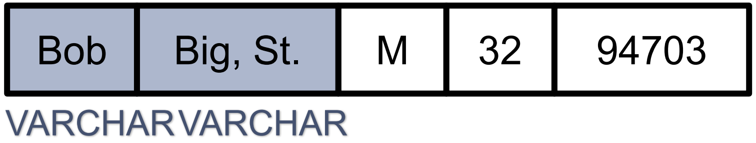
not fit

Alice	Boulevard of the Allies		32	94703

Record Formats: Variable Length, Pt 2.

- What happens if fields are variable length?

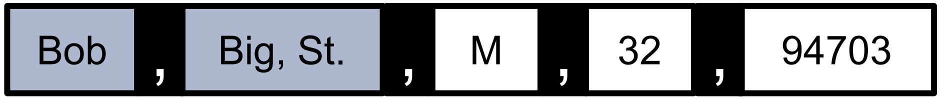
Record



Bob	Big, St.	M	32	94703
VARCHAR	VARCHAR			

- Could use delimiters (i.e., CSV):

Comma Separated Values (CSV)



Bob	,	Big, St.	,	M	,	32	,	94703

- Issues?

Record Formats: Variable Length, Pt. 3

- What happens if fields are variable length?

Record

Bob	Big, St.	M	32	94703
VARCHAR	VARCHAR			

- Could use delimiters (i.e., CSV):

Comma Separated Values (CSV)

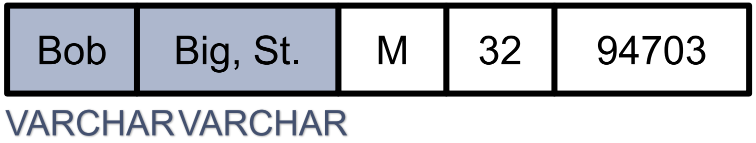
Bob	,	Big, St.	,	M	,	32	,	94703

- Requires scan to access field comma in data.
- What if text contains commas?

Record Formats: Variable Length, Pt 4.

- What happens if fields are variable length?

Record

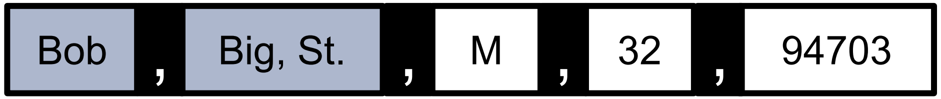


Bob | Big, St. | M | 32 | 94703

VARCHAR VARCHAR

- Store length information before fields:

Comma Separated Values (CSV)



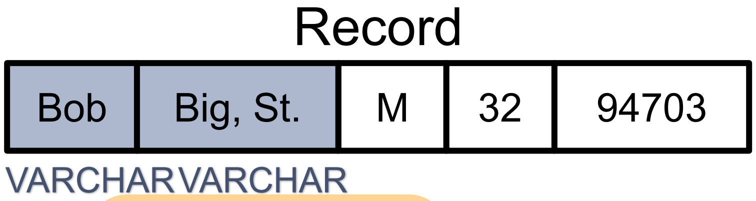
Bob , Big, St. , M , 32 , 94703

- Requires scan to access field
- Idea: Move all variable length fields to end enable fast access

length not fixed

Record Formats: Variable Length, Pt. 5

- What happens if fields are variable length?

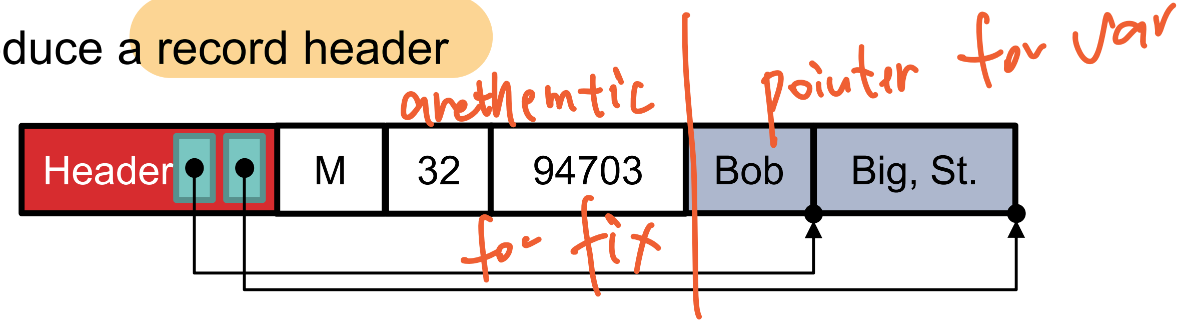


Record

Bob	Big, St.	M	32	94703

VARCHAR VARCHAR

- Introduce a record header



Header ● ●	M	32	94703	Bob	Big, St.

arethemtic

for fix

pointer for var

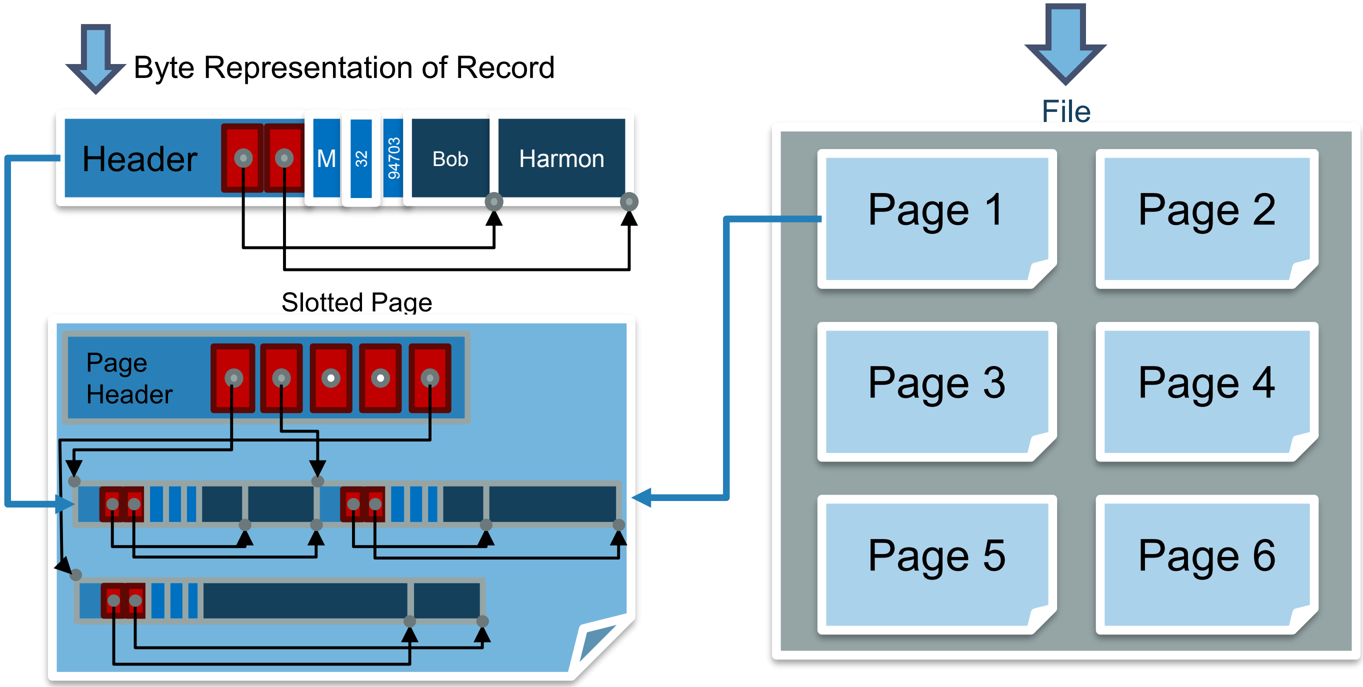
- Direct access & no “escaping”, other advantages?
  - Handle null fields easily → (to next)
  - useful for fixed length records too!

Summary 2

Record

Bob	Harmon	M	32	400
Varchar	Varchar	Char	Int	Int

SSN	Last Name	First Name	Age	Salary
123	Adams	Elmo	31	$400
443	Grouch	Oscar	32	$300
244	Oz	Bert	55	$140
134	Sanders	Ernie	55	$400


Byte Representation of Record
Header
M
32
94703
Bob
Harmon
Slotted Page
Page Header
File
Page 1
Page 2
Page 3
Page 4
Page 5
Page 6