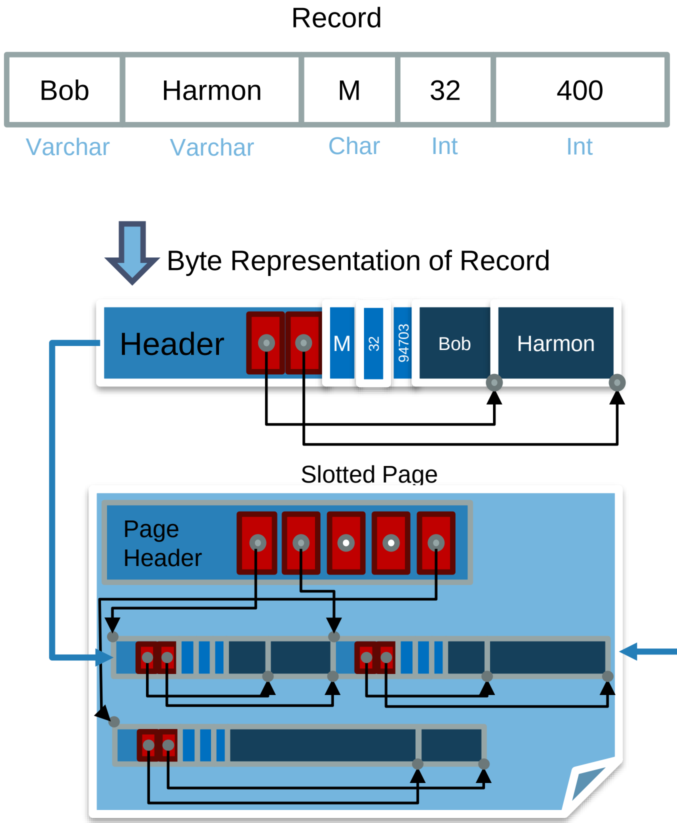
Disk Representations:
Files, Pages, Records

Prof. Joseph Hellerstein

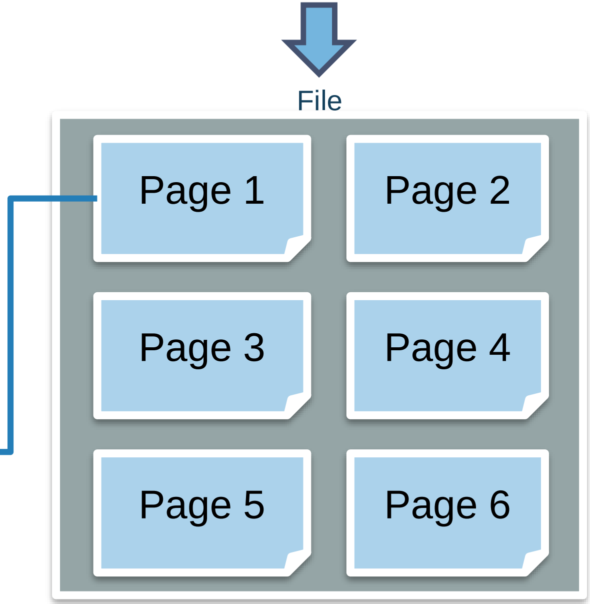
STORING DATA: FILES

FILE REPRESENTATIONS

Overview: Representations

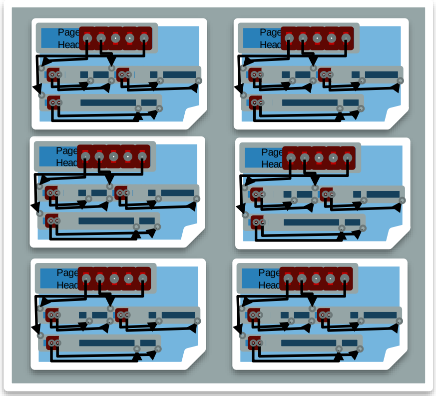


SSN	Last Name	First Name	Age	Salary
123	Adams	Elmo	31	$400
443	Grouch	Oscar	32	$300
244	Oz	Bert	55	$140
134	Sanders	Ernie	55	$400



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

- **<u>DB FILE</u>:** 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

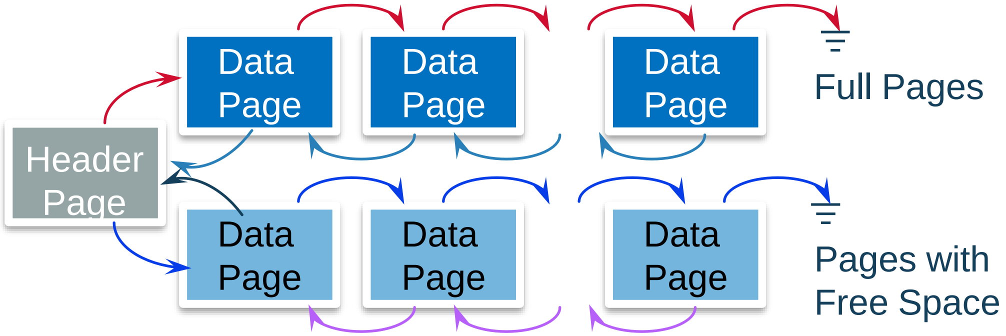
- Unordered Heap Files
  - Records placed arbitrarily across pages
- Clustered Heap Files
  - Records and pages are grouped
- Sorted Files
  - Pages and records are in sorted order
- Index Files
  - B+ Trees, Linear Hashing, …
  - May contain records or point to records in other files

Unordered Heap Files

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

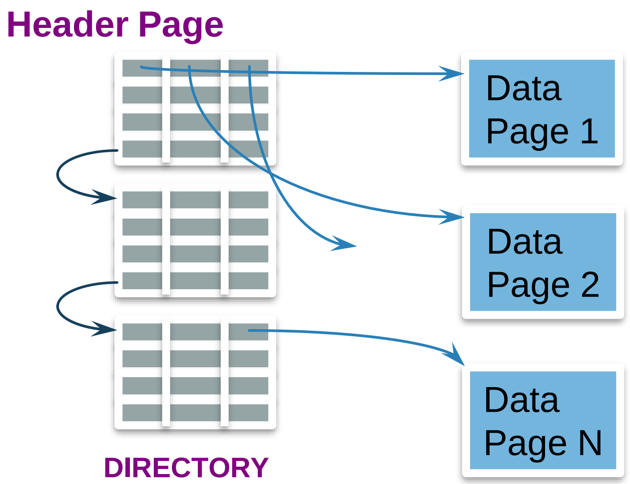
Heap File Implemented as List

- 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
- 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
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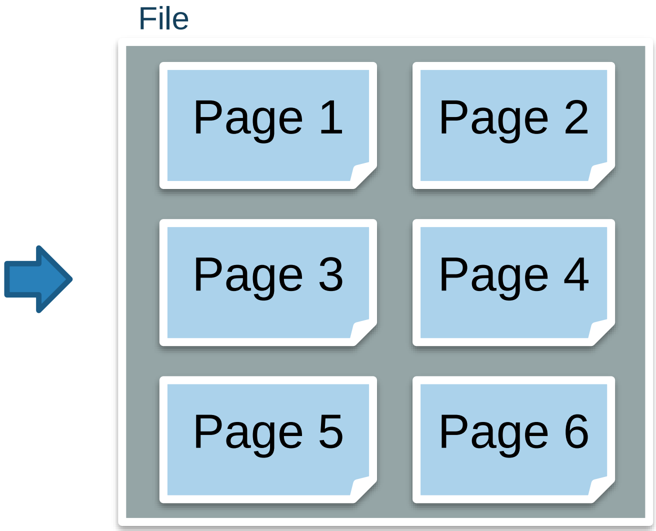


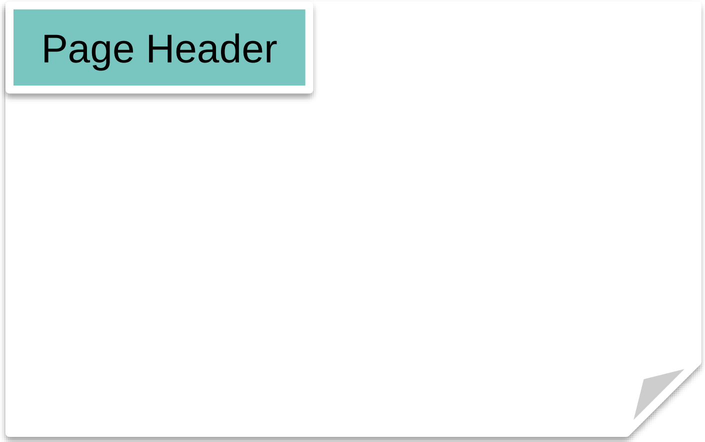
PAGE LAYOUT

Page Basics: The Header

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

Things to Address

- Record length? Fixed or Variable
- Find records by record id?
  - Record id = (Page, 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)

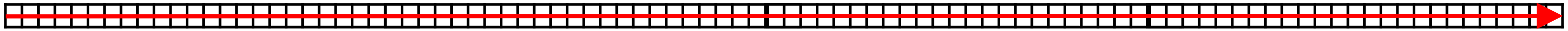
Indexes: Sneak Preview

- A Heap file allows us to retrieve records:
  - By specifying the record id (page id + offset)
  - By scanning all records sequentially
- Would like to fetch records by value, e.g.,
  - Find all students in the “CS” department
  - Find all students with a “GPA” > 3 AND “blue hair”
- Indexes: file structures for efficient value-based queries

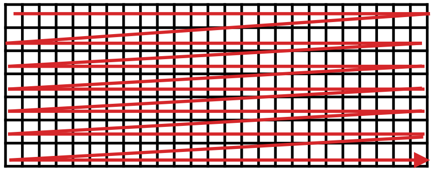
Content Break

A Note On Imagery

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

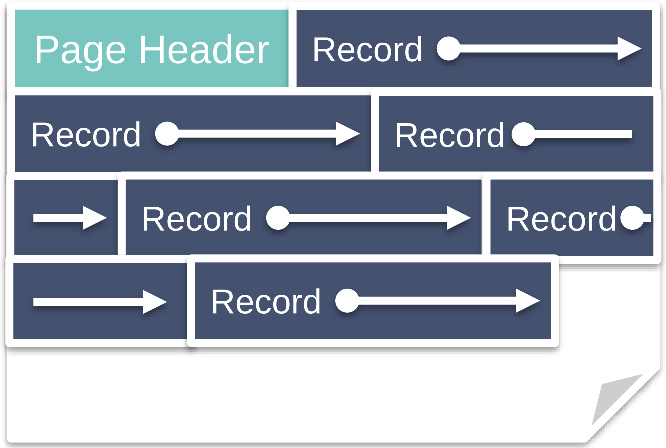


- This doesn't fit nicely on screen
  - So we will "wrap around" the linear order into a rectangle



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.

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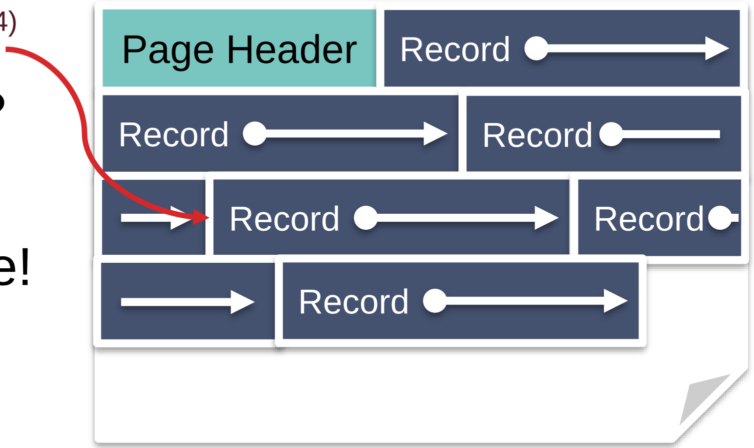

Fixed Length Records: Packed, Pt 3.

- Pack records densely
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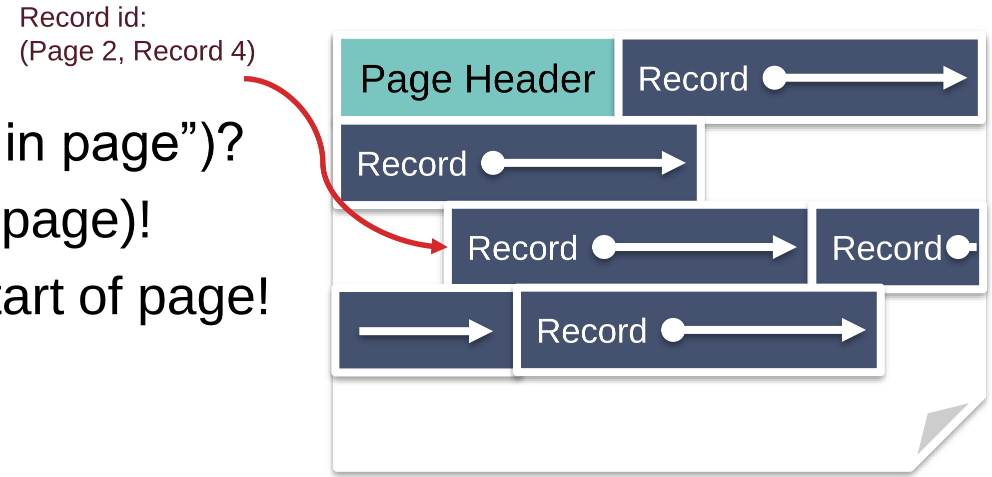
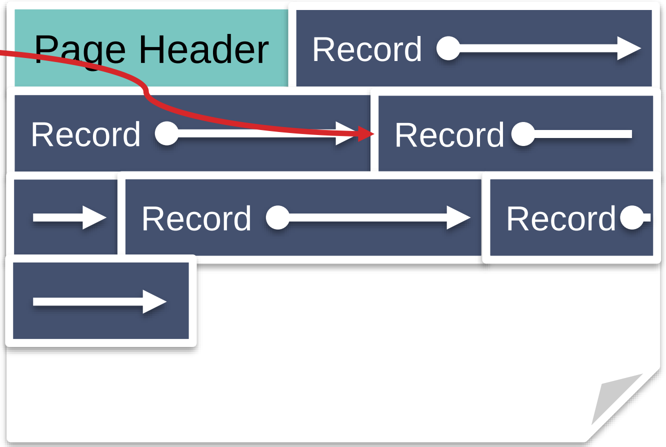


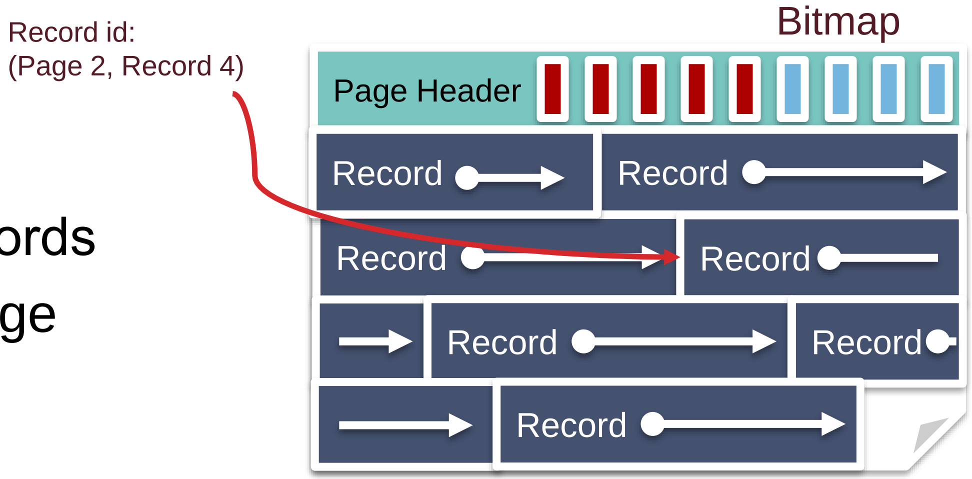
Fixed Length Records: Packed, Pt. 5

Record id:
(Page 2, Record **3**)

- 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.

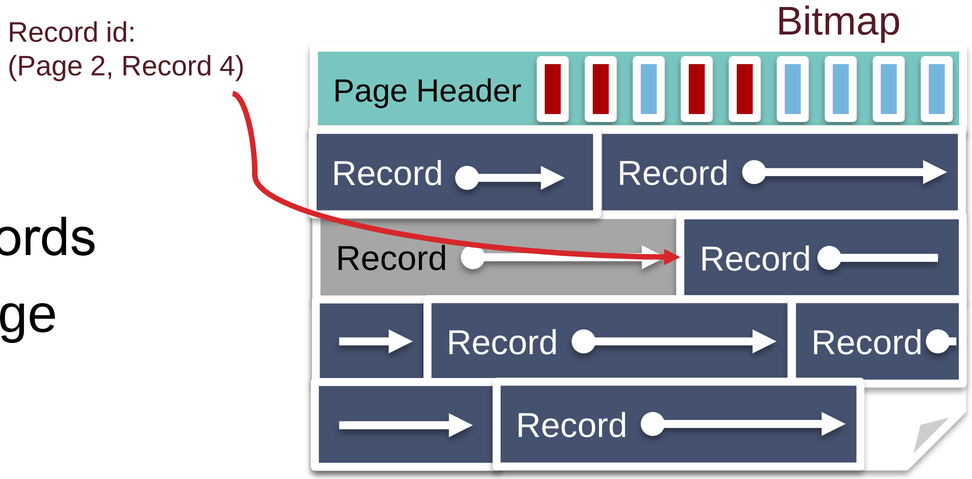


Fixed Length Records: Unpacked



- 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

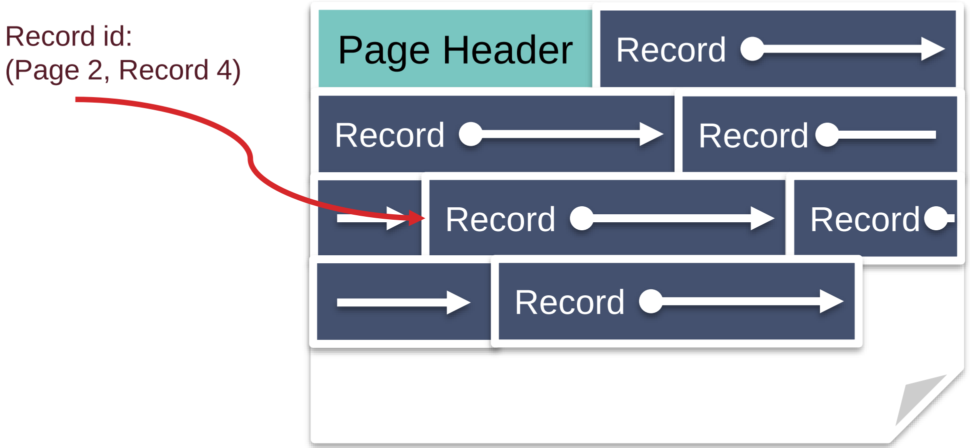


- Bitmap denotes “slots” with records
- Record id: record number in page
- **Insert**: find first empty slot
- **Delete**: Clear bit

Content Break 2

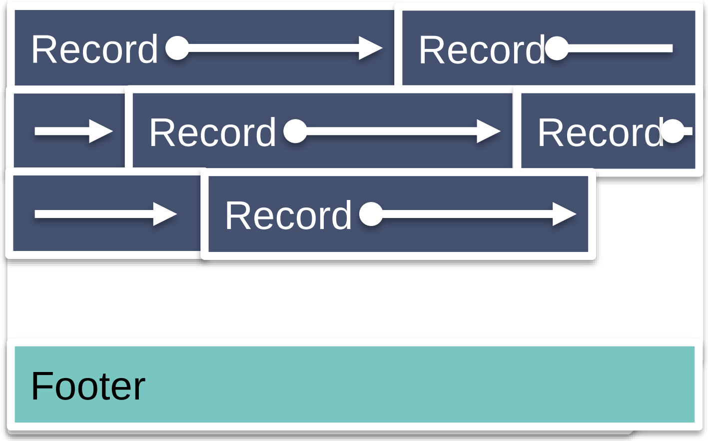
Variable Length Records

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



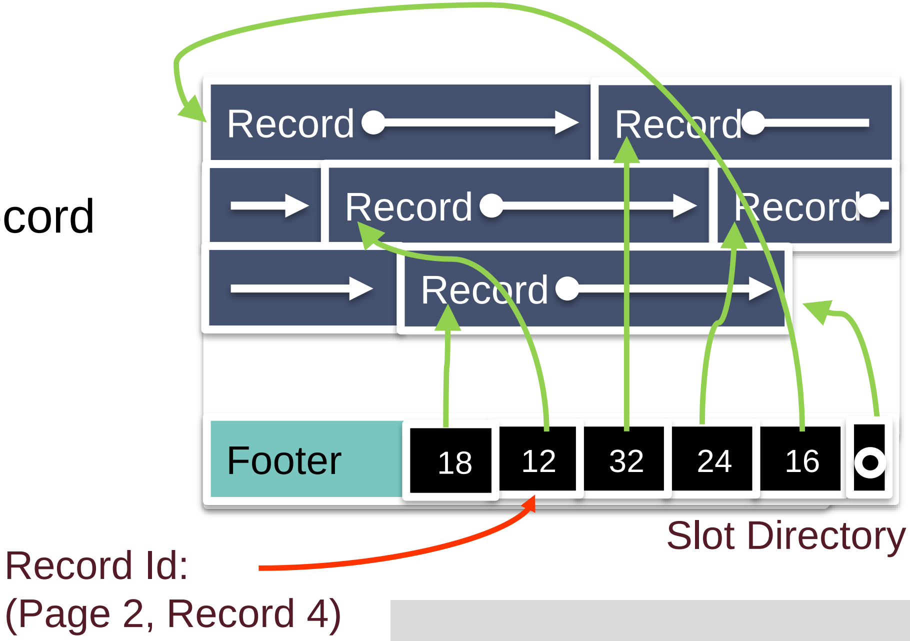
First: Relocate metadata to footer

- We’ll see why this is handy shortly…



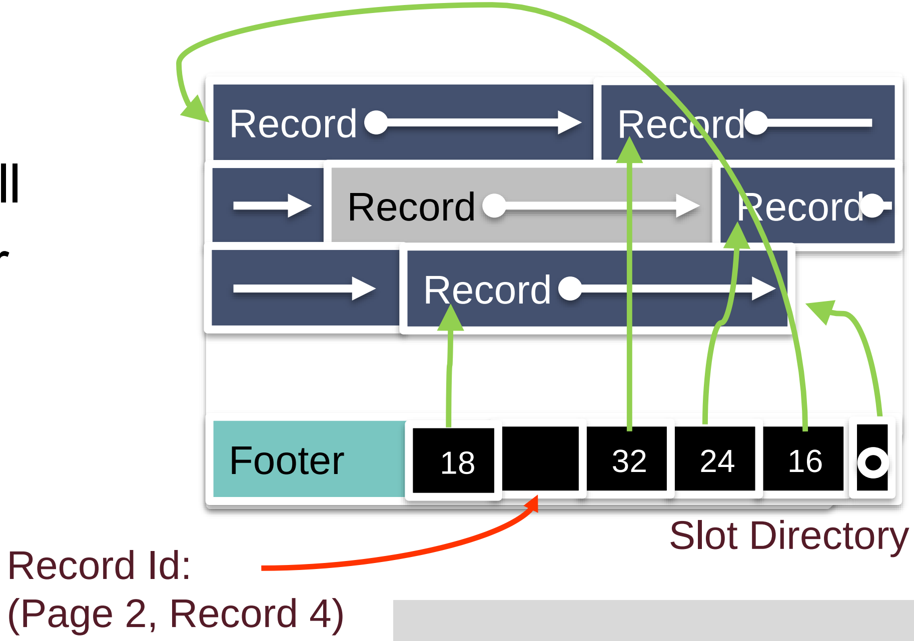
Slotted Page

- Introduce slot directory in footer
  - Pointer to free space
  - Length + Pointer to beginning of record
    - reverse order
- Record ID = location in slot table
  - from right
- Delete?
  - e.g., 4th record on the page



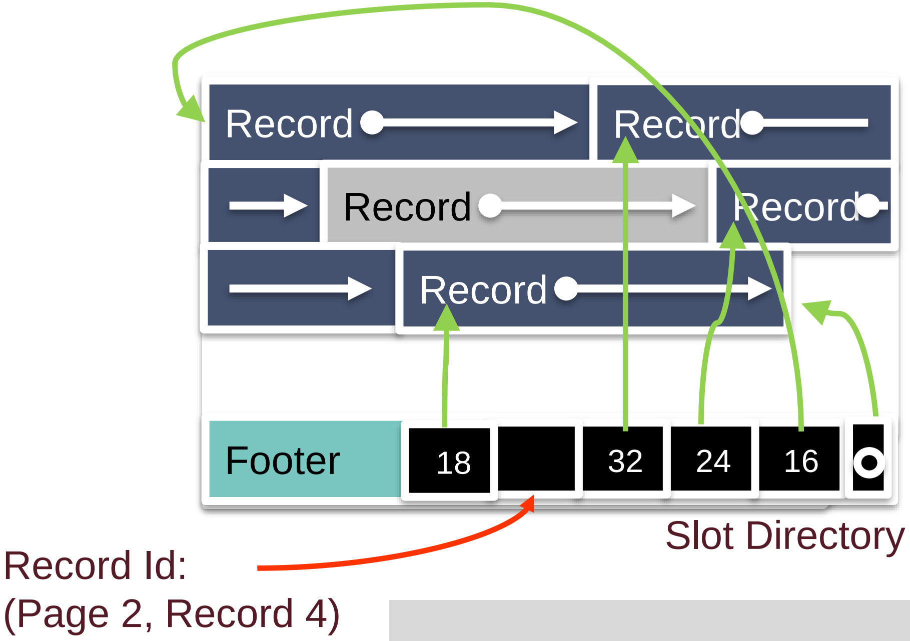
Slotted Page: Delete Record

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



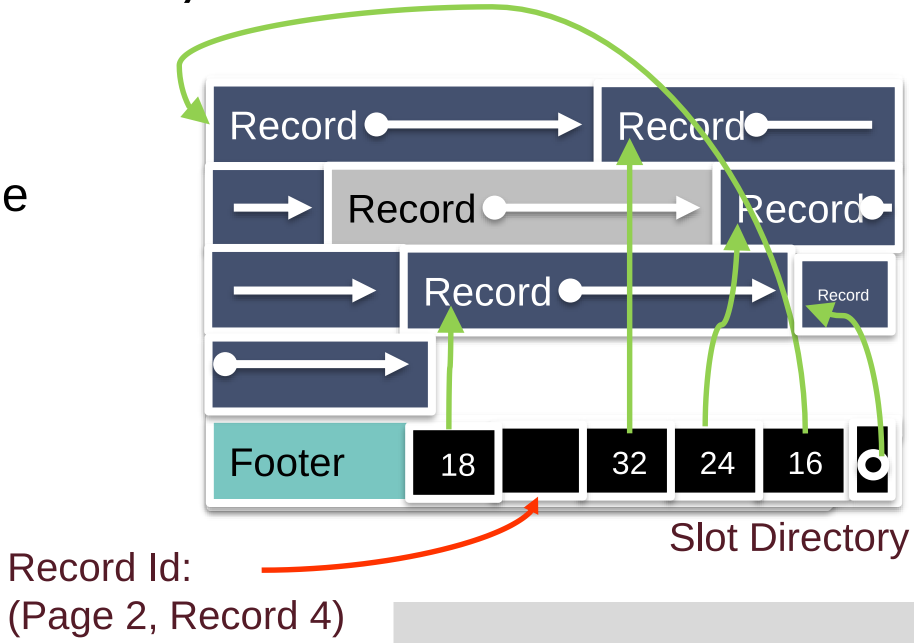
Slotted Page: Insert Record

- Insert:



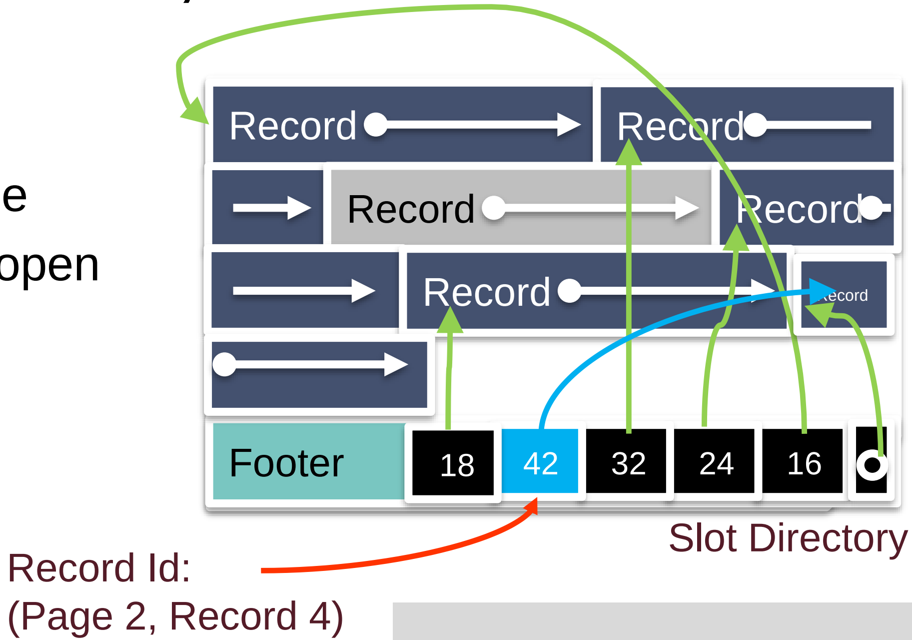
Slotted Page: Insert Record, Pt 2.

- Insert:
  - Place record in free space on page



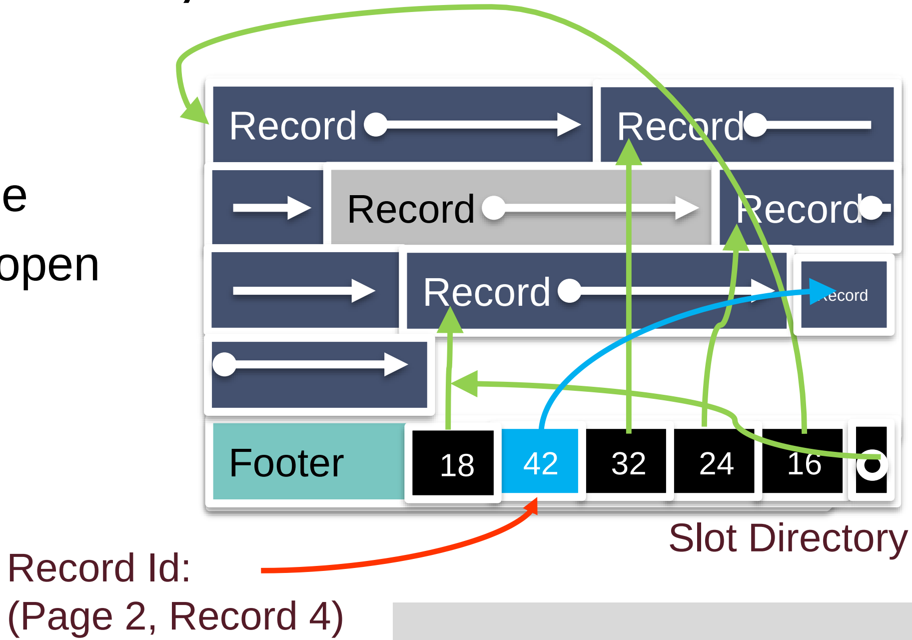
Slotted Page: Insert Record, Pt. 3

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



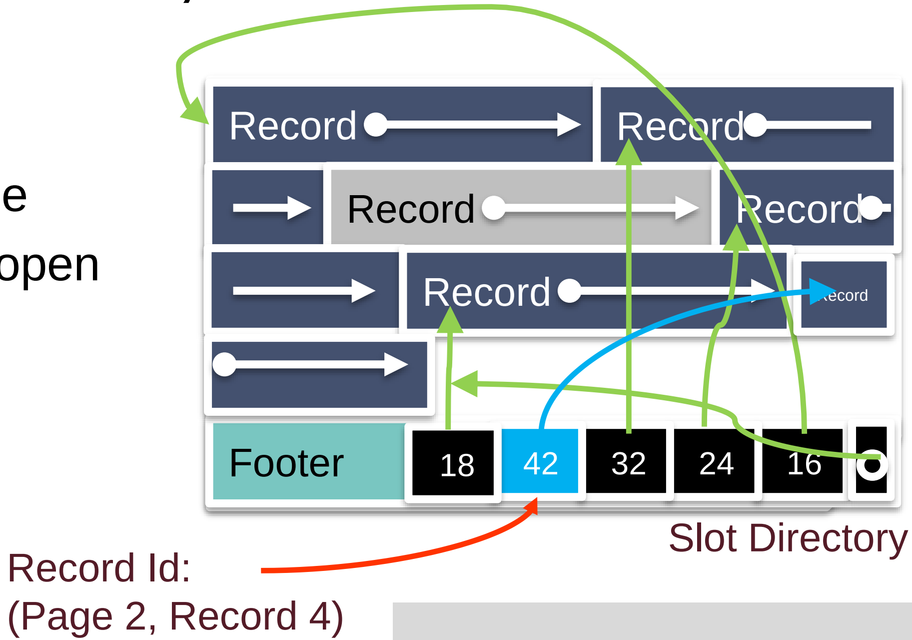
Slotted Page: Insert Record, Pt. 4

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



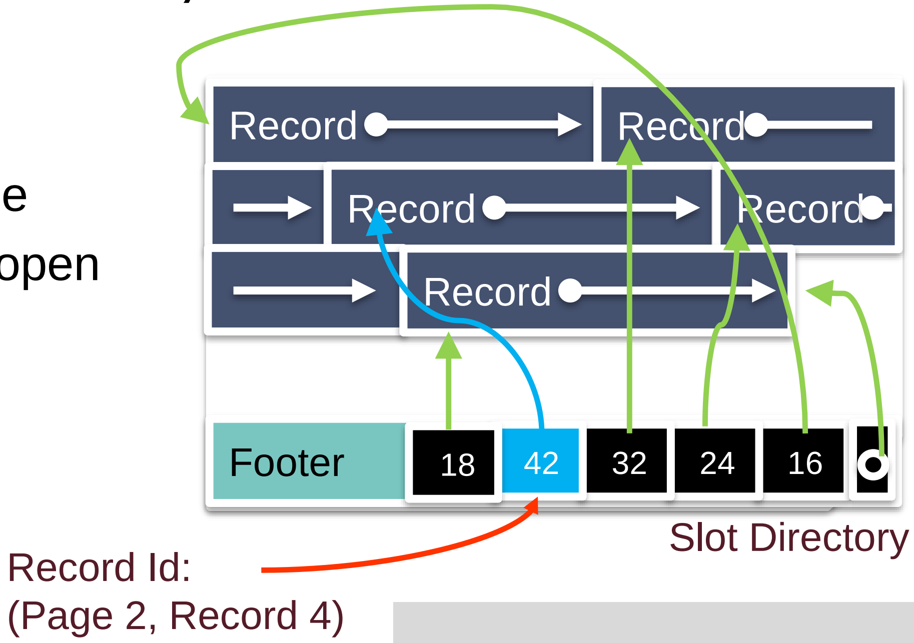
Slotted Page: Insert Record, Pt. 5

- 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?



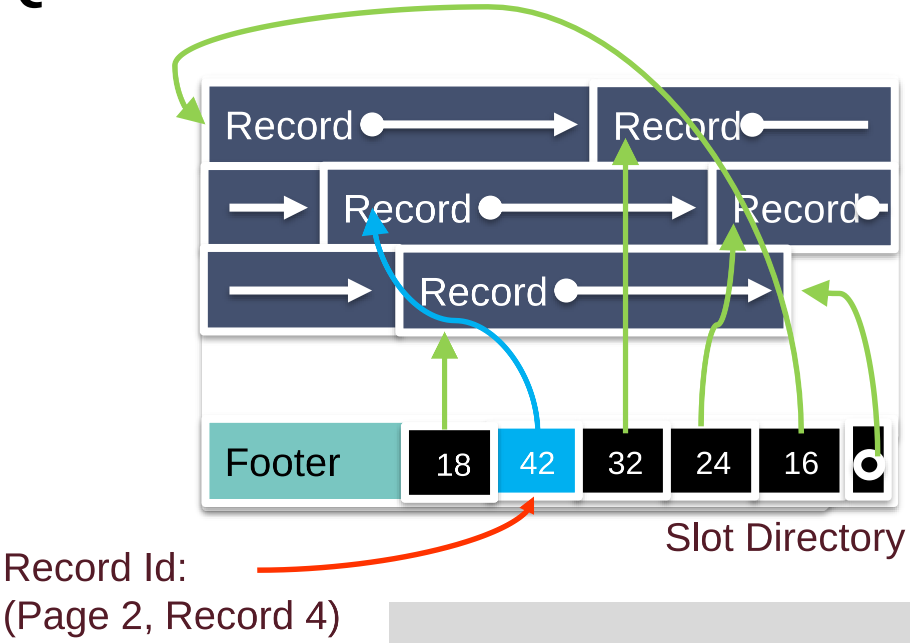
Slotted Page: Insert Record, Pt. 6

- 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!



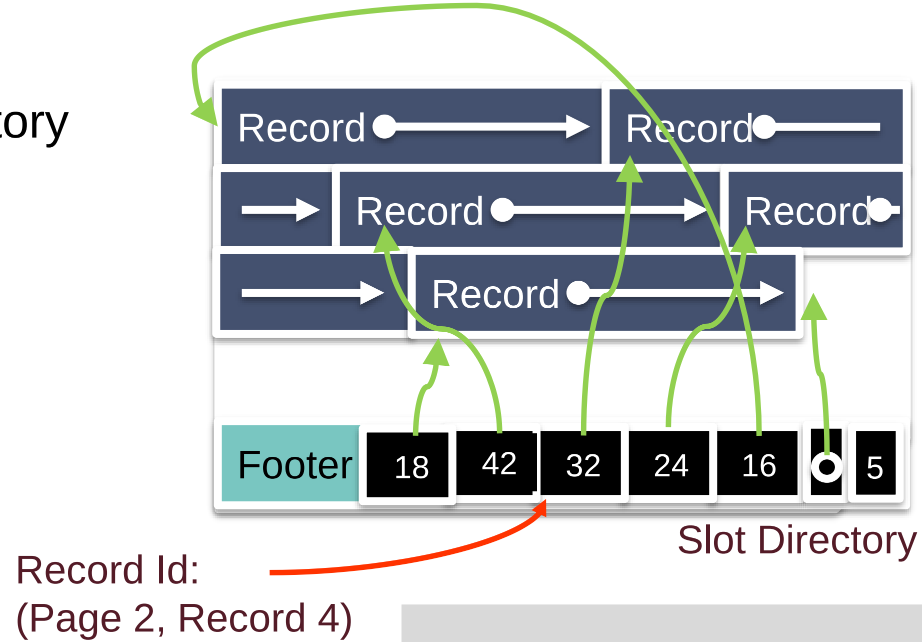
Slotted Page: Leading Questions

- Reorganize data on page
  - 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…



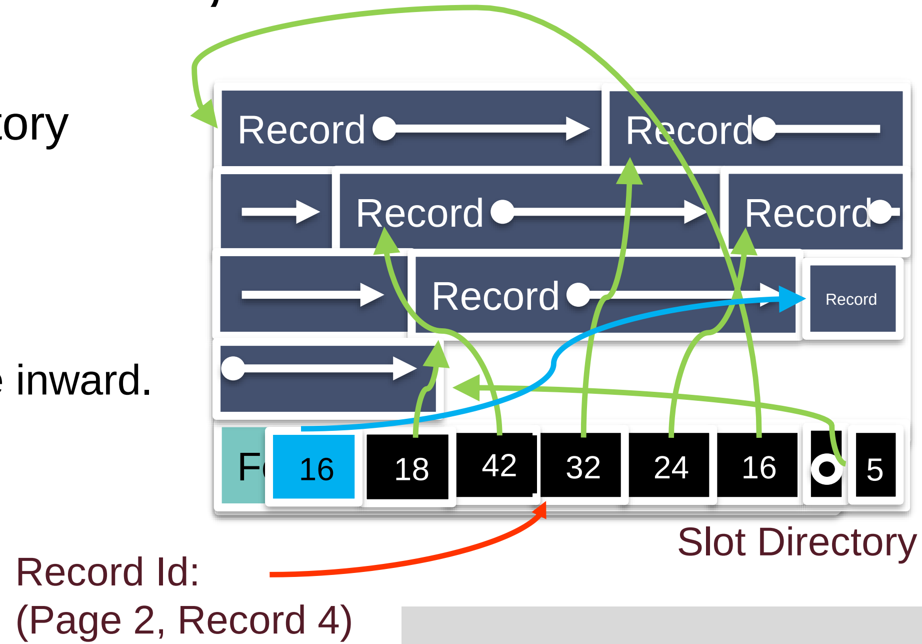
Slotted Page: Growing Slots

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



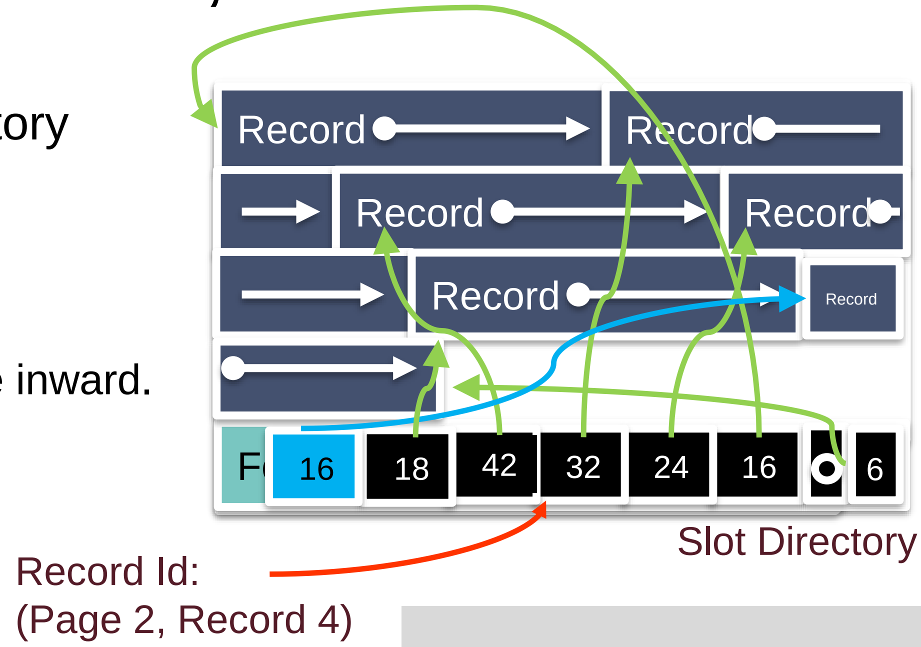
Slotted Page: Growing Slots, Pt. 2

- 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!

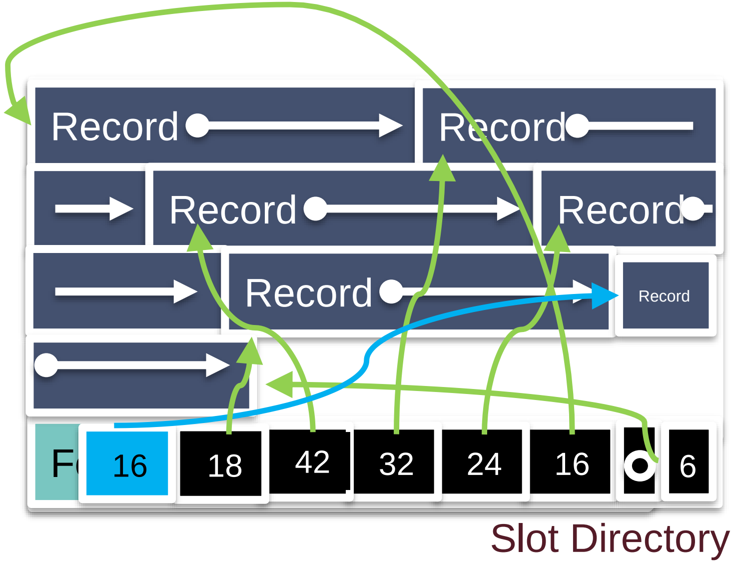


Slotted Page: Growing Slots, Pt. 3

- 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



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

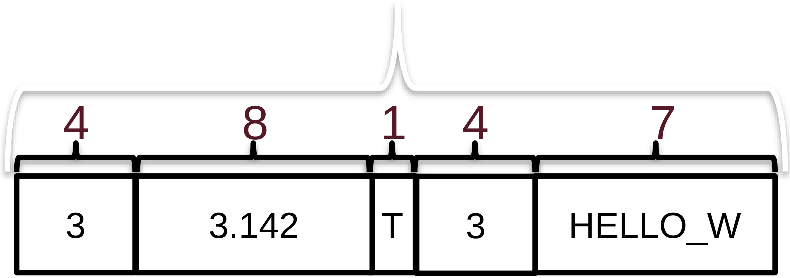
Record Formats

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

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

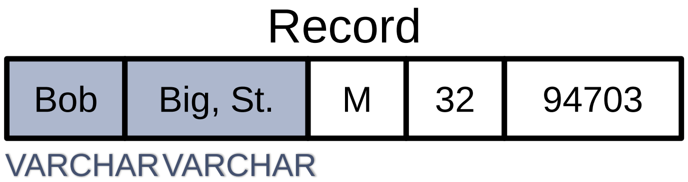
Record Formats: Fixed Length

- 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?)

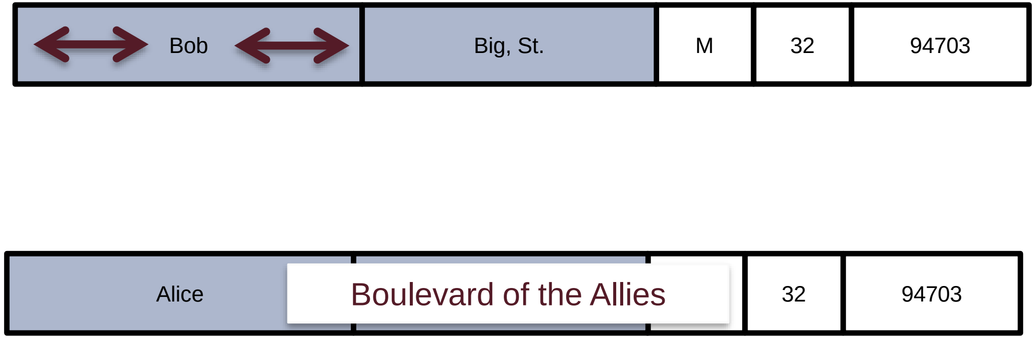


Record Formats: Variable Length

- What happens if fields are variable length?



- Could store with padding? (Fixed Length)



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):

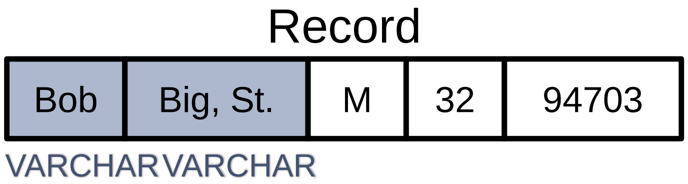
Comma Separated Values (CSV)

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

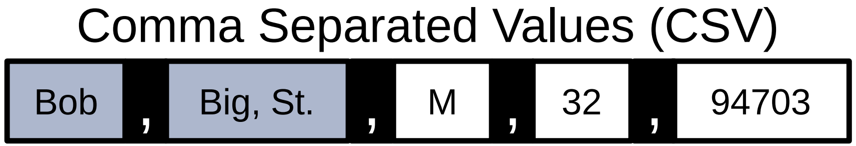
- Issues?

Record Formats: Variable Length, Pt. 3

- What happens if fields are variable length?



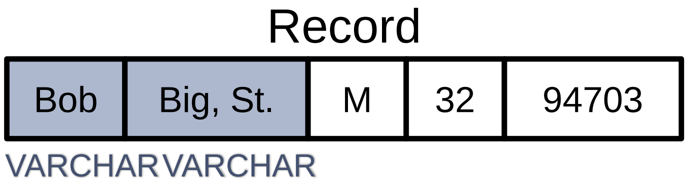
- Could use delimiters (i.e., CSV):



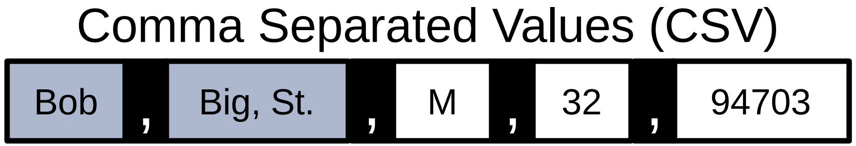
- Requires scan to access field
- What if text contains commas?

Record Formats: Variable Length, Pt 5.

- What happens if fields are variable length?



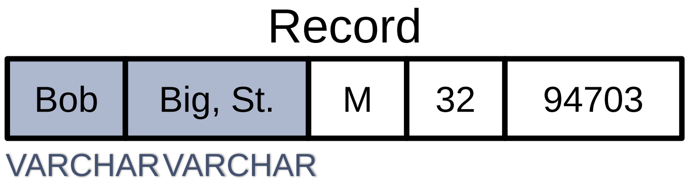
- Store length information before fields:



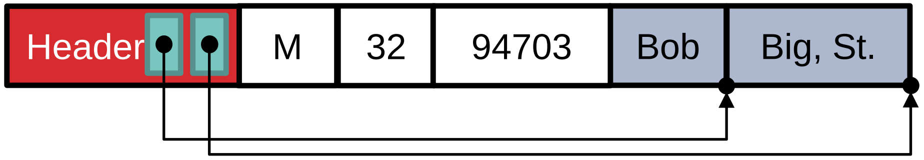
- Requires scan to access field
- Idea: Move all variable length fields to end enable fast access

Record Formats: Variable Length, Pt. 7

- What happens if fields are variable length?

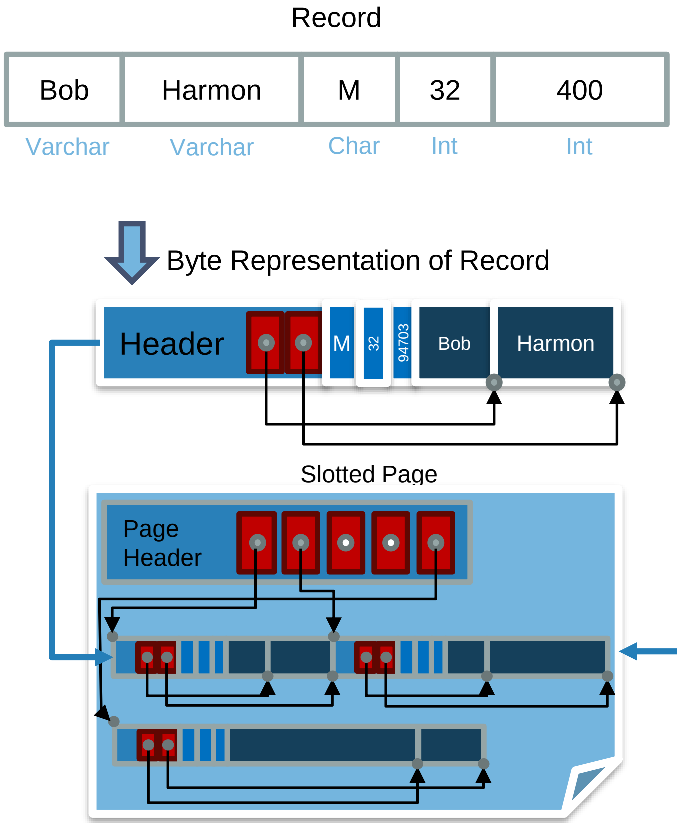


- Introduce a record header



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

Summary 2



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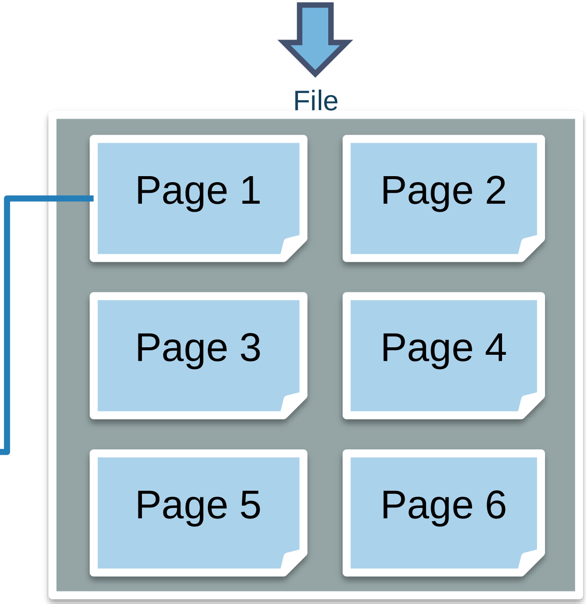


Content Break 3

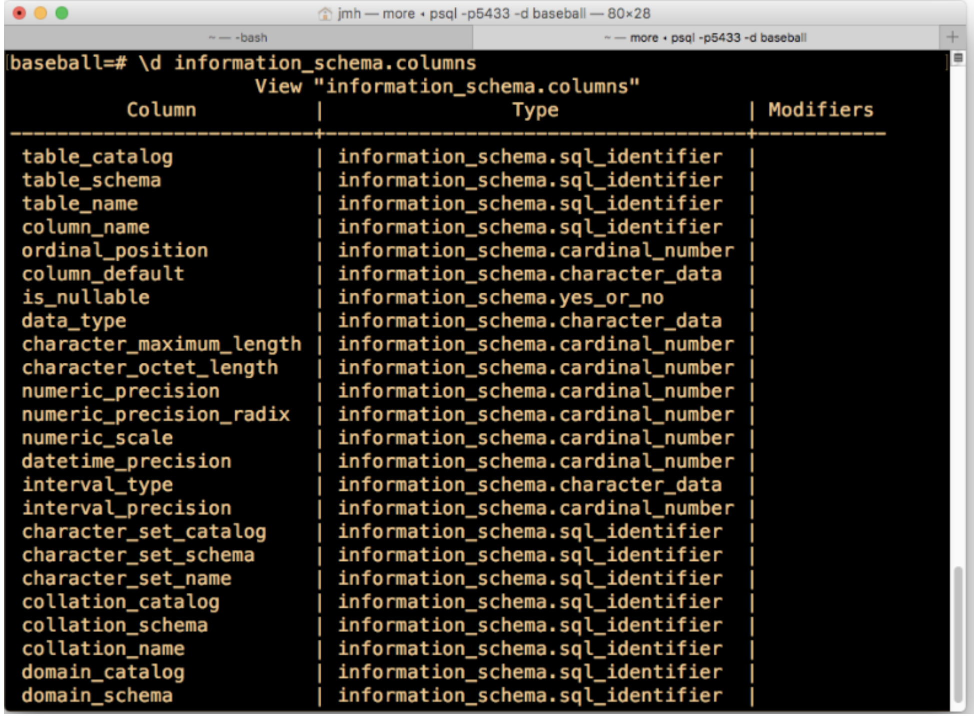
System Catalogs

- For each relation:
  - name, file location, file structure (e.g., Heap file)
  - attribute name and type, for each attribute
  - index name, for each index
  - integrity constraints
- For each index:
  - structure (e.g., B+ tree) and search key fields

System Catalogs Pt. 2

- For each view:
  - view name and definition
- Plus statistics, authorization, buffer pool size, etc
- **Catalogs are themselves stored as relation!**

PostgreSQL Information Schema



```
baseball=# \d information_schema.columns
                     View "information_schema.columns"
          Column          |                Type                | Modifiers
--------------------------+------------------------------------+-----------
 table_catalog            | information_schema.sql_identifier  |
 table_schema             | information_schema.sql_identifier  |
 table_name               | information_schema.sql_identifier  |
 column_name              | information_schema.sql_identifier  |
 ordinal_position         | information_schema.cardinal_number |
 column_default           | information_schema.character_data  |
 is_nullable              | information_schema.yes_or_no       |
 data_type                | information_schema.character_data  |
 character_maximum_length | information_schema.cardinal_number |
 character_octet_length   | information_schema.cardinal_number |
 numeric_precision        | information_schema.cardinal_number |
 numeric_precision_radix  | information_schema.cardinal_number |
 numeric_scale            | information_schema.cardinal_number |
 datetime_precision       | information_schema.cardinal_number |
 interval_type            | information_schema.character_data  |
 interval_precision       | information_schema.cardinal_number |
 character_set_catalog    | information_schema.sql_identifier  |
 character_set_schema     | information_schema.sql_identifier  |
 character_set_name       | information_schema.sql_identifier  |
 collation_catalog        | information_schema.sql_identifier  |
 collation_schema         | information_schema.sql_identifier  |
 collation_name           | information_schema.sql_identifier  |
 domain_catalog           | information_schema.sql_identifier  |
 domain_schema            | information_schema.sql_identifier  |
```

sqlite_master

jmh — sqlite3 — 80×28

```
sqlite> select * from sqlite_master;
type        name        tbl_name    rootpage    sql



----------  ----------  ----------  ----------  --------------------------------
--------------------------------------------------------------------------------
----
table       Sailors     Sailors     2           CREATE TABLE Sailors (
   sid INTEGER,
   sname CHAR(20),
   rating INTEGER,
   age REAL,
   PRIMARY KEY (sid))
table       Boats       Boats       3           CREATE TABLE Boats (
   bid INTEGER,
   bname CHAR (20),
   color CHAR(10),
   PRIMARY KEY (bid))
table       Reserves    Reserves    4           CREATE TABLE Reserves (
   sid INTEGER,
   bid INTEGER,
   day DATE,
  PRIMARY KEY (sid, bid, day),
  FOREI
index       sqlite_aut  Reserves    5


sqlite> 
```

Files: Summary

- DBMS “File” contains pages, and records within pages
  - Heap files: unordered records organized with directories
- Page layouts
  - Fixed-length packed and unpacked
  - Variable length records in slotted pages, with intra-page reorg
- Variable length record format
  - Direct access to i’th field and null values
- Catalog relations store information about relations, indexes and views.