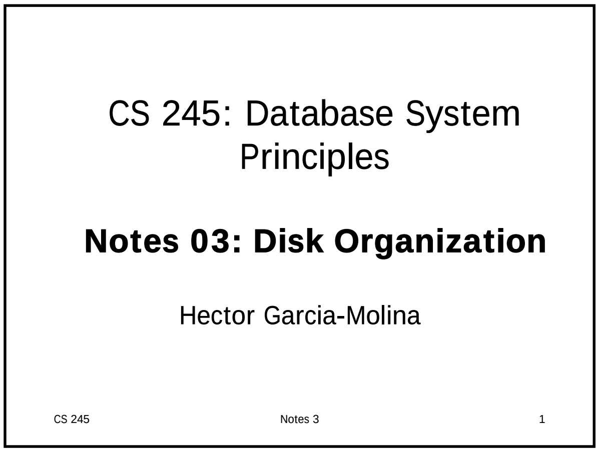
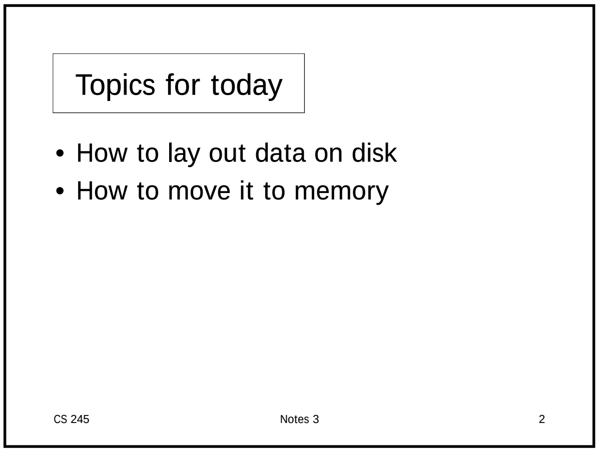


CS 245: Database System Principles

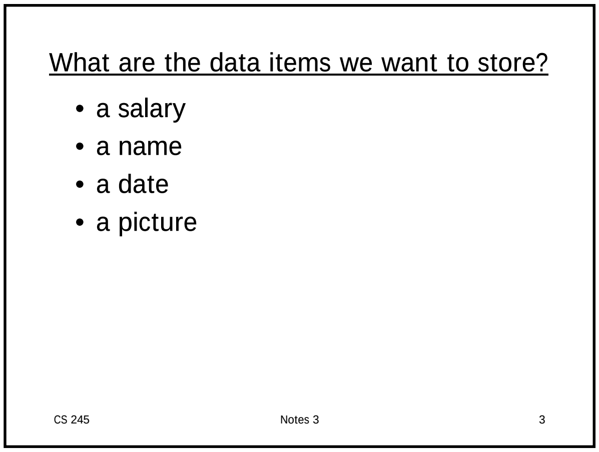
Notes 03: Disk Organization

Hector Garcia-Molina



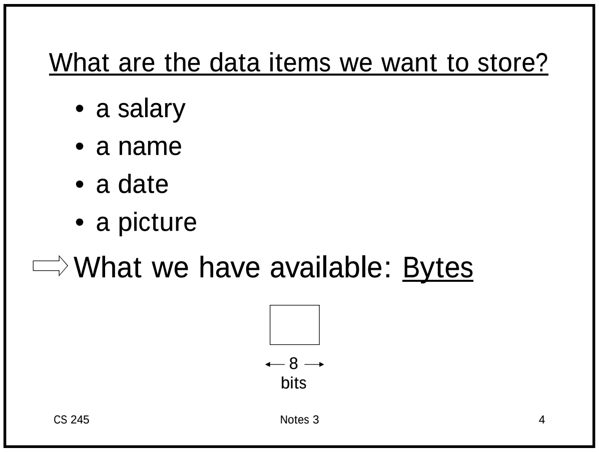
Topics for today

- How to lay out data on disk
- How to move it to memory



What are the data items we want to store?

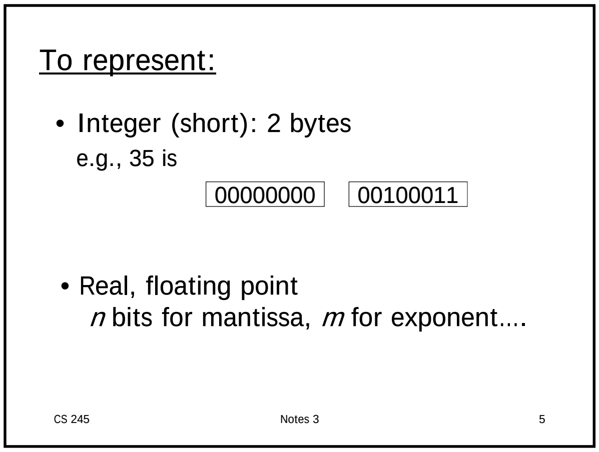
- a salary
- a name
- a date
- a picture



What are the data items we want to store?

- a salary
- a name
- a date
- a picture

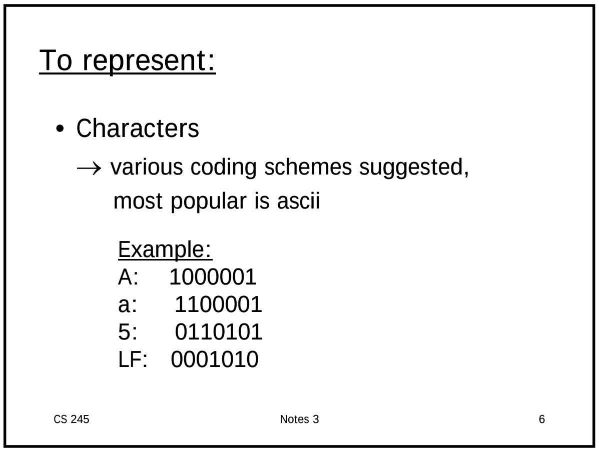
⇨ What we have available: Bytes



To represent:

- Integer (short): 2 bytes
  e.g., 35 is
  00000000 00100011

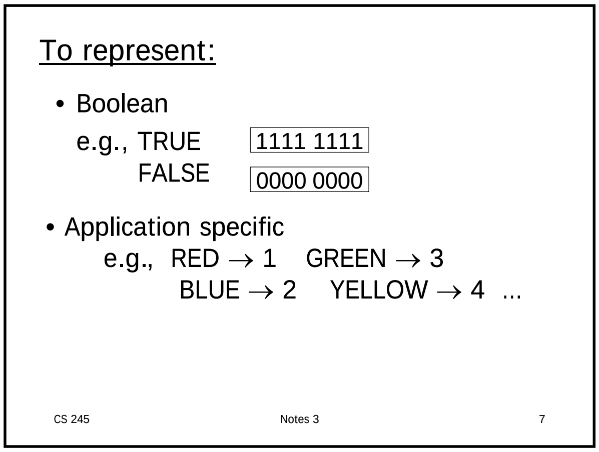
- Real, floating point
  n bits for mantissa, *m* for exponent….



To represent:

- Characters
  → various coding schemes suggested,
  most popular is ascii

Example:
A: 1000001
a: 1100001
5: 0110101
LF: 0001010



To represent:

- Boolean

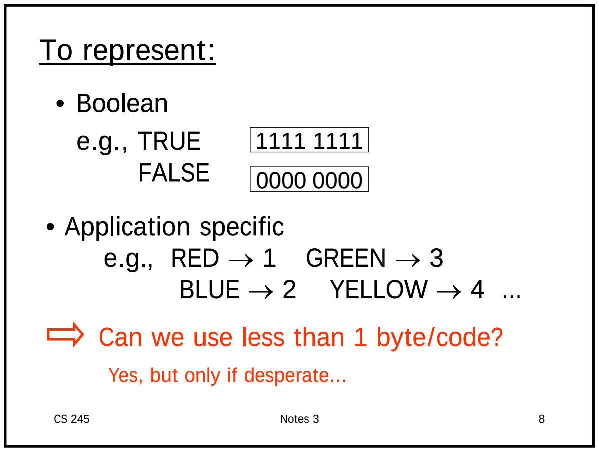
  e.g., TRUE $\boxed{1111\ 1111}$

  FALSE $\boxed{0000\ 0000}$

- Application specific

  e.g., RED → 1 GREEN → 3

  BLUE → 2 YELLOW → 4 ...



To represent:

- Boolean

  e.g., TRUE $\boxed{1111\ 1111}$

  FALSE $\boxed{0000\ 0000}$

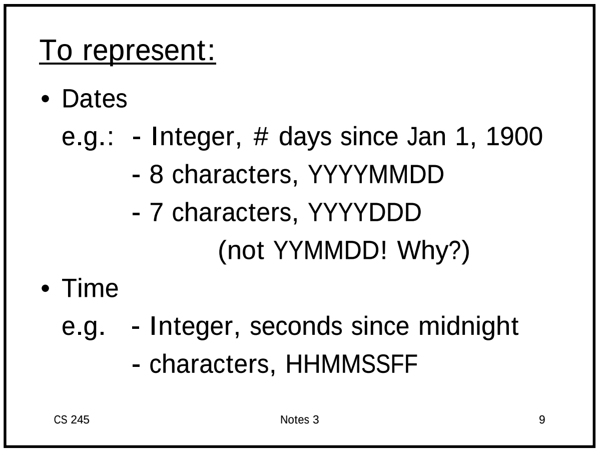
- Application specific

  e.g., RED → 1 GREEN → 3

  BLUE → 2 YELLOW → 4 ...

⇨ Can we use less than 1 byte/code?

Yes, but only if desperate...



To represent:

- Dates

  e.g.: - Integer, # days since Jan 1, 1900

  - 8 characters, YYYYMMDD

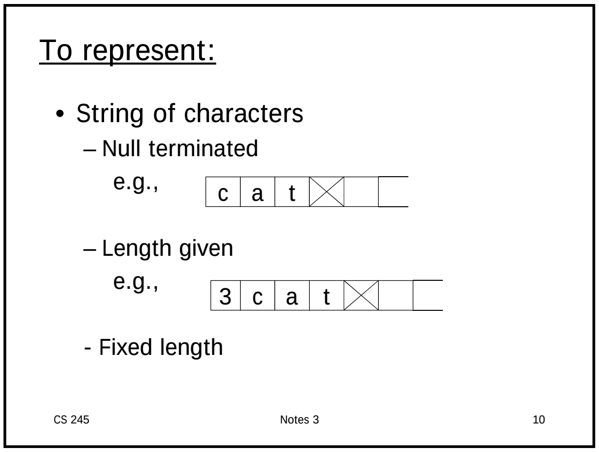
  - 7 characters, YYYYDDD

  (not YYMMDD! Why?)

- Time

  e.g. - Integer, seconds since midnight

  - characters, HHMMSSFF



To represent:

- String of characters
  - Null terminated

    e.g.,

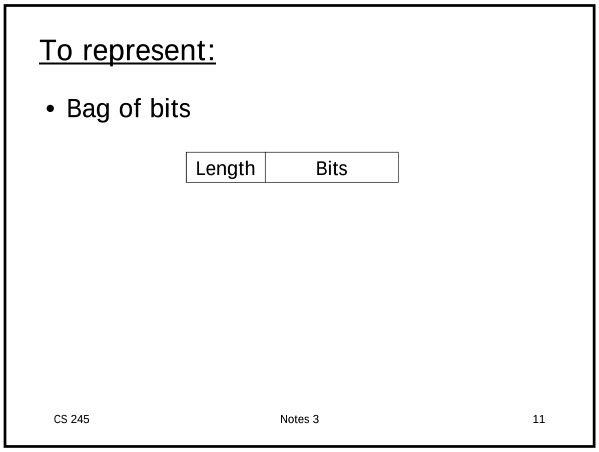
c	a	t	☒		

  - Length given

    e.g.,

3	c	a	t	☒		

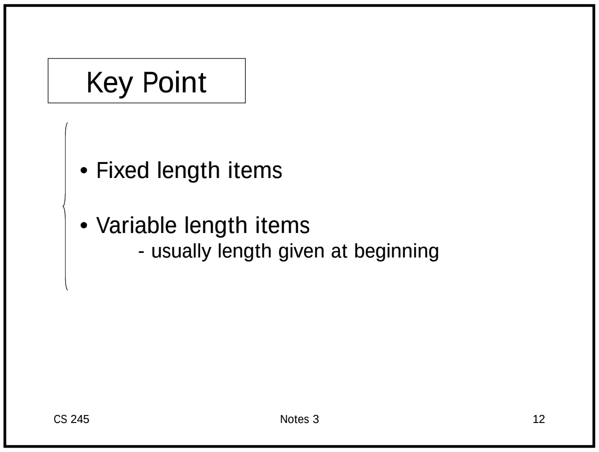
  - Fixed length



To represent:

- Bag of bits

Length	Bits



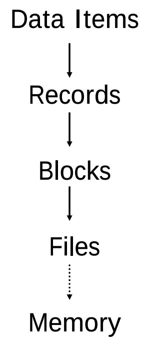
$\boxed{\text{Key Point}}$

- Fixed length items
- Variable length items
  - usually length given at beginning

Also

- Type of an item: Tells us how to interpret (plus size if fixed)

Overview


Data Items

Records

Blocks

Files

Memory

Record - Collection of related data items (called FIELDS)

E.g.: Employee record:
name field,
salary field,
date-of-hire field, ...

Types of records:

- Main choices:
  - FIXED vs VARIABLE FORMAT
  - FIXED vs VARIABLE LENGTH

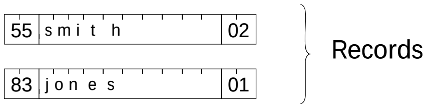
Fixed format

A SCHEMA (not record) contains following information
- # fields
- type of each field
- order in record
- meaning of each field

Example: fixed format and length

Employee record
(1) E#, 2 byte integer
(2) E.name, 10 char.
(3) Dept, 2 byte code

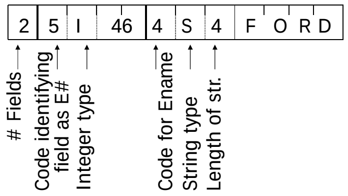
Schema



Variable format

- Record itself contains format
  “Self Describing”

Example: variable format and length



Field name codes could also be strings, i.e. TAGS

Variable format useful for:

- “sparse” records
- repeating fields
- evolving formats

→ But may waste space...

- EXAMPLE: var format record with repeating fields
  Employee → one or more → children

3	E_name: Fred	Child: Sally	Child: Tom

Note: Repeating fields does not imply
- variable format, nor
- variable size

John	Sailing	Chess	--

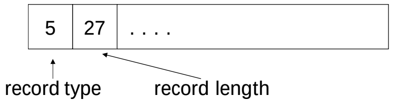
Note: Repeating fields does not imply
- variable format, nor
- variable size

John	Sailing	Chess	--

- Key is to allocate maximum number of repeating fields (if not used → null)

☆ Many variants between fixed - variable format:

Example: Include record type in record



record type tells me what to expect (i.e. points to schema)

record length

Record header - data at beginning that describes record

May contain:

- record type
- record length
- time stamp
- other stuff ...

Exercise: How to store XML data?

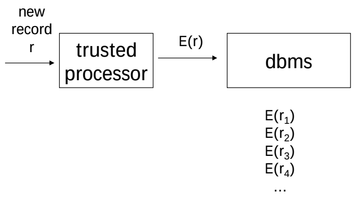
```
<table>
<description> people on the fourth floor <\description>
<people>
   <person>
         <name> Alan <\name>
         <age> 42 <\age>
         <email> agb@abc.com <\email>
   <\person>
   <person>
         <name> Sally <\name>
         <age> 30 <\age>
         <email> sally@abc.com <\email>
   <\person>
<\people>
<\table>
```

from:
Data on the Web,
Abiteboul et al

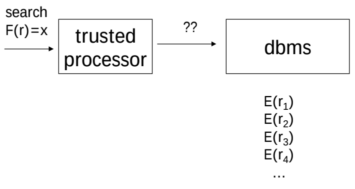
Other interesting issues:

- Compression
  - within record - e.g. code selection
  - collection of records - e.g. find common patterns
- Encryption

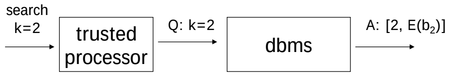
Encrypting Records



Encrypting Records



Search Key in the Clear



search k=2

trusted processor

Q: k=2

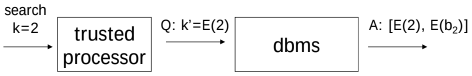
dbms

A: [2, E(b_2)]

[1, E(b_1)]
[2, E(b_2)]
[3, E(b_3)]
[4, E(b_4)]
...

- each record is [k,b]
- store [k, E(b)]
- can search for records with k=x

Encrypt Key



search k=2

trusted processor

Q: k'=E(2)

dbms

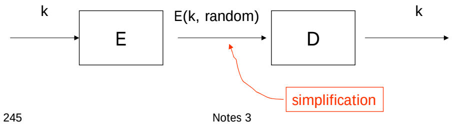
A: [E(2), E(b_2)]

[E(1), E(b_1)]
[E(2), E(b_2)]
[E(3), E(b_3)]
[E(4), E(b_4)]
...

- each record is [k,b]
- store [E(k), E(b)]
- can search for records with k=E(x)

Issues

- Hard to do range queries
- Encryption not good
- Better to use encryption that does not always generate same cyphertext



k

E

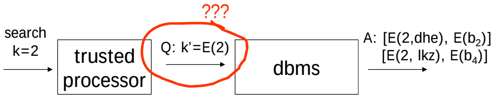
E(k, random)

D

k

simplification

How Do We Search Now?



???

search k=2

trusted processor

Q: k'=E(2)

dbms

A: [E(2,dhe), E(b_2)]
[E(2, lkz), E(b_4)]

[E(1, abc), E(b_1)]
[E(2, dhe), E(b_2)]
[E(3, nft), E(b_3)]
[E(2, lkz), E(b_4)]
...

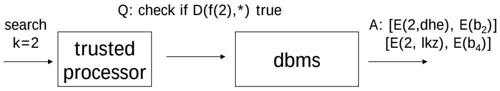
- each record is [k,b]
- store [E(k, rand), E(b)]
- can search for records with k=E(x,???)?

Solution?

- Develop new decryption function:
  D(f(k_1), E(k_2, rand)) is true if k_1=k_2

Solution?

- Develop new decryption function:
  D(f(k_1), E(k_2, rand)) is true if k_1=k_2



Q: check if D(f(2),*) true

search k=2

trusted processor

dbms

A: [E(2,dhe), E(b_2)]
[E(2, lkz), E(b_4)]

[E(1, abc), E(b_1)]
[E(2, dhe), E(b_2)]
[E(3, nft), E(b_3)]
[E(2, lkz), E(b_4)]
...

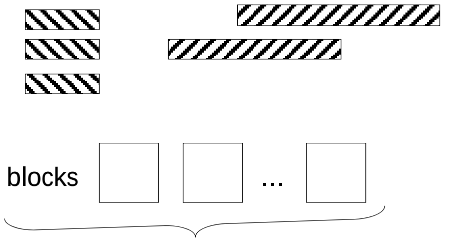
Issues?

- Cannot do non-equality predicates
- Hard to build indexes

What are choices/issues with data compression?

- Leaving search keys uncompressed not as bad
- Larger compression units:
  - better for compression efficiency
  - worse for decompression overhead
- Similar data compresses better
  - compress columns?

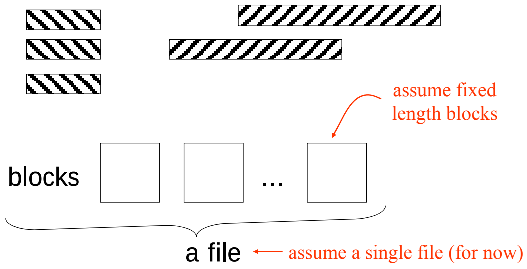
Next: placing records into blocks



blocks ...

a file

Next: placing records into blocks



blocks ...

assume fixed length blocks

a file ← assume a single file (for now)

Options for storing records in blocks:

(1) separating records

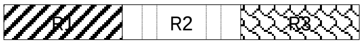
(2) spanned vs. unspanned

(3) sequencing

(4) indirection

(1) Separating records

Block



(a) no need to separate - fixed size recs.

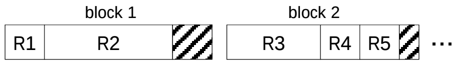
(b) special marker

(c) give record lengths (or offsets)

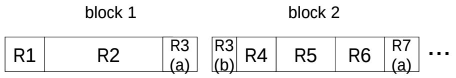
- within each record
- in block header

(2) Spanned vs. Unspanned

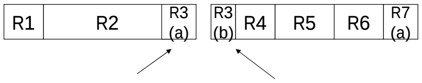
- Unspanned: records must be within one block



- Spanned



With spanned records:



need indication
of partial record
"pointer" to rest

need indication
of continuation
(+ from where?)

Spanned vs. unspanned:

- Unspanned is much simpler, but may waste space...
- Spanned essential if

  record size > block size

(3) Sequencing

- Ordering records in file (and block) by some key value

  Sequential file (⇒ sequenced)

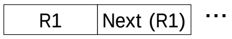
Why sequencing?

Typically to make it possible to efficiently read records in order

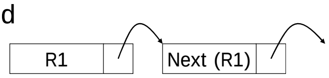
(e.g., to do a merge-join — discussed later)

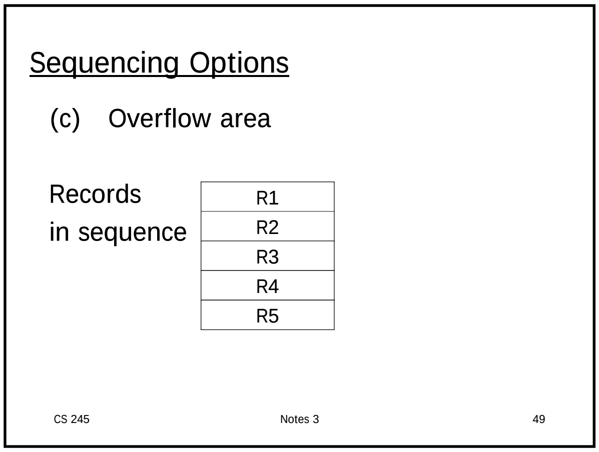
Sequencing Options

(a) Next record physically contiguous



(b) Linked



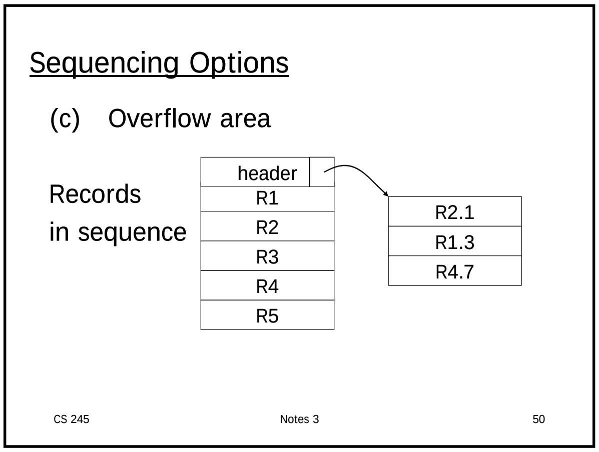


Sequencing Options

(c) Overflow area

Records in sequence

R1
R2
R3
R4
R5



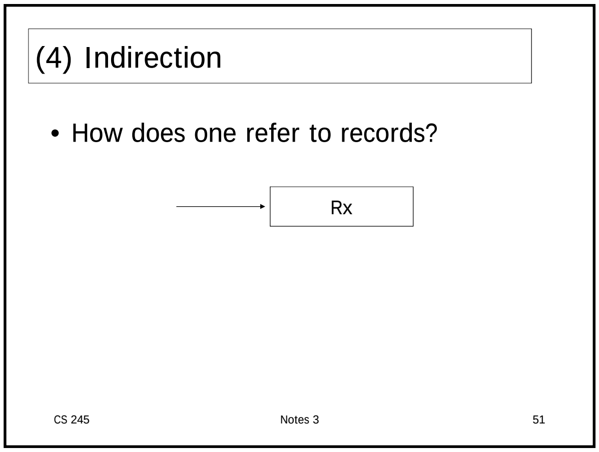
Sequencing Options

(c) Overflow area

Records in sequence

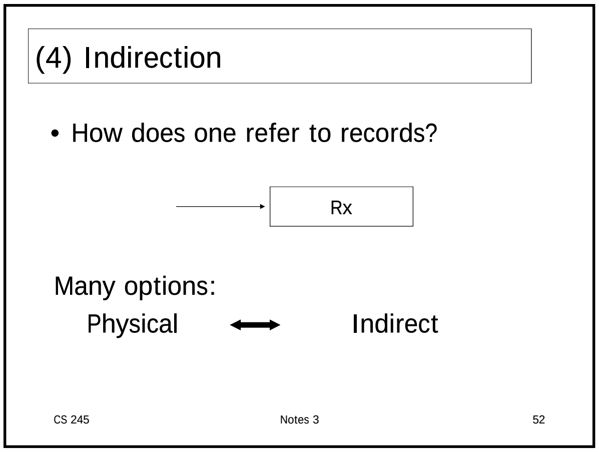
header
R1
R2
R3
R4
R5

R2.1
R1.3
R4.7



(4) Indirection

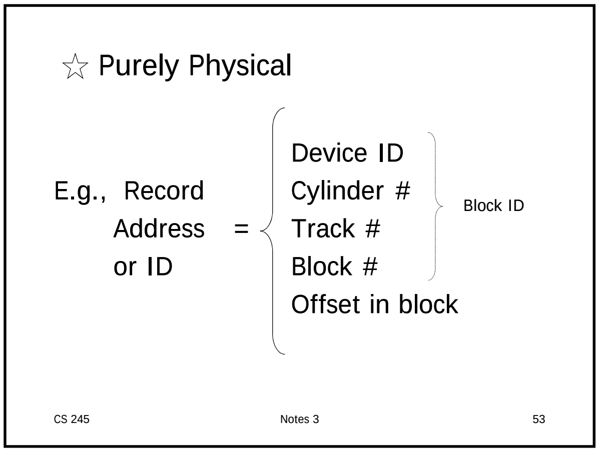
- How does one refer to records?



(4) Indirection

- How does one refer to records?

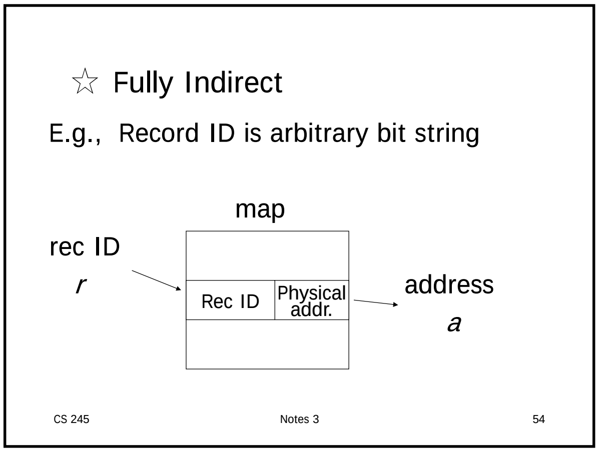
Many options:
Physical ⟷ Indirect



☆ Purely Physical

E.g., Record Address or ID = {Device ID, Cylinder #, Track #, Block #, Offset in block}

Device ID, Cylinder #, Track #, Block #: Block ID



☆ Fully Indirect

E.g., Record ID is arbitrary bit string

Tradeoff

Flexibility ⟷ Cost

to move records   of indirection

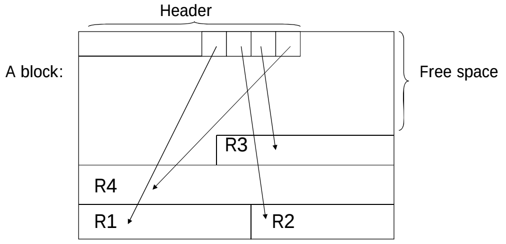
(for deletions, insertions)

Physical ⟷ Indirect

↑

Many options
in between ...

Example: Indirection in block



Block header - data at beginning that describes block

May contain:

- File ID (or RELATION or DB ID)
- This block ID
- Record directory
- Pointer to free space
- Type of block (e.g. contains recs type 4; is overflow, ...)
- Pointer to other blocks “like it”
- Timestamp ...

Options for storing records in blocks:

(1) separating records

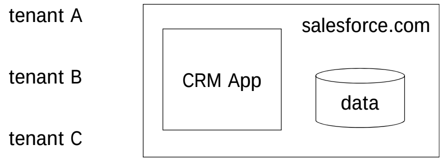
(2) spanned vs. unspanned

(3) sequencing

(4) indirection

Case Study: salesforce.com

- salesforce.com provides CRM services
- salesforce customers are *tenants*
- Tenants run apps and DBMS as service



Options for Hosting

- Separate DBMS per tenant
- One DBMS, separate tables per tenant
- One DBMS, shared tables

Tenants have similar data

tenant 1:

customer	A	B	C	D	E	F
	a1	b1	c1	d1	e1	-
	a2	b2	c2	-	e2	f2

tenant 2:

customer	A	B	C	D	G
	a3	b3	c2	-	-
	a1	b1	c1	-	g1
	a4	-	-	d1	

salesforce.com solution

customer	tenant	A	B	C
	1	a1	b1	c1
	1	a2	b2	c2
	2	a3	b3	c2
	2	a1	b1	c1

← fixed schema for all tenants

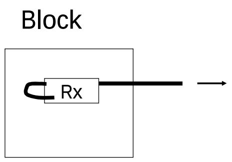
cust-other	tenant	A	f1	v1	f2	v2 ...
	1	a1	D	d1	E	e1
	1	a2	E	e2	F	f2
	2	a1	G	g1		
	3	a4	D	d1		

← var schema for all tenants

Other Topics

(1) Insertion/Deletion
(2) Buffer Management
(3) Comparison of Schemes

Deletion



Options:

(a) Immediately reclaim space
(b) Mark deleted

Options:

(a) Immediately reclaim space

(b) Mark deleted

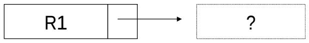
- May need chain of deleted records (for re-use)
- Need a way to mark:
  - special characters
  - delete field
  - in map

☆ As usual, many tradeoffs...

- How expensive is to move valid record to free space for immediate reclaim?
- How much space is wasted?
  - e.g., deleted records, delete fields, free space chains,...

Concern with deletions

Dangling pointers



Solution #1: Do not worry

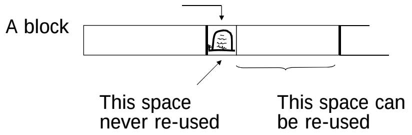
Solution #2: Tombstones

E.g., Leave “MARK” in map or old location

Solution #2: Tombstones

E.g., Leave “MARK” in map or old location

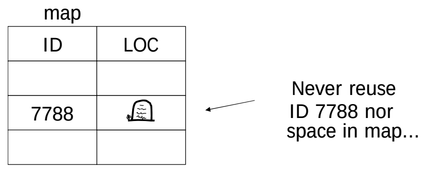
- Physical IDs



Solution #2: Tombstones

E.g., Leave “MARK” in map or old location

- Logical IDs



Insert

Easy case: records not in sequence

→ Insert new record at end of file or in deleted slot

→ If records are variable size, not as easy...

Insert

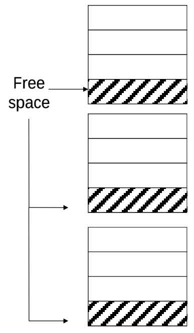
Hard case: records in sequence

→ If free space “close by”, not too bad...

→ Or use overflow idea...

Interesting problems:

- How much free space to leave in each block, track, cylinder?
- How often do I reorganize file + overflow?

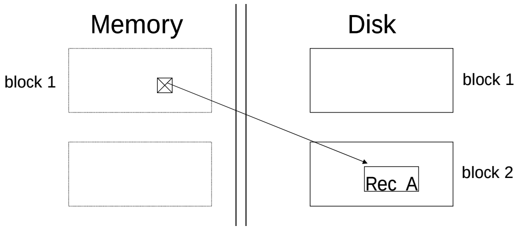


Buffer Management

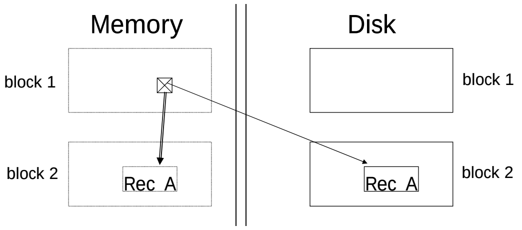
- DB features needed
- Why LRU may be bad
- Pinned blocks
- Forced output
- Double buffering → in Notes02
- Swizzling

} Read Textbook!

Swizzling



Swizzling



Row vs Column Store

- So far we assumed that fields of a record are stored contiguously (row store)...
- Another option is to store like fields together (column store)

Row Store

- Example: Order consists of
  - id, cust, prod, store, price, date, qty

id1	cust1	prod1	store1	price1	date1	qty1
id2	cust2	prod2	store2	price2	date2	qty2
id3	cust3	prod3	store3	price3	date3	qty3

Column Store

- Example: Order consists of
  - id, cust, prod, store, price, date, qty

id1	cust1
id2	cust2
id3	cust3
id4	cust4
...	...

id1	prod1
id2	prod2
id3	prod3
id4	prod4
...	...

id1	price1	qty1
id2	price2	qty2
id3	price3	qty3
id4	price4	qty4
...	...	...

ids may or may not be stored explicitly

Row vs Column Store

- Advantages of Column Store
  - more compact storage (fields need not start at byte boundaries)
  - efficient reads on data mining operations
- Advantages of Row Store
  - writes (multiple fields of one record)more efficient
  - efficient reads for record access (OLTP)

Interesting paper to read:

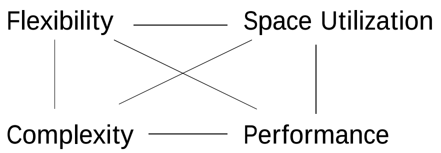
- Mike Stonebreaker, Elizabeth (Betty) O'Neil, Pat O'Neil, Xuedong Chen, et al. " C-Store: A Column-oriented DBMS," Presented at the 31st VLDB Conference, September 2005.
- http://www.cs.umb.edu/%7Eponeil/vldb05_cstore.pdf

Comparison

- There are 10,000,000 ways to organize my data on disk…

Which is right for me?

Issues:



☆ To evaluate a given strategy, compute following parameters:

-> space used for expected data

-> expected time to

- fetch record given key
- fetch record with next key
- insert record
- append record
- delete record
- update record
- read all file
- reorganize file

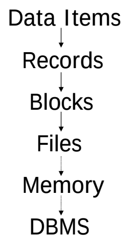
Example

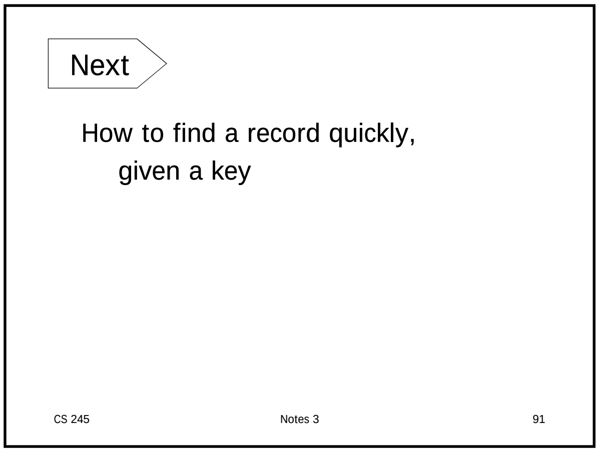
How would you design Megatron 3000 storage system? (for a relational DB, low end)

– Variable length records?
– Spanned?
– What data types?
– Fixed format?
– Record IDs ?
– Sequencing?
– How to handle deletions?

Summary

- How to lay out data on disk





Next

How to find a record quickly, given a key