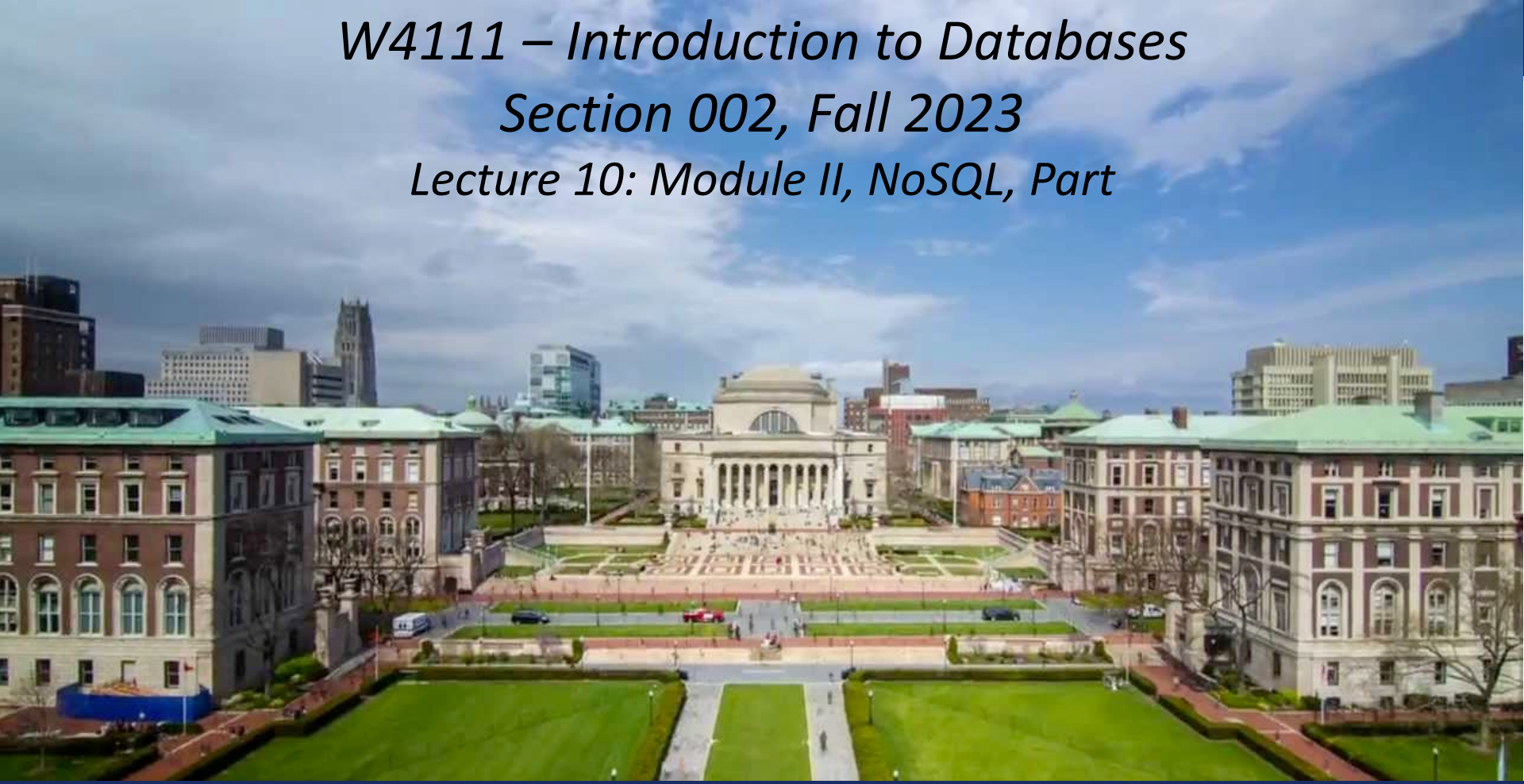
W4111 – Introduction to Databases
Section 002, Fall 2023
Lecture 10: Module II, NoSQL, Part

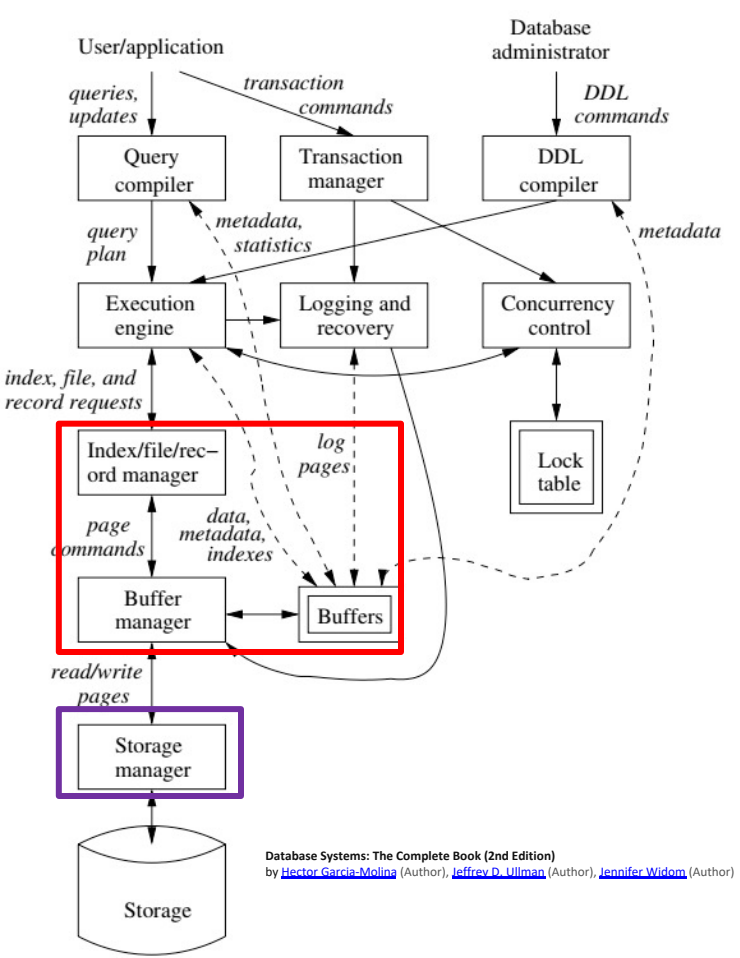


Indexes

Indexes

Today

- Find things quickly.



Basic Concepts

- Indexing mechanisms used to speed up access to desired data.
  - E.g., author catalog in library
- **Search Key** - attribute to set of attributes used to look up records in a file.
- An **index file** consists of records (called **index entries**) of the form

search-key	pointer

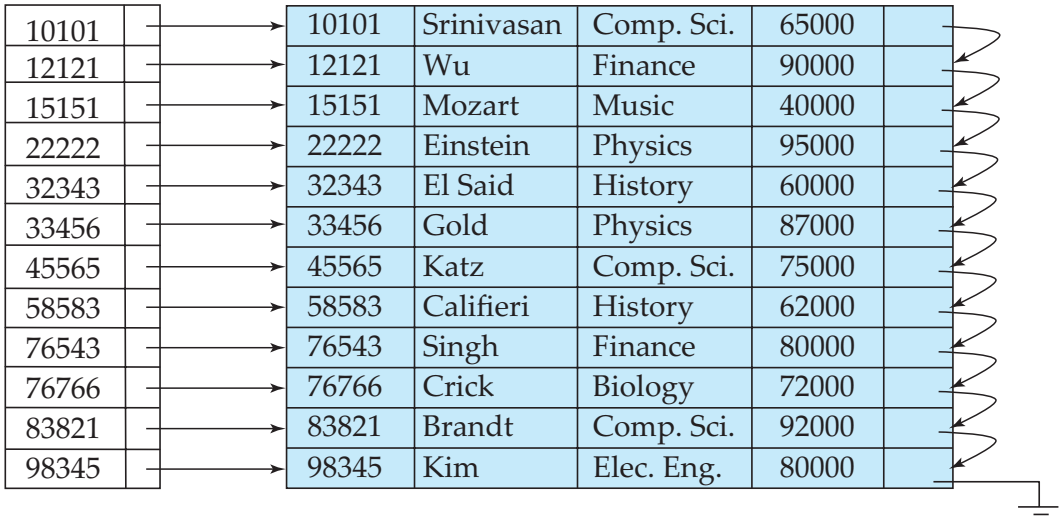
- Index files are typically much smaller than the original file
- Two basic kinds of indices:
  - **Ordered indices:** search keys are stored in sorted order
  - **Hash indices:** search keys are distributed uniformly across "buckets" using a "hash function".

Ordered Indices

- In an **ordered index,** index entries are stored sorted on the search key value.
- **Clustering index:** in a sequentially ordered file, the index whose search key specifies the sequential order of the file.
  - Also called **primary index**
  - The search key of a primary index is usually but not necessarily the primary key.
- **Secondary index**: an index whose search key specifies an order different from the sequential order of the file. Also called **nonclustering index.**
- **Index-sequential file:** sequential file ordered on a search key, with a clustering index on the search key.

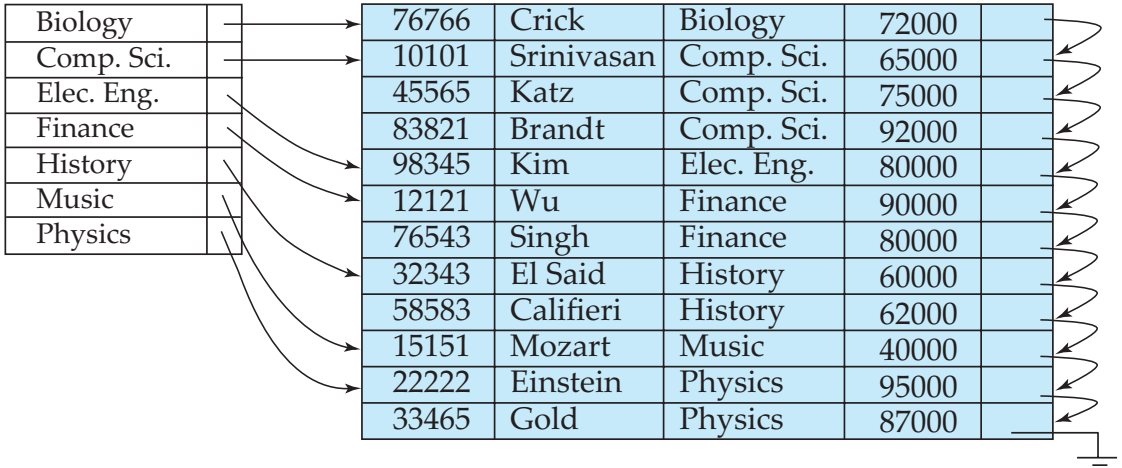
Dense Index Files

- **Dense index** — Index record appears for every search-key value in the file.
- E.g. index on *ID* attribute of *instructor* relation



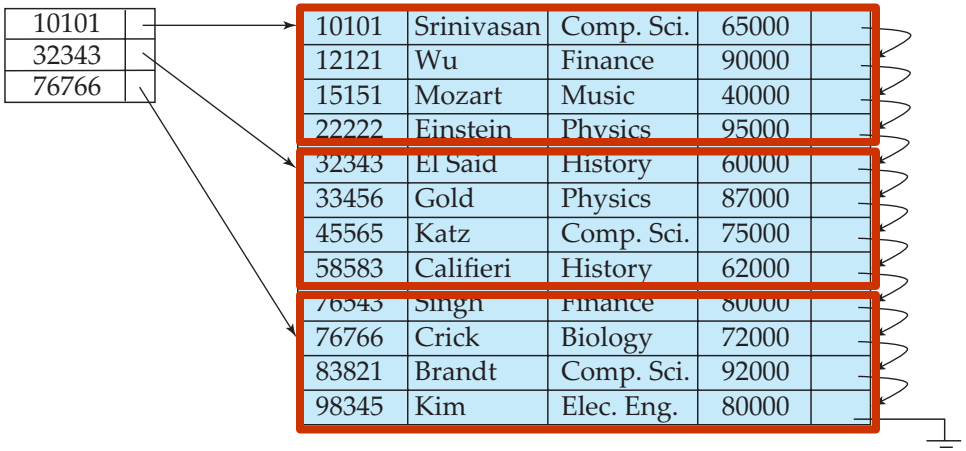
Dense Index Files (Cont.)

- Dense index on *dept_name*, with *instructor* file sorted on *dept_name*



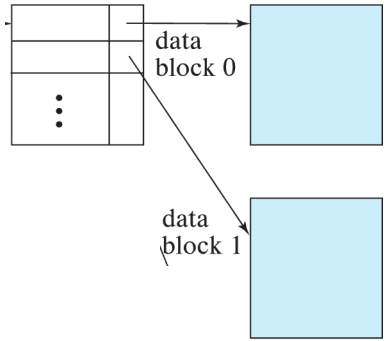
Sparse Index Files

- **Sparse Index**: contains index records for only some search-key values.
  - Applicable when records are sequentially ordered on search-key
- To locate a record with search-key value *K* we:
  - Find index record with largest search-key value < *K*
  - Search file sequentially starting at the record to which the index record points



Sparse Index Files (Cont.)

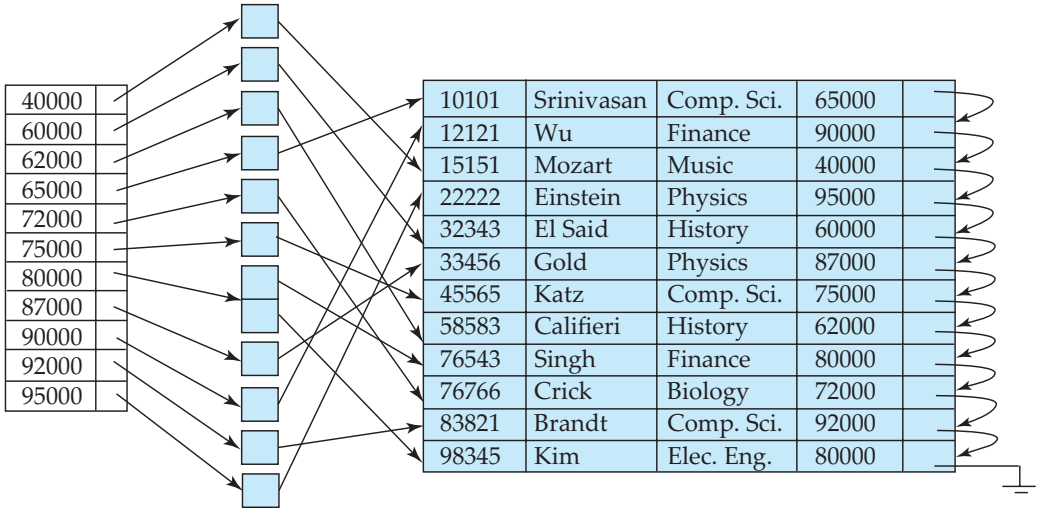
- Compared to dense indices:
  - Less space and less maintenance overhead for insertions and deletions.
  - Generally slower than dense index for locating records.
- **Good tradeoff**:
  - for clustered index: sparse index with an index entry for every block in file, corresponding to least search-key value in the block.



  - For unclustered index: sparse index on top of dense index (multilevel index)

Secondary Indices Example

- Secondary index on salary field of instructor



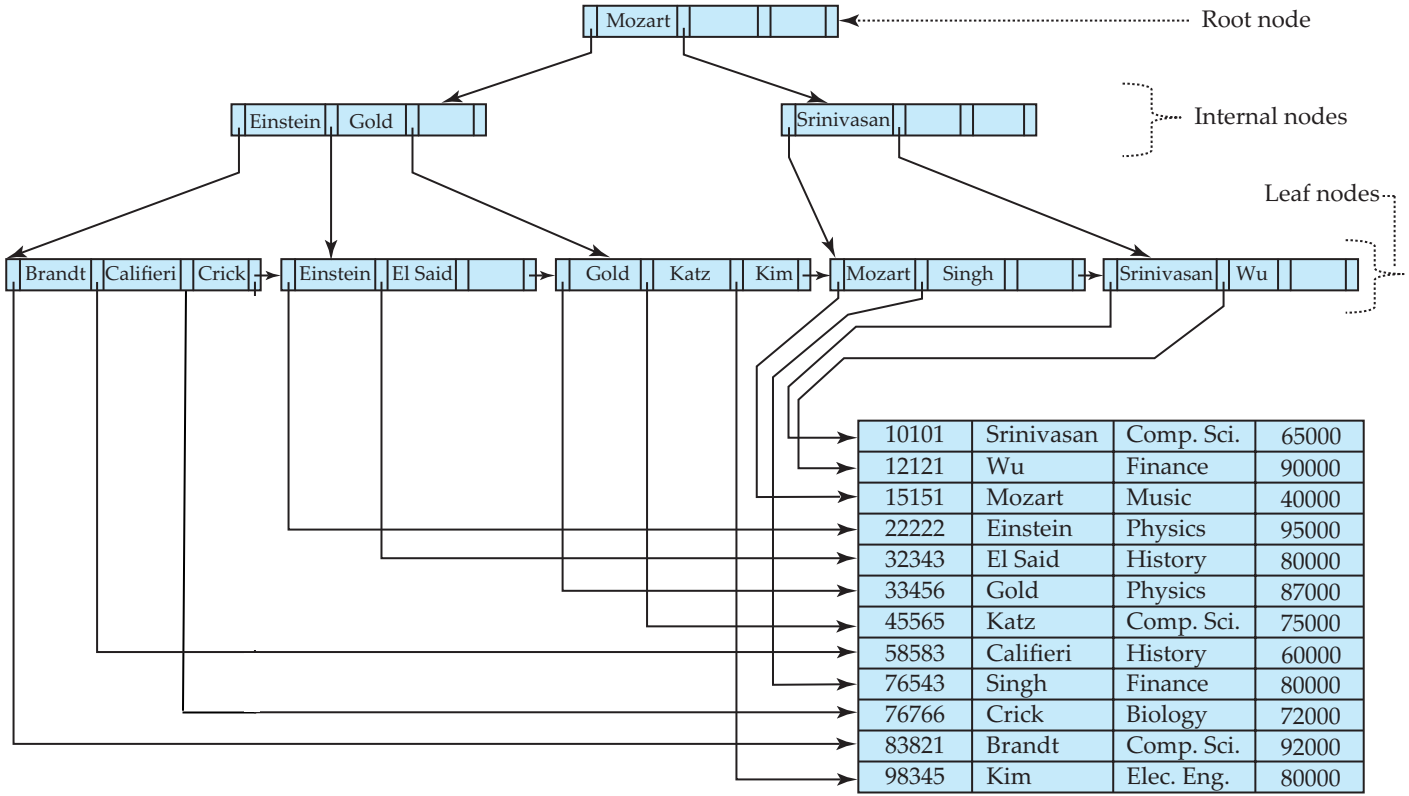
- Index record points to a bucket that contains pointers to all the actual records with that particular search-key value.
- Secondary indices have to be dense

Indices on Multiple Keys

- **Composite search key**
  - E.g., index on *instructor* relation on attributes (*name, ID*)
  - Values are sorted lexicographically
    - E.g. (John, 12121) < (John, 13514) and (John, 13514) < (Peter, 11223)
  - Can query on just *name*, or on (*name, ID*)

- (nameLast, nameFirst, birthyear)
  - nameLast [nameLast = “Ferguson”] [nameLast like “Fer%”]
  - nameLast, nameFirst
  - nameLast, nameFirst, birthyear
- NOT and index on
  - nameFirst, nameLast
  - birthyear
  - nameLast like [%er%]

Example of B+-Tree



B+-Tree Index Files (Cont.)

A B+-tree is a rooted tree satisfying the following properties:

- All paths from root to leaf are of the same length
- Each node that is not a root or a leaf has between $\lceil n/2 \rceil$ and n children.
- A leaf node has between $\lceil (n–1)/2 \rceil$ and $n–1$ values
- Special cases:
  - If the root is not a leaf, it has at least 2 children.
  - If the root is a leaf (that is, there are no other nodes in the tree), it can have between 0 and $(n–1)$ values.

B+-Tree Node Structure

- Typical node

P_1	K_1	P_2	…	P_{n-1}	K_{n-1}	P_n

  - K_i are the search-key values
  - P_i are pointers to children (for non-leaf nodes) or pointers to records or buckets of records (for leaf nodes).
- The search-keys in a node are ordered

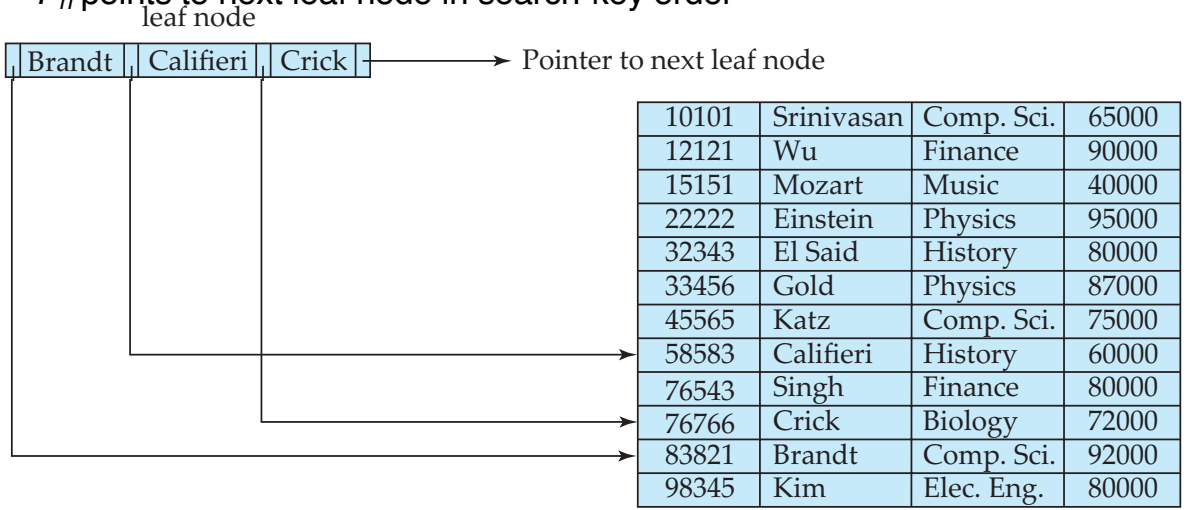
$$K_1 < K_2 < K_3 < \ldots < K_{n-1}$$

(Initially assume no duplicate keys, address duplicates later)

Leaf Nodes in B+-Trees

Properties of a leaf node:

- For $i = 1, 2, \ldots, n-1$, pointer P_i points to a file record with search-key value K_i,
- If L_i, L_j are leaf nodes and $i < j$, L_i's search-key values are less than or equal to L_j's search-key values
- P_n points to next leaf node in search-key order



10101	Srinivasan	Comp. Sci.	65000
12121	Wu	Finance	90000
15151	Mozart	Music	40000
22222	Einstein	Physics	95000
32343	El Said	History	80000
33456	Gold	Physics	87000
45565	Katz	Comp. Sci.	75000
58583	Califieri	History	60000
76543	Singh	Finance	80000
76766	Crick	Biology	72000
83821	Brandt	Comp. Sci.	92000
98345	Kim	Elec. Eng.	80000

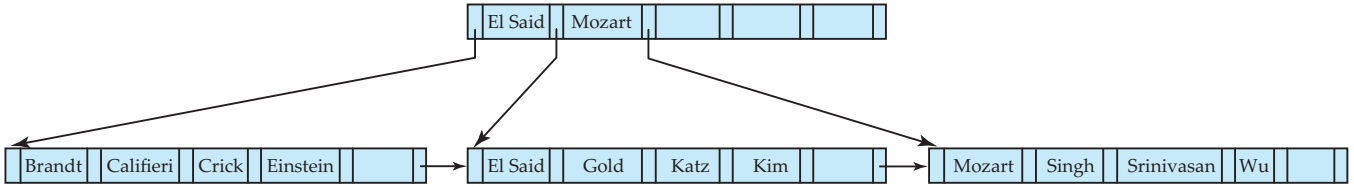
Non-Leaf Nodes in B+-Trees

- Non leaf nodes form a multi-level sparse index on the leaf nodes. For a non-leaf node with m pointers:
  - All the search-keys in the subtree to which P_1 points are less than K_1
  - For $2 \leq i \leq n - 1$, all the search-keys in the subtree to which P_i points have values greater than or equal to K_{i-1} and less than K_i
  - All the search-keys in the subtree to which P_n points have values greater than or equal to K_{n-1}
  - General structure

P_1	K_1	P_2	$\cdots$	P_{n-1}	K_{n-1}	P_n

Example of B+-tree

- B+-tree for *instructor* file ($n = 6$)



- Leaf nodes must have between 3 and 5 values ($\lceil (n-1)/2 \rceil$ and $n-1$, with $n = 6$).
- Non-leaf nodes other than root must have between 3 and 6 children ($\lceil (n/2 \rceil$ and n with $n = 6$).
- Root must have at least 2 children.

Observations about B^+-trees

- Since the inter-node connections are done by pointers, "logically" close blocks need not be "physically" close.
- The non-leaf levels of the B^+-tree form a hierarchy of sparse indices.
- The B^+-tree contains a relatively small number of levels
  - Level below root has at least $2* \lceil n/2 \rceil$ values
  - Next level has at least $2* \lceil n/2 \rceil * \lceil n/2 \rceil$ values
  - .. etc.
  - If there are K search-key values in the file, the tree height is no more than $\lceil \log_{\lceil n/2 \rceil}(K) \rceil$
  - thus searches can be conducted efficiently.
- Insertions and deletions to the main file can be handled efficiently, as the index can be restructured in logarithmic time (as we shall see).

Show the Simulator

https://www.cs.usfca.edu/~galles/visualization/BPlusTree.html

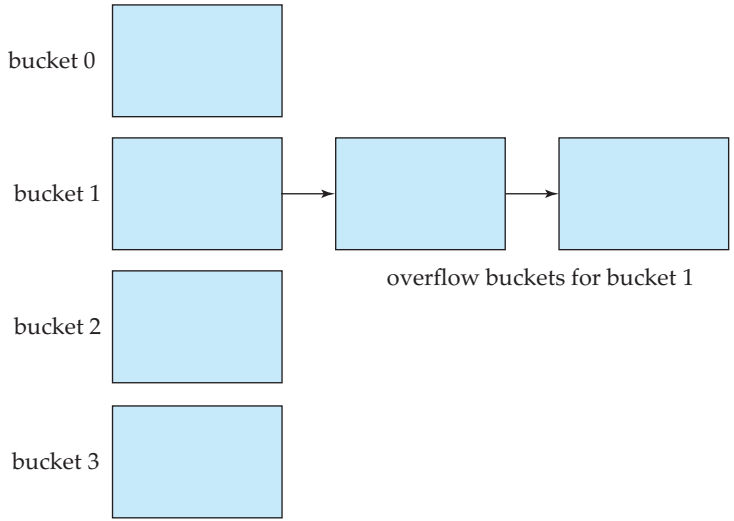
Hashing

Static Hashing

- A **bucket** is a unit of storage containing one or more entries (a bucket is typically a disk block).
  - we obtain the bucket of an entry from its search-key value using a **hash function**
- Hash function *h* is a function from the set of all search-key values *K* to the set of all bucket addresses *B.*
- Hash function is used to locate entries for access, insertion as well as deletion.
- Entries with different search-key values may be mapped to the same bucket; thus entire bucket has to be searched sequentially to locate an entry.
- In a **hash index**, buckets store entries with pointers to records
- In a **hash file-organization** buckets store records

Handling of Bucket Overflows (Cont.)

- **Overflow chaining** – the overflow buckets of a given bucket are chained together in a linked list.
- Above scheme is called **closed addressing (**also called **closed hashing or open hashing** depending on the book you use**)**
  - An alternative, called **open addressing (**also called **open hashing** or **closed hashing** depending on the book you use) which does not use over-flow buckets, is not suitable for database applications.



Example of Hash File Organization

Hash file organization of *instructor* file, using *dept_name* as key.

bucket 0

bucket 1

15151	Mozart	Music	40000

bucket 2

32343	El Said	History	80000
58583	Califieri	History	60000

bucket 3

22222	Einstein	Physics	95000
33456	Gold	Physics	87000
98345	Kim	Elec. Eng.	80000

bucket 4

12121	Wu	Finance	90000
76543	Singh	Finance	80000

bucket 5

76766	Crick	Biology	72000

bucket 6

10101	Srinivasan	Comp. Sci.	65000
45565	Katz	Comp. Sci.	75000
83821	Brandt	Comp. Sci.	92000

bucket 7

Deficiencies of Static Hashing

- In static hashing, function *h* maps search-key values to a fixed set of *B* of bucket addresses. Databases grow or shrink with time.
  - If initial number of buckets is too small, and file grows, performance will degrade due to too much overflows.
  - If space is allocated for anticipated growth, a significant amount of space will be wasted initially (and buckets will be underfull).
  - If database shrinks, again space will be wasted.
- One solution: periodic re-organization of the file with a new hash function
  - Expensive, disrupts normal operations
- Better solution: allow the number of buckets to be modified dynamically.

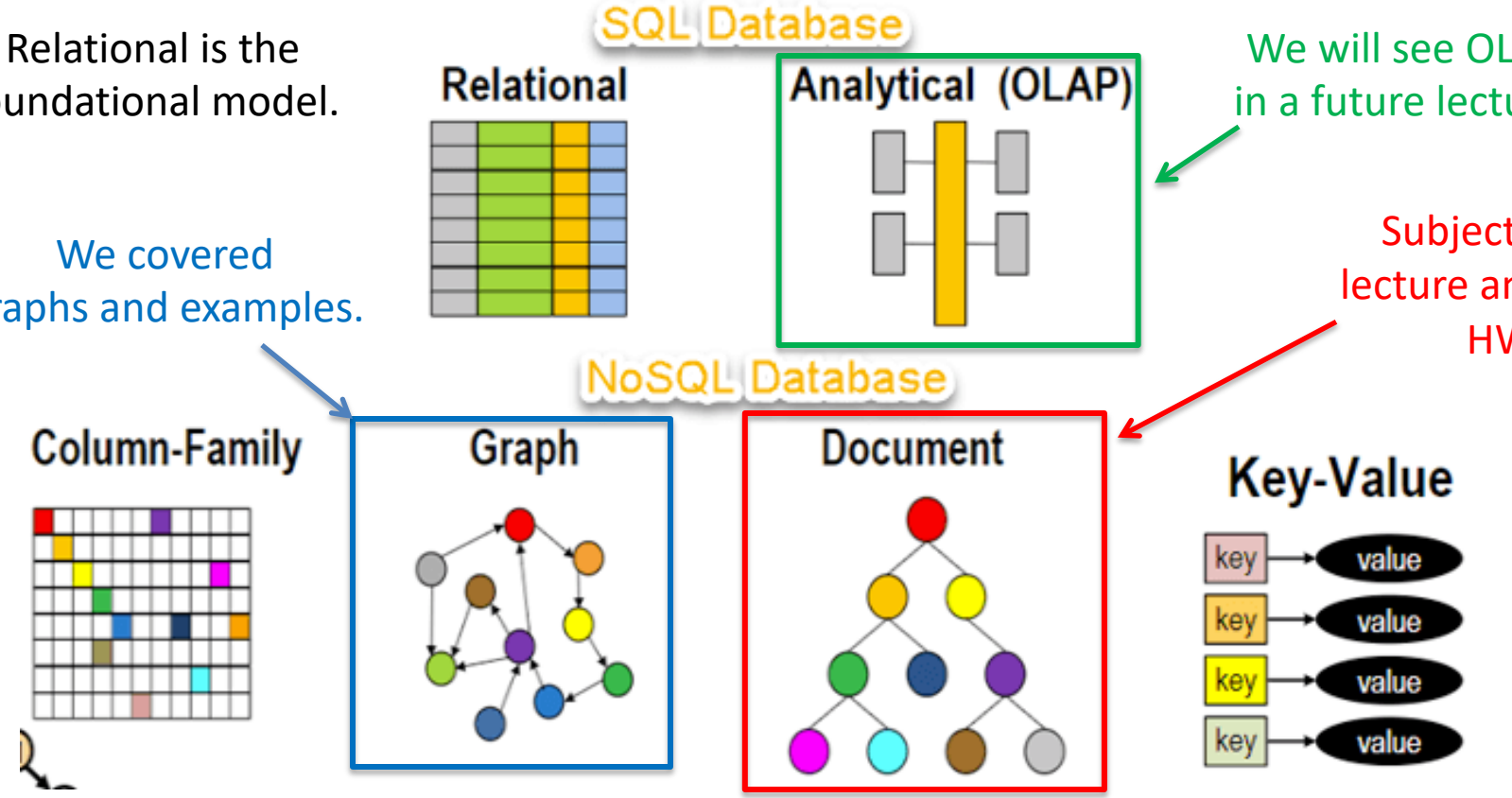
Show the Simulator

http://iswsa.acm.org/mphf/openDSAPerfectHashAnimation/perfectHashAV.html
https://opendsa-server.cs.vt.edu/ODSA/AV/Development/hashAV.html

NoSQL
GraphDB

Simplistic Classification (https://medium.com/swlh/4-types-of-nosql-databases-d88ad21f7d3b)

Relational is the foundational model.



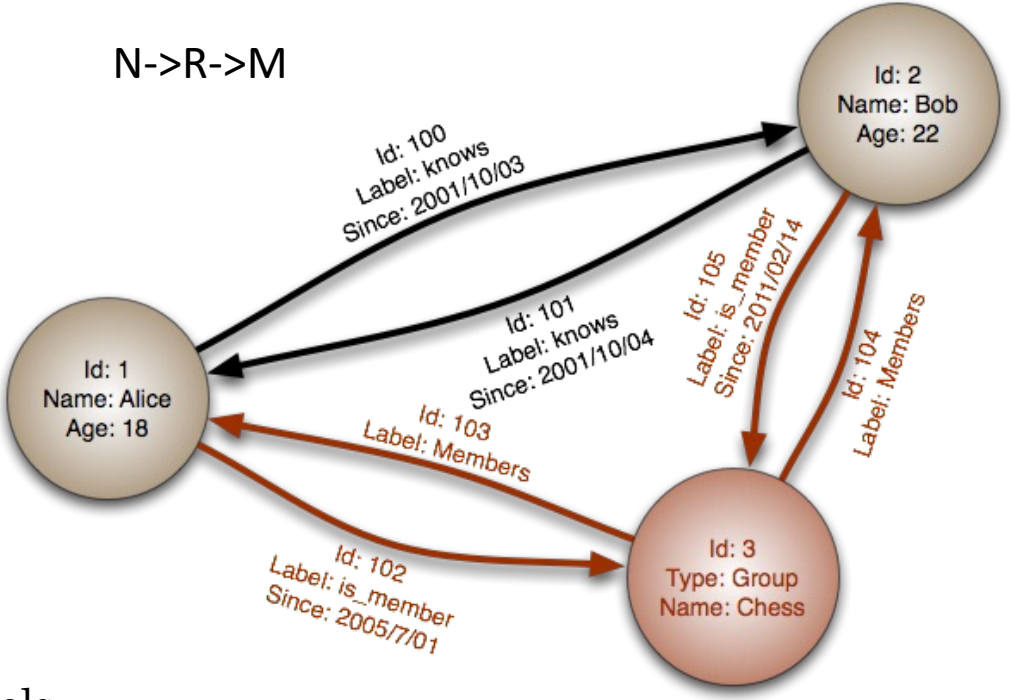
We will see OLAP in a future lecture.

We covered graphs and examples.

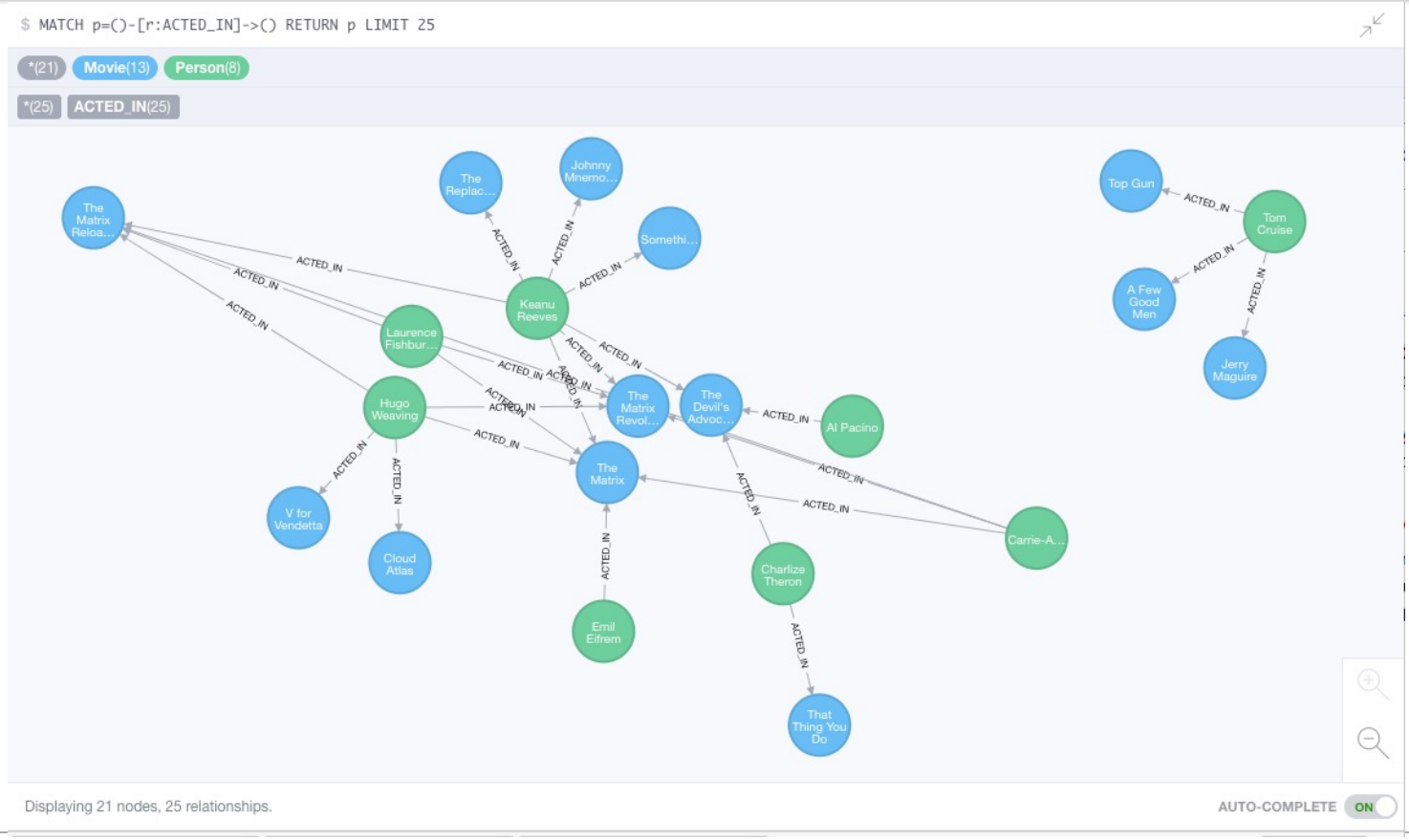
Subject of this lecture and part of HW4

Graph Database

- Exactly what it sounds like
- Two core types
  - Node
  - Edge (link)
- Nodes and Edges have
  - Label(s) = “Kind”
  - Properties (free form)
- Query is of the form
  - p1(n)-p2(e)-p3(m)
  - n, m are nodes; e is an edge
  - p1, p2, p3 are predicates on labels



Neo4J Graph Query



Why Graph Databases?

- Schema Less and Efficient storage of Semi Structured Information
- No O/R mismatch – very natural to map a graph to an Object Oriented language like Ruby.
- Express Queries as Traversals. Fast deep traversal instead of slow SQL queries that span many table joins.
- Very natural to express graph related problem with traversals (recommendation engine, find shortest parth etc..)
- Seamless integration with various existing programming languages.
- ACID Transaction with rollbacks support.
- Whiteboard friendly – you use the language of node,properties and relationship to describe your domain (instead of e.g. UML) and there is no need to have a complicated O/R mapping tool to implement it in your database. You can say that Neo4j is "Whiteboard friendly" !(http://video.neo4j.org/JHU6F/live-graph-session-how-allison-knows-james/)

Social Network "path exists" Performance

- Experiment:
  - ~1k persons
  - Average 50 friends per person
  - `pathExists(a,b)` limited to depth 4

	# persons	query time
Relational database	1000	2000ms
Neo4j	1000	2ms
Neo4j	1000000	2ms

Graph databases are

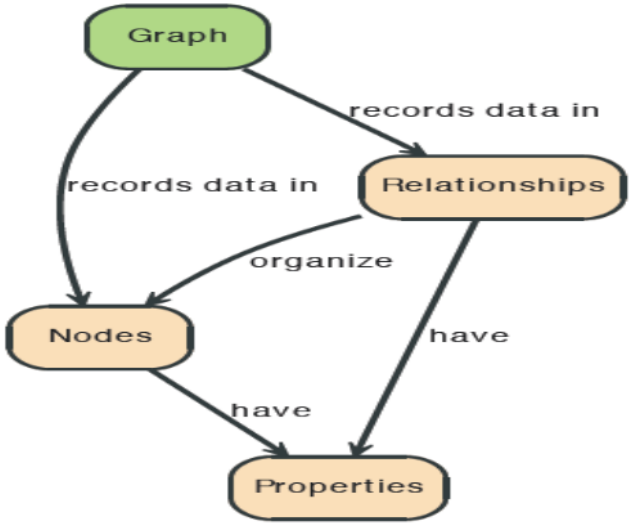
- Extremely fast for some queries and data models.
- Implement a language that vastly simplifies writing queries.

What are graphs good for?

- Recommendations
- Business intelligence
- Social computing
- Geospatial
- Systems management
- Web of things
- Genealogy
- Time series data
- Product catalogue
- Web analytics
- Scientific computing (especially bioinformatics)
- Indexing your *slow* RDBMS
- And much more!

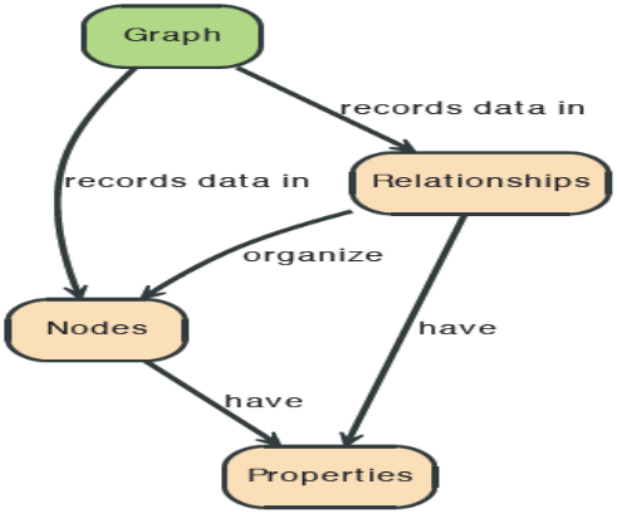
Graphs

- “A Graph —records data in→ Nodes —which have→ Properties”



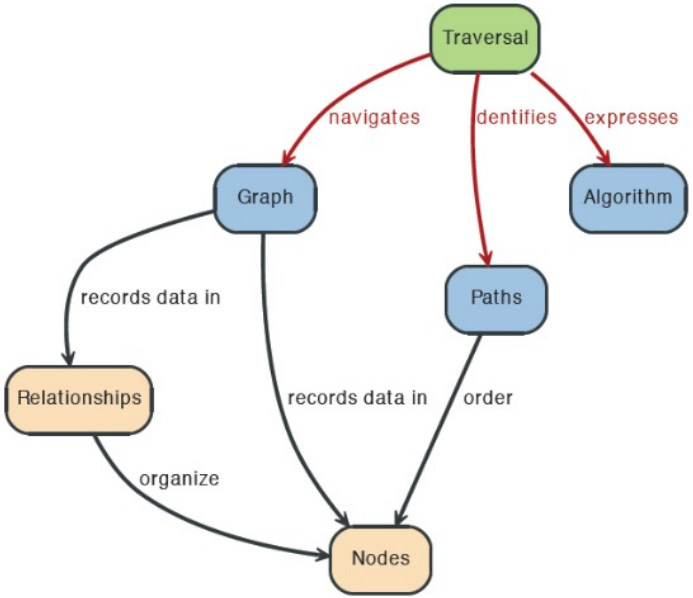
Graphs

- "Nodes —are organized by→ Relationships — which also have→ Properties"



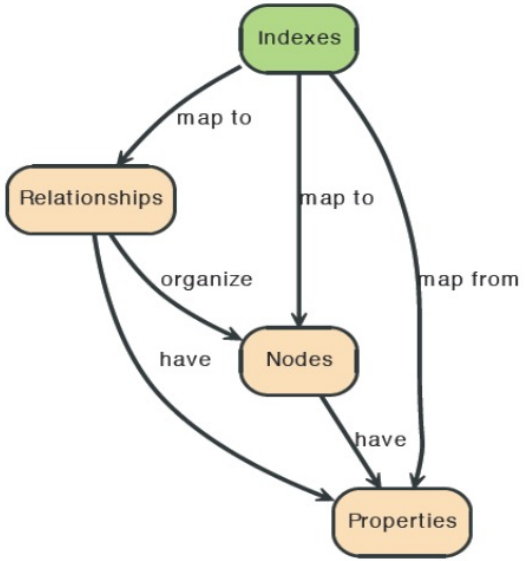
Query a graph with Traversal

- "A Traversal —navigates→ a Graph; it —identifies→ Paths —which order→ Nodes"

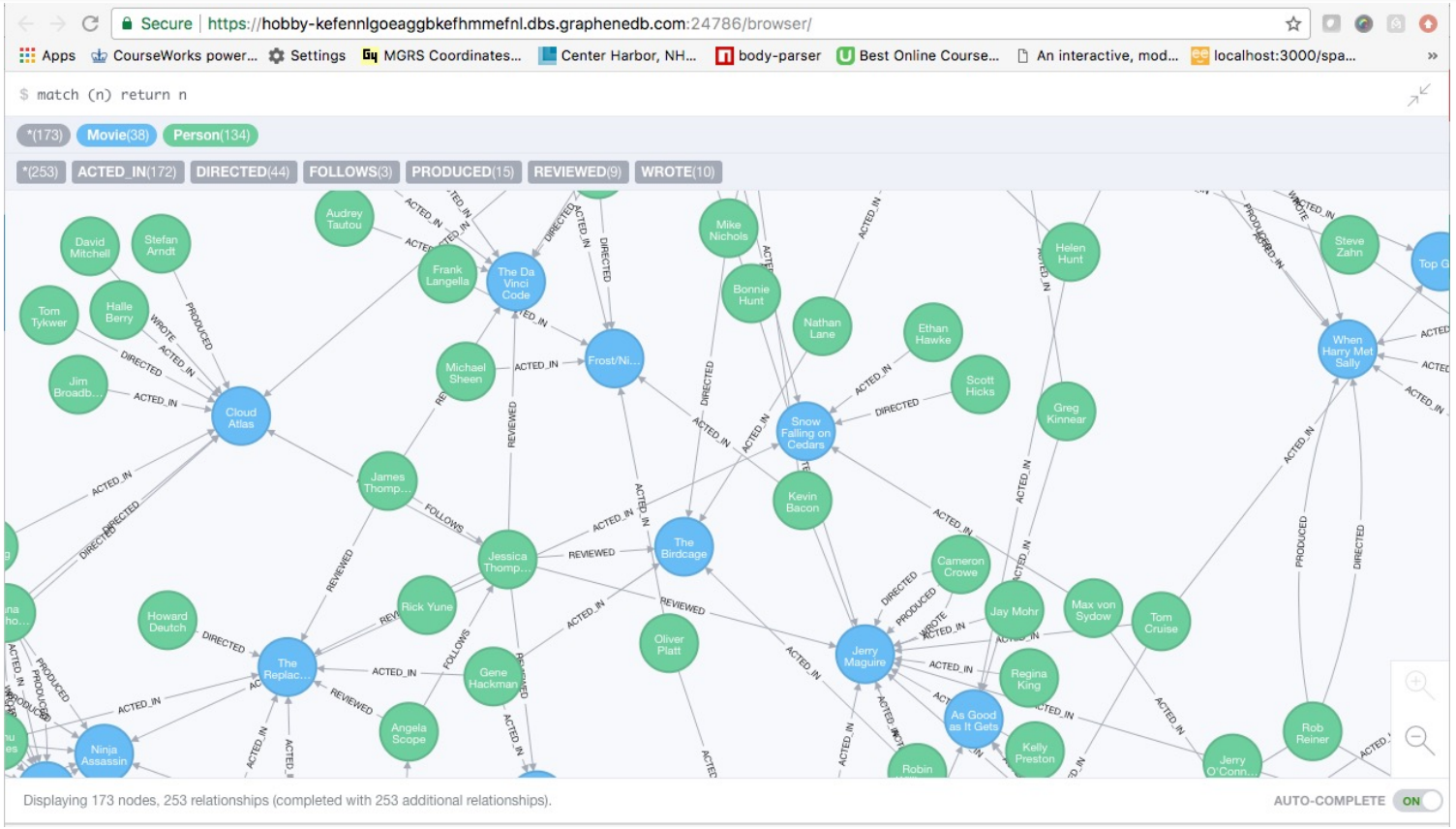


Indexes

- “An Index —maps from→ Properties —to either→ Nodes or Relationships”

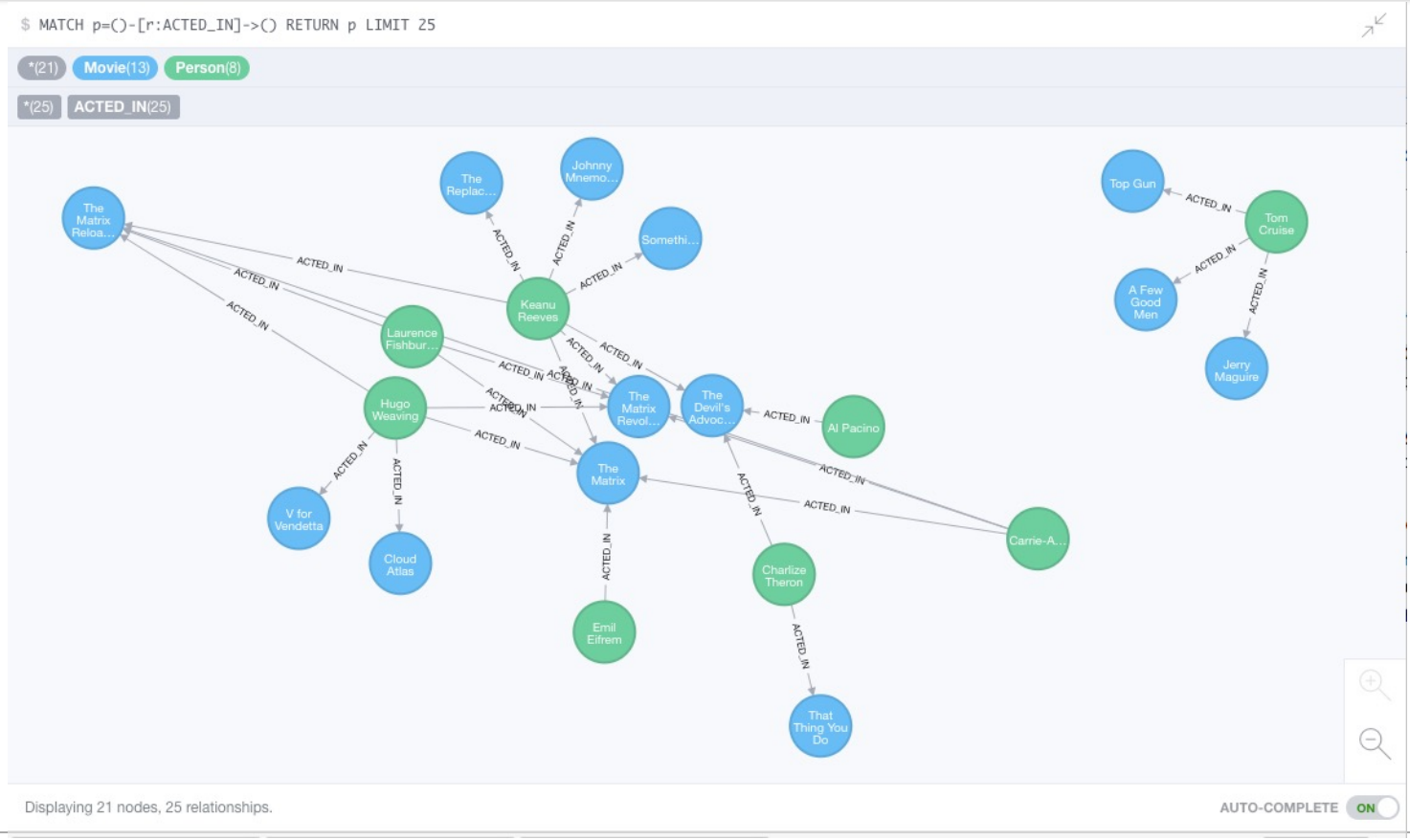


A Graph Database (Sample)



Neo4J Graph Query

Who acted in which movies?



Big Deal. That is just a JOIN.

- Yup. But that is simple.
- Try writing the queries below in SQL.

The Movie Graph

Recommend

Let's recommend new co-actors for Tom Hanks. A basic recommendation approach is to find connections past an immediate neighborhood which are themselves well connected.

For Tom Hanks, that means:

1. Find actors that Tom Hanks hasn't yet worked with, but his co-actors have.
2. Find someone who can introduce Tom to his potential co-actor.

Extend Tom Hanks co-actors, to find co-co-actors who haven't work with Tom Hanks...

```
MATCH (tom:Person {name:"Tom Hanks"})-[:ACTED_IN]->(m)<-[:ACTED_IN]-(coActors),
      (coActors)-[:ACTED_IN]->(m2)<-[:ACTED_IN]-(cocoActors)
WHERE NOT (tom)-[:ACTED_IN]->(m2)
RETURN cocoActors.name AS Recommended, count(*) AS Strength ORDER BY Strength DESC
```

Find someone to introduce Tom Hanks to Tom Cruise

```
MATCH (tom:Person {name:"Tom Hanks"})-[:ACTED_IN]->(m)<-[:ACTED_IN]-(coActors),
      (coActors)-[:ACTED_IN]->(m2)<-[:ACTED_IN]-(cruise:Person {name:"Tom Cruise"})
RETURN tom, m, coActors, m2, cruise
```

Recommend

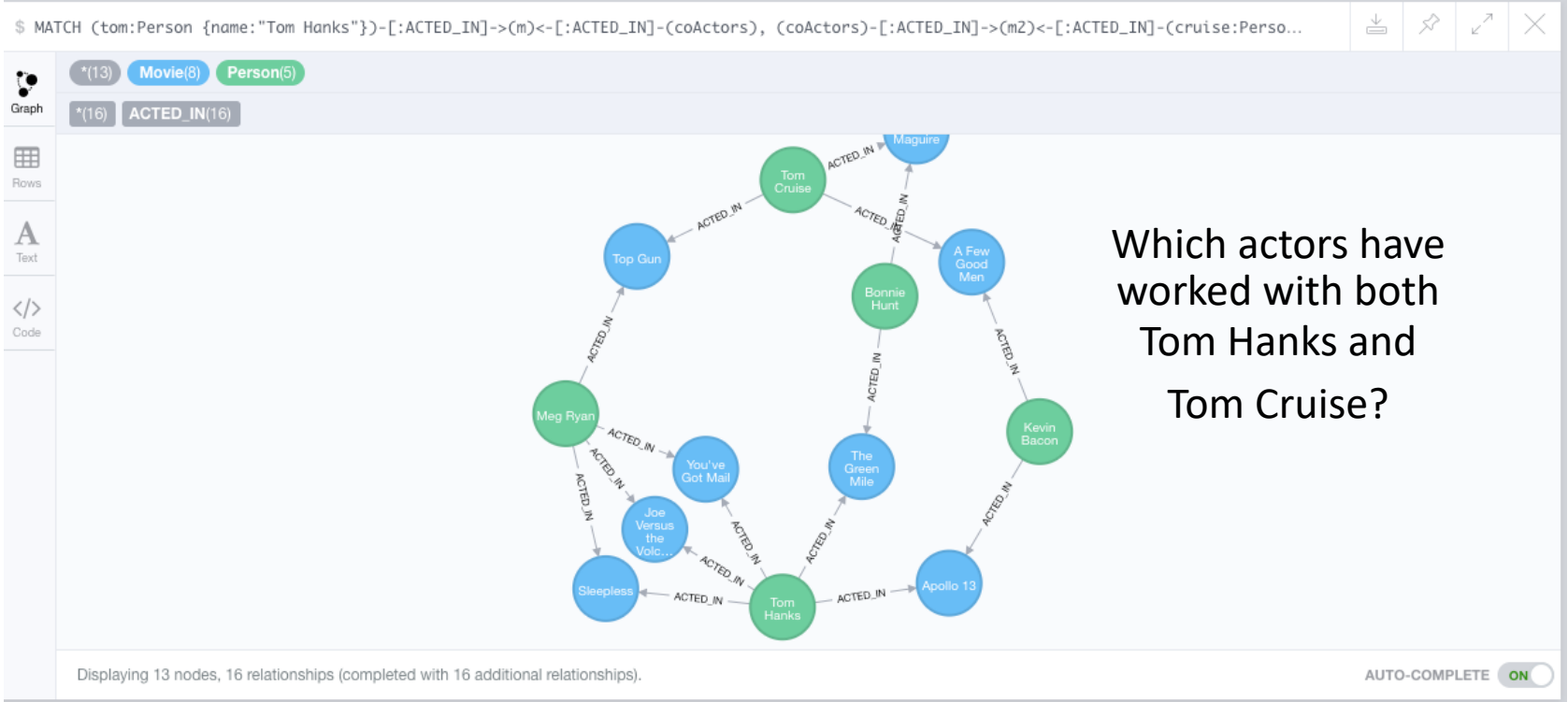
```
1 MATCH (tom:Person {name:"Tom Hanks"})-[:ACTED_IN]->(m)<-[:ACTED_IN]-(coActors),
2       (coActors)-[:ACTED_IN]->(m2)<-[:ACTED_IN]-(cocoActors)
3 WHERE NOT (tom)-[:ACTED_IN]->(m2)
4 RETURN cocoActors.name AS Recommended, count(*) AS Strength ORDER BY Strength DESC
```

$ MATCH (tom:Person {name:"Tom Hanks"})-[:ACTED_IN]->(m)<-[:ACTED_IN]-(coActors), (coActors)-[:ACTED_IN]->(m2)<-[:ACTED_IN]-(cocoActors) ...

Rows | Text | Code

Recommended	Strength
Tom Cruise	5
Zach Grenier	5
Helen Hunt	4
Cuba Gooding Jr.	4
Keanu Reeves	4
Tom Skerritt	3
Carrie-Anne Moss	3
Val Kilmer	3
Bruno Kirby	3
Philip Seymour Hoffman	3
Billy Crystal	3
Carrie Fisher	3

```
MATCH (tom:Person {name:"Tom Hanks"})-[:ACTED_IN]->(m)<-[:ACTED_IN]-(coActors),
      (coActors)-[:ACTED_IN]->(m2)<-[:ACTED_IN]-(cruise:Person {name:"Tom Cruise"})
RETURN tom, m, coActors, m2, cruise
```

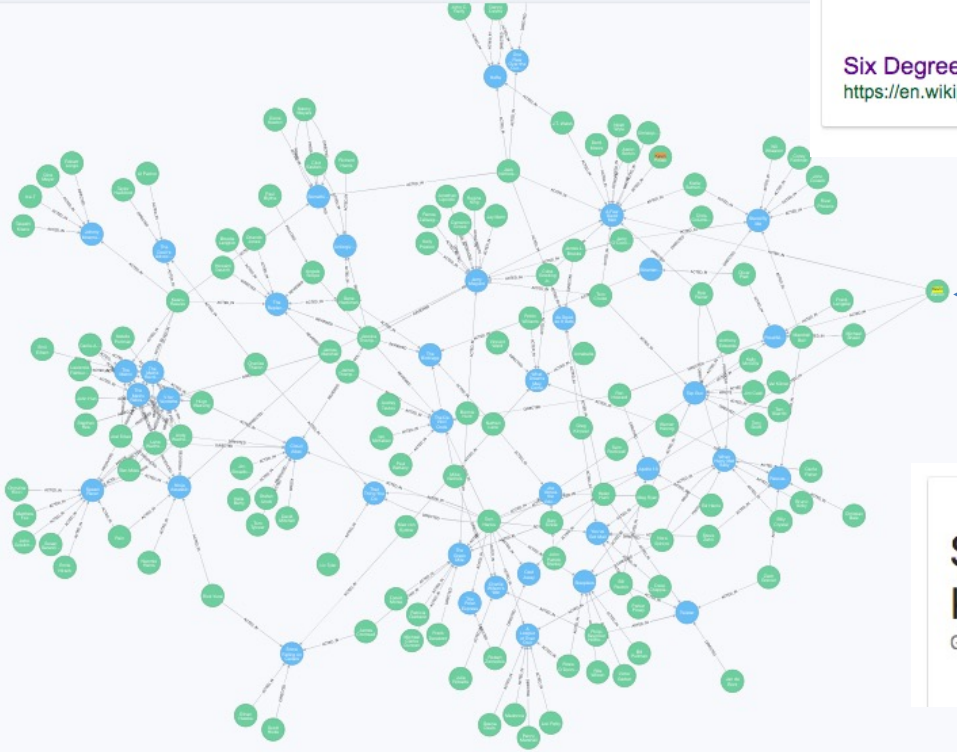


Which actors have worked with both Tom Hanks and Tom Cruise?

```
$ MATCH (s:Person { name: 'Kevin Bacon' })-[*0..6]-(m) return s,m
```

*(171) Movie(38) Person(133)

*(253) ACTED_IN(172) DIRECTED(44) FOLLOWS(3) PRODUCED(15) REVIEWED(9) WROTE(10)

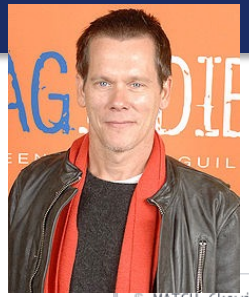


Six **Degrees of Kevin Bacon** is a parlour game based on the "six **degrees** of separation" concept, which posits that any two people on Earth are six or fewer acquaintance links apart. Movie buffs challenge each other to find the shortest path between an arbitrary actor and prolific actor **Kevin Bacon**.

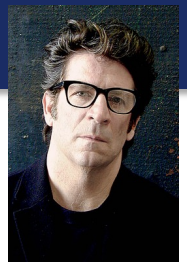
Six Degrees of Kevin Bacon - Wikipedia
https://en.wikipedia.org/wiki/Six_Degrees_of_Kevin_Bacon

About this result Feedback

Six Degrees of Kevin Bacon
Game



How do you get from Kevin Bacon to Robert Longo?

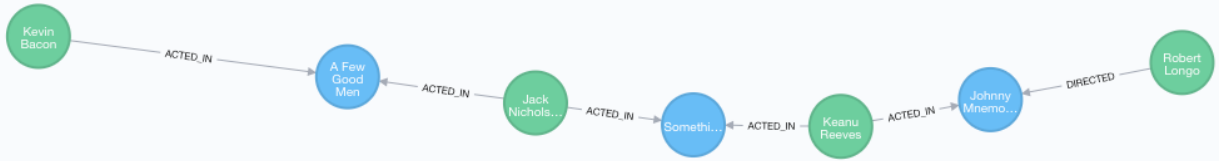


```
$ MATCH (kevin:Person { name: 'Kevin Bacon' }),(robert:Person { name: 'Robert Longo' }), p = shortestPath((kevin)-[*..15]-(robert)) RETURN p
```

Graph | Rows | Text | Code

*(7) Movie(3) Person(4)

*(6) ACTED_IN(5) DIRECTED(1)



Watch Professor Ferguson
Write Neo4j and MongoDB