PASSWORDS
TREES AND HIERARCHIES

CS121: Introduction to Relational Database Systems

Fall 2014 – Lecture 25

Account Password Management

- Mentioned a retailer with an online website…
- Need a database to store user account details
  - Username, password, other information
- How to store a user's password?
- What if the database application's security is compromised?
  - Can an attacker get a list of all user passwords?
  - Can the DB administrator be trusted?

- **Do we actually need to store the original password??**

A Naïve Approach

- A simple solution:
  - Store each password as plaintext

```
CREATE TABLE account (
    username VARCHAR(20) PRIMARY KEY,
    password VARCHAR(20) NOT NULL,
    ...
);
```

- Benefits:
  - If user forgets their password, we can email it to them
- Drawbacks:
  - Email is unencrypted – passwords can be acquired by eavesdropping
  - Users tend to use the same password for many different accounts
  - If database security is compromised, attacker gets <u>all</u> users' passwords
  - Of course, an unreliable administrator can also take advantage of this

Hashed Passwords

- A safer approach is to hash user passwords
  - Store hashed password, not the original
  - For authentication check:
    1. User enters password
    2. Database application hashes the password
    3. If hash matches value stored in DB, authentication succeeds
- Example using MD5 hash:

```
CREATE TABLE account (
    username VARCHAR(20) PRIMARY KEY,
    pw_hash  CHAR(32)    NOT NULL,
    ...
);
```

  - To store a password:

```
UPDATE account SET pw_hash = md5('new password')
    WHERE username = 'joebob';
```

Hashed Passwords (2)

- Want a <u>cryptographically secure</u> hash function:
  - Easy to compute a hash value from the input text
  - Even small changes in input text result in very large changes in the hash value
  - Hard to get a specific hash value by choosing input carefully
  - Should be <u>collision resistant</u>: hard to find two different messages that generate the same hash function
- MD5 is not collision resistant ☹
  - "[MD5] should be considered cryptographically broken and unsuitable for further use." – US-CERT
- SHA-1 was also discovered to not be very good
- Most people use SHA-2/3 hash algorithms now

Hashed Passwords (3)

- Benefits:
  - Passwords aren’t stored in plaintext anymore
- Drawbacks:
  - Handling forgotten passwords is a bit trickier
    - Need alternate authentication mechanism for users
  - Isn’t entirely secure! Still prone to dictionary attacks.
- Attacker computes a dictionary of common passwords, and each password’s hash value
  - If attacker gets the hash values from the database, can crack some subset of accounts

Hashed, Salted Passwords

- Solution: salt passwords before hashing
- Example:

```
CREATE TABLE account (
    username VARCHAR(20) PRIMARY KEY,
    pw_hash CHAR(32) NOT NULL,
    pw_salt CHAR(6) NOT NULL,
    ...
);
```

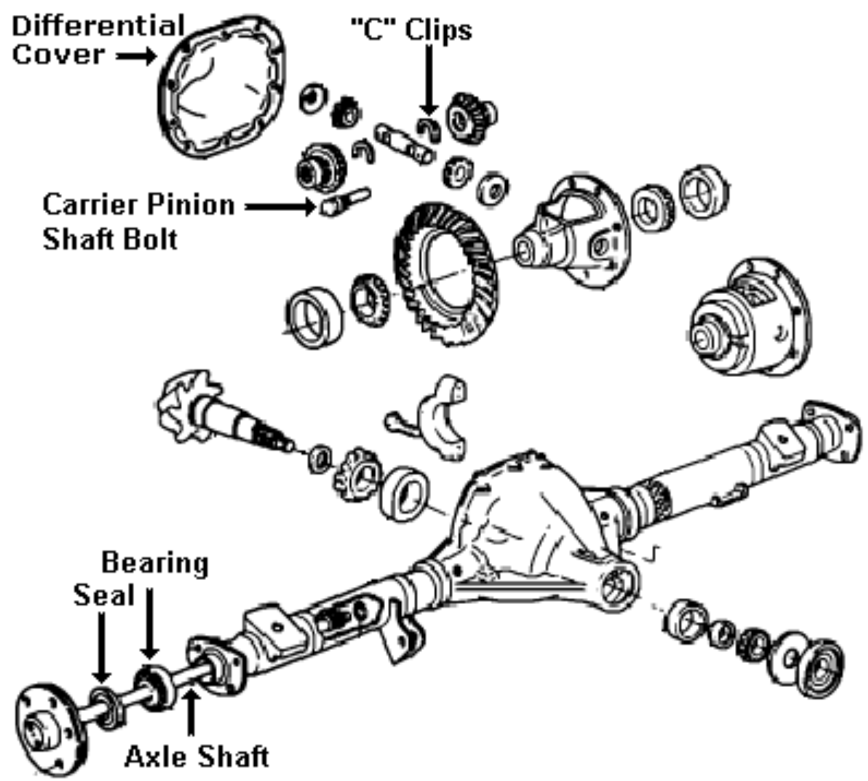
  - Each account is assigned a random salt value
    - Salt is always a specific length, e.g. 6 to 16 characters
  - Concatenate plaintext password with salt, before hashing
  - Attacker would have to compute a dictionary of hashes for each salt value… Prohibitively expensive!

Password Management

- Basically <u>no</u> reason to store passwords in plaintext!!
  - Users almost always use the same passwords in multiple places!
  - Only acceptable in the simplest circumstances
  - (You don't want to end up on the news because your system got hacked and millions of passwords leaked…)
- Almost always want to employ a secure password storage mechanism
  - Hashing is insufficient! Still need to protect against dictionary attacks by applying salt
  - Also need a good way to handle users that forget their passwords

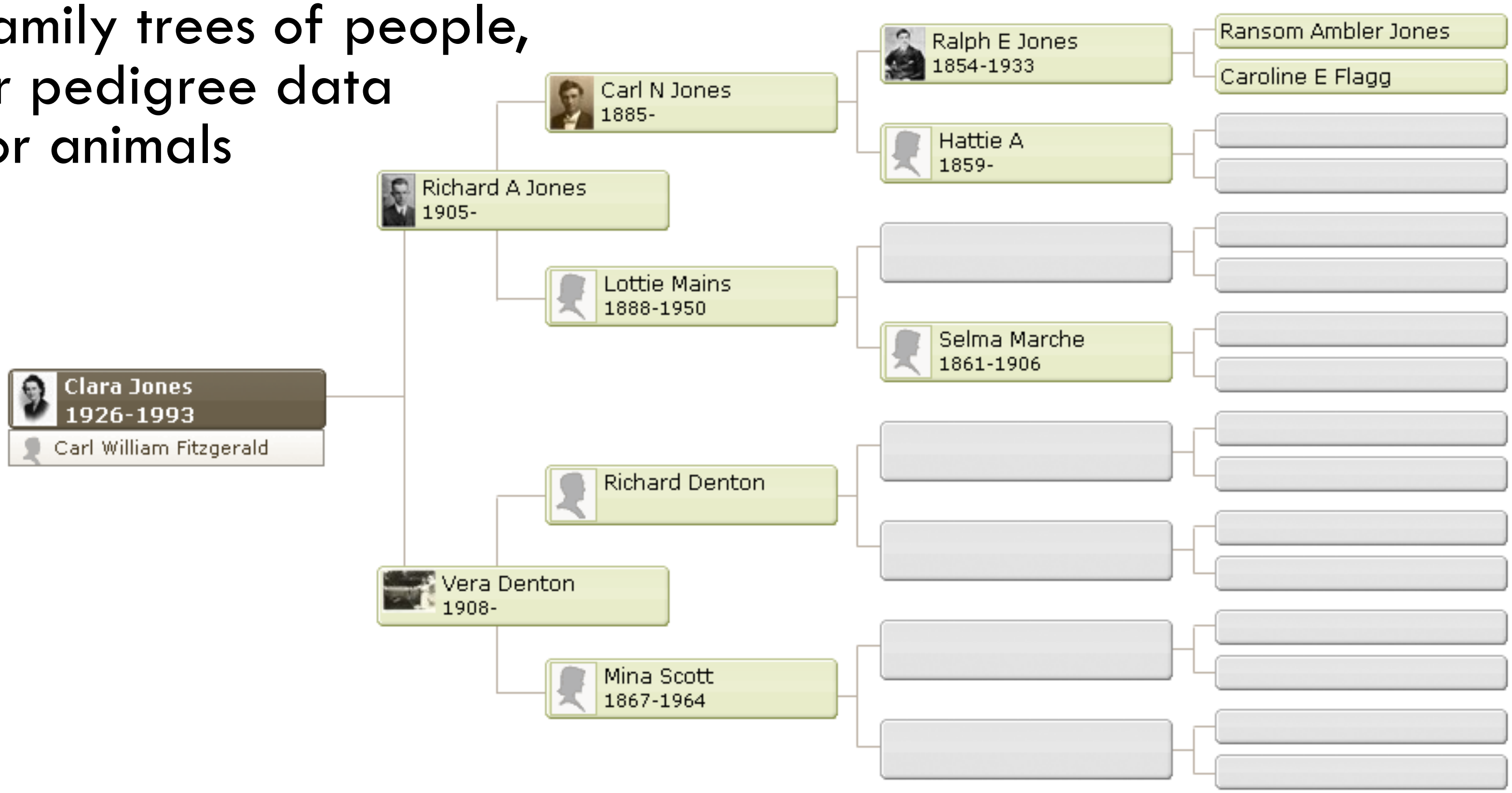
Trees and Hierarchies

- Many DB schemas need to represent trees or hierarchies of some sort
- Example: parts-explosion diagrams
  - “How are parts and subsystems assembled?”
  - “How much does a subsystem weigh?”
  - Other computations based on parts in subsystems



Trees and Hierarchies (2)

- Many kinds of relationships between people
  - Employee/manager relationships within an organization
  - Social graph data from a social network
  - Family trees of people, or pedigree data for animals



Trees and Hierarchies (3)

- Most common way of representing trees in the DB is an adjacency list model
  - Each node in the hierarchy specifies its parent node
  - Can represent arbitrary tree depths
- Example: employee database
  - *employee*(<u>*emp_name*</u>, *address*, *salary*)
  - *manages*(<u>*emp_name*</u>, *manager_name*)
  - Both attributes of *manages* are foreign keys referencing *employee* relation

Trees and Hierarchies (4)

- Adjacency list model is only one of several ways to represent trees and hierarchies
- Different approaches have different strengths and weaknesses
- Some approaches to consider:
  - Adjacency list models
  - Nested set models
  - Path enumeration models

General Design Questions

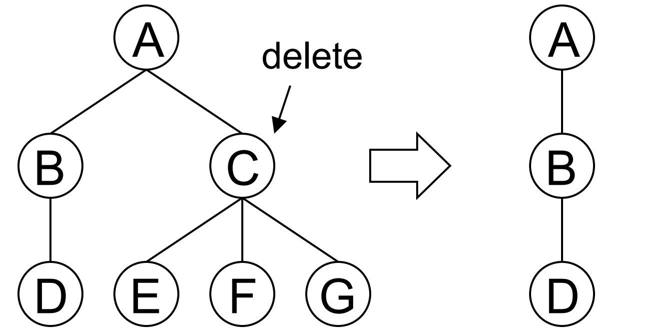
- How hard is it to access the tree?
  - Retrieve a specific node
  - Find the parent/children/siblings of a particular node
  - Retrieve all leaf nodes in the tree
  - Retrieve all nodes at a particular level in the tree
  - Retrieve a node and its entire subtree
- Also, path-based queries:
  - Retrieve a node corresponding to a particular path from the root
  - Retrieve nodes matching a path containing wildcards
  - Is a particular path in the hierarchy?

General Design Questions (2)

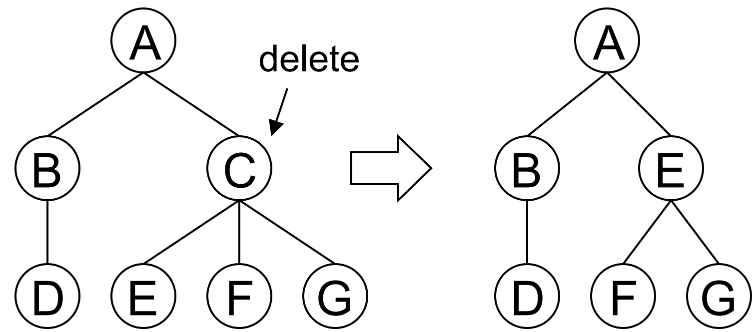
- How hard is it to modify the tree?
  - Add a single node
  - Delete a leaf node
  - Delete a non-leaf node
    - What to do with subtree of deleted node?
  - Move a subtree within the tree
- How to enforce constraints in the schema?
  - Enforce only one root
  - Disallow cycles in a tree
    - Simplest example: "my parent can't be myself"
  - Disallow multiple parents (tree vs. directed acyclic graph)
  - Enforce a maximum child-count, maximum depth, etc.

Deleting Nodes

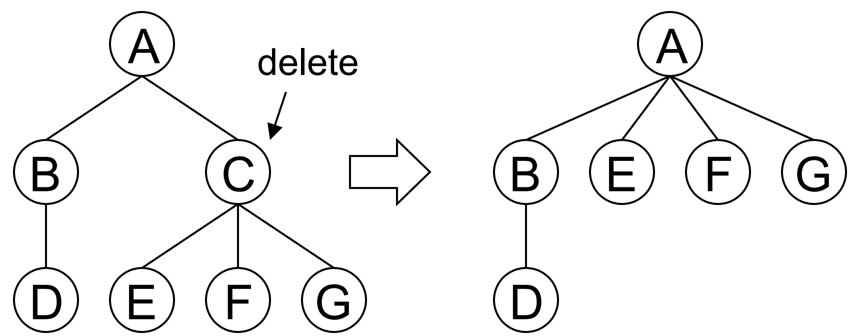
- What happens when a non-leaf node is deleted?
- Option 1:
  - Delete entire subtree as well



- Option 2:
  - Promote one child node into removed node's position
  - (Or, replace with placeholder)



- Option 3:
  - Make all child nodes into children of deleted node's parent



Adjacency List Model

- Very common approach for modeling trees
- Each node specifies its parent node
- Relationship between nodes are frequently stored in a separate table
  - e.g. *employee* and *manages*
  - Can represent multiple trees without *null* values
  - Can have employees that are not part of the hierarchy

Adjacency List Model (2)

- Strengths:
  - A very flexible model for representing and manipulating trees
  - Easy to add a new node anywhere in the tree
  - Easy to move a whole subtree
- Weaknesses:
  - Deleting a node often requires extra steps (to relocate children)
  - Operations on entire subtrees are expensive
  - Operations applied to a particular level across a tree are expensive
  - Looking for a node at a specific path is expensive
  - (All of these operations require multiple queries to identify the nodes affected by the operation.)

Queries on Subtrees

- Example query using subtrees:
  - For every manager reporting to a given Vice President, find the total number of employees under that manager, and their total salaries
  - Computing an aggregate over individual subtrees
- Another example:
  - Database containing parts in a mechanical assembly
    - Parts combined into sub-assemblies
    - Sub-assemblies and parts combined into larger assemblies
    - Top level assembly is the entire system
  - Find number of parts, the total cost, and the total weight of each sub-assembly in the system

Finding Nodes in Subtrees

- To find all nodes in a specific subtree, must iterate a query using a temporary table
  - Example: Find all employees under manager "Jones"

```
CREATE TEMPORARY TABLE emps
  ( emp_name VARCHAR(20) NOT NULL );

INSERT INTO emps VALUES ('Jones');
INSERT INTO emps SELECT emp_name FROM manages
  WHERE manager_name IN (SELECT * FROM emps)
    AND emp_name NOT IN (SELECT * FROM emps);
```

  - Iterate last statement until no new rows added to temp table
  - Databases often report a count of how many rows are inserted/modified/deleted by each DML operation

Finding Nodes in Subtrees (2)

- Can also store a "depth" value in the result

```
CREATE TEMPORARY TABLE emps (
  emp_name VARCHAR(20) NOT NULL,
  depth    INTEGER     NOT NULL
);

INSERT INTO emps VALUES ('Jones', 1);

-- Some variable i, where i = 1 initially:
INSERT INTO emps SELECT emp_name, i + 1 FROM manages
  WHERE manager_name IN
        (SELECT * FROM emps WHERE depth = i);
```

  - Each level of the hierarchy has the same depth value
  - Slightly more efficient than the previous version
    - Each iteration has fewer rows to consider

Finding Nodes in Subtrees (3)

- Best to implement this as a stored procedure
  - Don't involve command/response round-trips with application code, if possible!
  - Perform processing entirely within the DB for best performance
- Still acceptable if application has to drive the iteration process
  - Most DB connectivity APIs let you create temporary tables, get number of rows changed, etc.

Other Adjacency List Notes

- Must manually order siblings under a node
  - Add another column to the table for ordering siblings
- Adjacency list model is also good for representing graphs
  - Actually easier than using for trees, because less constraints are required
  - Traversing the graph requires temporary tables and iterative stored procedures
  - (Other representations we will discuss today aren't well-suited for graphs at all!)

Aside: Recursive Queries

- Briefly looked at this Datalog query last time:
  - Manager relation:

    manager(*employee_name*, *manager_name*)
  - Define view relation "empl" for all employees directly or indirectly managed by a particular manager.

    empl(X, Y) :- manager(X, Y)

    empl(X, Y) :- manager(X, Z), empl(Z, Y)
  - To find all employees managed by Jones:

    ? empl(X, "Jones")
  - Datalog iterates on the rule definitions until the result doesn't change (fixpoint)
- Datalog supports traversing hierarchies very easily

Recursive Queries in SQL

- For a long time, SQL did not support recursive queries
  - Only way to traverse adjacency-list data model was to use a temporary table and repeated queries, as described
- Now, most databases also support some form of recursive SQL query
  - e.g. PostgreSQL 8.4+, SQLServer, Oracle (not MySQL ☹)
  - If available, makes it much easier to traverse adjacency-list datasets
- Still requires repeated queries against the database…
  - Even though query is easier to write, it's still slow to execute!

Recursive Queries in PostgreSQL

- Example using SQL99/Postgres 8.4 syntax
- Find all employees directly or indirectly managed by Jones:

Initial Subquery

Recursive Subquery

```
WITH RECURSIVE empl AS (
       SELECT employee_name, manager_name
       FROM manager
     UNION ALL
       SELECT e.employee_name, m.manager_name
       FROM empl AS e JOIN manager AS m
         ON e.manager_name = m.employee_name)
SELECT * FROM empl
WHERE manager_name = 'Jones';
```

Recursive Queries in PostgreSQL (2)

- Can compute the depth in the hierarchy, too:

```
WITH RECURSIVE empl AS (
       SELECT employee_name, manager_name,
              1 as depth
       FROM manager
     UNION ALL
       SELECT e.employee_name, m.manager_name,
              e.depth + 1 AS depth
       FROM empl AS e JOIN manager AS m
         ON e.manager_name = m.employee_name)
SELECT * FROM empl
WHERE manager_name = 'Jones';
```

SQLServer Recursive Queries

- Microsoft SQLServer 2005/2008 also uses **WITH** clause for recursive queries
  - Similar approach, using a non-recursive subquery and a recursive subquery, combined with **UNION [ALL]**
  - Doesn't use a **RECURSIVE** modifier
- Neither Postgres nor SQLServer recursive queries can handle cycles in the data…
  - Introducing a cycle into the data causes the query to infinite-loop

Oracle Recursive Queries

- Oracle has <u>much</u> more sophisticated recursive query support
- A simple example:

```
SELECT employee_name, manager_name, LEVEL
FROM manager
CONNECT BY PRIOR employee_name = manager_name;
```

  - **PRIOR** modifier specifies parent in parent/child relationship
  - **LEVEL** is a pseudocolumn specifying level in the hierarchy
- Can also do *many* other things, such as:
  - Specify the initial data-set to iterate on
  - Specify the order of siblings in each level of hierarchy
  - Detect and report which nodes are leaves in the hierarchy
  - Detect and report cycles in the dataset
  - Generate the full path from root to each node in the result

Final Notes on Recursive SQL Queries

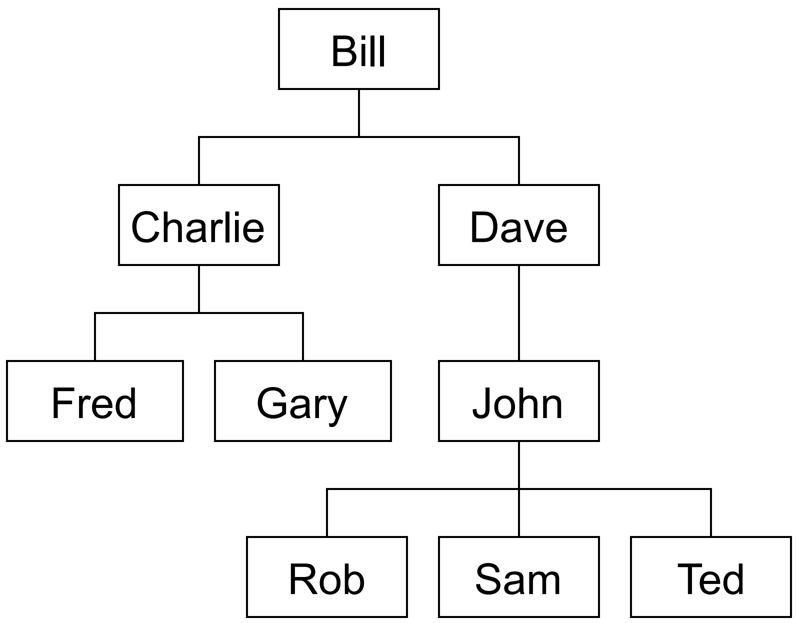
- As stated earlier:
  - Recursive SQL queries make it much easier to <u>write</u> the query that traverses adjacency-list data…
  - Still requires the DB engine to repeatedly issue queries until the entire hierarchy is traversed!
- If an application needs to store hierarchical or graph data, and must select entire subtrees <u>quickly</u>:
  - Adjacency-list model is *the most expensive* model to use!

Nested Set Model

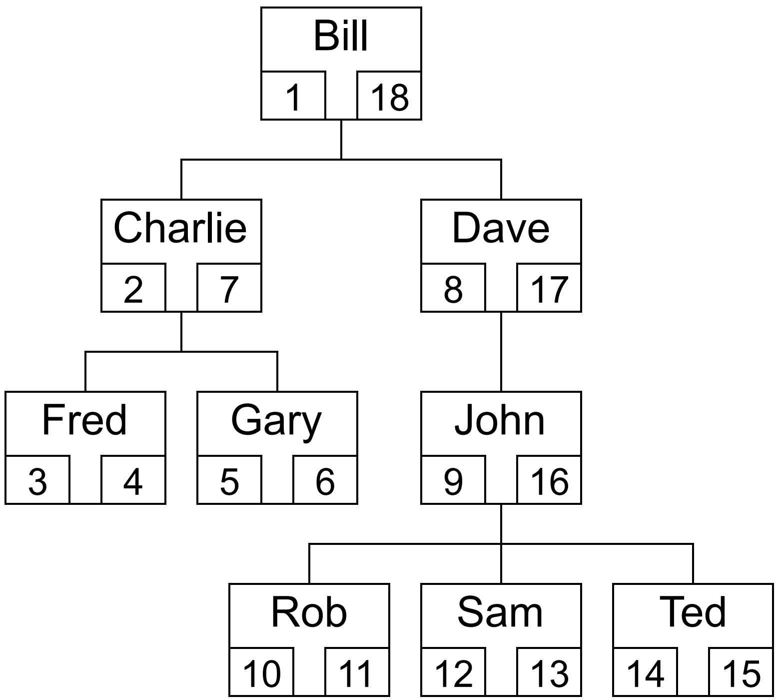
- A model optimized for selecting subtrees
- Represents hierarchy using containment
  - A node “contains” its children
- Give each node a “low” and “high” value
  - Specifies a range
  - Always: low < high
- Use this to represent trees:
  - A parent node’s [low, high] range contains the ranges of all child nodes
  - Sibling nodes have non-overlapping ranges

Example using Nested Sets

- Manager hierarchy:

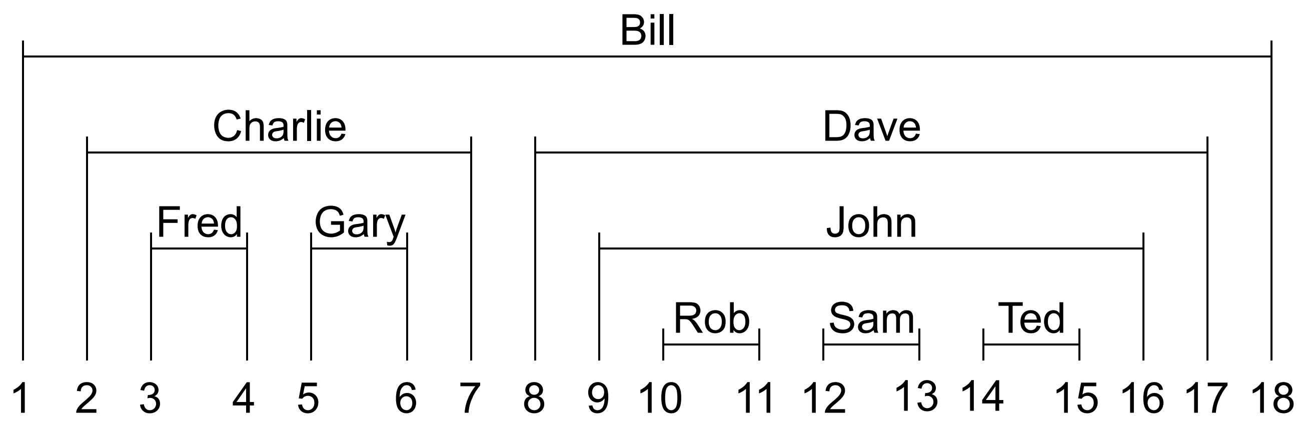


- Nested set hierarchy:



Selecting Subtrees

- Each parent node contains its children:



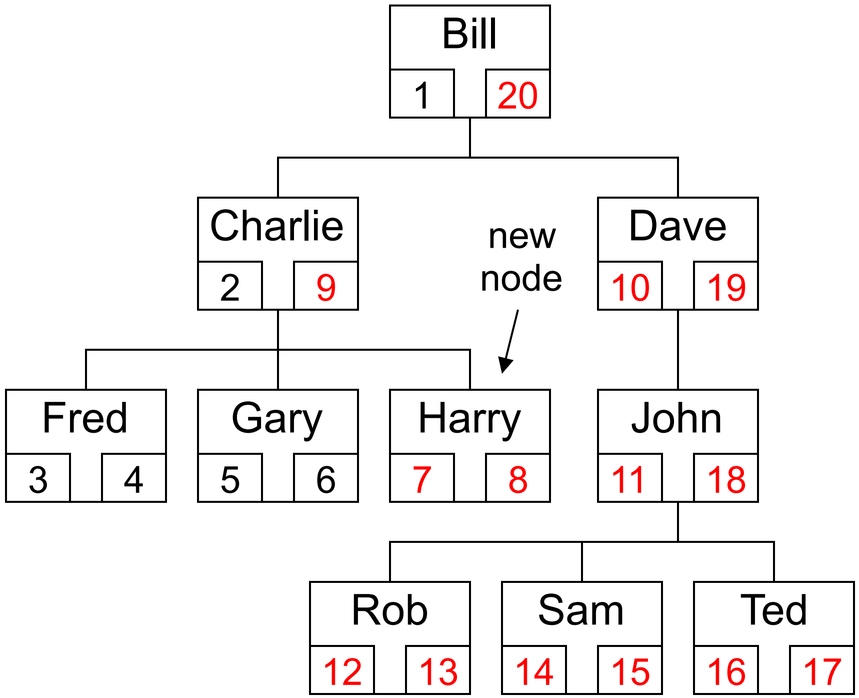
- Easy to select an entire subtree
  - Select all nodes with low (or high) value within node's range
- Can also select all leaf nodes [relatively] easily
  - If all range values separated by 1, find nodes with low + 1 = high
  - For arbitrary range sizes, find nodes that contain no other node's range values (requires self-join)

Nested Set Model

- Strengths:
  - Very easy to select a whole subtree
    - Very important for generating reports against subtrees
  - Tracking the order of siblings is built in
- Weaknesses:
  - Some selections are more expensive
    - e.g. finding all leaf nodes in tree requires self-join
  - Constraints on range values are expensive
    - **`CHECK`** constraint to ensure low < high is cheap…
    - **`CHECK`** constraint to verify other interval characteristics is expensive!
  - Pretty costly to insert nodes or restructure trees
    - Have to update node bounds properly

Adding Nodes In Nested Set Model

- If adding a node:
  - Must choose range values for new node correctly
  - Often need to update range values of many other nodes, even for simple updates
- Example:
  - Add new employee Harry under Charlie
  - Must update ranges of most nodes in the tree!



Supporting Faster Additions

- Can separate range values by larger amounts
  - e.g. spacing of 100 instead of 1
  - Situations requiring range-adjustments of many nodes will be far less frequent
- Can implement tree-manipulation operations as stored procedures
  - "Add a node," "move a subtree," etc.

Path Enumeration Models

- For each node in hierarchy:
  - Represent node's position in hierarchy as the path from the root to that node
  - Entire path is stored as a single string value
- Node enumeration:
  - Each node has some unique ID or name
  - A path contains the IDs of all nodes between root and a particular node
  - If ID values are fixed size, don't need a delimiter
  - If ID values are variable size, choose a delimiter that won't appear in node IDs or names

Path Enumeration Model (2)

- Path enumeration model is fastest when nodes are retrieved using full path
  - "Is a specified node in the hierarchy?"
  - "What are the details for a specified node?"
  - Adjacency list model and nested set model simply can't answer these queries quickly!
- Example:
  - A database-backed directory service (e.g. LDAP or Microsoft Active Directory)
  - Objects and properties form a hierarchy
  - Properties are accessed using full path names
    - "sales.printers.colorprint550.queue"

Strengths and Weaknesses

- Optimized for read performance
  - Retrieving a specific node using its path is *very* fast
  - Retrieving an entire subtree is also pretty fast
    - Requires text pattern-matching, but matching a prefix is fast, especially with a suitable index on the string
    - Example: Find all sales print servers
      - Use a condition: `path LIKE 'sales.printers.%'`
- Adding leaf nodes is fast
- Restructuring a tree can be very slow
  - Have to reconstruct many paths…
- Operations rely on string concatenation and string manipulation

Edge Enumeration

- Paths can enumerate edges instead of nodes
  - Each level of path specifies index of node to select
- Primary method used in books
  - Example:

Edge Enumeration	Section Name
3	SQL
3.1	Background
3.2	Data Definition
3.2.1	Basic Domain Types
3.2.2	Basic Schema Definition in SQL
…	…

- Like node enumeration, requires string manipulation for most operations

Summary: Trees and Hierarchies

- Can represent trees and hierarchies in several different ways
  - Adjacency list model
  - Nested set model
  - Path enumeration model
- Each approach has different strengths
  - Each is optimized for different kinds of usage
- When designing schemas that require hierarchy:
  - Consider functional and non-functional requirements
  - Choose a model that best suits the problem