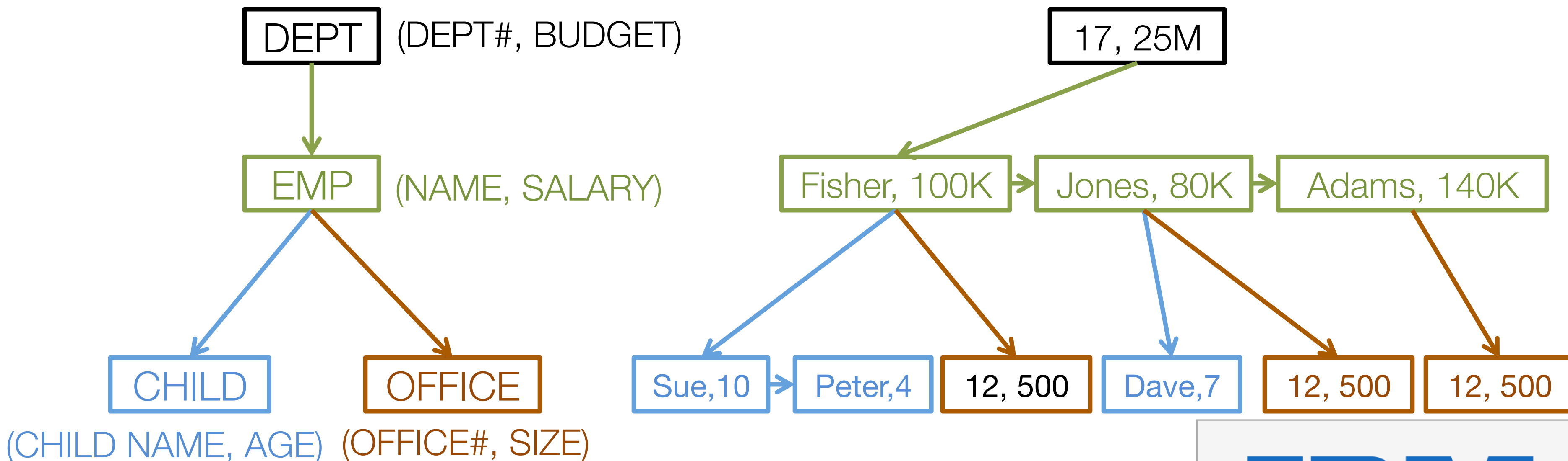
System R
cs262a, Lecture 2

Ion Stoica

(adapted from Joe Hellerstein's notes)

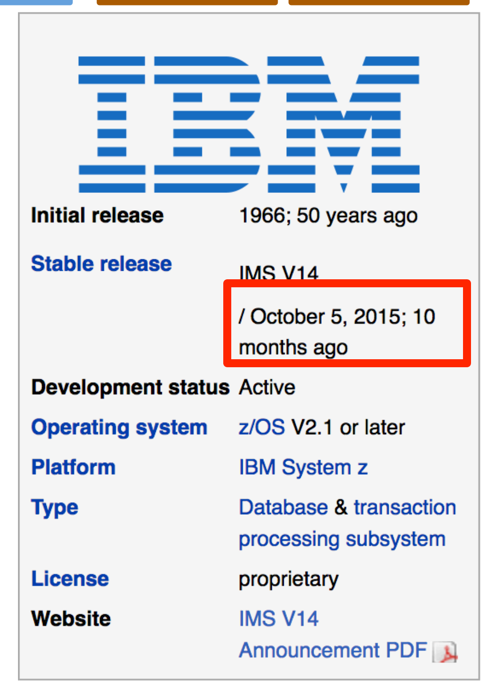
Hierarchical Model*



1966: IMS (IBM Management System)

» Designed for Apollo program for managing inventory for Saturn V and space vehicle

» Still in use today!



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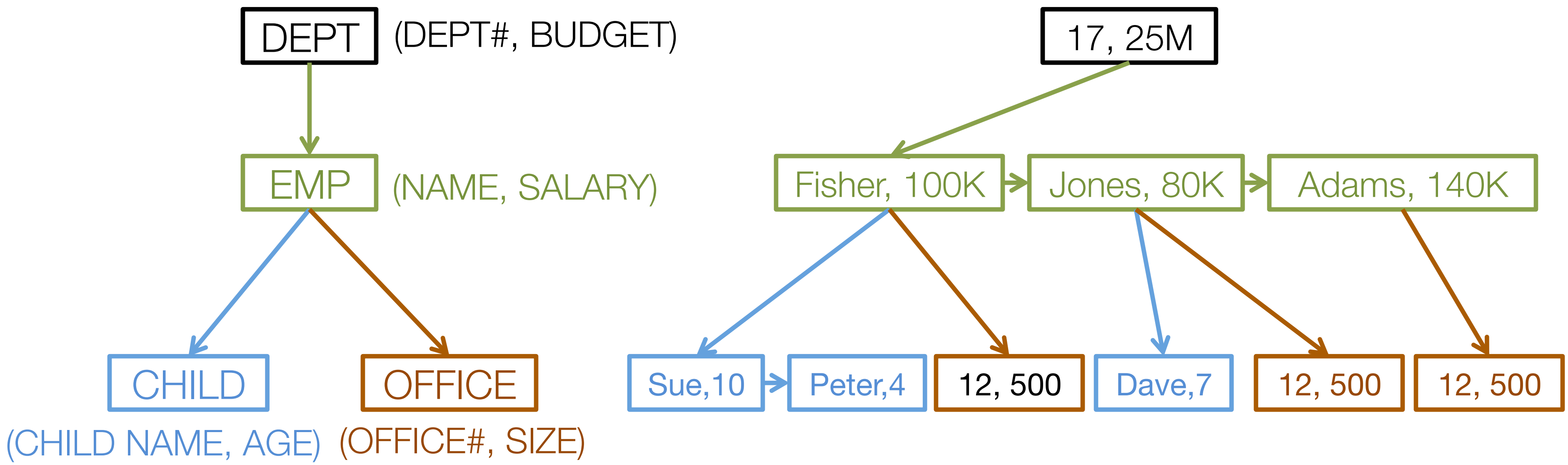


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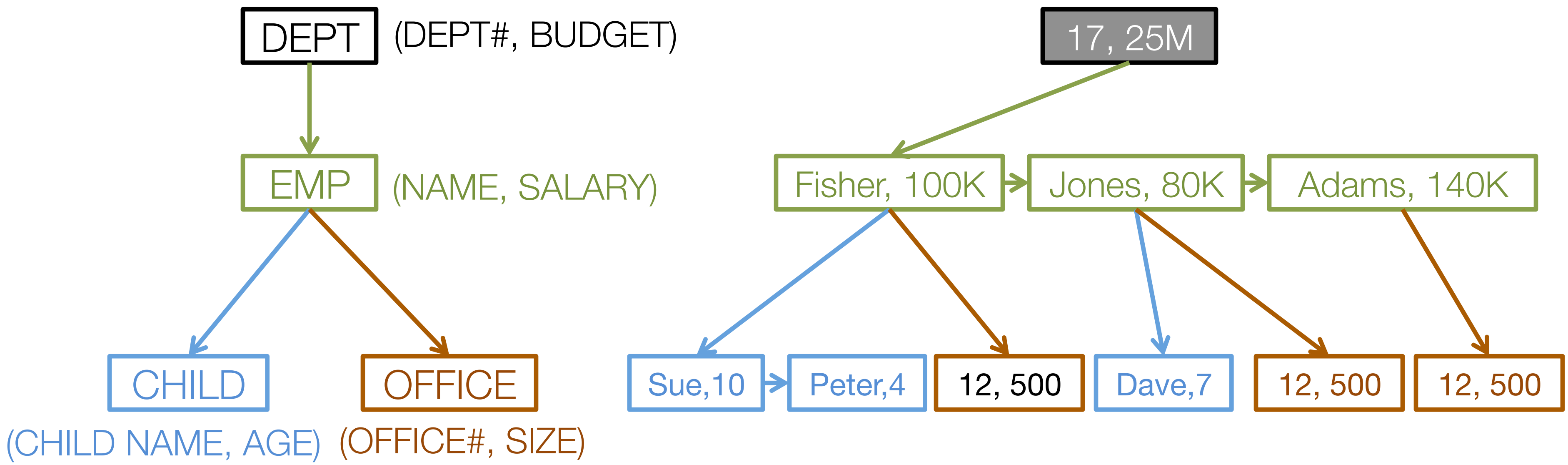


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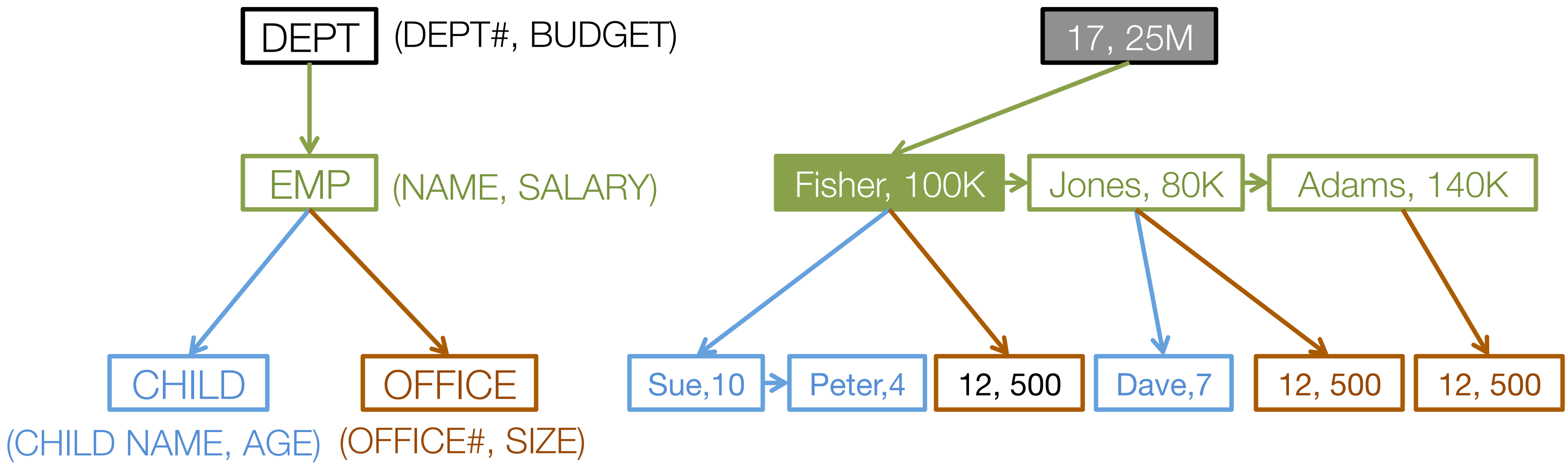


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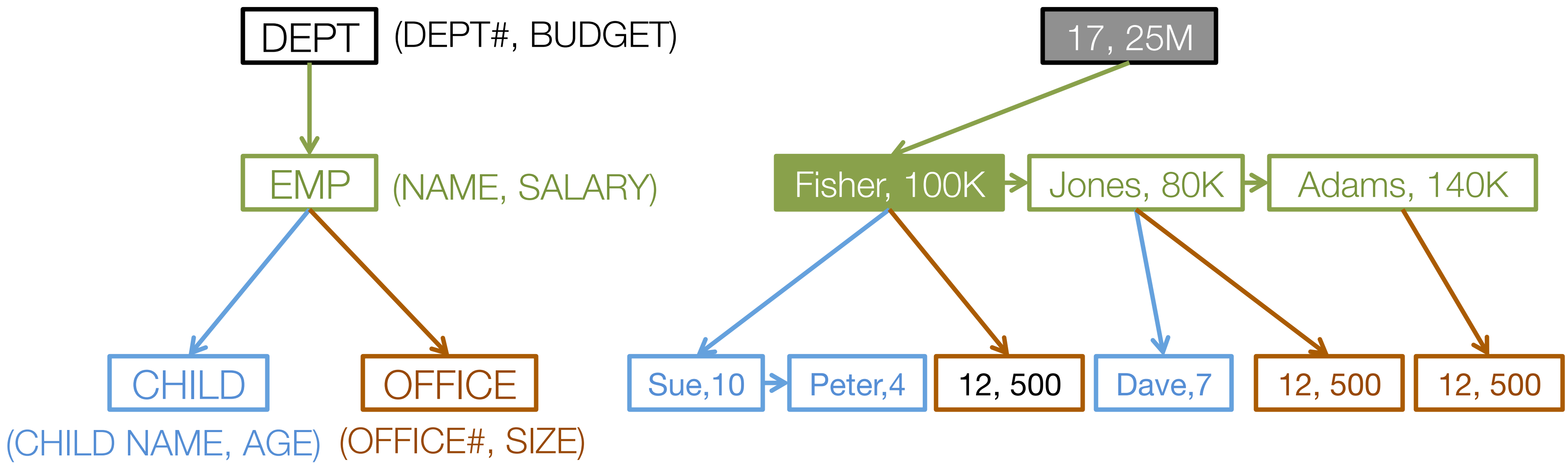


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Output: Fisher

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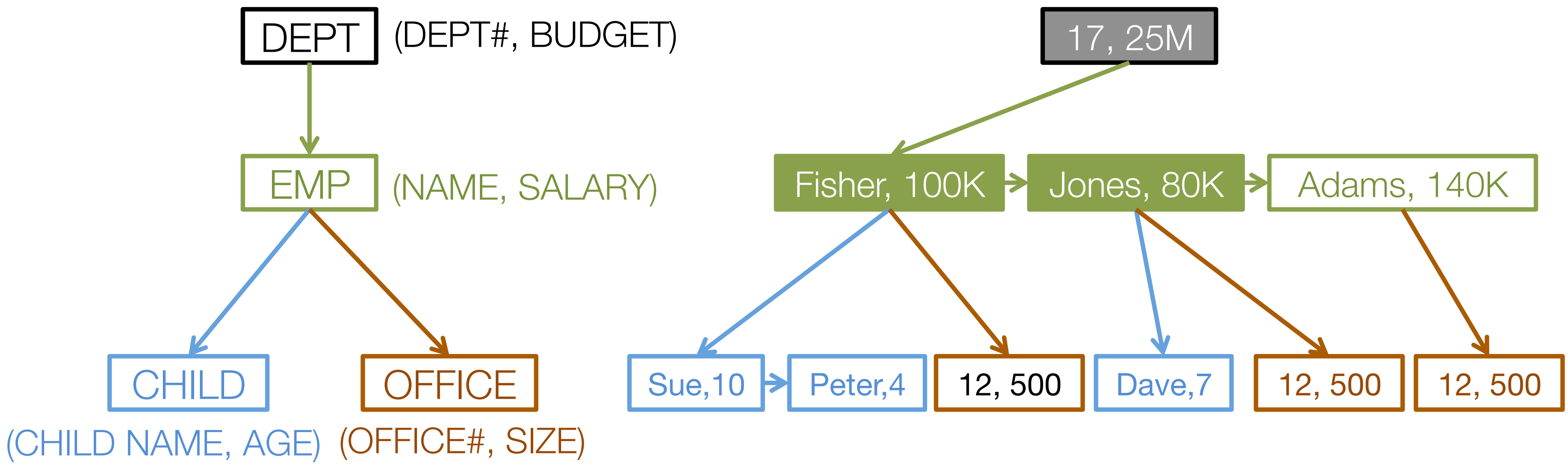


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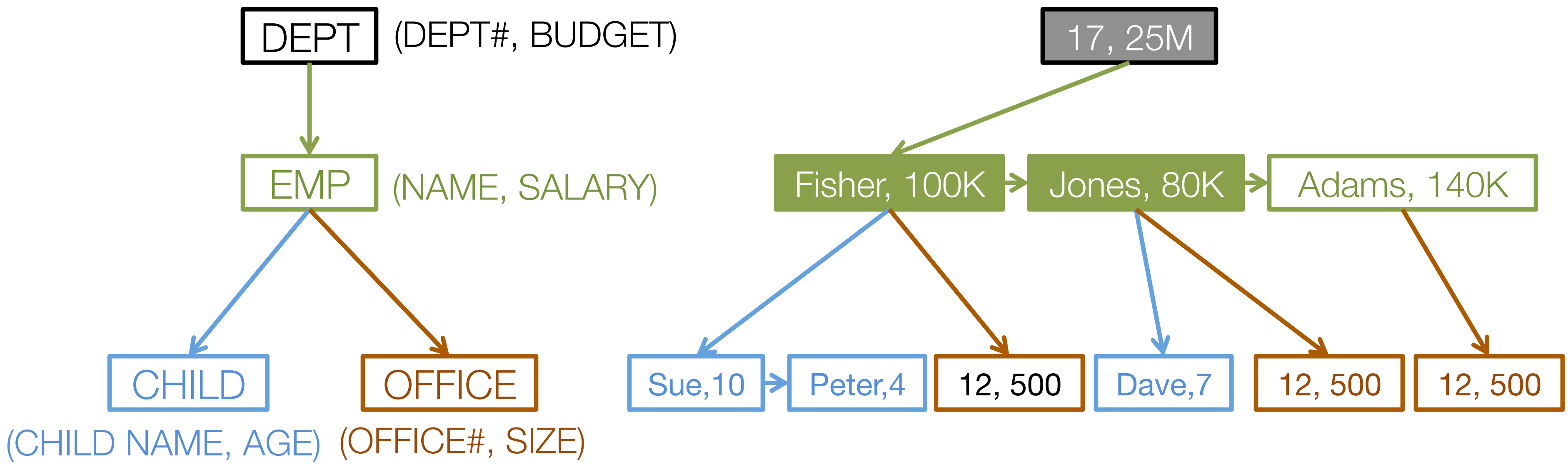


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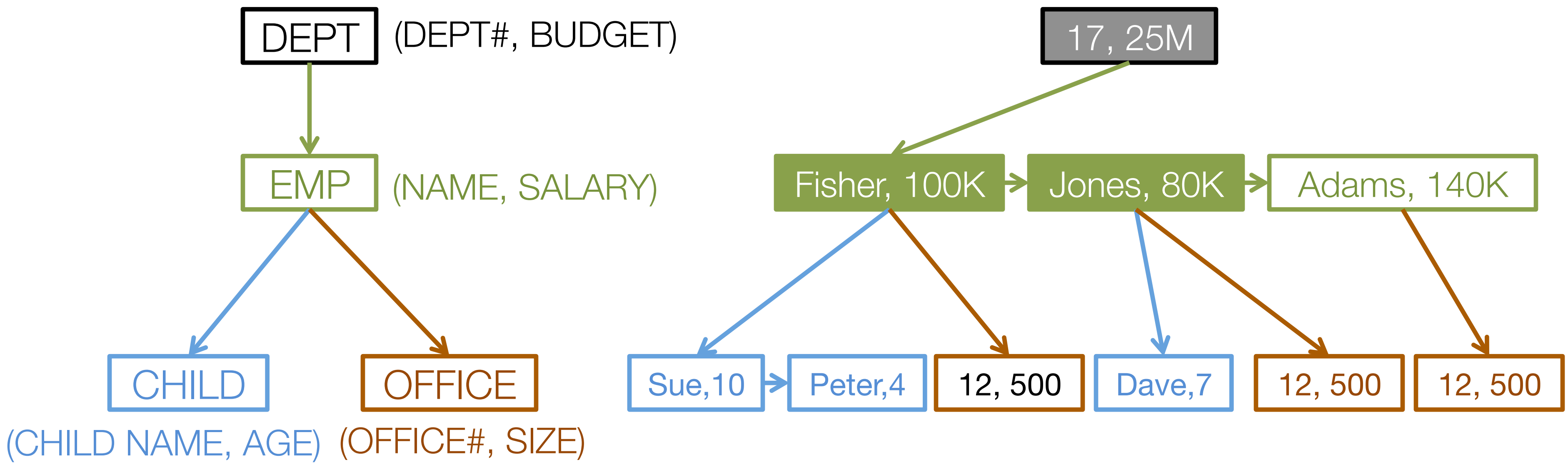


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Output: Fisher Jones
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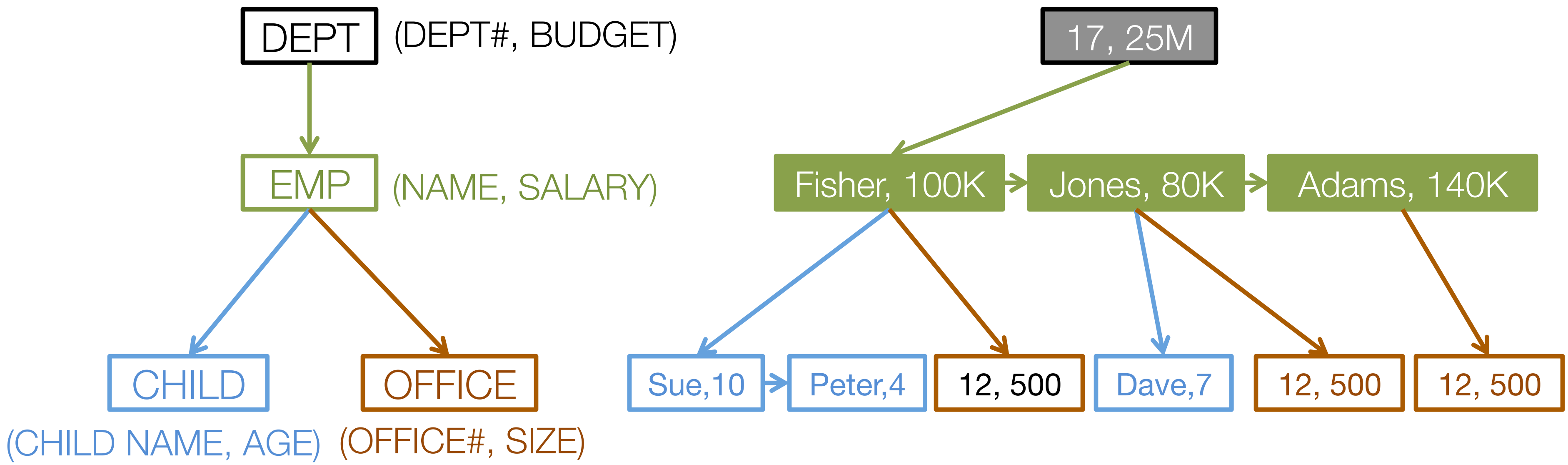


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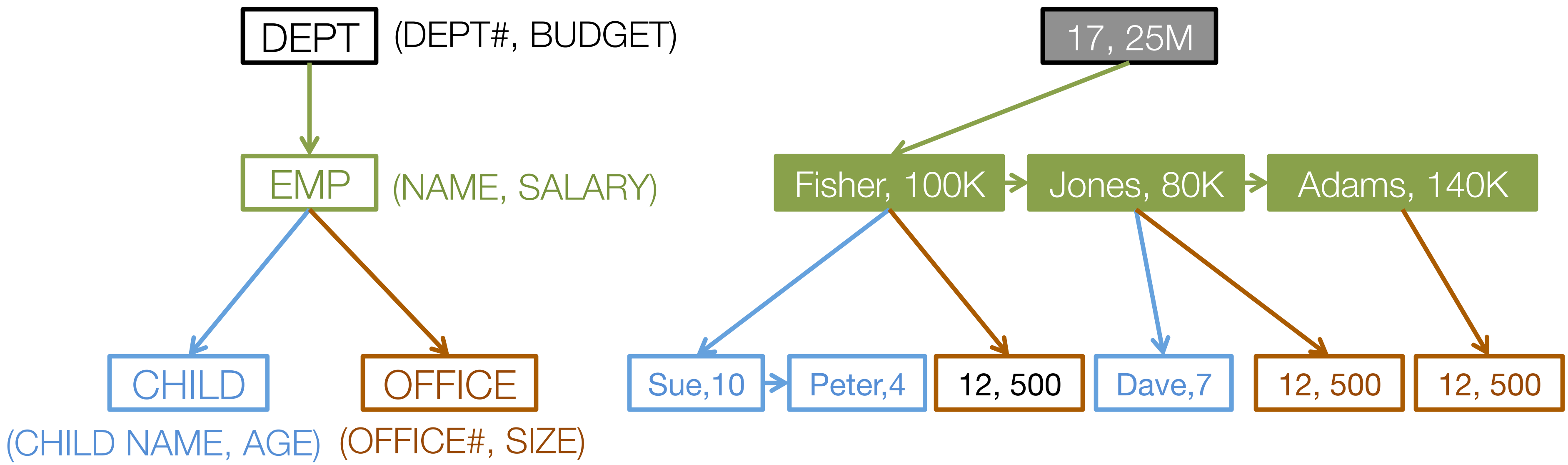


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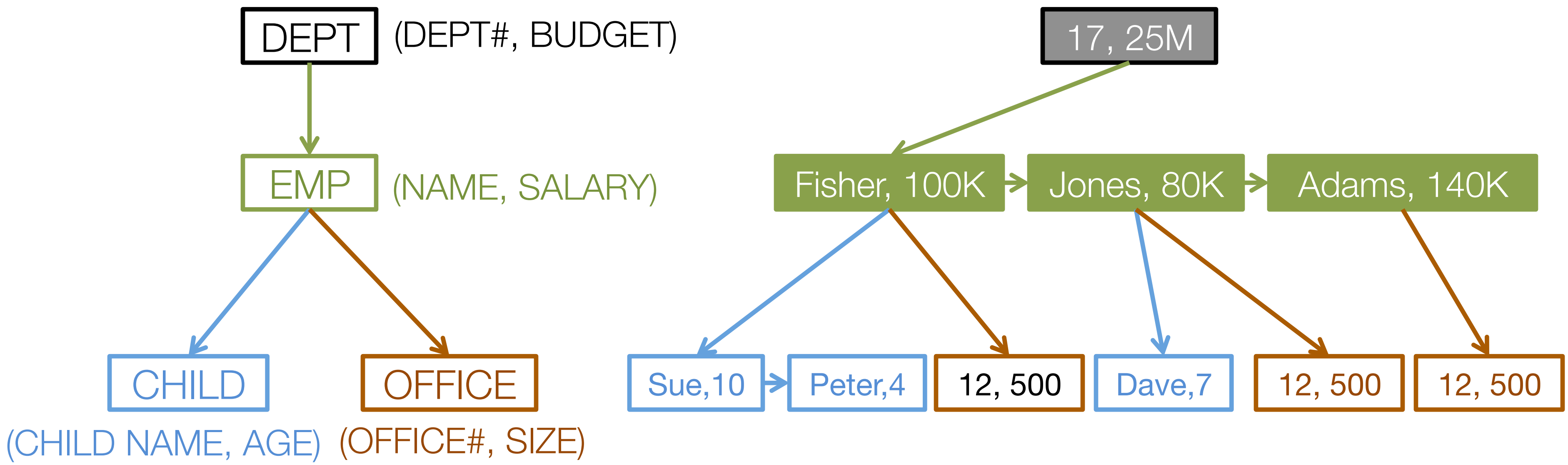


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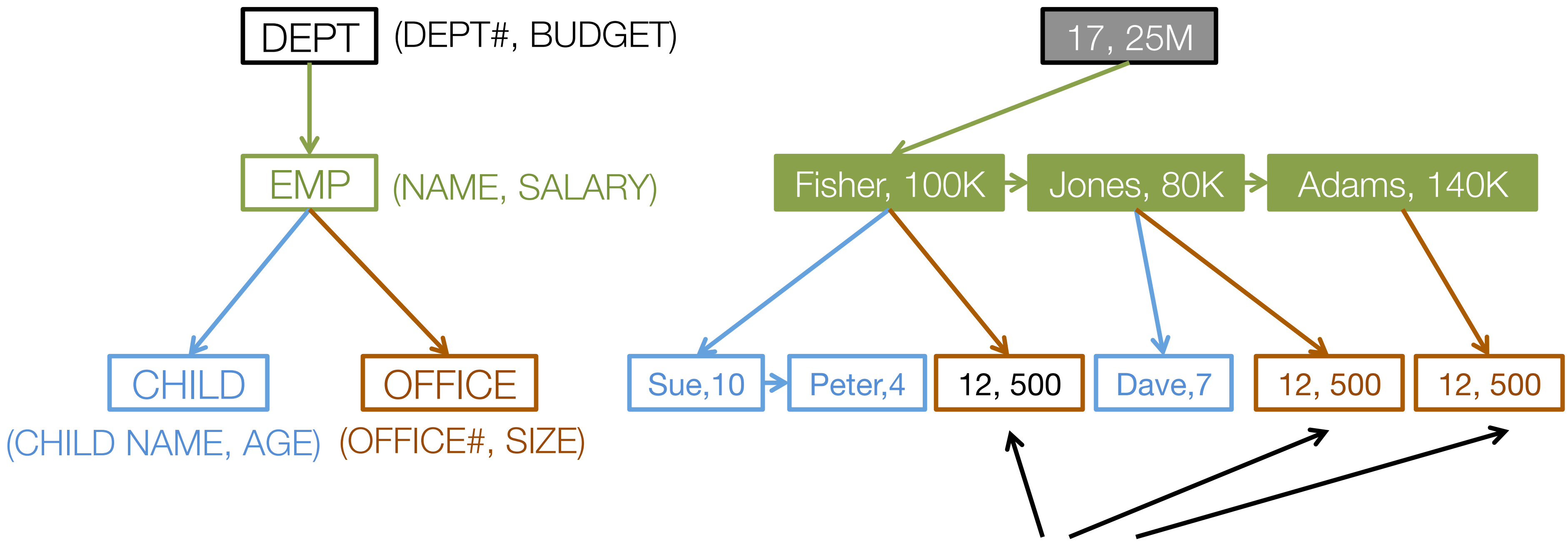
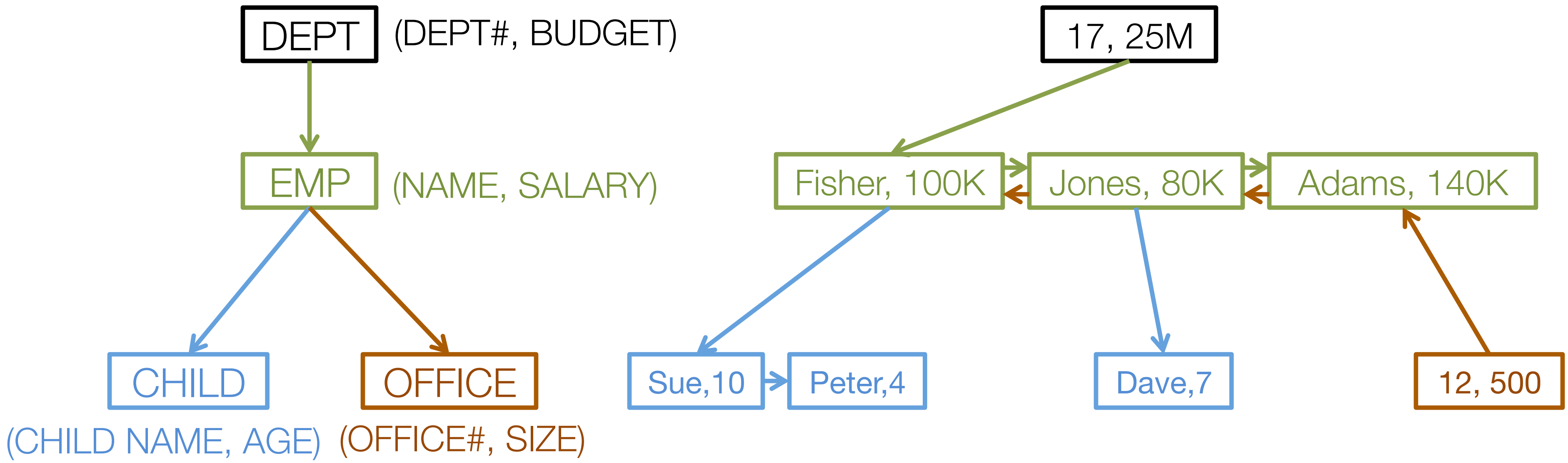
Hierarchical Model: Challenges



1) duplicate records
2) Requirements to have a parent; deletion anomalies

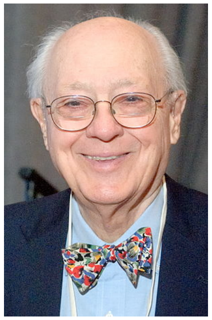
Network Model



CODASYL (Conference/Committee on Data Systems Languages)

» 1969: CODASYL data model
  Designed by **Charles Bachman**, Turing Award, 1973

» Also led to development of COBOL



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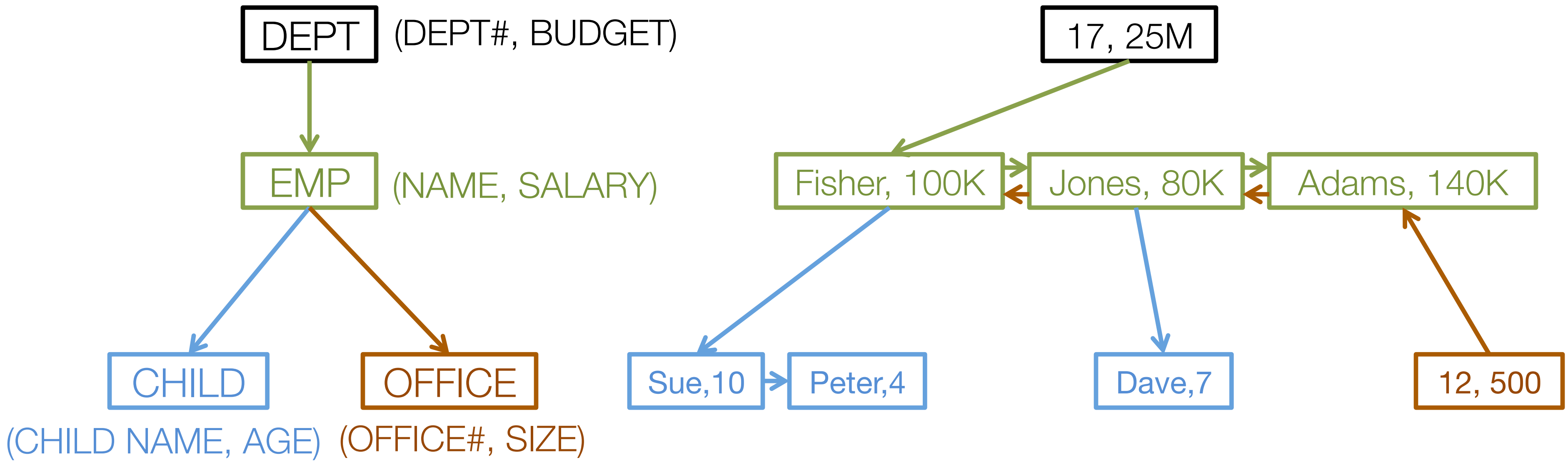


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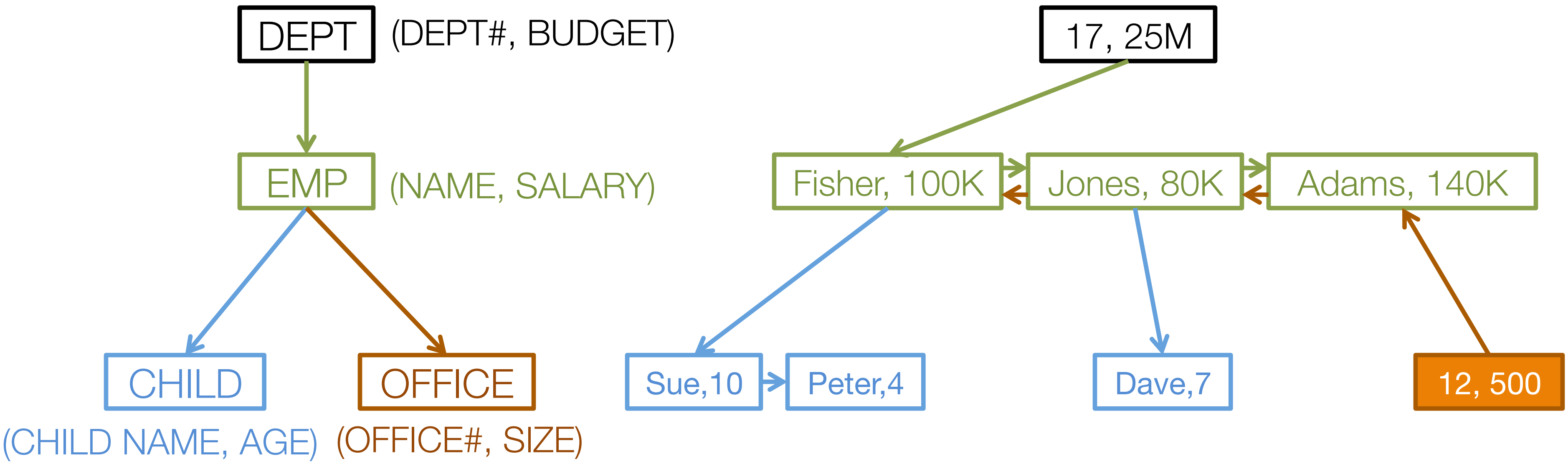


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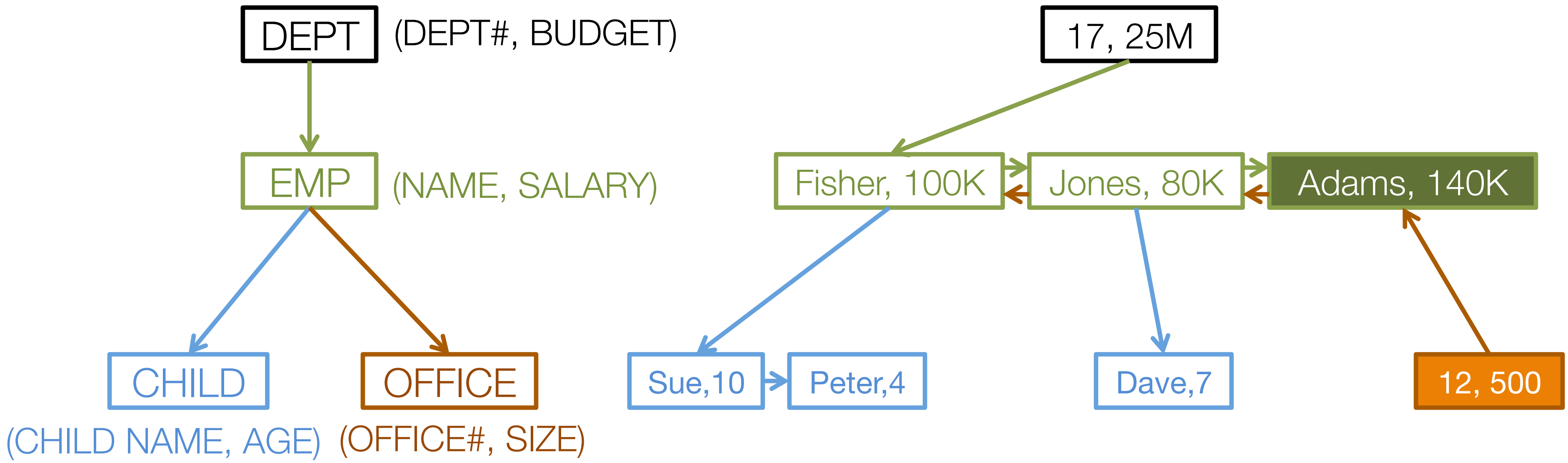


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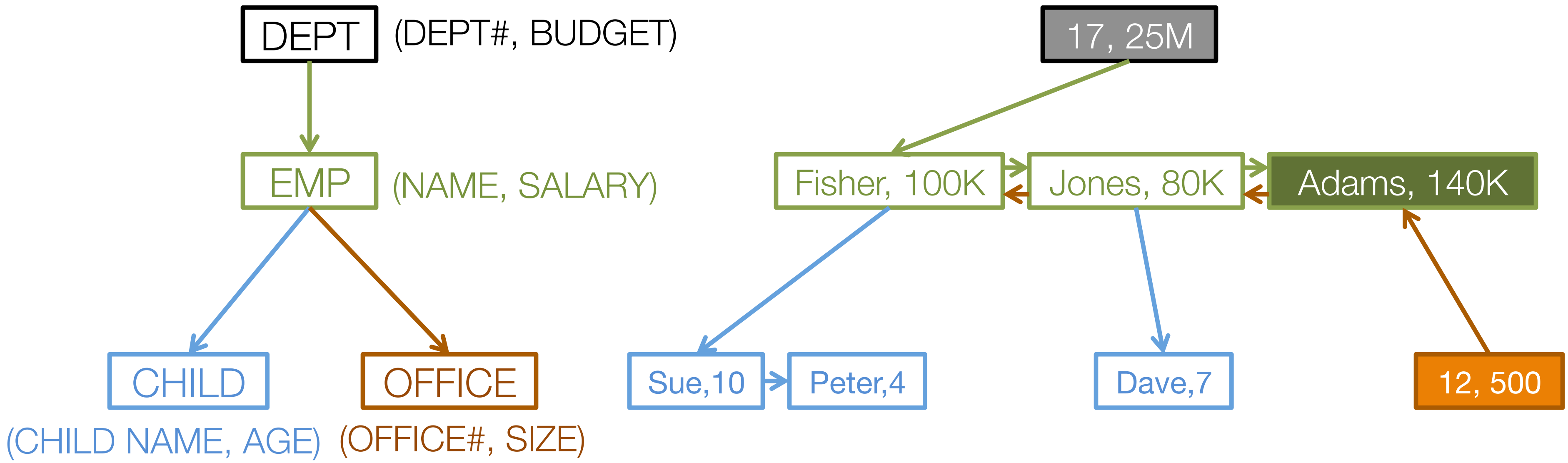


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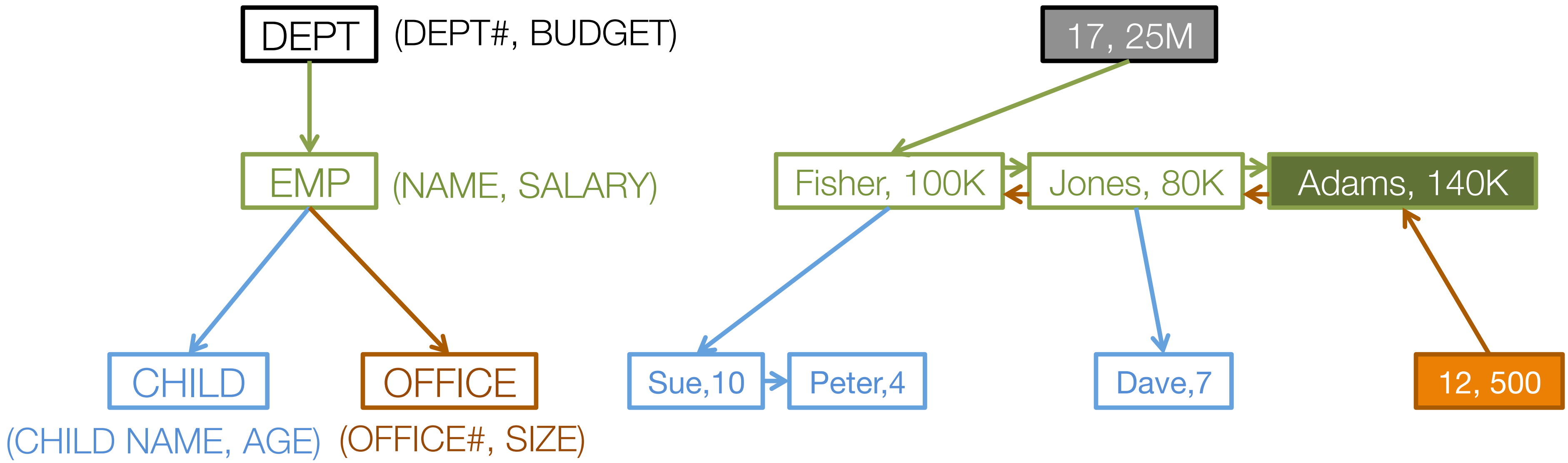


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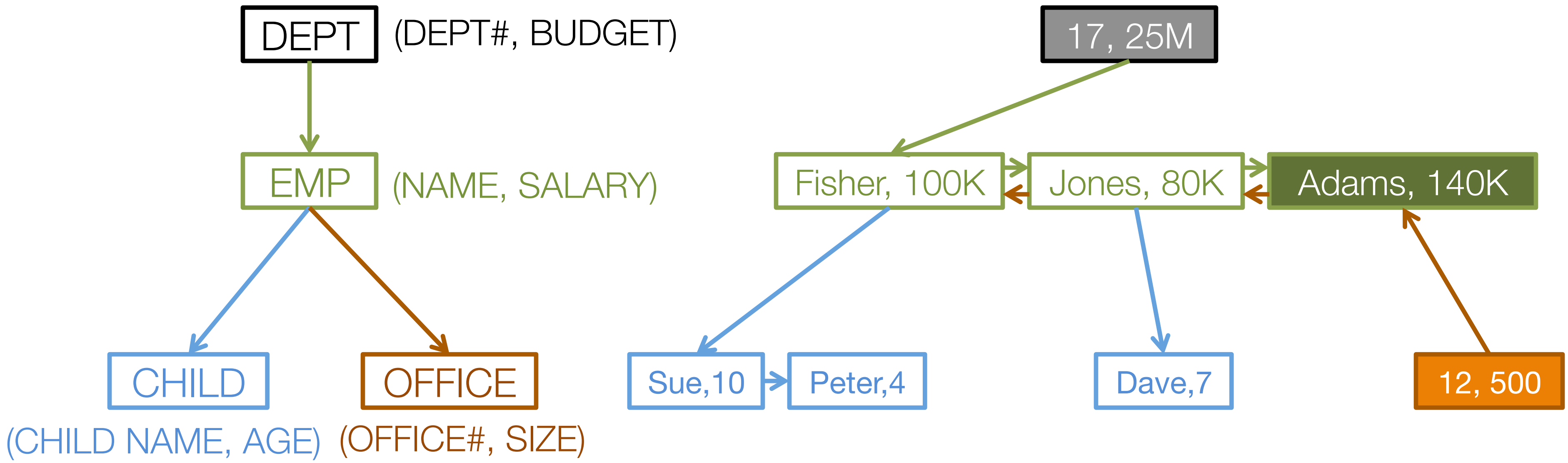


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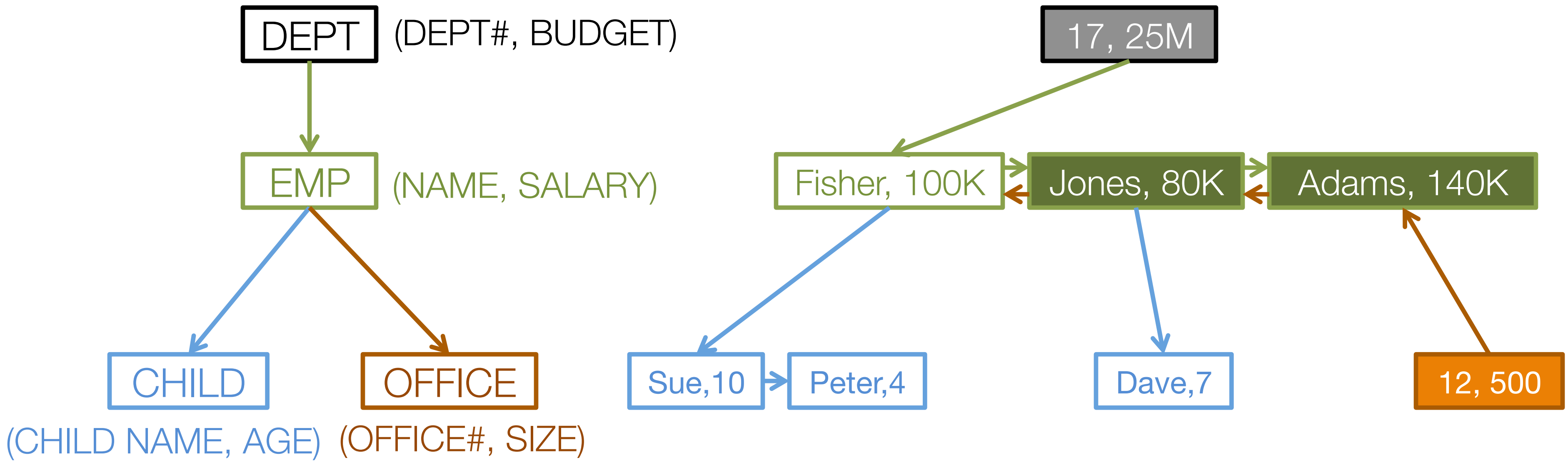


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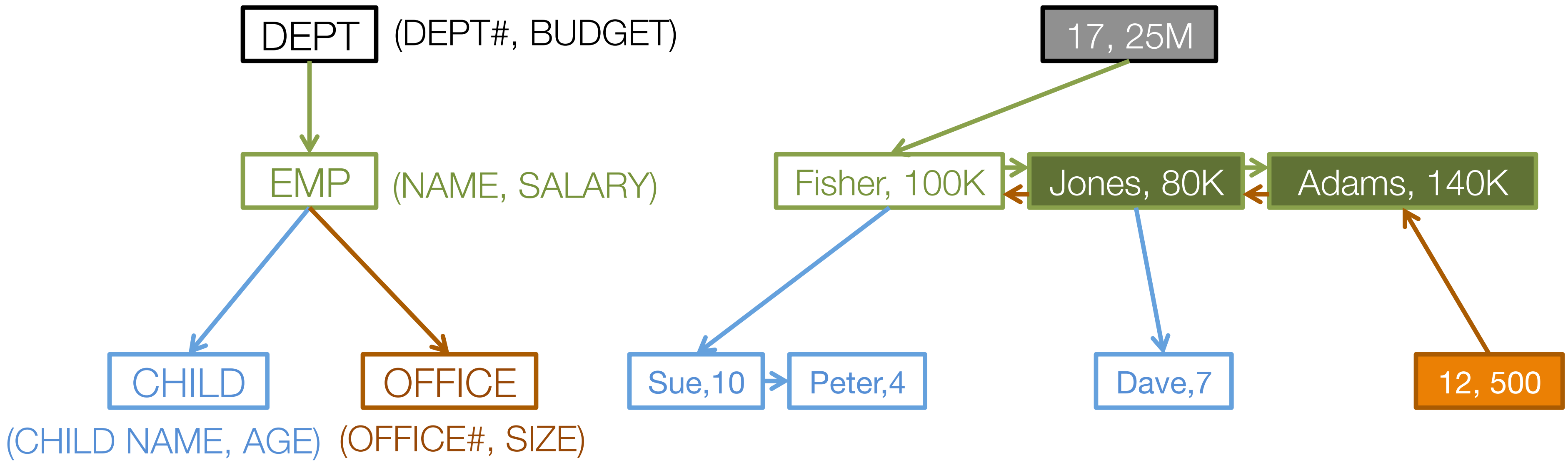


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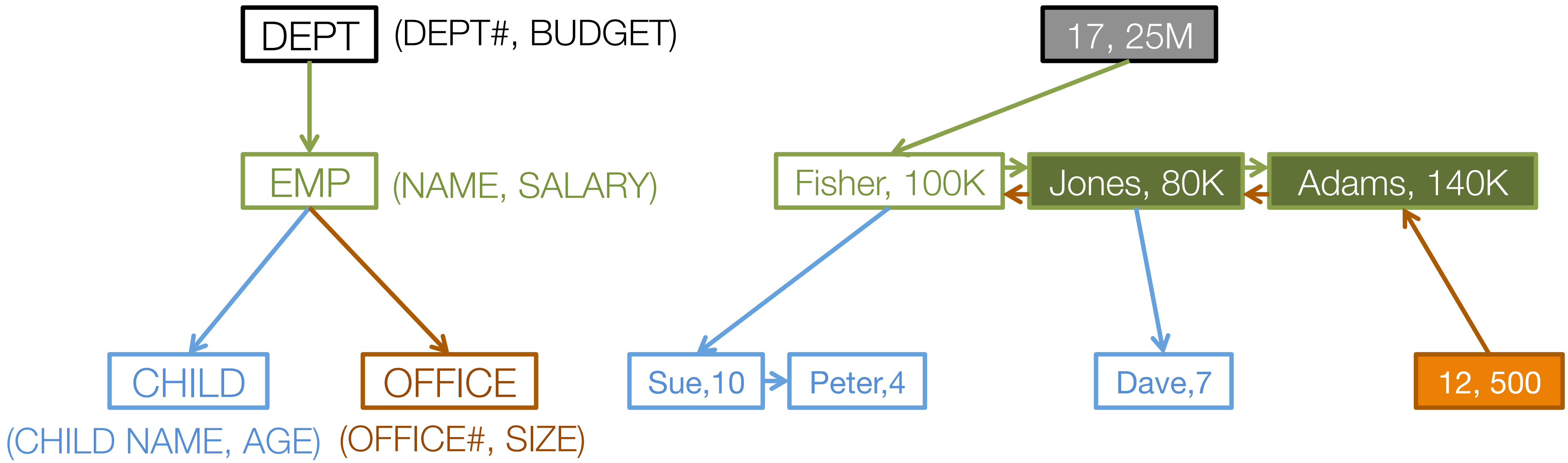


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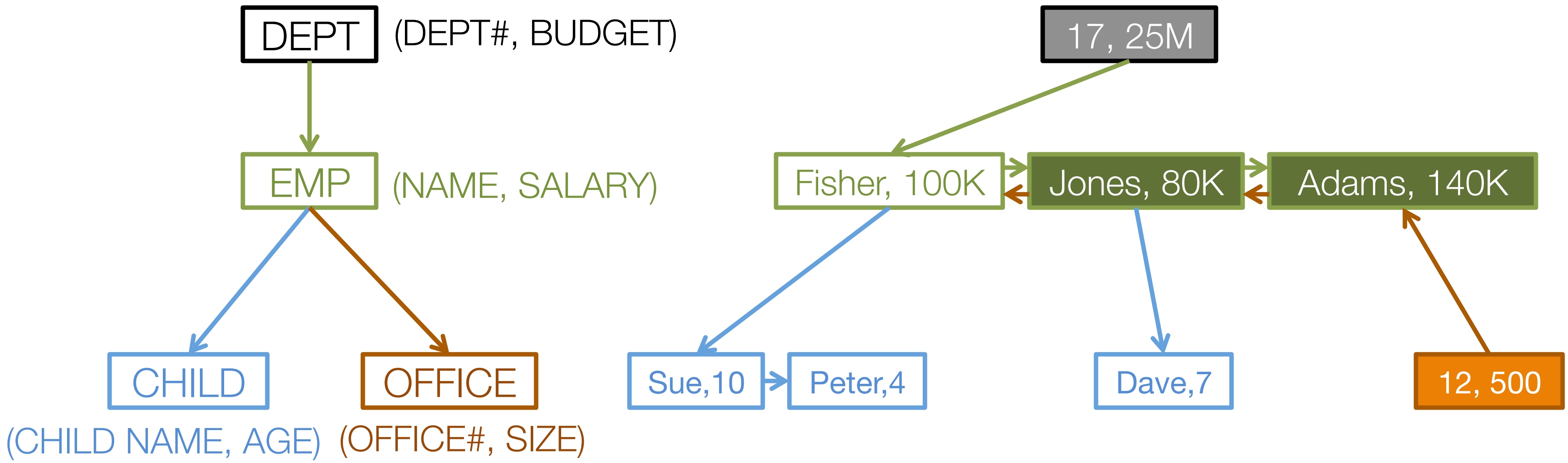


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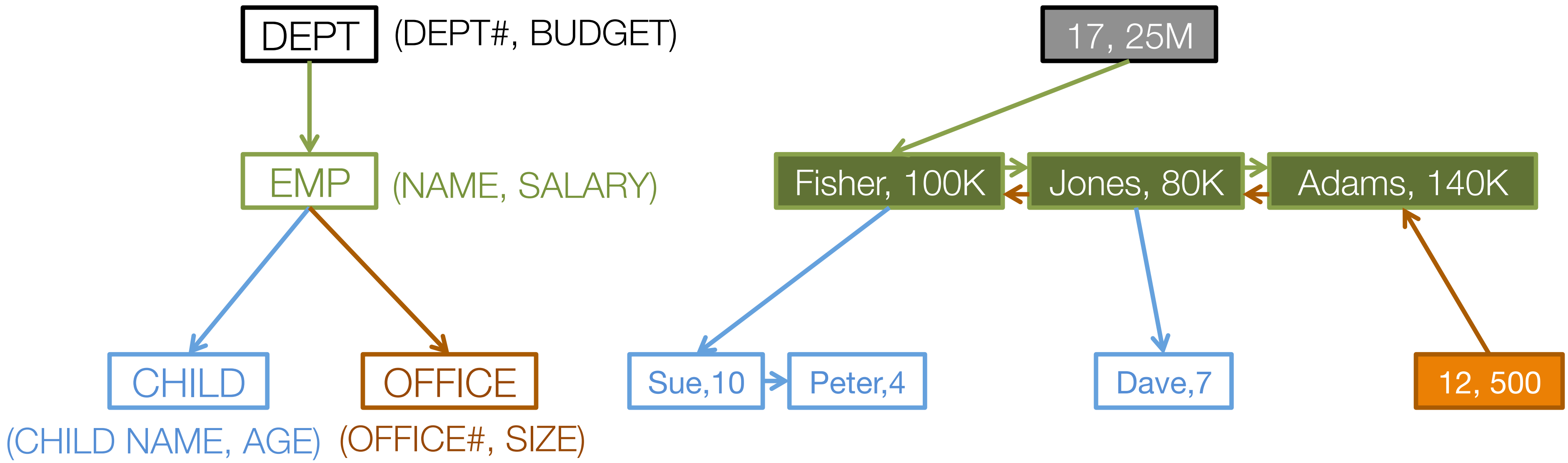


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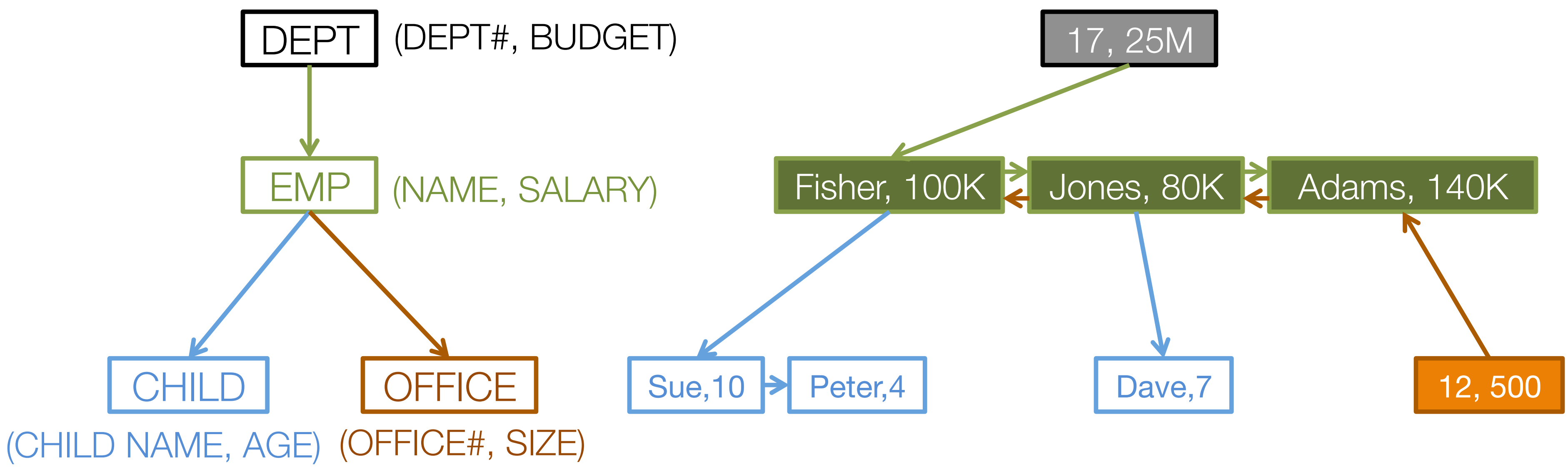


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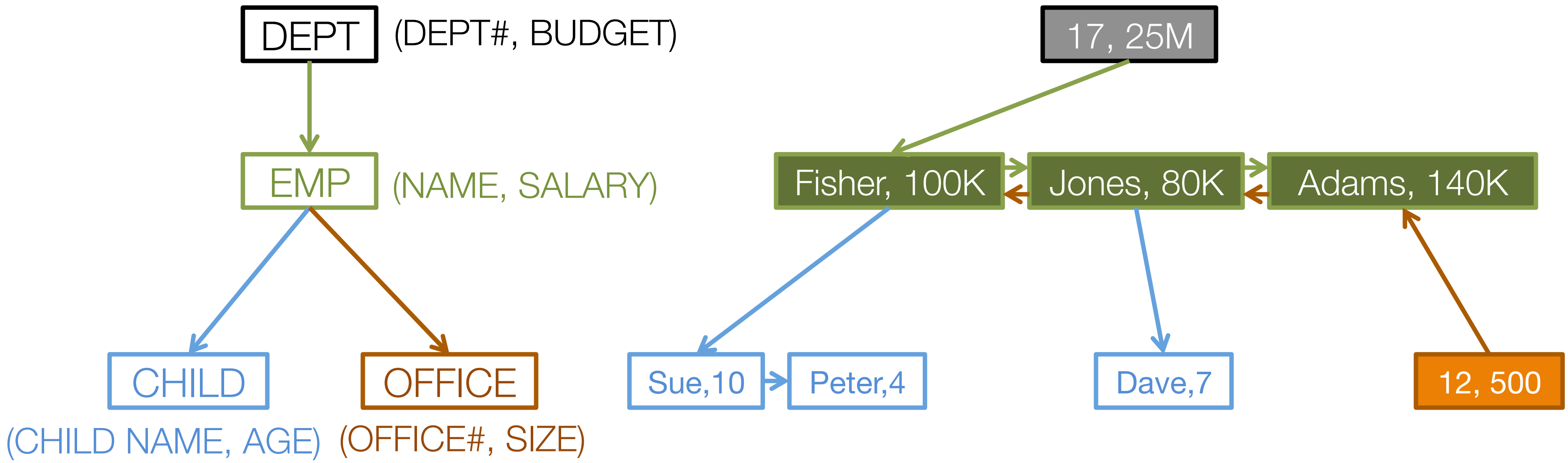


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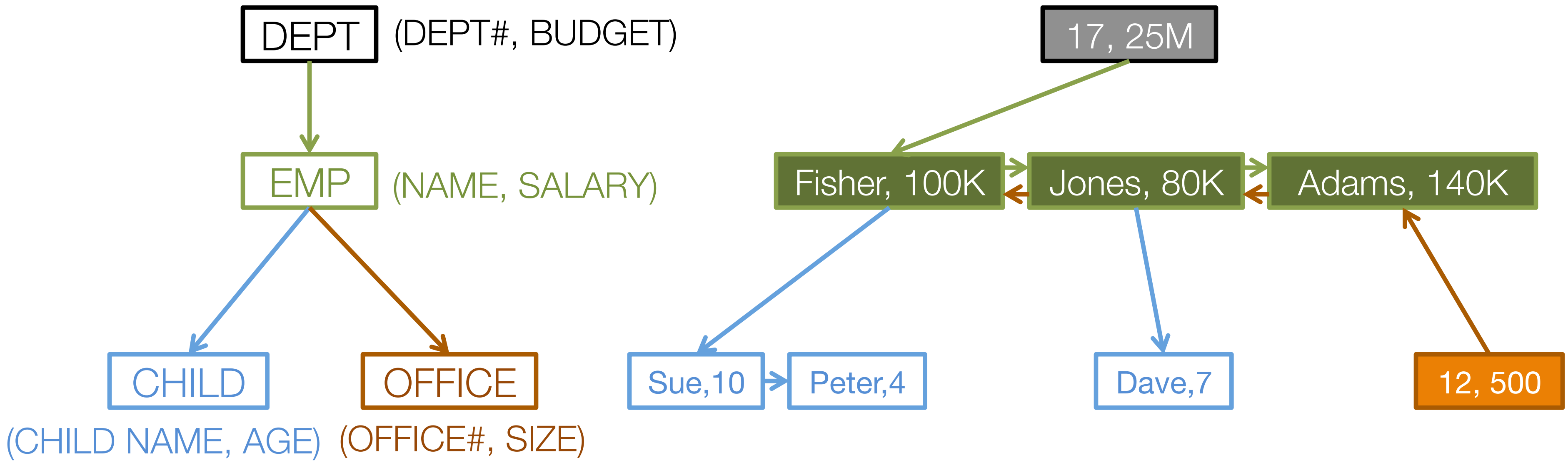


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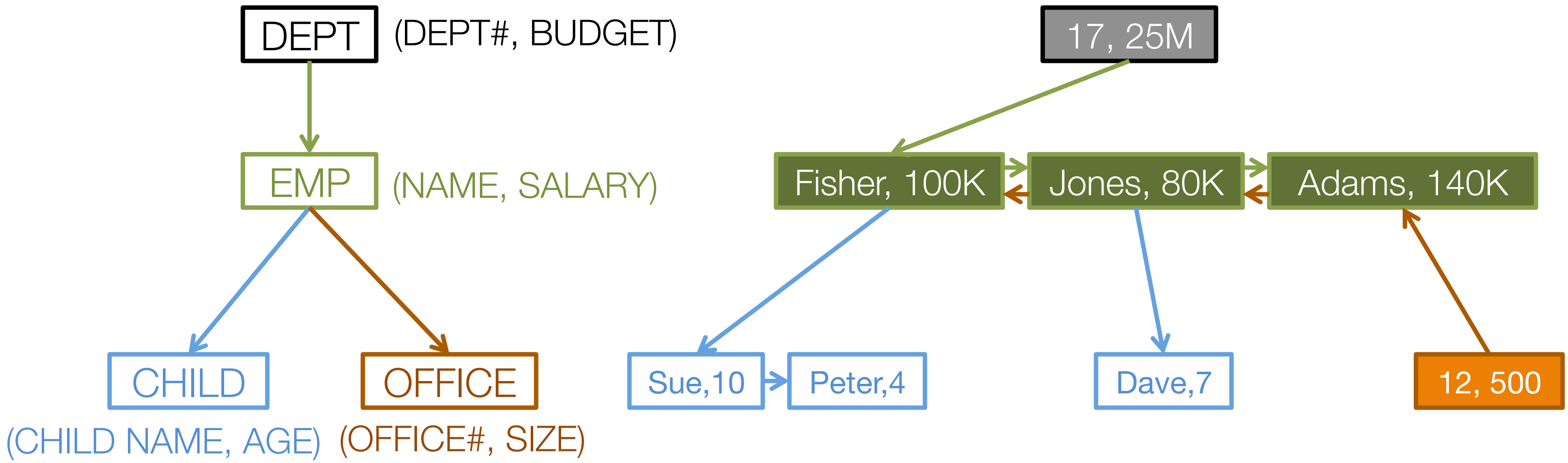


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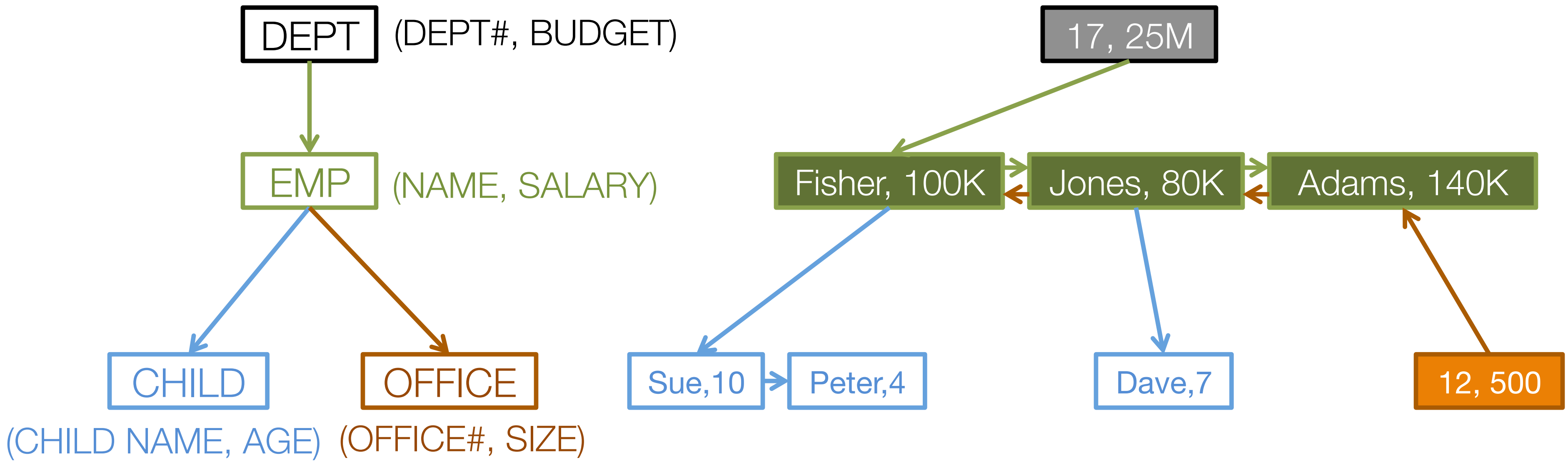


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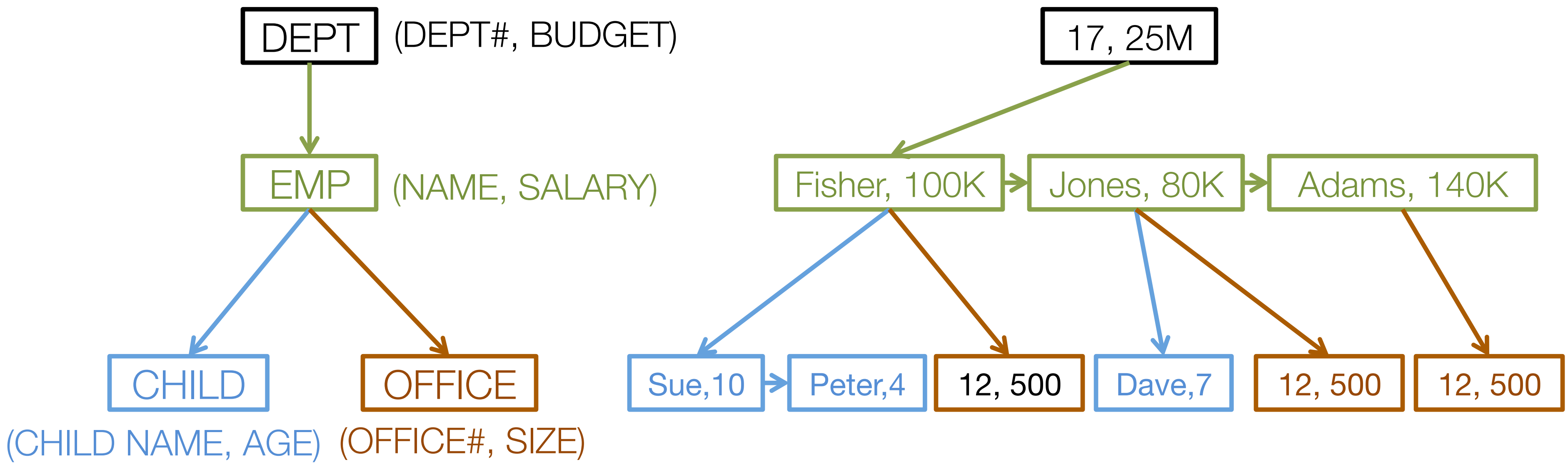
Data Dependence

Record-at-a-time Data Manipulation Language (DML)

Reflect physical data structures

If you want to change the data organization you need to change query!

Example: Changing Data Representation

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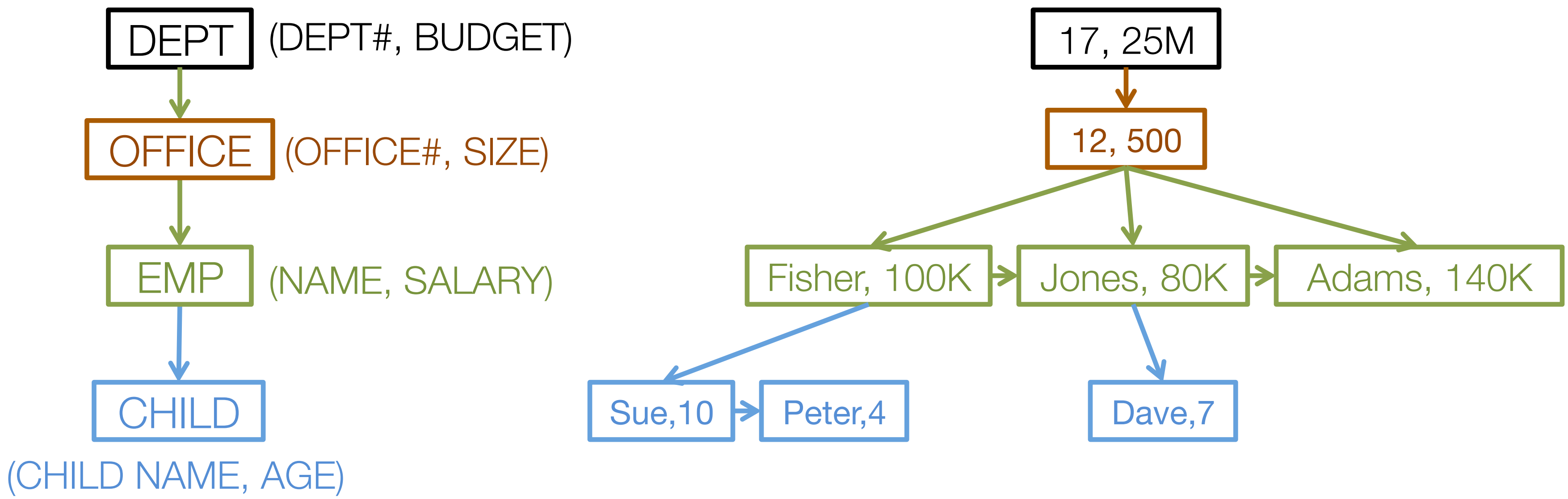


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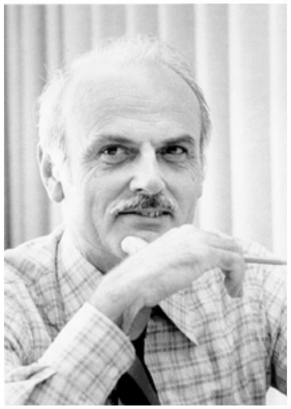
Relational Database



1970 Edgar Codd's paper; probably the most influential paper in DB research

» Set-at-a-time DML

» **Data independence**: allows for schema and physical storage structures to change

- *"as clear a paradigm shift as we can hope to find in computer science"* – Christos Papadimitriou

» 1981 Turing Award

Relational Model

Links represented as tables

DEPT	#	BUDGET
	17	25M

OFFICE	#	SIZE
	12	500

CHILD	C. NAME	C. NAME
	Sue	10
	Peter	4
	Dave	7

EMP	NAME	SALARY
	Fischer	100K
	Jones	80K
	Adams	140K

OFFSPRINGS	NAME	C. NAME
	Fischer	Sue
	Fischer	Peter
	Jones	Dave

WORKS	DEPT#	NAME
	17	Fisher
	17	Jones
	17	Adams

OCCUPIED	NAME	OFFICE#
	Fischer	12
	Jones	12
	Adams	12

```
# find department number of all employees in office 12
FIND ALL DEPT# in WORKS
    WHERE NAME = NAME IN OCCUPIED WHERE OFFICE# = 12
```

Data Independence

Separation into three levels:

- » physical storage
- » logical schema
- » multiple views

Two levels of independence:

- » physical data independence: you change the storage layout without affecting apps
- » logical data independence: isolates apps from changes in logical schema (almost, as it can’t update views in general)

Data Independence

Critical for database evolution – allow databases live and evolve for a long time!

Need data independence when environment changes much faster than applications

- Environment: physical storage, machine speed, machine workload

First Relational Databases

Mid 70's: Codd's vision implemented by two projects: ancestors of essentially all today's commercial systems!

» Ingres (UC Berkeley)
» System R (IBM)

Stated goal of both systems:

» take Codd's theory and turn it into a workable system as fast as CODASYL but easier to use and maintain

Lots of crosspollination between both groups

Ingres

1974-77, UC Berkeley: Stonebraker, Wong and many others

» 2015 Turing Award (Stonebraker)

Ancestor of:

» Ingres Corp (CA), CA-Universe, Britton-Lee, Sybase, MS SQL Server, Wang's PACE, Tandem Non-Stop SQL

System R

IBM San Jose (now Almaden)

- » 15 PhDs, including many Berkeley people:
  - Jim Gray (1st CS PhD @ Berkeley), Bruce Lindsay, Irv Traiger, Paul McJones, Mike Blasgen, Mario Schkolnick, Bob Selinger, Bob Yost
- » 1998 Turing Award (Gray)

Ancestor of:

- » IBM's SQL/DS & DB2, Oracle, HP's Allbase, Tandem Non-Stop SQL

Early 80’s Commercialization

Ellison's Oracle beats IBM to market by reading white papers ;-)

IBM releases multiple RDBMSs, settles down to DB2

Gray (System R), Jerry Held (Ingres) and others join Tandem (Non-Stop SQL)

Kapali Eswaran starts EsVal, which led to HP Allbase and Cullinet

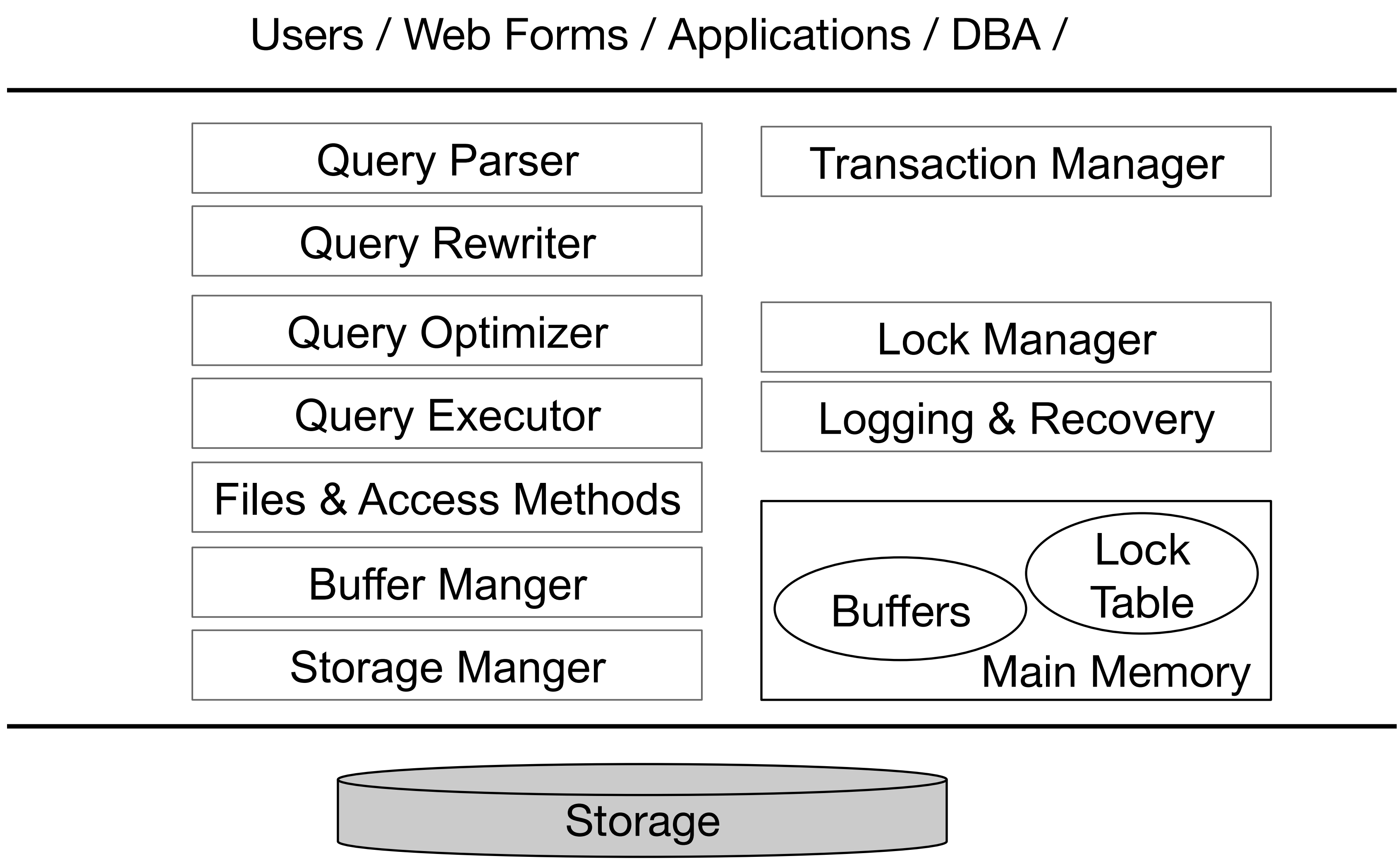
Relational Technology Inc (Ingres Corp), Britton-Lee/Sybase, Wang PACE grow out of Ingres group

CA releases CA-Universe, a commercialization of Ingres

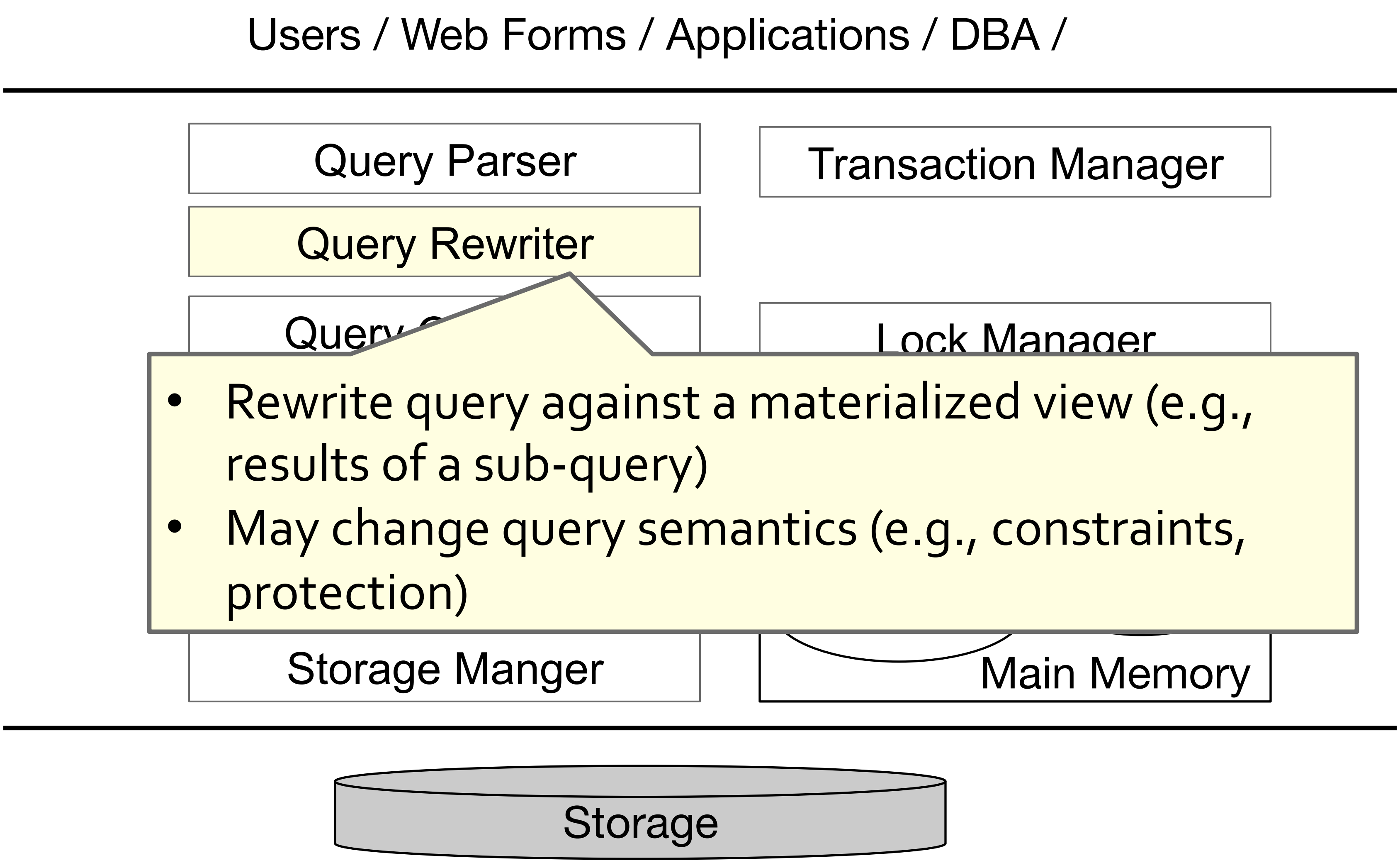
Informix started by Cal alum Roger Sippl (no pedigree to research).

Teradata started by a Cal Tech alums, based on proprietary networking technology

Database Architecture

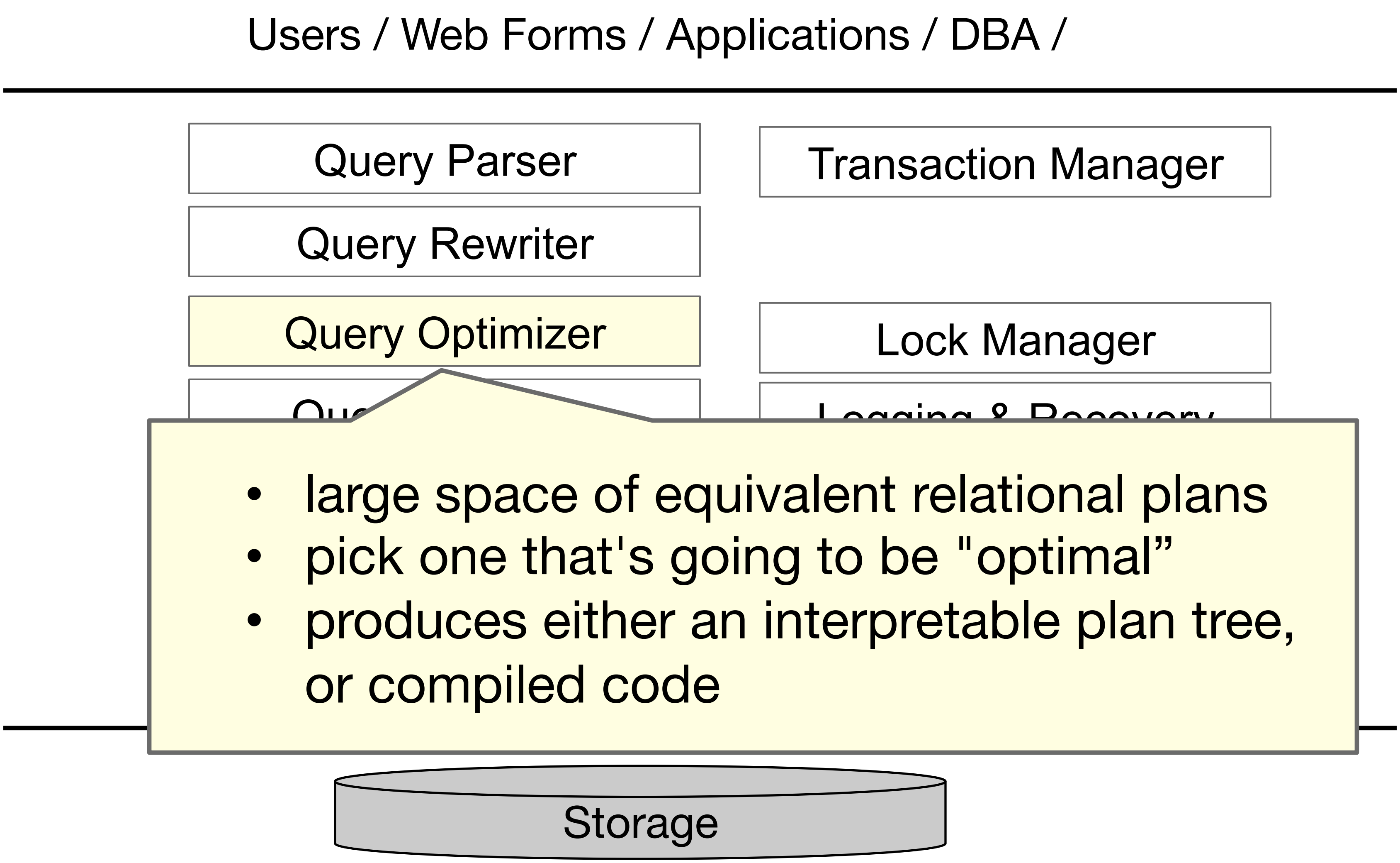


Database Architecture

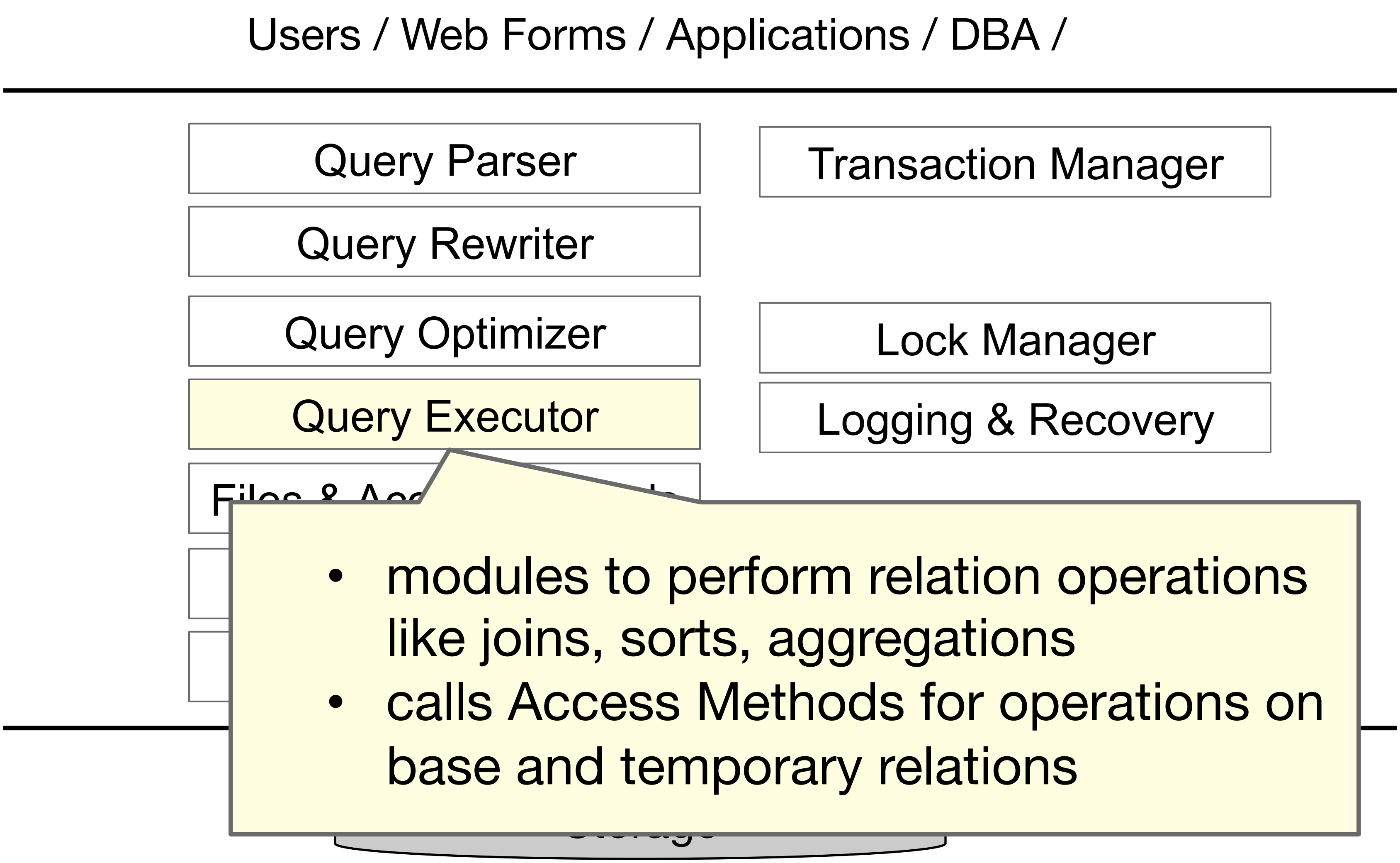


- Rewrite query against a materialized view (e.g., results of a sub-query)
- May change query semantics (e.g., constraints, protection)

Database Architecture

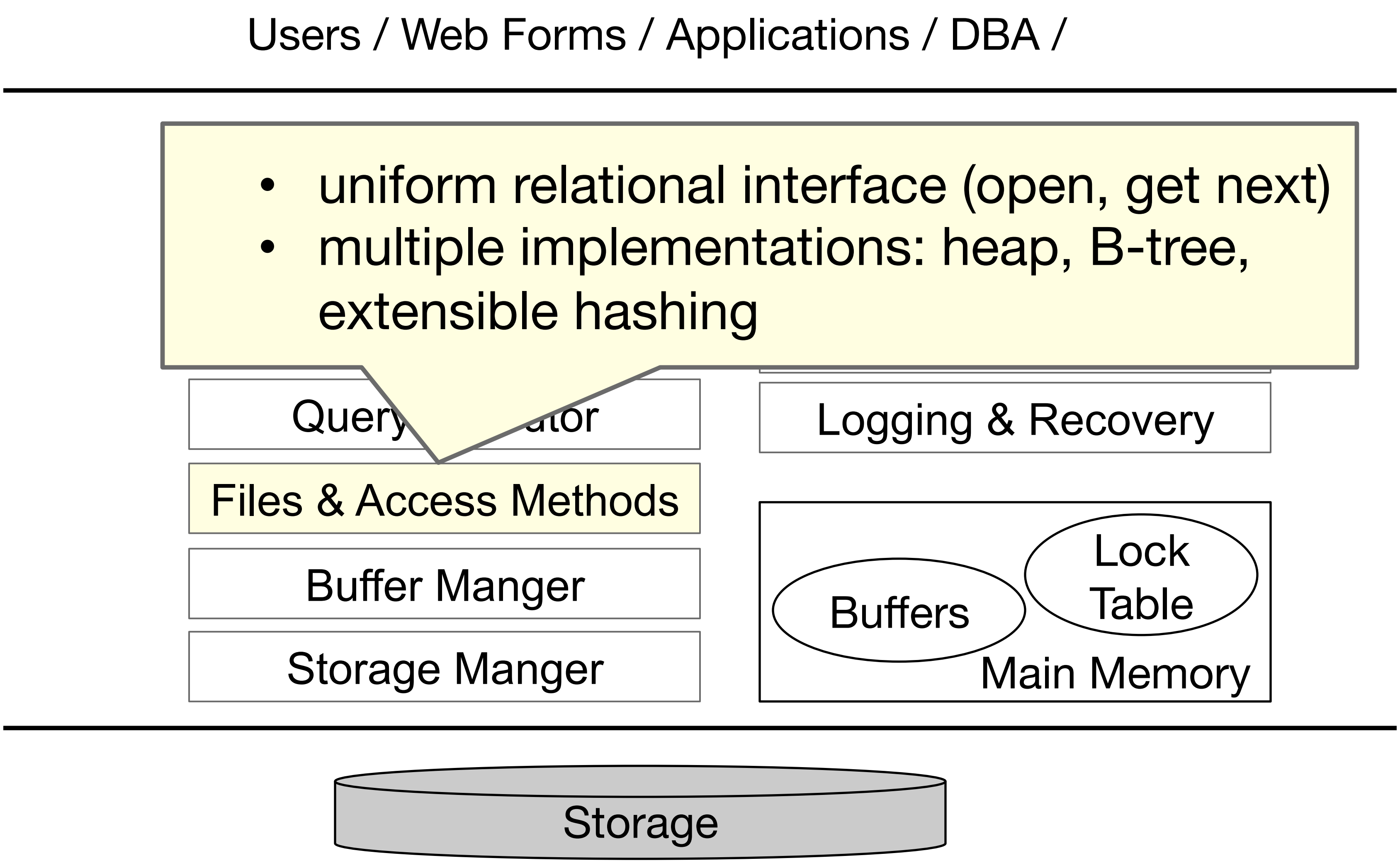


Database Architecture

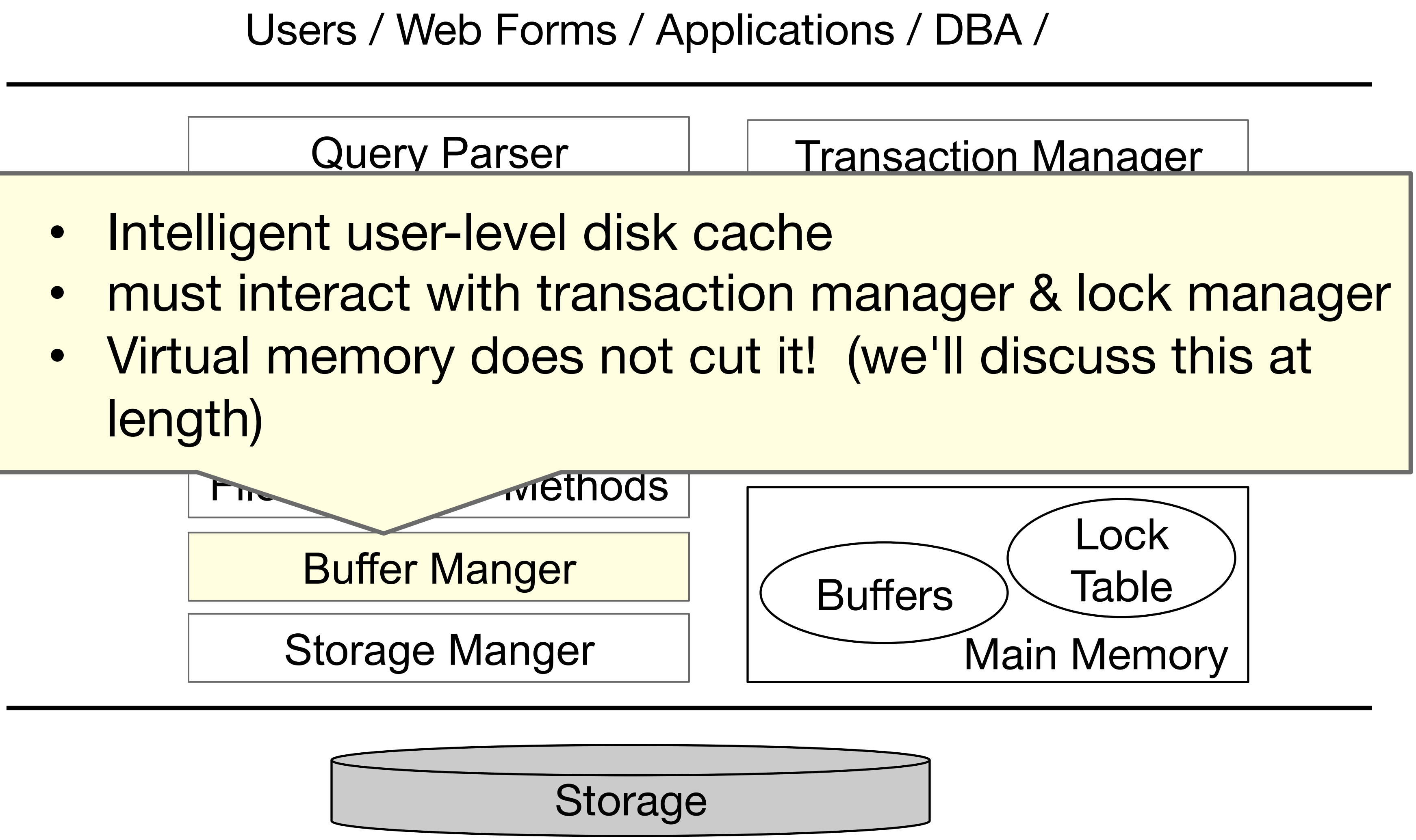


- modules to perform relation operations like joins, sorts, aggregations
- calls Access Methods for operations on base and temporary relations

Database Architecture



Database Architecture



- Intelligent user-level disk cache
- must interact with transaction manager & lock manager
- Virtual memory does not cut it! (we'll discuss this at length)

Database Architecture

Users / Web Forms / Applications / DBA /

Query Parser

Transaction Manager

Query Rewriter

Query Optimizer

Lock Manager

- must efficiently support lock table
- System R architecture influential:
  - multiple granularity of locks
  - set intent locks at high levels
  - we will study this in more detail later
- deadlock handling: detection

Database Architecture

Users / Web Forms / Applications / DBA /

Query Parser

Query Rewriter

Query Optimizer

Query Executor

Transaction Manager

Lock Manager

Logging & Recovery

- Use shadow page for updates
- checkpoint/restore facility for quick recovery
- "before/after" log on values
- Redo/Undo on restore

Storage

System R Paper Nuggets

Expect to throw out the 1st version of the system

Authors very familiar with

- What they want to build
- Implementation challenges

Similar to Unix:

- Ken Thomson and Dennis Ritchie both worked on Multics

System R Paper Nuggets

Reuse abstractions and mechanisms whenever possible, e.g.,

- catalogs as tables

Similar to Unix, e.g.,

- Shell, just another process
- Devices treated as files

System R Paper Nuggets

Optimize the fast path, e.g.,

Query optimization

- Phase Zero focus: optimize complex queries
- Phase One focus: optimize simple, most common queries

Locks

- “predicate locks” deemed to complicated
- Ended up with per object locks, albeit hierarchical and multiple granularity

System R Paper Nuggets

Interpretation vs. compilation

R Systems use compilation: compiler assembles from about 100 code fragments specially tailored for processing a given SQL query”

System R Paper Nuggets

Component failure as common case

Three failure cases:

1. System failure
2. Media (disk) failure
3. Transaction failure

Discussion: Storage Mechanism

Phase Zero: single user, XRM

- » Values of each column stored in a separate domain
- » Each field contains TID of corresponding domain/value
- » Inversions: mapping between values and TIDs

Phase One: multiuser, RSS

- » Tuple contains values
- » Indexes on one, more, or combination of columns

What are the tradeoffs?

Discussion: Cost Based Optimizer

Phase Zero: cost of fetching the tuple

Phase One: combination of

- » # of I/Os
- » # of calls (CPU activity)

Evaluated on uniformly distributed data

Questions

- » How well does it work?
- » Do you expect CPU to still be bottleneck today?

Discussion: Transactions

Level 1: Transactions can read uncommitted transactions but not write

Level 2: Transactions acquire lock for each reads but releases it right after reading

- Another transaction may update a value between two reads

Level 3: Once a transaction acquires a read lock it keeps it until the end

Discussion?

Discussion: Shadow Pages

Shadow pages:

- » New version is created for each page that is updated
- » Periodically new page is checkpointed on disk
- » "before/after" logs recording all database changes
- » On failure, revert to "old" page and use log to redo committed transactions and undo incomplete ones

Write Ahead Log (WAL):

- » Keep a log of all database updates
- » Write each update before writing back to disk the updates

Tradeoffs?

Unix vs. System R

UNIX paper: "The most important job of UNIX is to provide a file system”

- » UNIX and System R are both "information management" systems!
- » Both also provide programming APIs for apps

Difference in Focus

Bottom-Up (elegance of system) vs. Top-Down (elegance of semantics)

Main goal of UNIX: *present hardware to computer programmers*

- » small *elegant* set of mechanisms, and abstractions for developers (i.e. C programmers)

Main goal of System R & Ingres: *manage data for application programmer*

- » complete system that insulated programmers (i.e. SQL + scripting) from the system, while guaranteeing clearly defined *semantics* of data and queries.

Difference in Focus

Bottom-Up (elegance of system) vs. Top-Down (elegance of semantics)

Affects where the complexity goes: to system, or end-programmer?

Which one is better? In what environments?

Different Challenges

Achilles' heel of RDBMSs: closed box

- » Cannot leverage technology without going through the full SQL stack
- » One solution: make the system extensible, convince the world to download code into the DBMS
- » Another solution: componentize the system (hard, RSS is hard to bust up, due to transaction semantics)

Achilles' heel of OSes: hard to get "right" level of abstraction

- » Many UNIX abstractions (e.g. virtual memory) too high level, hide too much detail
  - In contrast, too low a level can cause too much programmer burden
- » One solution: make the system extensible, convince fancy apps to download code into the OS
- » Another solution: componentize the system (hard, due to protection)
  - But lot’s of work on this, e.g., Microkernel